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SimElectronics[®] Reference

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| - | |



${\bf Blocks-Alpha betical\ List}$

1

Index

Blocks — Alphabetical List

Accelerometer

Purpose Behavioral model of MEMS accelerometer

Library

Sensors

Description



The Accelerometer block implements a behavioral model of a MicroElectroMechanical Systems (MEMS) accelerometer. For the default output type Voltage level, the accelerometer provides an output voltage that is proportional to the acceleration rate presented at the mechanical translational physical port R. The output voltage is limited according to the values that you provide for maximum and minimum output voltage.

The block also has an alternative output type, PWM duty cycle. With this choice, the output of the block is a PWM signal with a duty cycle that is proportional to the measured acceleration. You can limit the variation in duty cycle to a specified range.

Optionally, you can model sensor dynamics by setting the **Dynamics** parameter to Model sensor bandwidth. Including dynamics adds a first-order lag between the angular rate presented at port R and the corresponding voltage applied to the electrical + and - ports.

If running your simulation with a fixed-step solver, or generating code for hardware-in-the-loop testing, MathWorks recommends that you set the **Dynamics** parameter to No dynamics Suitable for HIL, because this avoids the need for a small simulation time step if the sensor bandwidth is high.

Dialog Box and Parameters

| Accelerometer | | |
|--|--|--------|
| | lerometer. The acceleration at mechanical translation ity cycle of a PWM voltage across the electrical + an | |
| Parameters | | |
| Output type: | Voltage level | |
| Sensitivity: | 1000 | mV/gee |
| Output voltage for zero acceleration: | 2.5 | V |
| Maximum output voltage: | 4 | V |
| Minimum output voltage: | 1 | V |
| Dynamics: | No dynamics - Suitable for HIL | |
| | | |

Output type

Select one of the following options to define the block output type:

• Voltage level — The amplitude of the output voltage is proportional to the measured acceleration. This is the default option.

• PWM duty cycle — The duty cycle (on time divided by the pulse total time) is proportional to the measured acceleration.

Sensitivity

The change in output voltage level per unit change in acceleration when the output is not being limited. This parameter is only visible when you select Voltage level for the **Output type** parameter. The default value is 1000 mV/gee.

Output voltage for zero acceleration

The output voltage from the sensor when the acceleration is zero. This parameter is only visible when you select Voltage level for the **Output type** parameter. The default value is 2.5 V.

Maximum output voltage

The maximum output voltage from the sensor, which determines the sensor maximum measured positive acceleration. This parameter is only visible when you select Voltage level for the **Output type** parameter. The default value is 4 V.

Minimum output voltage

The minimum output voltage from the sensor, which determines the sensor maximum measured negative acceleration. This parameter is only visible when you select Voltage level for the **Output type** parameter. The default value is 1 V.

Duty cycle sensitivity (percent per unit acceleration)

The change in duty cycle per unit acceleration. Duty cycle is expressed as a percentage of the PWM period. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 10 percent/gee.

Duty cycle for zero acceleration (percent)

The duty cycle output by the sensor when the acceleration is zero. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 50%.

Maximum duty cycle (percent)

The maximum duty cycle output by the sensor. Increasing acceleration levels beyond this point will not register an increase

in duty cycle. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 75%.

Minimum duty cycle (percent)

The minimum duty cycle output by the sensor. Decreasing acceleration levels beyond this point will not register a decrease in duty cycle. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 25%.

PWM frequency

The frequency of the output pulse train. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 1 kHz.

Output voltage amplitude

The amplitude of the output pulse train when high. This parameter is only visible when you select PWM duty cycle for the **Output type** parameter. The default value is 5 V.

Dynamics

Select one of the following options for modeling sensor dynamics:

- No dynamics Suitable for HIL Do not model sensor dynamics. Use this option when running your simulation fixed step or generating code for hardware-in-the-loop testing, because this avoids the need for a small simulation time step if the sensor bandwidth is high. This is the default option.
- Model sensor bandwidth Model sensor dynamics with a first-order lag approximation, based on the **Bandwidth** and the **Initial angular rate** parameter values.

Bandwidth

Specifies the 3dB bandwidth for the measured acceleration assuming a first-order time constant. This parameter is only visible when you select Model sensor bandwidth for the **Dynamics** parameter. The default value is 3 kHz.

Initial acceleration

Determines the initial condition for the lag by specifying the initial output for the sensor, expressed in units of acceleration. This parameter is only visible when you select Model sensor bandwidth for the **Dynamics** parameter. The default value is 0 gee.

Ports

The block has the following ports:

R

+

_

Mechanical translational port.

Positive electrical port.

Negative electrical port.

- Purpose Model band-limited operational amplifier
- **Library** Integrated Circuits

Description

÷.

The Band-Limited Op-Amp block models a band-limited operational amplifier. If the voltages at the positive and negative ports are Vp and Vm, respectively, the output voltage is:

$$V_{out} = \frac{A(V_p - V_m)}{\frac{s}{2\pi f} + 1} - I_{out} * R_{out}$$

where:

- A is the gain.
- R_{out} is the output resistance.
- *I_{out}* is the output current.
- *s* is the Laplace operator.
- *f* is the 3-dB bandwidth.

The input current is:

$$\frac{V_p - V_m}{R_{in}}$$

where R_{in} is the input resistance.

The block does not use the initial condition you specify using the **Initial output voltage**, **V0** parameter if you select the **Start simulation from steady state** check box in the Simscape[™] Solver Configuration block.

Dialog Box and **Parameters**

| pins are denoted Vp and Vm, then the output voltage is given by Vout = A*(Vp-Vm)*1/(s/(2*pi*f)+1)-lout*Rout | | | | |
|---|-------|-------|--|--|
| where A is the gain, Rout is the output resistance, lout is the output current, s is the Laplace operator, and f is the 3dB bandwidth. The input current is given by (Vp-Vm)/Rin where Rin is the input resistance. The no-load output voltage is limited the range Vmin to Vmax, and the slew rate is limited to +-Vdot. | | | | |
| The Initial output voltage, V0, sets the initial op-amp output voltage. Note that this does not take account of any voltage drop across Rout. The initial condition is not used if you select the Start simulation from steady state option in the Solver Configuration block. | | | | |
| Gain, A: | 1000 | | | |
| Input resistance, Rin: | 1e+06 | Ohm 🔻 | | |
| Output resistance, Rout: | 100 | Ohm 💌 | | |
| Minimum output, Vmin: | -15 | V | | |
| Maximum output, Vmax: | 15 | V | | |
| Maximum slew rate, Vdot: | 1000 | V/s | | |
| Bandwidth, f: | 1e+05 | Hz 💌 | | |
| Initial output voltage, V0: | 0 | V | | |
| | | | | |
| | | | | |

Gain, A

The open-loop gain of the operational amplifier. The default value is 1000.

Input resistance, Rin

The resistance at the input of the operational amplifier that the block uses to calculate the input current. The default value is $1e+06 \Omega$.

Output resistance, Rout

The resistance at the output of the operational amplifier that the block uses to calculate the drop in output voltage due to the output current. The default value is 100Ω .

Minimum output, Vmin

The lower limit on the operational amplifier no-load output voltage. The default value is -15 V.

Maximum output, Vmax

The upper limit on the operational amplifier no-load output voltage. The default value is 15 V.

Maximum slew rate, Vdot

The maximum positive or negative rate of change of output voltage magnitude. The default value is 1000 V/s.

Bandwidth, f

The open-loop bandwidth, that is, the frequency at which the gain drops by 3 dB compared to the low-frequency gain, A. The default value is 1e+05 Hz.

Initial output voltage, V0

The output voltage at the start of the simulation when the output current is zero. The default value is 0 V.

Note This parameter value does not account for the voltage drop across the output resistor.

Ports The block has the following ports:

+

Positive electrical voltage.

Negative electrical voltage.

OUT

Output voltage.

See Also Simscape Op-Amp, Finite-Gain Op-Amp, Fully Differential Op-Amp

CMOS AND

Purpose Model CMOS AND gate behaviorally

Library Logic

Description The CMOS AND block represents a CMOS AND logic gate behaviorally:

- The block output logic level is HIGH if the logic levels of both of the gate inputs are 1.
- The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-12 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.
- You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that

the resistor-capacitor time constant equals the **Propagation delay** parameter value. For Quadratic output, the gate input demand is lagged to approximate the **Propagation delay** parameter value.

The block output voltage depends on the output model selected:

- For Linear model, output high is the **High level output voltage** parameter value, and output low is the **Low level output voltage** parameter value.
- For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the **Supply voltage** parameter value), and output low is zero volts.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the **Output current-voltage relationship** parameter). This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS AND

Dialog Box and Parameters

Inputs Tab

| e block implements a simplified model (rameters for the supply voltage used) rameters | | | output low and outp | achign |
|--|-------|--|---------------------|--------|
| Inputs Outputs Initial Condi | tions | | | |
| Low level input voltage: | 2 | | ۷ | • |
| High level input voltage: | 3 | | ۷ | Ŧ |
| Average input capacitance: | 5 | | pF | Ŧ |
| | | | | |
| | | | | |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is 3 V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS AND | | × | | | | |
|--|-----------|------------|--|--|--|--|
| -CMOS AND | | | | | | |
| The block implements a simplified model of a CMOS AND logic gate. Set the Input low, Input high, Output low and Output high parameters for the supply voltage used. Default values are for a supply voltage of 5 volts. | | | | | | |
| Parameters | | | | | | |
| Inputs Outputs Initial Conditio | 15 | | | | | |
| Output current-voltage relationship: | Linear | | | | | |
| Low level output voltage: | 0 | V | | | | |
| High level output voltage: | 5 | V | | | | |
| Output resistance: | 25 | Ohm 💌 | | | | |
| Propagation delay: | 25 | ns | | | | |
| | | | | | | |
| | OK Cancel | Help Apply | | | | |

| ameters | | |
|--|------------|-----|
| Inputs Outputs Initial Condition | s | |
| Output current-voltage relationship: | Quadratic | Ţ |
| Supply voltage: | 5 | V . |
| Measurement voltage: | 5 | V . |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I_OL: | [30 800] | Ohm |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage** relationship parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| Block Parameters: CMOS AND CMOS AND The block implements a simplified model of a CN parameters for the supply voltage used. Defau | MOS AND logic gate. Set the Input low, Input high, Output low and Output high ult values are for a supply voltage of 5 volts. |
|---|--|
| Parameters Inputs Outputs Initial Conditions Output initial state: | Low |
| | OK Cancel Help Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

Α

Electrical input port.

В

Electrical input port.

J

Electrical output port.

Purpose Model CMOS Buffer gate behaviorally

Library Logic

Description

•-----•

The CMOS Buffer block represents a CMOS Buffer logic gate behaviorally:

- The block output logic level is HIGH if the logic level of the gate input is 1.
- The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-20 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.

| | • You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the Propagation delay parameter value. For Quadratic output, the gate input demand is lagged to approximate the Propagation delay parameter value. |
|--|---|
| | The block output voltage depends on the output model selected: |
| | • For Linear model, output high is the High level output voltage parameter value, and output low is the Low level output voltage parameter value. |
| | • For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the Supply voltage parameter value), and output low is zero volts. |
| Basic Assumptions and Limitations | The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the Output current-voltage relationship parameter). This limitation has the following implications: |
| | • The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage. |
| | • The block does not accurately model dynamic response. |

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS Buffer

Dialog Box and Parameters

| | Tab |
|------|-----|
| puts | Iap |

| Inputs Outputs | Initial Conditions | | | |
|---------------------------|--------------------|--|----|---|
| Low level input voltage: | 2 | | V | • |
| High level input voltage: | 3 | | V | - |
| Average input capacitanc | e: 5 | | pF | - |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is 3 V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS Buffer | | × | | | | |
|--|-----------|------------|--|--|--|--|
| CMOS Buffer | | | | | | |
| The block implements a simplified model of a CMOS buffer gate. Set the Input low, Input high, Output low and Output high parameters for the supply voltage used. Default values are for a supply voltage of 5 volts. | | | | | | |
| Parameters | | | | | | |
| Inputs Outputs Initial Condition | s | | | | | |
| Output current-voltage relationship: | Linear | | | | | |
| Low level output voltage: | 0 | V | | | | |
| High level output voltage: | 5 | V | | | | |
| Output resistance: | 25 | Ohm 💌 | | | | |
| Propagation delay: | 25 | ns | | | | |
| | | | | | | |
| | | | | | | |
| | OK Cancel | Help Apply | | | | |

| ameters | | |
|--|------------|-------|
| Inputs Outputs Initial Conditio | ıs | |
| Output current-voltage relationship: | Quadratic | • |
| Supply voltage: | 5 | V |
| Measurement voltage: | 5 | V |
| Logic HIGH output resistance at zero current and at I OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I OL: | [30 800] | Ohm 💌 |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V . |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| 🙀 Block Parameters: CMO5 Buffer | |
|--|---|
| CMOS Buffer | |
| The block implements a simplified model of a C for the supply voltage used. Default values an | MOS buffer gate. Set the Input low, Input high, Output low and Output high parameters e for a supply voltage of 5 volts. |
| -Parameters | |
| Inputs Outputs Initial Conditions |] |
| Output initial state: | Low |
| | |
| | |
| | |
| | |
| | |
| | |
| | OK Cancel Help Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

А

Electrical input port.

J

Electrical output port.

Purpose Model CMOS NAND gate behaviorally

Library Logic

Description



The CMOS NAND block represents a CMOS NAND logic gate behaviorally:

- The block output logic level is HIGH if the logic levels of both of the gate inputs are 0.
- The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-28 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.

| | • You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the Propagation delay parameter value. For Quadratic output, the gate input demand is lagged to approximate the Propagation delay parameter value. |
|--|---|
| | The block output voltage depends on the output model selected: |
| | • For Linear model, output high is the High level output voltage parameter value, and output low is the Low level output voltage parameter value. |
| | • For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the Supply voltage parameter value), and output low is zero volts. |
| Basic Assumptions and Limitations | The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the Output current-voltage relationship parameter). This limitation has the following implications: |
| | • The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage. |
| | • The block does not accurately model dynamic response. |

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS NAND

Dialog Box and Parameters

Inputs Tab

| e block implements a simplified mode rameters for the supply voltage use rameters | | | Output low and Out | put high |
|---|---------|------|--------------------|----------|
| Inputs Outputs Initial Con | ditions | | | |
| Low level input voltage: | 2 | | V | • |
| High level input voltage: | 3 | | V | • |
| Average input capacitance: | 5 | | pF | • |
| | | | | |
| | | | | |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is **3** V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS NAND | | × | | | | | |
|--|-----------|------------|--|--|--|--|--|
| CMOS NAND | | | | | | | |
| The block implements a simplified model of a CMOS NAND logic gate. Set the Input low, Input high, Output low and Output high parameters for the supply voltage used. Default values are for a supply voltage of 5 volts. | | | | | | | |
| Parameters | | | | | | | |
| Inputs Outputs Initial Condition | s | | | | | | |
| Output current-voltage relationship: | Linear | | | | | | |
| Low level output voltage: | 0 | V | | | | | |
| High level output voltage: | 5 | V | | | | | |
| Output resistance: | 25 | Ohm 💌 | | | | | |
| Propagation delay: | 25 | ns 💌 | | | | | |
| | | | | | | | |
| | | | | | | | |
| | OK Cancel | Help Apply | | | | | |

| ameters | | |
|--|------------|-----|
| Inputs Outputs Initial Condition | s | |
| Output current-voltage relationship: | Quadratic | |
| Supply voltage: | 5 | V |
| Measurement voltage: | 5 | V |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I OL: | [30 800] | Ohm |
| _ Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V • |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| Block Parameters: CMO | S NAND | | x |
|-------------------------------|--------------------|---|----|
| The block implements a simpli | | CMOS NAND logic gate. Set the Input low, Input high, Output low and Output high ault values are for a supply voltage of 5 volts. | |
| Parameters | | | |
| Inputs Outputs I | Initial Conditions | | |
| Output initial state: | | Low | |
| | | OK Cancel Help App | V. |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

Α

Electrical input port.

В

Electrical input port.

J

Electrical output port.

Purpose Model CMOS NOR gate behaviorally

Library Logic

Description The CMOS NOR block represents a CMOS NOR logic gate behaviorally:



- The block output logic level is LOW if the logic levels of any of the gate inputs are 1.
- The block output logic level is HIGH otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-36 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.
- You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that

the resistor-capacitor time constant equals the **Propagation delay** parameter value. For Quadratic output, the gate input demand is lagged to approximate the **Propagation delay** parameter value.

The block output voltage depends on the output model selected:

- For Linear model, output high is the **High level output voltage** parameter value, and output low is the **Low level output voltage** parameter value.
- For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the **Supply voltage** parameter value), and output low is zero volts.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the **Output current-voltage relationship** parameter). This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS NOR

Dialog Box and Parameters

| In | puts | Ta | h |
|----|------|----|---|
| n | puts | IQ | D |

| rameters Inputs Outputs Initial | Conditions | | | |
|------------------------------------|------------|--|----|---|
| Low level input voltage: | 2 | | V | - |
| High level input voltage: | 3 | | V | - |
| Average input capacitance: | 5 | | pF | - |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is **3** V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS NOR | | × |
|--------------------------------------|--|-----------------------|
| CMOS NOR | | |
| | CMOS NOR logic gate. Set the Input low, Input high, Outpu fault values are for a supply voltage of 5 volts. | t low and Output high |
| Parameters | | |
| Inputs Outputs Initial Condition | ;] | |
| Output current-voltage relationship: | Linear | |
| Low level output voltage: | 0 | V |
| High level output voltage: | 5 | V |
| Output resistance: | 25 | Ohm 💌 |
| Propagation delay: | 25 | ns |
| | | |
| | | |
| | OK Cancel | Help Apply |

| ameters | | | |
|--|------------|-----|---|
| Inputs Outputs Initial Condition | 5 | | |
| Output current-voltage relationship: | Quadratic | | • |
| Supply voltage: | 5 | V | • |
| Measurement voltage: | 5 | V | • |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm | • |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA | - |
| Logic LOW output resistance at zero current and at I_OL: | [30 800] | Ohm | - |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA | - |
| Propagation delay: | 25 | ns | • |
| Protection diode on resistance: | 5 | Ohm | • |
| Protection diode forward voltage: | 0.6 | V | - |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| Block Parameters: CM | OS NOR | | × |
|------------------------------|--------------------|--|-------|
| parameters for the supply | | CMOS NOR logic gate. Set the Input low, Input high, Output low and Output high ault values are for a supply voltage of 5 volts. | |
| Parameters Inputs Outputs | Initial Conditions |] | 1 |
| Output initial state: | | Low | |
| | | OK Cancel Help | Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

А

Electrical input port.

В

Electrical input port.

J

Electrical output port.

CMOS NOT

Purpose Model CMOS NOT gate behaviorally

Library Logic

Description

- The CMOS NOT block represents a CMOS NOT logic gate behaviorally:
 - The block output logic level is HIGH if the logic level of the gate input is 0.
 - The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-44 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.

| | • You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the Propagation delay parameter value. For Quadratic output, the gate input demand is lagged to approximate the Propagation delay parameter value. |
|--|---|
| | The block output voltage depends on the output model selected: |
| | • For Linear model, output high is the High level output voltage parameter value, and output low is the Low level output voltage parameter value. |
| | • For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the Supply voltage parameter value), and output low is zero volts. |
| Basic Assumptions and Limitations | The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the Output current-voltage relationship parameter). This limitation has the following implications: |
| | • The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage. |
| | • The block does not accurately model dynamic response. |

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS NOT

Dialog Box and Parameters

Inputs Tab

| ne block implements a simplified mode arameters for the supply voltage use arameters | d. Default values an | | tput low and Output | : high |
|--|----------------------|--|---------------------|--------|
| Inputs Outputs Initial Con | iditions | | | |
| Low level input voltage: | 2 | | V | • |
| High level input voltage: | 3 | | V | • |
| Average input capacitance: | 5 | | pF | • |
| | | | | |
| | | | | |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is **3** V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS NOT | | × | | | | | | | |
|--------------------------------------|--|------------|--|--|--|--|--|--|--|
| CMOS NOT | | | | | | | | | |
| | The block implements a simplified model of a CMOS NOT logic gate. Set the Input low, Input high, Output low and Output high parameters for the supply voltage used. Default values are for a supply voltage of 5 volts. | | | | | | | | |
| Parameters | | | | | | | | | |
| Inputs Outputs Initial Condition | s | | | | | | | | |
| Output current-voltage relationship: | Linear | | | | | | | | |
| Low level output voltage: | 0 | V | | | | | | | |
| High level output voltage: | 5 | V | | | | | | | |
| Output resistance: | 25 | Ohm 💌 | | | | | | | |
| Propagation delay: | 25 | ns | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | OK Cancel | Help Apply | | | | | | | |

| rameters | | |
|--|------------|-------|
| Inputs Outputs Initial Condition | s | |
| Output current-voltage relationship: | Quadratic | • |
| Supply voltage: | 5 | V . |
| Measurement voltage: | 5 | V |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I_OL: | [30 800] | Ohm 💌 |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| Block Parameters: CM CMOS NOT The block implements a sim parameters for the supply | plified model of a Cf | | | | ut low and Output | x high |
|---|-----------------------|-----|---------------------|--------|-------------------|------------------|
| Parameters Outputs | Initial Conditions | | supply volcage of 3 | voits. | | |
| Output initial state: | | Low | | | | • |
| | | | OK | Cancel | Help | Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

А

Electrical input port.

J

Electrical output port.

Purpose Model CMOS OR gate behaviorally

Library Logic

Description The CMOS OR block represents a CMOS OR logic gate behaviorally:

- The block output logic level is HIGH if the logic levels of any of the gate inputs are 1.
 - The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-52 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.
- You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that

the resistor-capacitor time constant equals the **Propagation delay** parameter value. For Quadratic output, the gate input demand is lagged to approximate the **Propagation delay** parameter value.

The block output voltage depends on the output model selected:

- For Linear model, output high is the **High level output voltage** parameter value, and output low is the **Low level output voltage** parameter value.
- For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the **Supply voltage** parameter value), and output low is zero volts.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the **Output current-voltage relationship** parameter). This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

Dialog Box and Parameters

| In | puts | Tab |
|----|------|-----|
| | | |

| Inputs Outputs Initial Co | nditions | | | |
|----------------------------|----------|--|----|---|
| Low level input voltage: | 2 | | V | - |
| High level input voltage: | 3 | | V | - |
| Average input capacitance: | 5 | | pF | • |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is **3** V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🖬 Block Parameters: CMO5 OR | | | | | × |
|---|--------|----|--------|-------------------|--------|
| CMOS OR | | | | | |
| The block implements a simplified model of a parameters for the supply voltage used. D | | | | ow and Output hig | Jh |
| Parameters | | | | | |
| Inputs Outputs Initial Condition | ns | | | | |
| Output current-voltage relationship: | Linear | | | | • |
| Low level output voltage: | 0 | | | ۷ | - |
| High level output voltage: | 5 | | | V | • |
| Output resistance: | 25 | | | Ohm | • |
| Propagation delay: | 25 | | | ns | • |
| | | | | | |
| | | | Cancel | Holp | ů poly |
| | | ОК | Cancel | Help | Apply |

| ameters | | |
|--|------------|-----|
| Inputs Outputs Initial Condition | s | |
| Output current-voltage relationship: | Quadratic | |
| Supply voltage: | 5 | V |
| Measurement voltage: | 5 | V |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I_OL: | [30 800] | Ohm |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| | nplified model of a CI | CMOS OR logic gate. Set the Input low, Input high, Output low and Output high fault values are for a supply voltage of 5 volts. | × |
|-----------------------|------------------------|---|-------|
| Parameters | | | |
| Inputs Outputs | Initial Conditions | 5 | |
| Output initial state: | | Low | • |
| | | OK Cancel Help | Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

А

Electrical input port.

В

Electrical input port.

J

Electrical output port.

CMOS XOR

Purpose Model CMOS XOR gate behaviorally

Library Logic

Description



- The CMOS XOR block represents a CMOS XOR logic gate behaviorally:
 - The block output logic level is HIGH if the logic level of exactly one of the gate inputs is 1.
 - The block output logic level is LOW otherwise.

The block determines the logic levels of the gate inputs as follows:

- If the gate voltage is greater than the threshold voltage, the block interprets the input as logic 1.
- Otherwise, the block interprets the input as logic 0.

The *threshold voltage* is the voltage value at midpoint between the **High level input voltage** parameter value and the **Low level input voltage** parameter value.

Note To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. See "Basic Assumptions and Limitations" on page 1-60 for details.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.
- You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that

the resistor-capacitor time constant equals the **Propagation delay** parameter value. For Quadratic output, the gate input demand is lagged to approximate the **Propagation delay** parameter value.

The block output voltage depends on the output model selected:

- For Linear model, output high is the **High level output voltage** parameter value, and output low is the **Low level output voltage** parameter value.
- For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the **Supply voltage** parameter value), and output low is zero volts.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the **Output current-voltage relationship** parameter). This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.

Circuits that involve a feedback path around a set of logic gates may require a nonzero propagation delay to be set on one or more gates.

CMOS XOR

Dialog Box and Parameters

Inputs Tab

| e block implements a simplified mode rameters for the supply voltage use rameters | | | utput low and Output | : high |
|---|---------|------|----------------------|--------|
| Inputs Outputs Initial Con | ditions | | | |
| Low level input voltage: | 2 | | V | • |
| High level input voltage: | 3 | | V | • |
| Average input capacitance: | 5 | | pF | • |
| | | | | |
| | | | | |
| | | | | |

Low level input voltage

Voltage value below which the block interprets the input voltage as logic LOW. The default value is 2 V.

High level input voltage

Voltage value above which the block interprets the input voltage as logic HIGH. The default value is **3** V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. The MOSFET capacitance depends on the applied voltage. When you drive this block with another gate, the **Average input capacitance** produces a rise time similar to that of the MOSFET. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero may result in faster simulation times.

Outputs Tab

| 🙀 Block Parameters: CMOS XOR | | | | | × |
|---|--------|----|--------|------------------|-------|
| CMOS XOR | | | | | |
| The block implements a simplified model of parameters for the supply voltage used. D | | | | ow and Output hi | gh |
| Parameters | | | | | |
| Inputs Outputs Initial Conditio | ns | | | | |
| Output current-voltage relationship: | Linear | | | | • |
| Low level output voltage: | 0 | | | ۷ | • |
| High level output voltage: | 5 | | | V | • |
| Output resistance: | 25 | | | Ohm | • |
| Propagation delay: | 25 | | | ns | • |
| | | | | | |
| | | | | | |
| | | ОК | Cancel | Help | Apply |

| ameters | | |
|--|------------|-------|
| Inputs Outputs Initial Condition | 5 | |
| Output current-voltage relationship: | Quadratic | • |
| Supply voltage: | 5 | V . |
| Measurement voltage: | 5 | V . |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I OL; | [30 800] | Ohm 💌 |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm |
| Protection diode forward voltage: | 0.6 | V • |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| | nplified model of a Cl | 2MOS XOR logic gate. Set the Input low, Input high, Output low and Output high ault values are for a supply voltage of 5 volts. | × |
|-----------------------|------------------------|--|-------|
| Parameters | | | |
| Inputs Outputs | Initial Conditions | | |
| Output initial state: | | Low | |
| | | OK Cancel Help | Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

The block has the following ports:

Α

Electrical input port.

В

Electrical input port.

J

Electrical output port.

Comparator

| Purpose | Model a | comparator | behaviorally |
|---------|---------|------------|--------------|
|---------|---------|------------|--------------|

Library Integrated Circuits

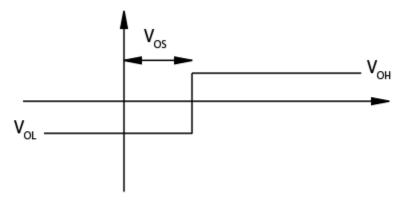
Description



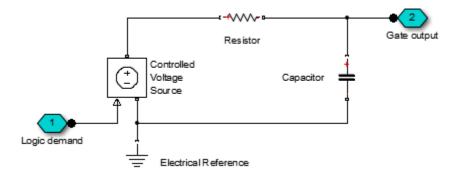
The Comparator block is an abstracted behavioral model of a comparator integrated circuit. It does not model an internal transistor-level implementation. Therefore, the block runs quickly during simulation but retains the correct I/O behavior. The block models differential inputs electrically as having infinite resistance and a finite or zero capacitance.

The block models the gate output as a voltage source driving a series resistor and a capacitor that connects to ground. The output pin connects to the resistor-capacitor connection node. If the difference in the inputs is greater than the input threshold voltage, then the output

is equal to the **High level output voltage** (V_{OL}) . Otherwise, the output is equal to the **Low level output voltage** (V_{OH}) .



The output model is shown in the following illustration.



Basic Assumptions and Limitations

Modeling of the output as a controlled voltage source is representative of a totem-pole or push-pull output stage. To model a device with an open-collector:

- **1** Connect the output pin to the base of an NPN Bipolar Transistor or PNP Bipolar Transistor block.
- 2 Set the **Output resistance** parameter to a suitable value.

Comparator

Dialog Box and Parameters

| Inputs | Tab |
|--------|-----|
|--------|-----|

| 🙀 Block Parameters: Comparator | | | × |
|--|----|-----------|------------------------------|
| Comparator This block implements a simplified mod voltage used. Default output paramet | | | high voltages for the supply |
| Parameters Inputs Outputs | | | 1 |
| Input offset voltage: Average input capacitance: | 5 | | pF V |
| Average input tapatitaine. | Ju | | |
| | | OK Cancel | Help Apply |

Input offset voltage

The voltage which the difference in the input voltages must be greater than so that the comparator gives a logic output 1. The default value is 5 mV.

Average input capacitance

You can usually find this capacitance value on a manufacturer datasheet. The default value is 0 pF. Setting this value to zero can result in faster simulation times.

Outputs Tab

| Block Parameters: Comparator | | | | × |
|--|----|-------|--------------------------------|----------|
| Comparator This block implements a simplified mod voltage used. Default output paramet | | | output high voltages for the s | supply |
| Parameters Inputs Outputs | | | | |
| Low level output voltage: | 0 | | V | - |
| High level output voltage: | 5 | | V | - |
| Output resistance: | 50 | | Ohm | - |
| Propagation delay: | 0 | | s | - |
| | | | | |
| | | OK Ca | ncel Help | Apply |

Low level output voltage

The steady-state output voltage, V_{OL} , when the voltage difference across the inputs is less than or equal to the threshold voltage, and the output current is zero. The default value is 0 V.

High level output voltage

The steady-state output voltage, V_{OH} , when the voltage difference across the inputs is greater than the threshold voltage, and the output current is zero. The default value is 5 V.

Output resistance

This parameter is the ratio of output voltage drop to output

current. Set this parameter to $(V_{OH} - V_{OH1}) / I_{OH1}$, where V_{OH1} is the reduced output high voltage when the output current is

 I_{OH1} . The default value is 50 Ω .

Propagation delay

Set this value based on the high-to-low and low-to-high propagation delays. The default value is 0 s.

| Ports | This block has the following ports: | |
|----------|-------------------------------------|---------------------------------|
| | + | Positive electrical input port. |
| | - | Negative electrical input port. |
| | OUT | Electrical output port. |
| See Also | CMO | DS Buffer . |

Controlled PWM Voltage

Purpose Model pulse-width modulated voltage source

Library Drivers

Description



The Controlled PWM Voltage block represents a pulse-width modulated (PWM) voltage source that depends on the reference voltage V_{ref} across its +ref and -ref ports. The demanded duty cycle is

$$100*rac{V_{ref}-V_{\min}}{V_{\max}-V_{\min}}$$
 percent

where:

- V_{\min} is the minimum reference voltage
- V_{max} is the maximum reference voltage

The value of the **Output voltage amplitude** parameter determines amplitude of the output voltage.

At time zero, the pulse is initialized as high, unless the **Pulse delay time** parameter is greater than zero, or the demanded duty cycle is zero.

You can use parameters **Pulse delay time** and **Pulse width offset** to add a small turn-on delay and a small turn-off advance. This can be useful when fine-tuning switching times so as to minimize switching losses.

In PWM mode, the block has two options for the type of switching event when moving between output high and output low states:

• Asynchronous Best for variable-step solvers — Asynchronous events are better suited to variable step solvers, because they require fewer simulation steps for the same level of accuracy. In asynchronous mode the PWM switching events generate zero crossings, and therefore switching times are always determined accurately, regardless of the simulation maximum step size. • Discrete time Best for fixed-step solvers — Discrete-time events are better suited to fixed-step operation, because then the switching events are always synchronized with the simulation step. Using an asynchronous implementation with fixed-step solvers may sometimes result in events being up to one simulation step late. For more information, see "Simulating with Fixed Time Step — Local and Global Fixed-Step Solvers".

If you use a fixed-step or local solver and the discrete-time switching event type, the following restrictions apply to the **Sample time** parameter value:

- The sample time must be a multiple of the simulation step size.
- The sample time must be small compared to the PWM period, to ensure sufficient resolution.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The REF output of this block is floating, it is not tied to the Electrical Reference. One consequence of this is that if you connect the PWM and REF electrical ports directly to the H-Bridge PWM and REF electrical ports, you must attach an Electrical Reference block to the REF connection line.
- Do not use the Controlled PWM block to drive a motor block directly. A PWM motor driver goes open circuit in between pulses. Use the H-Bridge block to drive a motor block.
- When driving a motor via the H-Bridge block, set the **Simulation mode** parameter to Averaged to speed up simulations. You must also set the **Simulation mode** parameter of the H-Bridge block to Averaged mode. This applies the average of the demanded PWM voltage to the motor. The Averaged mode assumes that the impedance of the motor inductive term is small at the **PWM frequency**. To verify this assumption, run the simulation using the PWM mode and compare the results to those obtained from using the Averaged mode.

- If you are linearizing your model, set the **Simulation mode** parameter to Averaged and ensure that you have specified the operating point of the block correctly. You can only linearize the block for inputs corresponding to a duty cycle greater than zero and less than 100 percent.
- When you use this block in PWM mode with the Use local solver option selected in the Solver Configuration block, set the Switching event type parameter to Discrete time Best for fixed-step solvers. Using the Asynchronous Best for variable-step solvers option in this situation may produce inaccuracies, because simulation with the local solver implies fixed step, and the PWM events will not always coincide precisely with the simulation steps. This results in PWM events sometimes occurring one simulation step late.

Dialog Box and Parameters

🙀 Block Parameters: Controlled PWM Voltage

Controlled PWM Voltage

This block represents a Pulse-Width Modulated (PWM) voltage source across its PWM and REF ports that depends on the reference voltage Vref across its +ref and -ref ports. The duty cycle in percent is given by 100*(Vref-Vmin)/(Vmax-Vmin) where Vmin and Vmax are the minimum and maximum values for Vref. The output voltage is zero when the pulse is low, and is set equal to the Output voltage amplitude parameter who high.

At time zero, the pulse is initialized as high unless the duty cycle is set to zero or the Pulse delay time is greater than zero.

The Simulation mode can be set to PWM or Averaged. In PWM mode, the output is a PWM signal. In Averag mode, the output is constant with value equal to the averaged PWM signal.

| Parameters | | |
|---------------------------------------|---|------|
| PWM frequency: | 1000 | Hz |
| Pulse delay time: | 0 | s |
| Pulse width offset: | 0 | S |
| Input value Vmin for 0% duty cycle: | 0 | ٧ |
| Input value Vmax for 100% duty cycle: | 5 | ٧ |
| Output voltage amplitude: | 5 | V |
| Simulation mode: | PWM | |
| Switching event type: | Asynchronous - Best for variable-step solvers | |
| | OK Cancel | Help |

PWM frequency

Frequency of the PWM output signal. The default value is 1000 Hz.

Pulse delay time

The pulse train does not start until the simulation time is equal to the **Pulse delay time**. You can specify a small value for **Pulse delay time** to fine-tune switching times and ensure that an off-going device is fully off before the on-going device starts to turn on. You can also use larger delay times, for example, if you need the pulse train to start only after a number of cycles. The value you provide must be greater than or equal to zero. This parameter is only visible when you select PWM for the **Simulation mode** parameter. The default value is 0 s.

Pulse width offset

The demanded pulse width as defined by the product of the demanded duty cycle and one over the pulse frequency can be offset by the value you provide for **Pulse width offset**. A positive value acts to lengthen the pulse by a fixed amount. A negative value acts to shorten the pulse. You can use this parameter, along with the **Pulse delay time**, to fine-tune switching times so as to minimize switching losses in some circuits. This parameter is only visible when you select PWM for the **Simulation mode** parameter. The default value is 0 s.

Input value Vmin for 0% duty cycle

Value of the input voltage at which the PWM signal has a 0% duty cycle. The default value is 0 V.

Input value Vmax for 100% duty cycle

Value of the input voltage at which the PWM signal has a 100% duty cycle. The default value is 5 V.

Output voltage amplitude

Amplitude of the PWM signal when the output is high. The default value is 5 V.

Simulation mode

The type of output voltage can be PWM or Averaged. The default mode, PWM, produces a pulse-width modulated signal. In Averaged mode, the output is a constant whose value is equal to the average value of the PWM signal.

Switching event type

This parameter is only visible when you select PWM for the **Simulation mode** parameter. Select the switching event type when moving between output high and output low states:

- Asynchronous Best for variable-step solvers This option is more efficient for desktop simulation with variable-step solvers, because it requires fewer simulation steps for the same level of accuracy. This is the default.
- Discrete time Best for fixed-step solvers Use with fixed-step solvers, including the local solver. For more information, see "Simulating with Fixed Time Step Local and Global Fixed-Step Solvers".

Sample time

The time between updates of the block output state. The sample time must be a multiple of the simulation step size. In order for the PWM control to have sufficient resolution, set the sample time to less than one hundredth of the PWM period. (The PWM period is one over the PWM frequency.) This parameter is only visible when you select Discrete time Best for fixed-step solvers for the Switching event type parameter. The default value is 1e-6 s.

Ports The block has the following ports:

+ref

Positive electrical reference voltage.

-ref

Negative electrical reference voltage.

| | PWM Pulse-width modulated signal. |
|----------|---|
| | REF Floating zero volt reference. |
| Examples | See the Linear Electrical Actuator (System-Level Model) and Linear Electrical Actuator (Implementation Model) examples. |
| See Also | Stepper Motor Driver |

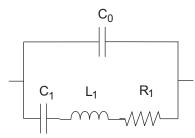
Crystal

- PurposeModel stable resonator
- **Library** Passive Devices

Description

•-**-**

The Crystal block represents the electrical characteristics of a crystal. The following figure shows the equivalent circuit model of the Crystal block.



You specify the equivalent circuit parameters for this model when you set the **Parameterization** parameter to Equivalent circuit parameters.

- The capacitor *C0* corresponds to the capacitance you specify in the **Shunt capacitance**, **C0** parameter.
- The capacitor *C1* corresponds to the capacitance you specify in the **Motional capacitance**, **C1** parameter.
- The inductor *L1* corresponds to the inductance you specify in the **Motional inductance**, **L1** parameter.
- The resistor *R1* corresponds to the resistance you specify in the **Equivalent series resistance**, **R1** parameter.

Most datasheets specify crystal frequency rather than inductance, so the block optionally accepts frequency data. • When you set the **Parameterization** parameter to Series resonance data, the block uses the following relationship to calculate *L1* from the series resonant frequency:

$$f_s = \frac{1}{2\pi\sqrt{L_1C_1}}$$

Where f_s is the **Series resonance**, **fs** parameter value.

• When you set the **Parameterization** parameter to **Parallel** resonance data, the block uses the following relationship to calculate *L1* from the parallel resonant frequency:

$$f_a = \frac{1}{2\pi \sqrt{L_1 C_1 (C_0 + C_L)/(C_1 + C_0 + C_L)}}$$

Where:

- f_a is the **Parallel resonance**, fa parameter value.
- C_L is the **Load capacitance**, **CL** parameter value.

Some datasheets specify quality factor rather than equivalent series resistance, so the block optionally accepts quality factor data. When you set the **R1 parameterization** parameter to Quality factor Q, the block uses the following relationship to calculate R1 from the quality factor:

$$Q = \frac{2\pi f L_1}{R_1}$$

Where Q is the **Quality factor**, \mathbf{Q} parameter value.

Note The **R1 parameterization** parameter is only visible when you select Series resonance data or Parallel resonance data for the **Parameterization** parameter.

Basic Assumptions and Limitations

Dialog Box and Parameters

| 🙀 Block Parameters: Crystal | | × |
|--|---|-----------------------|
| Crystal | | |
| This block implements an electrical equi represent the mechanical dynamics, p | uivalent circuit for a crystal. The equivalent circuit consists of a s olus a parallel shunt capacitance C0. | eries R1-L1-C1 arm to |
| Parameters | | |
| Parameterization: | Series resonance data | • |
| Series resonance, fs: | 32.764 | kHz 💌 |
| R1 parameterization: | Equivalent series resistance R1 | • |
| Equivalent series resistance, R1: | 15 | kOhm |
| Motional capacitance, C1: | 0.0035 | pF 💌 |
| Shunt capacitance, C0: | 1.6 | pF 💌 |
| Initial voltage: | 0 | V |
| | | |
| | OK Cancel | Help Apply |

The Crystal block models only the fundamental crystal vibration mode.

Parameterization

Select one of the following methods for block parameterization:

- Series resonance data Provide series resonant frequency and capacitance data for the crystal. This method is the default.
- Parallel resonance data Provide parallel resonant frequency and capacitance data for the crystal.
- Equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the crystal.

Series resonance, fs

Crystal series resonant frequency. This parameter is only visible when you select Series resonance data for the **Parameterization** parameter. The default value is 32.764 kHz.

Parallel resonance, fa

Crystal parallel resonant frequency that corresponds to operating with a parallel load capacitance specified by the **Load capacitance**, **CL** parameter. This parameter is only visible when you select Parallel resonance data for the **Parameterization** parameter. The default value is 32.768 kHz.

Motional inductance, L1

Inductance that represents the mechanical mass of the crystal. This parameter is only visible when you select Equivalent circuit parameters for the **Parameterization** parameter. The default value is 6.742e+03 H.

R1 parameterization

Select one of the following methods for series resistance parameterization:

- Equivalent series resistance R1 Provide the resistance value directly. This is the default method.
- Quality factor Q Provide the quality factor that the block uses to calculate the resistance value.

This parameter is only visible when you select Series resonance data or Parallel resonance data for the **Parameterization** parameter.

Quality factor, Q

Crystal quality factor. This parameter is only visible when you make one of the following selections:

• Series resonance data for the **Parameterization** parameter and Quality factor Q for the **R1 parameterization** parameter • Parallel resonance data for the **Parameterization** parameter and Quality factor Q for the **R1 parameterization** parameter The default value is 9e+04.

Equivalent series resistance, R1

Motional damping term. This parameter is only visible when you make one of the following selections:

- Series resonance data for the **Parameterization** parameter and Equivalent series resistance R1 for the **R1 parameterization** parameter
- Parallel resonance data for the **Parameterization** parameter and Equivalent series resistance R1 for the **R1 parameterization** parameter
- Equivalent circuit parameters for the **Parameterization** parameter

The default value is $15~\mathrm{k}\Omega.$

Motional capacitance, C1

Capacitance that represents crystal mechanical stiffness under load. The default value is 0.0035 pF.

Load capacitance, CL

Load capacitance that corresponds to the **Parallel resonance**, **fa** parameter value. This parameter is only visible when you select Parallel resonance data for the **Parameterization** parameter. The default value is **12.5** pF.

Shunt capacitance, C0

Electrical capacitance between the two crystal electrical connections. The parameter value must be greater than zero. The default value is **1.6** pF.

Initial voltage

The output voltage at the start of the simulation when the output current is zero. The default value is 0 V.

Ports The block has the following ports:

Crystal

Positive electrical port.

+

-

Negative electrical port.

 Purpose
 Model current-controlled switch with hysteresis

SPICE-Compatible Components/Passive Devices

Description

Library



The Current-Controlled Switch block represents the electrical characteristics of a switch whose state is controlled by the current through the input ports (the *controlling current*):

- When the controlling current is greater than the sum of the **Threshold current, IT** and **Hysteresis current, IH** parameter values, the switch is closed and has a resistance equal to the **On resistance, RON** parameter value.
- When the controlling current is less than the **Threshold current**, **IT** parameter value minus the **Hysteresis current**, **IH** parameter value, the switch is open and has a resistance equal to the **Off resistance**, **ROFF** parameter value.
- When the controlling current is greater than or less than the **Threshold current, IT** parameter value by an amount less than or equal to the **Hysteresis current, IH** parameter value, the current is in the *crossover region* and the state of the switch remains unchanged.

Basic Assumptions and Limitations

The block output resistance model is discontinuous during switching. The discontinuity might cause numerical issues. Try the following actions to resolve the issues:

- Set the **On resistance**, **RON** and **Off resistance**, **ROFF** parameter values to keep the ratio *RON/ROFF* as small as possible, and less than 1e+12.
- Increase the **Hysteresis current**, **IH** parameter value to reduce switch chatter.
- Decrease the **Max step size** parameter value (in the Configuration Parameters block dialog box).

Note This increases the simulation time.

| Dial | og |
|------|---------|
| Box | and |
| Parc | Imeters |

| The block represents a current of the hysteresis current the switch the threshold current minus the l | n is closed and its resistan hysteresis current then th | ce value is RON. If the switch is open and | ne controlling curre | ent is less than the | e difference of |
|---|--|--|----------------------|----------------------|-----------------|
| current value is within the crosso | over region, the switch po | isition is unchanged. | | | |
| Parameters | | | | | |
| Threshold current, IT: | 0 | | | A | - |
| Hysteresis current, IH: | 0 | | | A | • |
| On resistance, RON: | 1 | | | Ohm | • |
| Off resistance, ROFF: | 1e+12 | | | Ohm | |
| Initial switch state: | On | | | | • |

Threshold current, IT

The current above which the block interprets the controlling current as HIGH. The default value is 0 A.

Note The controlling current must differ from the threshold current by at least the **Hysteresis current**, **IH** parameter value to change the state of the switch.

Hysteresis current, IH

The amount by which the controlling current must exceed or fall below the **Threshold current**, **IT** parameter value to change the state of the switch. The default value is **0** A.

| | On resistance, RON The resistance of the switch when it is closed. The default value is 1 Ω . |
|-------|---|
| | Off resistance, ROFF The resistance of the switch when it is open. The default value is $1e+12 \Omega$. |
| | Initial switch state Select one of the following options for the state of the switch at the start of the simulation: |
| | • On — The switch is initially closed and its resistance value is equal to the On resistance , RON parameter value. This is the default option. |
| | • Off — The switch is initially open and its resistance value is equal to the Off resistance , ROFF parameter value. |
| Ports | The block has the following ports: |
| | + Positive electrical input and output ports. |
| | - Negative electrical input and output ports. |

Current Source

| Purpose | Simulate current source with DC, AC, and noise components |
|---------|---|
|---------|---|

Library Sources

Description

The Current Source block implements a current source with DC, AC, and noise components. The current flowing through the source from the – terminal to the + terminal is given by:

```
i = i_{DC} + i_{AC} \sin\left(2\pi f t + \phi\right) + i_N
```

where:

- $i_{\rm DC}$ is the steady-state DC current component.
- i_{AC} is the amplitude of the AC current component.
- *f* is the frequency of the AC component.
- φ is the phase offset of the AC component.
- $i_{\rm N}$ is the noise current.

You can configure your source as DC-only, AC-only, or a combination of both. By default, both AC and DC components are set to 0. Define the AC/DC current by specifying nonzero parameter values after placing the block in your model.

The noise component is also optional. If you set the **Noise mode** parameter to **Enabled**, then the added noise current is given by:

$$i_N = \sqrt{P_i/2} \frac{N(0,1)}{\sqrt{h}}$$

where:

- $P_{\rm i}$ is the single-sided noise power spectral density for a 1 ohm load, in A^2/Hz.

- *N* is a Gaussian random number with zero mean and standard deviation of one.
- *h* is the sampling interval.

By default, the **Noise mode** parameter is set to **Disabled**, and the current source generates no thermal noise.

Noise Options

The block generates Gaussian noise by using the Random Number source in the Simscape Foundation library. You can control the random number seed by setting the **Repeatability** parameter:

• Not repeatable — Every time you simulate your model, the block resets the random seed using the MATLAB[®] random number generator:

seed = $randi(2^{32-1});$

- Repeatable The block uses a hidden parameter, called auto_seed, to always start the simulation with the same random number. The value of auto_seed is set whenever you copy the Resistor block from the block library to the model, or when you make a new copy of the Resistor block from an existing one in a model. The block sets the value using the MATLAB random number generator command shown above.
- Specify seed If you select this option, the additional **Seed** parameter lets you directly specify the random number seed value.

Basic Assumptions and Limitations

Simulating with noise enabled slows down simulation. Choose the sample time (h) so that noise is generated only at frequencies of interest, and not higher.

Dialog DC & AC Components Tab Box and Parameters

| Block Parameters: Current Source | | | | |
|---|----|----------------|--|--|
| Current Source | | | | |
| This block models a current source with DC, AC and noise components. The output current is defined by $i = i_dc + i_ac * sin(2*pi*f*t + phi) + i_n$ where i_dc is the DC amplitude, i_ac is the peak AC amplitude, f is the frequency, phi is the phase shift and i_n is the noise current. | | | | |
| Parameters | | | | |
| DC & AC Components Noise | | | | |
| DC current: | 0 | A • | | |
| AC current peak amplitude: | 0 | A • | | |
| AC current phase shift: | 0 | deg 👻 | | |
| AC current frequency: | 60 | Hz ▼ | | |
| <u>[</u> | | | | |
| | OK | cel Help Apply | | |

DC current

The DC component of the output current. The default value is 0 A. Enter a nonzero value to add a DC component to the current source.

AC current peak amplitude

Amplitude of the AC component of the output current. The default value is 0 A. Enter a nonzero value to add an AC component to the current source.

AC current phase shift

Phase offset of the AC component of the output current. The default value is **0** degrees.

AC current frequency

Frequency of the AC component of the output current. The default value is $60\ \mathrm{Hz}.$

Noise Tab

| 📔 Block Parameters: Current Source | | | | |
|---|----------------------|--|--|--|
| Current Source | | | | |
| This block models a current source with DC, AC and noise components. The output current is defined by $i = i_dc + i_ac * sin(2*pi*f*t + phi) + i_n$ where i_dc is the DC amplitude, i_ac is the peak AC amplitude, f is the frequency, phi is the phase shift and i_n is the noise current. | | | | |
| Parameters | Parameters | | | |
| DC & AC Components Noise | | | | |
| Noise mode: | Disabled 🔹 | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | OK Cancel Help Apply | | | |

Noise mode

Select the noise option:

- **Disabled** No noise is produced by the current source. This is the default.
- Enabled The current source generates thermal noise, and the associated parameters become visible on the **Noise** tab.

Power spectral density

The single-sided spectrum noise power. Strictly-speaking, this is a density function for the square of the current, commonly thought

of as a power into a 1 ohm load, and therefore units are A^2/Hz . To avoid this unit ambiguity, some datasheets quote noise current as a noise density with units of A/\sqrt{Hz} . In this case, you should enter the square of the noise density quoted in the datasheet as the parameter value. The default value is 0 A^2/Hz .

Sample time

Defines the rate at which the noise source is sampled. Choose it to reflect the frequencies of interest in your model. Making the sample time too small will unnecessarily slow down your simulation. The default value is 1e-3 s.

Repeatability

Select the noise control option:

- Not repeatable The random sequence used for noise generation is not repeatable. This is the default.
- Repeatable The random sequence used for noise generation is repeatable, with a system-generated seed.
- Specify seed The random sequence used for noise generation is repeatable, and you control the seed by using the Seed parameter.

Seed

Random number seed used by the noise random number generator. This parameter is visible only if you select Specify seed for the **Repeatability** parameter. The default value is 0.

Ports The block has the following ports:

Positive electrical port.

Negative electrical port.

See Also Resistor, Voltage Source.

+

DC Current Source

| Purpose Mode | l constant current source |
|--------------|---------------------------|
|--------------|---------------------------|

Library SPICE-Compatible Components/Sources

Description The DC Current Source block represents a constant current source whose output current value is independent of the voltage across its terminals.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the + and - ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e–12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

| Dialog _. | Block Parameters: DC Current Source | | | |
|-----------------------|---|--|--|--|
| Box and Parameters | DC Current Source The DC Current Source block maintains a time-invariant (constant) current through its terminals, independent of the voltage across its terminals. The SPICE AC parameters are not supported. | | | |
| | Parameters Constant value, DC: 0 A | | | |
| | OK Cancel Help Apply | | | |

Constant value, DC

The value of the DC output current. The default value is 0 A.

Ports The block has the following ports:

DC Current Source

Positive electrical voltage.

Negative electrical voltage.

See Also DC Voltage Source

+

_

Purpose DC motor model with electrical and torque characteristics

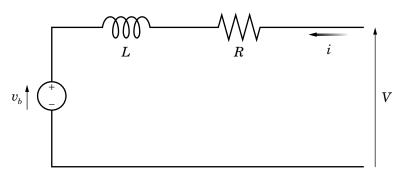
Rotational Actuators

Description

Library

| _ 1 | ţ |
|----------------|-----|
| Q | ·-@ |
| | ę |

The DC Motor block represents the electrical and torque characteristics of a DC motor using the following equivalent circuit model:



You specify the equivalent circuit parameters for this model when you set the **Model parameterization** parameter to By equivalent circuit parameters. The resistor R corresponds to the resistance you specify in the **Armature resistance** parameter. The inductor L corresponds to the inductance you specify in the **Armature inductance** parameter. The permanent magnets in the motor induce the following back emf $v_{\rm b}$ in the armature:

 $v_h = k_v \omega$

where k_v is the **Back-emf constant** and ω is the angular velocity. The motor produces the following torque, which is proportional to the motor current *i*:

$$T_E = k_t i$$

where k_t is the **Torque constant**. The DC Motor block assumes that there are no electromagnetic losses. This means that mechanical power is equal to the electrical power dissipated by the back emf in the armature. Equating these two terms gives:

 $T_E \omega = v_b i$ $k_t i \omega = k_v \omega i$ $k_v = k_t$

As a result, you specify either k_v or k_t in the block dialog box.

The torque-speed characteristic for the DC Motor block is related to the parameters in the preceding figure. When you set the **Model parameterization** parameter to By stall torque & no-load speed or By rated power, rated speed & no-load speed, the block solves for the equivalent circuit parameters as follows:

- **1** For the steady-state torque-speed relationship, *L* has no effect.
- **2** Sum the voltages around the loop and rearrange for *i*:

$$i = \frac{V - v_b}{R} = \frac{V - k_v \omega}{R}$$

3 Substitute this value of *i* into the equation for torque:

$$T_E = \frac{k_t}{R} \left(V - k_v \omega \right)$$

When you set the **Model parameterization** parameter to By stall torque & no-load speed, the block uses the preceding equation to determine values for R and k_t (and equivalently k_v).

When you set the **Model parameterization** parameter to By rated power, rated speed & no-load speed, the block uses the rated speed and power to calculate the rated torque. The block uses the rated torque and no-load speed values in the preceding equation to determine values for R and k_t . The block models motor inertia J and damping λ for all values of the **Model parameterization** parameter. The resulting torque across the block is:

$$T = \frac{k_t}{R} (V - k_v \omega) - J \dot{\omega} - \lambda \omega$$

It is not always possible to measure rotor damping, and rotor damping is not always provided on a manufacturer datasheet. An alternative is to use the no-load current to infer a value for rotor damping.

For no-load, the electrically-generated mechanical torque must equal the rotor damping torque:

$$k_t i_{noload} = \lambda \omega_{noload}$$

where i_{noload} is the no-load current. If you select By no-load current for the **Rotor damping parameterization** parameter, then this equation is used in addition to the torque-speed equation to determine values for λ and the other equation coefficients.

The value for rotor damping, whether specified directly or in terms of no-load current, is taken into account when determining equivalent circuit parameters for **Model parameterization** options By stall torque and no-load speed and By rated power, rated speed and no-load speed.

When a positive current flows from the electrical + to - ports, a positive torque acts from the mechanical C to R ports.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box. Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

Dialog Electrical Torque Tab Box and Parameters

| 🙀 Block Parameters: DC Motor | | | | |
|--|--|--|--|--|
| DC Motor | | | | |
| This block represents the electrical and torque characteristics of a DC motor. | | | | |
| same numerical value when in SI un speed and stall torque. If no informa small non-zero value. When a positive current flows from t | agnetic energy is lost, and hence the back-emf and its. Motor parameters can either be specified direct tion is available on armature inductance, this param the electrical + to - ports, a positive torque acts from changed by altering the sign of the back-emf or toro | ly, or derived from no-load heter can be set to some n the mechanical C to R | | |
| Parameters Electrical Torque Mechanical | | | | |
| Model parameterization: By equivalent circuit parameters | | | | |
| Armature resistance: | 3.9 | Ohm 👻 | | |
| Armature inductance: | 1.2e-5 | H 🔻 | | |
| Define back-emf or torque constant: | Specify back-emf constant | • | | |
| Back-emf constant: | 7.2e-5 | V/rpm 👻 | | |
| Rotor damping parameterization: | By damping value | • | | |
| | OK Cancel | Help Apply | | |

Model parameterization

Select one of the following methods for block parameterization:

- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor. This is the default method.
- By stall torque & no-load speed Provide torque and speed parameters that the block converts to an equivalent circuit model of the motor.
- By rated power, rated speed & no-load speed Provide power and speed parameters that the block converts to an equivalent circuit model of the motor.

Armature resistance

Resistance of the conducting portion of the motor. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is 3.9Ω .

Armature inductance

Inductance of the conducting portion of the motor. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. The default value is 1.2e-05 H.

Define back-emf or torque constant

Indicate whether you will specify the motor's back-emf constant or torque constant. When you specify them in SI units, these constants have the same value, so you only specify one or the other in the block dialog box. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is Specify back-emf constant.

Back-emf constant

The ratio of the voltage generated by the motor to the speed at which the motor is spinning. The default value is 7.2e-05 V/rpm. This parameter is only visible when you select Specify back-emf constant for the **Define back-emf or torque constant** parameter.

Torque constant

The ratio of the torque generated by the motor to the current delivered to it. This parameter is only visible when you select Specify torque constant for the **Define back-emf or torque constant** parameter. The default value is 6.876e-04 N*m/A.

Stall torque

The amount of torque generated by the motor when the speed is approximately zero. This parameter is only visible when you select By stall torque & no-load speed for the **Model parameterization** parameter. The default value is 2.4e-04 N*m.

No-load speed

Speed of the motor when not driving a load. This parameter is only visible when you select By stall torque & no-load speed or By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 1.91e+04 rpm.

Rated speed (at rated load)

Motor speed at the rated mechanical power level. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 1.5e+04 rpm.

Rated load (mechanical power)

The mechanical power the motor is designed to deliver at the rated speed. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 0.08 W.

Rated DC supply voltage

The voltage at which the motor is rated to operate. This parameter is only visible when you select By stall torque & no-load speed or By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 1.5 V.

Rotor damping parameterization

Select one of the following methods to specify rotor damping:

- By damping value Specify a value for rotor damping directly, by using the **Rotor damping** parameter on the **Mechanical** tab. This is the default.
- By no-load current The block calculates rotor damping based on the values that you specify for the No-load current and DC supply voltage when measuring no-load current parameters. If you select this option, the Rotor damping parameter is not available on the Mechanical tab.

No-load current

Specify the no-load current value, to be used for calculating the rotor damping. This parameter is only visible when you select By no-load current for the **Rotor damping parameterization** parameter. The default value is 0 A.

DC supply voltage when measuring no-load current

Specify the DC supply voltage corresponding to the no-load current value, to be used for calculating the rotor damping. This parameter is only visible when you select By no-load current for the **Rotor damping parameterization** parameter. The default value is 1.5 V.

Mechanical Tab

| 🙀 Block Parameters: DC Motor | | | | | |
|---|-----------|---------------|--|--|--|
| DC Motor | | | | | |
| This block represents the electrical and torque characteristics of a DC motor. | | | | | |
| The block assumes that no electromagnetic energy is lost, and hence the back-emf and torque constants have the same numerical value when in SI units. Motor parameters can either be specified directly, or derived from no-load speed and stall torque. If no information is available on armature inductance, this parameter can be set to some small non-zero value. When a positive current flows from the electrical + to - ports, a positive torque acts from the mechanical C to R ports. Motor torque direction can be changed by altering the sign of the back-emf or torque constants. | | | | | |
| Parameters | | | | | |
| Electrical Torque Mechanical | | | | | |
| Rotor inertia: | 0.01 | g*cm^2 ▼ | | | |
| Rotor damping: | 0 | N*m/(rad/s) - | | | |
| Initial rotor speed: | 0 | rpm 🔻 | | | |
| | | | | | |
| | OK Cancel | Help Apply | | | |

Rotor inertia

Resistance of the rotor to change in motor motion. The default value is $0.01 \text{ g}^{*}\text{cm}^{2}$. The value can be zero.

Rotor damping

Energy dissipated by the rotor. This parameter is only visible when you select By damping value for the **Rotor damping**

DC Motor

| | parameterization parameter on the Electrical tab. The defauvalue is $1e-08$ N*m/(rad/s). The value can be zero. | | | | | | |
|------------|---|--|--|--|--|--|--|
| | Initial rotor speed Speed of the rotor at the start of the simulation. The default value is 0 rpm. | | | | | | |
| Ports | The block has the following ports: | | | | | | |
| | + Positive electrical input. | | | | | | |
| | - Negative electrical input. | | | | | | |
| | C Mechanical rotational conserving port. | | | | | | |
| | R Mechanical rotational conserving port. | | | | | | |
| Examples | See the following DC motor examples: | | | | | | |
| | • Linear Electrical Actuator (Motor Model) | | | | | | |
| | Linear Electrical Actuator (System-Level Model) | | | | | | |
| | Linear Electrical Actuator (Implementation Model) | | | | | | |
| References | [1] Bolton, W. Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 3rd edition Pearson Education, 2004. | | | | | | |
| See Also | Induction Motor, Servomotor, Shunt Motor, and Universal Motor. | | | | | | |

| Purpose | Model constant voltage source |
|-------------|---|
| Library | SPICE-Compatible Components/Sources |
| Description | The DC Voltage Source block represents a constant voltage source whose output voltage value is independent of the current through the source. |

Dialog Box and Parameters

Ÿ

| Block Parameter: | s: DC Voltage Source | | × | | |
|--|----------------------|-----------|-------|--|--|
| DC Voltage Source— | | | | | |
| The DC Voltage Source block maintains a time-invariant (constant) voltage across its output terminals, independent of the current through the source. The SPICE AC parameters are not supported. | | | | | |
| Parameters | | | | | |
| Constant value, DC: | 0 | V | • | | |
| | | | | | |
| | OK Ca | ncel Help | Apply | | |

Constant value, DC

The value of the DC output voltage. The default value is $0\ V.$

| Ports | The block has the following ports: | | | |
|-------|------------------------------------|--|--|--|
| | + Positive electrical voltage. | | | |
| | - Negative electrical voltage. | | | |
| C A1 | | | | |

See Also DC Current Source

DC-DC Converter

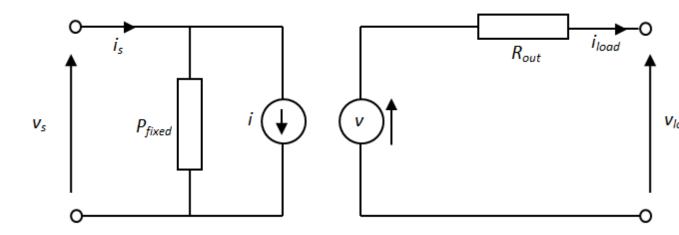
Library Sources

Description



The DC-DC Converter block represents a behavioral model of a power converter. This power converter regulates voltage on the load side, and the required amount of power is drawn from the supply side so as to balance input power, output power, and losses. Optionally the converter can support regenerative power flow from load to supply.

The following circuit illustrates the behavior of the converter.



The $P_{\rm fixed}$ component draws a constant power, and corresponds to converter losses that are independent of load current. The power drawn is set by the **Fixed converter losses independent of loading** parameter value. The resistor $R_{\rm out}$ corresponds to losses that increase with load current, and is determined from the value you specify for the **Percentage efficiency at rated output power** parameter.

The voltage source is defined by the following equation:

 $v = v_{\rm ref} - i_{\rm load}D + i_{\rm load}R_{\rm out}$

where:

- $v_{\rm ref}$ is the load side voltage set point, as defined by the value you specify for the **Output voltage reference demand** parameter.
- *D* is the value you specify for the **Output voltage droop with output current** parameter. Having a separate value for droop makes control of how output voltage varies with load independent of load-dependent losses.

The current source value i is calculated so that the power flowing in to the converter equals the sum of the power flowing out plus the converter losses.

If the voltage presented by the load is higher than the converter output voltage reference demand, then power will flow from the load to the converter. If you set the **Power direction** parameter to Unidirectional power flow from supply to regulated side, then the power is absorbed by the converter, and the current source current iis zero. If you set the **Power direction** parameter to **Bidirectional** power flow, then the power is transmitted to the supply side, and i becomes negative.

Optionally the block can include voltage regulation dynamics. If you select Specify voltage regulation time constant for the **Dynamics** parameter, then a first-order lag is added to the equation defining the voltage source value. With the dynamics enabled, a step change in load results in a transient change in output voltage, the time constant being defined by the **Voltage regulation time constant** parameter.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The two electrical networks connected to the supply-side and regulated-side terminals must each have their own Electrical Reference block.
- The supply-side equation defines a power constraint on the product of the voltage (v_s) and the current (i_s) . For simulation, the solver

must be able to uniquely determine $v_{\rm s}.$ To ensure that the solution is unique, the block implements two assertions:

- $v_s > 0$
- $i_{\rm s} < i_{\rm max}$

The first assertion ensures that the sign of v_s is uniquely defined. The second deals with the case when the voltage supply to the block has a series resistance. When there is a series resistance, there are two possible steady-state solutions for i_s that satisfy the power constraint, the one with the smaller magnitude being the desired one. You should set the value for the **Maximum expected supply-side current** parameter (i_{max}) to be larger than the expected maximum current. This will ensure that when the model is initialized the initial current does not start at the undesired solution.

Dialog Box and Parameters

- "Main Tab" on page 1-109
- "Losses Tab" on page 1-111
- "Dynamics Tab" on page 1-113

Main Tab

| Block Parameters: DC-DC Converter | | | | | | | |
|--|---|---------------------|--|--|--|--|--|
| DC-DC Converter | | | | | | | |
| Behavioral model of an ideal DC-DC converter. The block can be used to represent unidirectional or bidirection converters without the need to simulate individual switching events. The supply-side can be connected to an voltage, and the regulated-side voltage has optional droop. | | | | | | | |
| Note that the two electrical networks Electrical Reference block. | s connected to the primary and secondary windings r | nust each have thei | | | | | |
| Parameters | | | | | | | |
| Main Losses Dynamics | | | | | | | |
| Output voltage reference demand: | 10 | V | | | | | |
| Output voltage droop with output current: | 0.1 | Ohm | | | | | |
| Power direction: | Unidirectional power flow from supply to regulated | side | | | | | |
| Maximum expected supply-side current: | 2 | A | | | | | |
| | OK Cancel | Help | | | | | |

Output voltage reference demand

The set point for the voltage regulator, and the output voltage value when there is no output current. The default value is 10 V.

Output voltage droop with output current

The number of volts that the output voltage will drop from the set point for an output current of 1 A. The default value is 0.1 V/A.

Power direction

Select one of the following methods for the direction of power conversion:

- Unidirectional power flow from supply to regulated side Most small power regulators are unidirectional. This is the default option.
- Bidirectional power flow Larger power converters can be bidirectional, for example, converters used in electric vehicles to allow regenerative braking

Maximum expected supply-side current

Set this value to a value greater than the maximum expected supply-side current in your model. Using twice the expected maximum current is generally sufficient. For more information, see "Basic Assumptions and Limitations" on page 1-107. The default value is 2 A.

Losses Tab

| Block Parameters: DC-DC Converter | | | | | | |
|---|---|---------------------|--|--|--|--|
| DC-DC Converter | | | | | | |
| Behavioral model of an ideal DC-DC converter. The block can be used to represent unidirectional or bidirect converters without the need to simulate individual switching events. The supply-side can be connected to an voltage, and the regulated-side voltage has optional droop. | | | | | | |
| Note that the two electrical networks Electrical Reference block. | s connected to the primary and secondary windings | must each have thei | | | | |
| Parameters | | | | | | |
| Main Losses Dynamics | | | | | | |
| Rated output power: | 10 | W | | | | |
| Percentage efficiency at rated output power: | 80 | | | | | |
| Fixed converter losses independent of loading: | 1 | W | | | | |
| | | | | | | |
| | | | | | | |
| | OK Cancel | Help | | | | |

Rated output power

The output power for which the percentage efficiency value is given. The default value is 10 W.

Percentage efficiency at rated output power

The efficiency as defined by 100 times the output load power divided by the input supply power. The default value is **80** percent.

Fixed converter losses independent of loading

The power drawn by the P_{fixed} component in the equivalent circuit diagram, which corresponds to converter losses that are independent of load current. The default value is 1 W.

Dynamics Tab

| Block Parameters: DC-DC Converter | | | | | | | |
|---|--|--|--|--|--|--|--|
| DC-DC Converter | | | | | | | |
| Behavioral model of an ideal DC-DC converter. The block can be used to represent unidirectional or bidirection converters without the need to simulate individual switching events. The supply-side can be connected to any voltage, and the regulated-side voltage has optional droop. | | | | | | | |
| Note that the two electrical networks connected to the primary and secondary windings must each have their Electrical Reference block. | | | | | | | |
| Parameters | | | | | | | |
| Main Losses Dynamics | | | | | | | |
| Dynamics: No dynamics | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| OK Cancel Help | | | | | | | |

Dynamics

Specify whether to include voltage regulation dynamics:

• No dynamics — Do not consider the voltage regulation dynamics. This is the default option.

• Specify voltage regulation time constant — Add a first-order lag to the equation defining the voltage source value. With the dynamics enabled, a step change in load results in a transient change in output voltage.

Voltage regulation time constant

The time constant associated with voltage transients when the load current is stepped. This parameter is only visible when you select Specify voltage regulation time constant for the **Dynamics** parameter. The default value is 0.02 s.

Initial output voltage demand

This is the value of $v_{\rm ref}$ at time zero. Normally, $v_{\rm ref}$ is defined by the **Output voltage reference demand** parameter. However, if you want to initialize the model with no transients when delivering a steady-state load current, you can set the initial $v_{\rm ref}$ value by using this parameter, and increase it accordingly to take account of output resistance and droop. This parameter is only visible when you select Specify voltage regulation time constant for the **Dynamics** parameter. The default value is 10 V.

Ports The block has four electrical conserving ports. Polarity is indicated by the + and - signs.

Purpose Diode model; piecewise linear, piecewise linear zener, or exponential diode

Library Semiconductor Devices

Description The Diode block represents one of the following types of diodes:

- ▫+ੑੑੑੑੑੑੑੑੑੑੑੑੑੑ
- "Piecewise Linear" on page 1-115
- "Piecewise Linear Zener" on page 1-115
- "Exponential" on page 1-116

Piecewise Linear

The piecewise linear diode model is the same model found in the Simscape Diode block, with the addition of a fixed junction capacitance. If the diode forward voltage exceeds the value specified in the **Forward voltage** parameter, the diode behaves as a linear resistor with the resistance specified in the **On resistance** parameter. Otherwise, the diode behaves as a linear resistor with the small conductance specified in the **Off conductance** parameter. Zero voltage across the diode results in zero current flowing.

Piecewise Linear Zener

The piecewise linear zener diode model behaves like the piecewise linear diode model for bias voltages above -Vz, where Vz is the **Reverse breakdown voltage Vz** parameter value. For voltages less than -Vz, the diode behaves as a linear resistor with the low Zener resistance specified in the **Zener resistance Rz** parameter. This diode model also includes a fixed junction capacitance.

Note The **Reverse breakdown voltage Vz** parameter is defined as a positive number. The p-n voltage at breakdown is -Vz, which is negative.

Exponential

The exponential diode model provides the following relationship between the diode current I and the diode voltage V:

$$I = IS \cdot \left(e^{\frac{qV}{NkT_{m1}}} - 1 \right) \qquad V > -BV$$
$$I = -IS \cdot \left(e^{\frac{-q(V+Vz)}{kT_{m1}}} - e^{\frac{qV}{NkT_{m1}}} \right) \qquad V \le -BV$$

where:

- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e–23 J/K).
- BV is the Reverse breakdown voltage BV parameter value.
- *N* is the emission coefficient.
- *IS* is the saturation current.
- T_{m1} is the temperature at which the diode parameters are specified, as defined by the **Measurement temperature** parameter value.

When $(qV / NkT_{m1}) > 80$, the block replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV / NkT_{m1} - 79)e^{80}$, which matches the gradient of the diode current at $(qV / NkT_{m1}) = 80$ and extrapolates linearly. When $(qV / NkT_{m1}) < -79$, the block

replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV / NkT_{m1} + 80)e^{-79}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

When you select Use parameters IS and N for the Parameterization parameter, you specify the diode in terms of the Saturation current

IS and **Emission coefficient N** parameters. When you select Use I-V curve data points for the **Parameterization** parameter, you specify two voltage and current measurement points on the diode I-V curve and the block derives the *IS* and *N* values. The block then calculates *IS* and *N* as follows:

- $N = ((V_1 V_2) / V_t) / (\log(I_1) \log(I_2))$
- IS = $(I_1 / (\exp(V_1 / (NV_t)) 1) + I_2 / (\exp(V_2 / (NV_t)) 1))/2$

where:

- $V_{\rm t} = kT_{\rm m1} / q$.
- V₁ and V₂ are the values in the Voltages [V1 V2] vector.
- I_1 and I_2 are the values in the **Currents** [I1 I2] vector.

When you select Use an I-V data point and IS for the **Parameterization** parameter, then the block calculates *N* as follows:

$$N = V_1 \left(V_t \log \left(\frac{I_1}{IS} + 1 \right) \right)$$

When you select Use an I-V data point and N for the **Parameterization** parameter, then the block calculates *IS* as follows:

$$IS = I_1 / (\exp(V_1 / (NV_t) - 1))$$

The exponential diode model provides the option to include a junction capacitance:

- When you select Include fixed or zero junction capacitance for the **Junction capacitance** parameter, the capacitance is fixed.
- When you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter, the block uses the coefficients

Diode

CJO, *VJ*, *M*, and *FC* to calculate a junction capacitance that depends on the junction voltage.

- When you select Use C-V curve data points for the Junction capacitance parameter, the block uses three capacitance values on the C-V capacitance curve to estimate *CJO*, *VJ*, and *M* and uses these values with the specified value of *FC* to calculate a junction capacitance that depends on the junction voltage. The block calculates *CJO*, *VJ*, and *M* as follows:
 - $CJ0 = C_1((V_{R2} V_{R1})/(V_{R2} V_{R1}(C_2/C_1)^{-1/M}))^M$
 - $VJ = -(-V_{R2}(C_1/C_2)^{-1/M} + V_{R1})/(1 (C_1/C_2)^{-1/M})$
 - $M = \log(C_3 / C_2) / \log(V_{R2} / V_{R3})$ where:
 - V_{R1}, V_{R2}, and V_{R3} are the values in the Reverse bias voltages [VR1 VR2 VR3] vector.
 - C₁, C₂, and C₃ are the values in the Corresponding capacitances [C1 C2 C3] vector.

It is not possible to estimate FC reliably from tabulated data, so you must specify its value using the **Capacitance coefficient FC** parameter. In the absence of suitable data for this parameter, use a typical value of 0.5.

The reverse bias voltages (defined as positive values) should satisfy $V_{R3} > V_{R2} > V_{R1}$. This means that the capacitances should satisfy $C_1 > C_2 > C_3$ as reverse bias widens the depletion region and hence reduces capacitance. Violating these inequalities results in an error. Voltages V_{R2} and V_{R3} should be well away from the Junction potential VJ. Voltage V_{R1} should be less than the Junction potential VJ, with a typical value for V_{R1} being 0.1 V.

The voltage-dependent junction is defined in terms of the capacitor charge storage Q_i as:

• For $V < FC \cdot VJ$:

$$Q_{i} = CJ0 \cdot (VJ / (M - 1)) \cdot ((1 - V / VJ)^{1 - M} - 1)$$

• For $V \ge FC \cdot VJ$:

$$Q_{j} = CJ0 \cdot F_{1} + (CJ0/F_{2}) \cdot (F_{3} \cdot (V - FC \cdot VJ) + 0.5(M/VJ) \cdot (V^{2} - (FC \cdot VJ))$$

where:

- $F_1 = (VJ / (1 M)) \cdot (1 (1 FC)^{1 M}))$
- $F_2 = (1 FC)^{1+M}$))
- $F_3 = 1 FC \cdot (1 + M)$

These equations are the same as used in [2], except that the temperature dependence of VJ and FC is not modeled. This model does not include the diffusion capacitance term that affects performance for high frequency switching applications.

Modeling Charge

For applications such as commutation diodes it can be important to model diode charge dynamics. When a forward-biased diode has a reverse voltage applied across it, it takes time for the charge to dissipate and hence for the diode to turn off. The time taken for the diode to turn off is captured primarily by the transit time parameter. Once the diode is off, any remaining charge then dissipates, the rate at which this happens being determined by the carrier lifetime.

The Diode block uses the model of Lauritzen and Ma [3] to capture these effects. The three defining equations are:

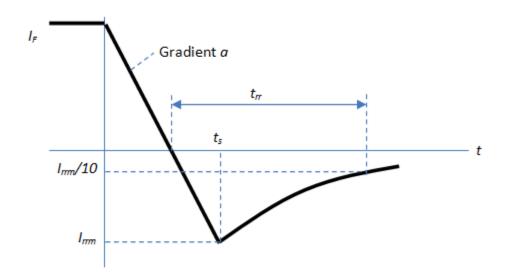
$$I = \frac{q_E - q_M}{TT}$$

$$\begin{split} & \frac{dq_M}{dt} + \frac{q_M}{\tau} - \frac{q_E - q_M}{TT} = 0 \\ & q_E = \left(\tau + TT\right) IS \left(\exp\left(\frac{V}{N \cdot V_t}\right) - 1 \right) \end{split}$$

where:

- *I* is the diode current.
- *V* is the diode voltage.
- *N* is the emission coefficient.
- $q_{\rm E}$ is the junction charge.
- $q_{\rm M}$ is the total stored charge.
- *TT* is the transit time.
- τ is the carrier lifetime.

Datasheets do not typically provide values for TT and τ . Therefore the Diode block provides an alternative parameterization in terms of **Peak reverse current, Irrm** and **Reverse recovery time, trr**. Equivalent values for TT and τ are calculated from these values, plus information on the initial forward current and rate of change of current used in the test circuit when measuring $I_{\rm rrm}$ and $t_{\rm rr}$. The test circuit can consist of a series voltage source, resistor, inductor and the diode. The polarity of the voltage source is switched so as to move the diode from forward conduction to reverse biased. The following figure shows an idealized diode current response.



The value of the series resistor and applied voltage value determine the initial current $I_{\rm F}$. The value of the series inductance and the applied reverse voltage value determine the current gradient, a.

The precise values of peak reverse current and reverse recovery time depend on the test circuit used. Also, junction capacitance has some effect on the current recovery characteristic. However, a junction capacitor value that dominates the response is physically unrealistic.

Only the exponential diode supports modeling of the diode charge dynamics. If you select the Exponential for the **Diode model** parameter, then the **Capacitance** tab contains an additional parameter called **Charge dynamics**. Select between the three options:

- Do not model charge dynamics
- Use peak reverse current and reverse recovery time
- Use transit time and carrier lifetime

Modeling Temperature Dependence

The default behavior for the Diode is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. The Exponential diode model contains several options for modeling the dependence of the diode current-voltage relationship on the temperature during simulation. Temperature dependence of the junction capacitance is not modeled, this being a much smaller effect.

When including temperature dependence, the diode defining equation remains the same. The measurement temperature value, $T_{\rm m1}$, is replaced with the simulation temperature, $T_{\rm s}$. The saturation current, *IS*, becomes a function of temperature according to the following equation:

$$IS_{Ts} = IS_{Tm1} \cdot (T_s / T_{m1})^{XTI/N} \cdot \exp\left(-\frac{EG}{NkT_s}(1 - T_s / T_{m1})\right)$$

where:

- T_{m1} is the temperature at which the diode parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_{s} is the simulation temperature.
- IS_{Tm1} is the saturation current at measurement temperature.
- IS_{Ts} is the saturation current at simulation temperature. This is the saturation current value used in the standard diode equation when temperature dependence is modeled.
- *EG* is the energy gap for the semiconductor type measured in Joules. The value for silicon is usually taken to be 1.11 eV, where 1 eV is 1.602e-19 Joules.
- *XTI* is the saturation current temperature exponent. This is usually set to 3.0 for pn-junction diodes, and 2.0 for Schottky barrier diodes.
- *N* is the emission coefficient.

• k is the Boltzmann constant (1.3806503e-23 J/K).

Appropriate values for XTI and EG depend on the type of diode and the semiconductor material used. Default values for particular material types and diode types capture approximate behavior with temperature. The block provides default values for common types of diode.

In practice, the values of *XTI* and *EG* need tuning to model the exact behavior of a particular diode. Some manufacturers quote these tuned values in a SPICE Netlist, and you can read off the appropriate values. Otherwise you can determine improved estimates for *EG* by using a datasheet-defined current-voltage data point at a higher temperature. The block provides a parameterization option for this. It also gives the option of specifying the saturation current at a higher temperature IS_{Tm2} directly.

You can also tune the values of *XTI* and *EG* yourself, to match lab data for your particular device. You can use Simulink[®] Design OptimizationTM software to help tune the values for *XTI* and *EG*.

Caution Device temperature behavior is also dependent on the emission coefficient. An inappropriate value for the emission coefficient can give incorrect temperature dependence, because saturation current is a function of the ratio of EG to N.

If defining a finite reverse breakdown voltage BV, then the value of the reverse breakdown voltage is modulated by the reverse breakdown temperature coefficient TCV (specified using the **Reverse breakdown voltage temperature coefficient**, **dBV/dT** parameter):

$$BV_{\text{Ts}} = BV_{\text{Tm1}} - TCV \cdot (T_{\text{s}} - T_{\text{m1}})$$

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**.

Diode

| | This action displays the thermal port H on the block icon, and adds the Thermal port tab to the block dialog box. |
|--|--|
| | Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the Thermal port tab parameters, see "Simulating Thermal Effects in Semiconductors". |
| Basic Assumptions and Limitations | The Exponential diode model has the following limitations: When you select Use I-V curve data points for the Parameterization parameter, choose a pair of voltages near the diode turn-on voltage. Typically, this is in the range from 0.05 to 1 Volt. Using values outside of this region may lead to numerical issues and poor estimates for <i>IS</i> and <i>N</i>. |
| | • The block does not account for temperature-dependent effects on the junction capacitance. |
| | • You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the |

simulation may run faster with these values set to zero.

Dialog Main Tab Box and Parameters

| 🙀 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. | | | | | | |
| Saturation current, Vt is the thermal | [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 C | Ohmic Resistance | Capacitance | Temperature De | pendence | | |
| Diode model: | Piecewise Linear | (Foundation Libr | rary) | | | |
| Forward voltage: | 0.6 | 6 V | | V · | | |
| On resistance: | 0.3 | | Ohm 👻 | | | |
| Off conductance: | 1e-8 S | | S • | | | |
| | | | | | | |
| | | ОК | Cancel | Help Apply | | |

Diode model

Select one of the following diode models:

- Piecewise Linear (Foundation Library) Use a piecewise linear model for the diode, as described in "Piecewise Linear" on page 1-115. This is the default method.
- Piecewise Linear Zener Use a piecewise linear model with reverse breakdown characteristics for the diode, as described in "Piecewise Linear Zener" on page 1-115.
- Exponential Use a standard exponential model for the diode, as described in "Exponential" on page 1-116.

Forward voltage

Minimum voltage that needs to be applied for the diode to become forward-biased. This parameter is only visible when you select Piecewise Linear (Foundation Library) or Piecewise Linear Zener for the **Diode model** parameter. The default value is **0.6** V.

On resistance

The resistance of the diode when it is forward biased. This parameter is only visible when you select Piecewise Linear (Foundation Library) or Piecewise Linear Zener for the **Diode model** parameter. The default value is 0.3Ω .

Off conductance

The conductance of the diode when it is reverse biased. This parameter is only visible when you select Piecewise Linear (Foundation Library) or Piecewise Linear Zener for the **Diode model** parameter. The default value is $1e-08 \ 1/\Omega$.

Parameterization

Select one of the following methods for model parameterization:

- Use two I-V curve data points Specify measured data at two points on the diode I-V curve. This is the default method.
- Use parameters IS and N Specify saturation current and emission coefficient.

- Use an I-V data point and IS Specify measured data at a single point on the diode I-V curve in combination with the saturation current.
- Use an I-V data point and $N-{\rm Specify}$ measured data at a single point on the diode I-V curve in combination with the emission coefficient.

This parameter is only visible when you select Exponential for the **Diode model** parameter.

Currents [I1 I2]

A vector of the current values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use two I-V curve data points for the **Parameterization** parameter. The default value is [0.0137 0.545] A.

Voltages [V1 V2]

A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use two I-V curve data points for the **Parameterization** parameter. The default value is [0.6 0.7] V.

Current I1

A current value at the point on the diode I-V curve that the block uses for calculations. This parameter is only visible when you select Exponential for the **Diode model** parameter and either Use an I-V data point and IS or Use an I-V data point and N for the **Parameterization** parameter. Depending on the **Parameterization** value, the block uses this parameter to calculate either N or IS. The default value is 0.07 A.

Voltage V1

A voltage value at the point on the diode I-V curve that the block uses for calculations. This parameter is only visible when you

Diode

select Exponential for the **Diode model** parameter and either Use an I-V data point and IS or Use an I-V data point and N for the **Parameterization** parameter. Depending on the **Parameterization** value, the block uses this parameter to calculate either N or IS. The default value is 0.7 V.

Saturation current IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Exponential for the **Diode model** parameter and either Use parameters IS and N or Use an I-V data point and IS for the **Parameterization** parameter. The default value is 1e-14 A.

Measurement temperature

The temperature $T_{\rm m1}$ at which IS or the I-V curve was measured. This parameter is only visible when you select Exponential for the **Diode model** parameter. The default value is 25 °C.

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Exponential for the **Diode model** parameter and either Use parameters IS and N or Use an I-Vdata point and N for the **Parameterization** parameter. The default value is 1.

Reverse Breakdown Tab

| 🙀 Block Parameters: Diode | | | | | | | |
|--|--|-------------|-----------------|---------|-------|--|--|
| Diode | | | | | | | |
| This block represents a diode. Use the | This block represents a diode. Use the Diode model parameter to select one of the following model types: | | | | | | |
| [1] Piecewise Linear Diode. This opti | [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 O | hmic Resistance | Capacitance | Temperature Dep | endence | | | |
| Zener resistance, Rz: | 0.3 | | Ohm 👻 | | | | |
| Reverse breakdown voltage, Vz: | 50 V | | - | | | | |
| | | | | | | | |
| | | ОК | Cancel | Help | Apply | | |

Zener resistance Rz

The resistance of the diode when the voltage is less than the **Reverse breakdown voltage Vz** value. This parameter is only visible when you select Piecewise Linear Zener for the **Diode model** parameter. The default value is 0.3Ω .

Reverse breakdown voltage Vz

The reverse voltage below which the diode resistance changes to the **Zener resistance Rz** value. This parameter is only visible when you select Piecewise Linear Zener for the **Diode model** parameter. The default value is 50 V.

Reverse breakdown voltage BV

The reverse voltage below which to model the rapid increase in conductance that occurs at diode breakdown. This parameter is only visible when you select Exponential for the **Diode model** parameter. The default value is Inf V, which effectively omits reverse breakdown from the model.

Ohmic Resistance Tab

| 🙀 Block Parameters: Diode | | | | | X | | |
|--|------------------|-------------|----------------|----------|----------|--|--|
| 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 | Capacitance | Temperature De | pendence | | | |
| Ohmic resistance, RS: | 0.01 | | | Ohm | • | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | |] | | |
| | | ОК | Cancel | Help | Apply | | |

Ohmic resistance RS

The series diode connection resistance. This parameter is only visible when you select Exponential for the **Diode model** parameter. The default value is 0.01 Ω .

Capacitance Tab

| 🙀 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 | Capacitance | Temperature Depe | ndence | | | |
| Junction capacitance: | Fixed or zero junction capacitance | | | | | | |
| Zero-bias junction capacitance, CJ0: | 5 | | F | DF ▼ | | | |
| Charge dynamics: | Do not model charge dynamics | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | OK | Cancel | Help Apply | | | |

Junction capacitance

• When you select Piecewise Linear (Foundation Library) or Piecewise Linear Zener for the **Diode model** parameter, the **Junction capacitance** parameter is the fixed junction capacitance value. The default value is 5 pF.

- When you select Exponential for the **Diode model** parameter, the **Junction capacitance** parameter lets you select one of the following options for modeling the junction capacitance:
 - Include fixed or zero junction capacitance Model the junction capacitance as a fixed value.
 - Use C-V curve data points Specify measured data at three points on the diode C-V curve.
 - Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Exponential for the **Diode model** parameter and Include fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 5 pF.

Reverse bias voltages [VR1 VR2 VR3]

A vector of the reverse bias voltage values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use C-V curve data points for the **Junction capacitance** parameter. The default value is [0.1 10 100] V.

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use C-V curve data points for the **Junction capacitance** parameter. The default value is [3.5 1 0.4] pF.

Junction potential VJ

The junction potential. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 1 V.

Grading coefficient M

The grading coefficient. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Capacitance coefficient FC

Fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use C-V curve data points or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Charge model

Select one of the following methods for charge dynamics parameterization:

- Do not model charge dynamics Do not include charge dynamics modeling. This is the default method.
- Use peak reverse current and reverse recovery time Model charge dynamics by providing values for peak reverse current, $I_{\rm rrm}$, and reverse recovery time, $t_{\rm rr}$, plus information on the initial forward current and rate of change of current used in the test circuit when measuring $I_{\rm rrm}$ and $t_{\rm rr}$. Use this option if the manufacturer datasheet does not provide values for transit time, TT, and carrier lifetime, τ .
- Use transit time and carrier lifetime Model charge dynamics by providing values for transit time, TT, and carrier lifetime, τ .

Peak reverse current, Irrm

The peak reverse current measured in a test circuit. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use peak reverse current and reverse recovery time for the **Charge model** parameter. The default value is 7.15 A.

Starting forward current when measuring Irrm

The initial forward current when measuring peak reverse current. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use peak reverse current and reverse recovery time for the **Charge model** parameter. The default value is 4 A.

Rate of change of current when measuring Irrm

The rate of change of current when measuring peak reverse current. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use peak reverse current and reverse recovery time for the **Charge model** parameter. The default value is -750 A/us.

Reverse recovery time, trr

The time between the point where the current initially goes to zero when the diode turns off, and the point where the current falls to less than ten percent of the peak reverse current. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use peak reverse current and reverse recovery time for the **Charge model** parameter. The default value is 115 ns.

Transit time, TT

A measure of how long it takes carriers to cross the diode junction. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use transit time and carrier lifetime for the **Charge model** parameter. The default value is 50 ns.

Carrier lifetime, tau

A measure of how long it takes for the carriers to dissipate once the diode is no longer conducting. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use transit time and carrier lifetime for the **Charge model** parameter. The default value is 100 ns.

Temperature Dependence Tab

This tab is applicable for Exponential diode models only.

| 🙀 Block Parameters: Diode | | | | X | | | |
|---|---|-------------|------------------------|----------|--|--|--|
| 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 | Capacitance | Temperature Dependence | | | | |
| Parameterization: | None - Use characteristics at parameter measurement temperature | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | ОК | Cancel Help | Apply | | | |

Parameterization

Select one of the following methods for temperature dependence parameterization:

• None Simulate at parameter measurement temperature — Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified

by the **Measurement temperature** parameter on the **Main** tab). This is the default method.

- Use an I-V data point at second measurement temperature If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and the current and voltage values at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify saturation current at second measurement temperature If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and saturation current value at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify the energy gap, EG Specify the energy gap value directly.

Current I1 at second measurement temperature

Specify the diode current I1 value when the voltage is V1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature for the **Parameterization** parameter. The default value is 0.245 A.

Voltage V1 at second measurement temperature

Specify the diode voltage V1 value when the current is I1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature for the **Parameterization** parameter. The default value is 0.5 V.

Saturation current, IS, at second measurement temperature Specify the saturation current *IS* value at the second measurement temperature. This parameter is only visible when you select Specify saturation current at second measurement temperature for the **Parameterization** parameter. The default value is 1.25e-7 A.

Second measurement temperature

Specify the value for the second measurement temperature. This parameter is only visible when you select either Use an I-V data point at second measurement temperature or Specify saturation current at second measurement temperature for the **Parameterization** parameter. The default value is 125 C.

Energy gap parameterization

This parameter is only visible when you select Specify the energy gap, EG for the **Parameterization** parameter. It lets you select a value for the energy gap from a list of predetermined options, or specify a custom value:

- Use nominal value for silicon (EG=1.11eV) This is the default.
- Use nominal value for 4H-SiC silicon carbide (EG=3.23eV)
- Use nominal value for 6H-SiC silicon carbide (EG=3.00eV)
- Use nominal value for germanium (EG=0.67eV)
- Use nominal value for gallium arsenide (EG=1.43eV)
- Use nominal value for selenium (EG=1.74eV)
- Use nominal value for Schottky barrier diodes (EG=0.69eV)
- Specify a custom value If you select this option, the **Energy gap, EG** parameter appears in the dialog box, to let you specify a custom value for *EG*.

Energy gap, EG

Specify a custom value for the energy gap, EG. This parameter is only visible when you select Specify a custom value for the **Energy gap parameterization** parameter. The default value is 1.11 eV.

Saturation current temperature exponent parameterization

Select one of the following options to specify the saturation current temperature exponent value:

- Use nominal value for pn-junction diode (XTI=3) This is the default.
- Use nominal value for Schottky barrier diode (XTI=2)
- Specify a custom value If you select this option, the Saturation current temperature exponent, XTI parameter appears in the dialog box, to let you specify a custom value for *XTI*.

Saturation current temperature exponent, XTI

Specify a custom value for the saturation current temperature exponent, *XTI*. This parameter is only visible when you select Specify a custom value for the **Saturation current temperature exponent parameterization** parameter. The default value is 3.

Reverse breakdown voltage temperature coefficient, dBV/dT

This coefficient modulates the reverse breakdown voltage BV. If you define the reverse breakdown voltage BV as a positive quantity, a positive value for TCV implies that the magnitude of the reverse breakdown voltage decreases with temperature. The default value is 0 V/K.

Device simulation temperature

Specify the value for the temperature $T_{\rm s}$, at which the device is to be simulated. The default value is 25 C.

Ports The block has the following ports:

+

Electrical conserving port associated with the diode positive terminal.

Electrical conserving port associated with the diode negative terminal.

References [1] MH. Ahmed and P.J. Spreadbury. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

[2] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993.

[3] Lauritzen, P.O. and C.L. Ma. "A Simple Diode Model with Reverse Recovery." *IEEE® Transactions on Power Electronics*. Vol. 6, No. 2, April 1991.

See Also Simscape Diode, SPICE Diode

DPDT Switch

Passive Devices/Switches

Library

Description



The DPDT Switch block models a double-pole double-throw switch:

- When the switch is closed, ports c1 and c2 are connected to ports s12 and s22, respectively.
- When the switch is open, ports c1 and c2 are connected to ports s11 and s21, respectively.

Closed connections are modeled by a resistor with value equal to the **Closed resistance** parameter value. Open connections are modeled by a resistor with value equal to the reciprocal of the **Open conductance** parameter value.

The switch is closed if the voltage presented at the vT control port exceeds the value of the **Threshold** parameter.

Optionally, you can add a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing. To enable the delay, on the **Dynamics** tab, set the **Model dynamics** parameter to Model turn-on and turn-off times.

Dialog Box and Parameters

- "Main Tab" on page 1-143
- "Dynamics Tab" on page 1-144

Main Tab

| 🙀 Block Parameters: DPDT Switch | 1 | |
|---------------------------------|--|---|
| DPDT Switch | | |
| | -Pole Double-Throw (DPDT) switch then the switch is closed, otherwise | controlled by an external control signal vT. the switch is open. |
| Parameters | | |
| Main Dynamics | | |
| Closed resistance: | 0.01 | Ohm |
| Open conductance: | 1e-6 | S |
| Threshold: | 0 | V |
| | | |
| | | OK Cancel Help A |

Closed resistance

Resistance between the c and s electrical ports when the switch is closed. The value must be greater than zero. The default value is 0.01Ω .

Open conductance

Conductance between the c and s electrical ports when the switch is open. The value must be greater than zero. The default value is 1e-6 S.

Threshold

The threshold voltage for the control physical signal input vT above which the switch will turn on. The default value is 0 V.

Dynamics Tab

| 🙀 Block Parameters: DPDT Switch | |
|---------------------------------|---|
| DPDT Switch | |
| | puble-Throw (DPDT) switch controlled by an external control signal vT. If vT switch is closed, otherwise the switch is open. |
| Parameters | |
| Main Dynamics | |
| Model dynamics: | No dynamics 🔹 |
| | |
| | |
| | |
| | OK Cancel Help Apply |

Model dynamics

Select whether the block models a switching delay:

- No dynamics Do not model the delay. This is the default option.
- Model turn-on and turn-off times Use additional parameters to model a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing.

Turn-on delay

Time between the input voltage exceeding the threshold voltage and the switch closing. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Turn-off delay

Time between the input voltage falling below the threshold voltage and the switch opening. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Initial input value, vT

The value of the physical signal input vT at time zero. This value is used to initialize the delayed control voltage parameter internally. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The default value is 0 V.

Ports This block has the following ports:

vТ

Physical signal that opens and closes the switch.

c1, c2, s11, s12, s21, s22 Electrical conserving ports.

See Also DPST Switch

SPDT Switch

SPST Switch

Simscape Switch

DPST Switch

| Purpose | Model double-pole single-throw switch |
|-------------|---|
| Library | Passive Devices/Switches |
| Description | The DPST Switch block models a double-pole single-throw switch. When the switch is closed, ports c1 and c2 are connected to ports s1 and s2, respectively. |
| | Closed connections are modeled by a resistor with value equal to the Closed resistance parameter value. Open connections are modeled by a resistor with value equal to the reciprocal of the Open conductance |

parameter value.

The switch is closed if the voltage presented at the vT control port exceeds the value of the **Threshold** parameter.

Optionally, you can add a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing. To enable the delay, on the **Dynamics** tab, set the **Model dynamics** parameter to Model turn-on and turn-off times.

Dialog Box and Parameters

- "Main Tab" on page 1-147
- "Dynamics Tab" on page 1-148

Main Tab

| 🙀 Block Parameters: DPST Switch | | |
|---------------------------------|--|---|
| DPST Switch | | |
| | P-Pole Single-Throw (DPST) switch then the switch is closed, otherwise | controlled by an external control signal vT. e the switch is open. |
| Parameters | | |
| Main Dynamics | | |
| Closed resistance: | 0.01 | Ohm |
| Open conductance: | 1e-6 | S |
| Threshold: | 0 | V |
| | | |
| | | OK Cancel Help A |

Closed resistance

Resistance between the c and s electrical ports when the switch is closed. The value must be greater than zero. The default value is 0.01Ω .

Open conductance

Conductance between the c and s electrical ports when the switch is open. The value must be greater than zero. The default value is $1e-6\ {\rm S}.$

Threshold

The threshold voltage for the control physical signal input vT above which the switch will turn on. The default value is 0 V.

Dynamics Tab

| 1 | 🙀 Block Parameters: DPST Switc | |
|---|--------------------------------|---|
| | DPST Switch | |
| | | e-Pole Single-Throw (DPST) switch controlled by an external control signal vT. If vT then the switch is closed, otherwise the switch is open. |
| | Parameters | |
| | Main Dynamics | |
| | Model dynamics: | No dynamics 🔹 |
| | | |
| | | |
| | | |
| | | OK Cancel Help Apply |

Model dynamics

Select whether the block models a switching delay:

- No dynamics Do not model the delay. This is the default option.
- Model turn-on and turn-off times Use additional parameters to model a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing.

| Turn-on | delay |
|---------|-------|
|---------|-------|

Time between the input voltage exceeding the threshold voltage and the switch closing. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Turn-off delay

Time between the input voltage falling below the threshold voltage and the switch opening. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Initial input value, vT

The value of the physical signal input vT at time zero. This value is used to initialize the delayed control voltage parameter internally. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The default value is 0 V.

| Ports | This | block | has | the | following | ports: |
|-------|------|-------|-----|-----|-----------|--------|
| | | | | | | |

vТ

Physical signal that opens and closes the switch.

c1, c2, s1, s2

Electrical conserving ports.

See Also DPDT Switch

SPDT Switch

SPST Switch

Simscape Switch

Exponential Current Source

| Pur | pose | Model | exponential | pulse | current sour | ce |
|-----|------|-------|-------------|-------|--------------|----|
| | | | | | | |

Library SPICE-Compatible Components/Sources

Description

The Exponential Current Source block represents a current source whose output current value is an exponential pulse as a function of time and is independent of the voltage across the terminals of the source. The following equations describe the current through the source as a function of time:

$$\begin{split} I_{out} \left(0 \leq Time \leq TDR \right) &= I1 \\ I_{out} \left(TDR < Time \leq TDF \right) = I1 + (I2 - I1) * (1 - e^{-(Time - TDR)/TR}) \\ I_{out} \left(TDF < Time \right) = I1 + (I2 - I1) * (e^{-(Time - TDF)/TF} - e^{-(Time - TDR)/TR}) \end{split}$$

where:

- *I1* is the **Initial value**, **I1** parameter value.
- *I2* is the **Pulse value**, **I2** parameter value.
- *TDR* is the **Rise delay time**, **TDR** parameter value.
- *TR* is the **Rise time**, **TR** parameter value.
- *TDF* is the **Fall delay time**, **TDF** parameter value.
- *TF* is the **Fall time**, **TF** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the + and - ports of the device and has a conductance *GMIN*:

• By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.

tered.

• To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| terminals, independent | urce t Source block maintains an exponer of the voltage across its terminals. ' ough the exponential source as a fu | The following equations |
|--|--|-------------------------|
| | · · | anction of time: |
| Iout(0<=Time<=TDR) | | |
| Iout(TDR <time<=tdf)< td=""><td>= I1+(I2-I1)*(1-exp(-(Time-TDR)))</td><td>/TR))</td></time<=tdf)<> | = I1+(I2-I1)*(1-exp(-(Time-TDR))) | /TR)) |
| Iout(TDF < Time) = I1 + TDF)/TF)) | -(I2-I1)*(1-exp(-(Time-TDR)/TR))+(| I1-I2)*(1-exp(-(Time- |
| fall times are one nanos | ies for TR, TF and TDF differ from S econd (1e-9), and the values of TR value for the fall delay time is zero. | and TF must be greater |
| middle equation above i Parameters | | |
| middle equation above i | | |
| middle equation above i Parameters | is not used. | |
| middle equation above i Parameters Initial value, I1: | o | A |
| middle equation above i Parameters Initial value, I1: Pulse value, I2: | o | A v |
| middle equation above i Parameters Initial value, I1: Pulse value, I2: Rise delay time, TDR: | 0 0 0 | A A S |
| middle equation above i Parameters Initial value, I1: Pulse value, I2: Rise delay time, TDR: Rise time, TR: | o 0 0 0 1e-09 | A A S S |

Initial value, I1

The value of the output current at time zero. The default value is $0\ \rm A.$

| | Pulse value, I2 The asymptotic value of the output current when the output is high. The default value is 0 A. |
|----------|--|
| | Rise delay time, TDR The rise time delay. The default value is 0 s. |
| | Rise time, TR The time it takes the output current to rise from the Initial Value, I1 value to the Pulse Value, I2 value. The default value is 1e-09 s. The value must be greater than 0. |
| | Fall delay time, TDR The fall time delay. The default value is 0 s, which differs from the SPICE default value. |
| | Fall time, TF The time it takes the output current to fall from the Pulse value, I2 value to the Initial value, I1 value. The default value is 1e-09 s. The value must be greater than 0. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | Exponential Voltage Source |

Purpose Model exponential pulse voltage source

Library SPICE-Compatible Components/Sources

Description

The Exponential Voltage Source block represents a voltage source whose output voltage value is an exponential pulse as a function of time and is independent of the current through the source. The following equations describe the output current as a function of time:

$$V_{out} \left(0 \le Time \le TDR \right) = V1$$

$$V_{out} \left(TDR < Time \le TDF \right) = V1 + \left(V2 - V1 \right) * \left(1 - e^{-(Time - TDR)/TR} \right)$$

$$V_{out} \left(TDF < Time \right) = V1 + \left(V2 - V1 \right) * \left(e^{-(Time - TDF)/TF} - e^{-(Time - TDR)/TR} \right)$$

where:

- V1 is the Initial value, V1 parameter value.
- V2 is the Pulse value, V2 parameter value.
- *TDR* is the **Rise delay time**, **TDR** parameter value.
- *TR* is the **Rise time**, **TR** parameter value.
- *TDF* is the **Fall delay time**, **TDF** parameter value.
- *TF* is the **Fall time**, **TF** parameter value.

Dialog Box and Parameters

| 🙀 Block Parameters: I | xponential Volt | age Source | | X | | | | |
|---|----------------------------|------------------|-----------------|---------|--|--|--|--|
| Exponential Voltage Sou | Exponential Voltage Source | | | | | | | |
| The Exponential Voltage Source block maintains an exponential voltage across its terminals, independent of the current through its terminals. The following equations describe the voltage across the exponential source as a function of time: | | | | | | | | |
| Vout(0<=Time<=TDR) = V1 | | | | | | | | |
| Vout(TDR <time<=tdf)< td=""><td>$= V1 + (V2 - V1)^*(2)$</td><td>l-exp(-(Time-TDR</td><td>)/TR))</td><td></td></time<=tdf)<> | $= V1 + (V2 - V1)^*(2)$ | l-exp(-(Time-TDR |)/TR)) | | | | | |
| Vout(TDF <time) =="" v1-<br="">TDF)/TF))</time)> | +(V2-V1)*(1-exp(-(| (Time-TDR)/TR))+ | (V1-V2)*(1-exp(| -(Time- | | | | |
| TR is the rise time. TF is the fall time. TDR is the rise time delay. TDF is the fall time delay. The default values for TR, TF and TDF differ from SPICE. The default rise and fall times are one nanosecond (1e-9), and the values of TR and TF must be greater than zero. The default value for the fall delay time is zero. If TDF is less than TDR, the middle equation above is not used. | | | | | | | | |
| Parameters | | | | | | | | |
| Initial value, V1: | 0 | | ٧ | • | | | | |
| Pulse value, V2: | 0 | | ٧ | - | | | | |
| Rise delay time, TDR: | 0 s 💌 | | | | | | | |
| Rise time, TR: | 1e-09 s | | | | | | | |
| Fall delay time, TDF: | 0 s 💌 | | | | | | | |
| Fall time, TF: | 1e-09 s | | | | | | | |
| | | | | | | | | |
| | ОК | Cancel | Help | Apply | | | | |

Initial value, V1

The value of the output voltage at time zero. The default value is 0 $\ensuremath{\mathrm{V}}.$

Pulse value, V2

The asymptotic value of the output voltage when the output is high. The default value is 0 V.

| | Rise delay time, TDR The rise time delay. The default value is 0 s. |
|----------|--|
| | Rise time, TR The time it takes the output voltage to rise from the Initial value, I1 value to the Pulse value, I2 value. The default value is 1e-09 s. The value must be greater than 0. |
| | Fall delay time, TDR The fall time delay. The default value is 0 s. |
| | Fall Time, TF The time it takes the output voltage to fall from the Pulse value, I2 value to the Initial value, I1 value. The default value is 1e-09 s. The value must be greater than 0. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | Exponential Current Source |

FEM-Parameterized Linear Actuator

Purpose Model linear actuator defined in terms of magnetic flux

Library

Translational Actuators

Description



The FEM-Parameterized Linear Actuator block implements a model of a linear actuator defined in terms of magnetic flux. Use this block to model custom solenoids and linear motors where magnetic flux depends on both distance and current. You parameterize the block using data from a third party Finite Element Magnetic (FEM) package.

The block has two options for the electrical equation. The first, Define in terms of dPhi(i,x)/dx and dPhi(i,x)/di, defines the current in terms of partial derivatives of the magnetic flux (Φ) with respect to distance (x) and current (i), the equations for which are:

$$\frac{di}{dt} = \left(v - iR - \frac{\partial \Phi}{\partial x}\frac{dx}{dt}\right) / \frac{\partial \Phi}{\partial i}$$

The second option, Define in terms of Phi(i,x), defines the voltage across the component directly in terms of the flux, the equation for which is:

$$v = iR + \frac{d}{dt}\Phi(x,i)$$

Numerically, defining the electrical equation in terms of flux partial derivatives is better because the back-emf is piecewise continuous. If using the flux directly, using a finer grid size for current and position will improve results, as will selecting cubic or spline interpolation.

In both cases, you specify the force as a function of current and position. If the finite element package does not provide force, then you can calculate it from the flux using the following equation:

$$F = \int_{0}^{i} \frac{\partial \Phi(x,i)}{\partial x} di$$

See the Finite Element Parameterized Solenoid example for more information on how to use this and other parameterization options.

You can define Φ and its partial derivatives for just positive, or positive and negative currents. If defining for just positive currents, then the block assumes that $\Phi(-i,x) = -\Phi(i,x)$. Therefore, if the current vector is positive only:

- The first current value must be zero.
- The flux corresponding to zero current must be zero.
- The partial derivative of flux with respect to displacement must be zero for zero current.

To model a linear motor with a repeated flux pattern, set the **Flux dependence on displacement** parameter to Cyclic. When selecting this option, the force and flux (or force and flux partial derivatives depending on the option chosen) must have identical first and last columns.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

FEM-Parameterized Linear Actuator

Basic Assumptions and Limitations

Dialog

Box and Parameters This block has the following limitations:

- It is imperative that you supply a consistent set of force and flux data. There is no checking that the force matrix is consistent with the flux data.
- When driving the FEM-Parameterized Linear Actuator block via a series inductor, you may need to include a parallel conductance in the inductor component.

Magnetic Force Tab

| | chanical characteristics of a linear motor or solenoid for which m roke may optionally be limited by mechanical hard stops. | agnetic flux linkage depe |
|---|--|---------------------------|
| | | - Dt- |
| positive current i from the electrical + to | - ports results in the force $F(i,x)$ acting from the mechanical C t | o R ports. |
| arameters | | |
| Magnetic Force Mechanical | | |
| Electrical model : | Define in terms of dPhi(i,x)/dx and dPhi(i,x)/di | |
| Current vector, i: | [00.10.20.30.40.50.60.70.80.91] | A |
| · | | |
| Displacement vector, x: | [00.050.10.150.2] | mm |
| Flux partial derivative wrt to current, dPhi(i,x)/di: | .024 0.028 0.033 0.037; 0.01 0.016 0.021 0.027 0.032] | Wb/A |
| Flux partial derivative wrt to displacement, dPhi(i,x)/dx: | -18.26 -17.9 -17.54 -17.18; -8.66 -8.43 -8.2 -7.97 -7.73] | Wb/m |
| Force matrix, F(i,x): | 7 -23.1 -21.1 -19.4 -18.2; -26.5 -24.1 -22.2 -20.9 -20.1] | N |
| Flux dependence on displacement: | Unique | • |
| Interpolation method: | Linear | - |
| Extrapolation method: | From last 2 points | • |
| Winding resistance: | 14 | Ohm |
| | | |

Electrical model

Select one of the following parameterization options, based on the underlying electrical model:

- Define in terms of dPhi(i,x)/dx and dPhi(i,x)/di

 Define the current through the block in terms of partial derivatives of the magnetic flux with respect to distance and current. This is the default method.
- Define in terms of Phi(i,x) Define the voltage across the block terminals directly in terms of the flux.

Current vector, i

Specify a vector of monotonically increasing current values corresponding to your force-flux data. If you specify positive currents only, the first element must be zero. The default value is $[0\ 0.1\ 0.2\ 0.3\ 0.4\ 0.5\ 0.6\ 0.7\ 0.8\ 0.9\ 1\]$ A.

Displacement vector, **x**

Specify a vector of monotonically increasing displacement values corresponding to your force-flux data. The default value is [0 0.05 0.1 0.15 0.2] m/m.

Flux partial derivative wrt current, Phi(i,x)/di

Specify a matrix of the flux partial derivatives with respect to current. This parameter is used if **Electrical model** is set to Define in terms of dPhi(i,x)/dx and dPhi(i,x)/di. The default value, in Wb/A, is:

[0.104 0.098 0.091 0.085 0.078; 0.095 0.089 0.084 0.079 0.073; 0.085 0.081 0.077 0.073 0.069; 0.076 0.073 0.07 0.067 0.064; 0.067 0.065 0.063 0.061 0.06; 0.057 0.057 0.056 0.056 0.055; 0.048 0.049 0.049 0.05 0.05; 0.038 0.04 0.042 0.044 0.046; 0.029 0.032 0.035 0.038 0.041; 0.02 0.024 0.028 0.033 0.037; 0.01 0.016 0.021 0.027 0.032]

Flux partial derivative wrt displacement, Phi(i,x)/dx

Specify a matrix of the flux partial derivatives with respect to displacement. This parameter is used if **Electrical model** is set to Define in terms of dPhi(i,x)/dx and dPhi(i,x)/di. The default value, in Wb/m, is:

```
[ 0 0 0 0 0;
-11.94 -10.57 -9.19 -7.81 -6.43;
-21.17 -19.92 -18.67 -17.42 -16.16;
-27.99 -26.87 -25.75 -24.62 -23.5;
-32.42 -31.43 -30.43 -29.43 -28.44;
-34.46 -33.59 -32.72 -31.85 -30.98;
-34.09 -33.35 -32.61 -31.87 -31.12;
-31.33 -30.72 -30.1 -29.49 -28.87;
-26.17 -25.68 -25.2 -24.71 -24.22;
-18.62 -18.26 -17.9 -17.54 -17.18;
-8.66 -8.43 -8.2 -7.97 -7.73 ]
```

Flux linkage matrix, Phi(i,x)

Specify a matrix of the total flux linkage, that is, flux times the number of turns. This parameter is used if **Electrical model** is set to Define in terms of Phi(i,x). The default value, in Wb, is:

[0 0 0 0 0; 0.0085 0.0079 0.0075 0.0071 0.0067; 0.0171 0.016 0.0151 0.0143 0.0137; 0.0254 0.0239 0.0226 0.0215 0.0206; 0.033 0.0312 0.0297 0.0283 0.0271; 0.0396 0.0377 0.036 0.0345 0.0331; 0.0452 0.0433 0.0415 0.0399 0.0384; 0.0495 0.0478 0.0461 0.0446 0.0431; 0.0526 0.0512 0.0498 0.0485 0.0472; 0.0545 0.0537 0.0528 0.0519 0.0508; 0.0554 0.0553 0.0551 0.0548 0.0542]

Force matrix, F(i,x)

Specify a matrix of the electromagnetic force applied to the plunger or moving part. The default value, in N, is:

 $\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ -0.6 & -0.5 & -0.4 & -0.3 & -0.3 \\ -2.3 & -2 & -1.7 & -1.4 & -1.2 \\ -4.9 & -4.3 & -3.7 & -3.2 & -2.7 \\ -8.3 & -7.3 & -6.4 & -5.5 & -4.7 \\ -12.2 & -10.7 & -9.4 & -8.2 & -7.2 \\ -16.2 & -14.4 & -12.7 & -11.3 & -10 \\ -20 & -17.9 & -15.9 & -14.3 & -12.9 \\ -23.3 & -20.9 & -18.8 & -17.1 & -15.7 \\ -25.7 & -23.1 & -21.1 & -19.4 & -18.2 \\ -26.5 & -24.1 & -22.2 & -20.9 & -20.1 \end{bmatrix}$

Flux dependence on displacement

Specify the flux pattern:

- Unique No flux pattern present. This is the default option.
- Cyclic Select this option to model a linear motor with a repeated flux pattern. The force and flux (or force and flux partial derivatives, depending on the **Electrical model** option chosen) must have identical first and last columns.

Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- Linear Uses a bilinear interpolation algorithm, which is an extension of linear interpolation for functions in two variables.
- Cubic Uses the bicubic interpolation algorithm.
- Spline Uses the bicubic spline interpolation algorithm.

For more information on interpolation algorithms, see the PS Lookup Table (2D) block reference page.

Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- From last 2 points Extrapolates using the linear method (regardless of the interpolation method specified), based on the last two output values at the appropriate end of the range. That is, the block uses the first and second specified output values if the input value is below the specified range, and the two last specified output values if the input value is above the specified range.
- From last point Uses the last specified output value at the appropriate end of the range. That is, the block uses the last specified output value for all input values greater than the last specified input argument, and the first specified output value for all input values less than the first specified input argument.

For more information on extrapolation algorithms, see the PS Lookup Table (2D) block reference page.

This parameter is not available if you set the **Flux dependence** on displacement parameter to Cyclic.

Winding resistance

Total resistance of the electrical winding. The default value is 14 Ohm.

Mechanical Tab

| Block Parameters: FEM-Parame | terized Linear Actuator | |
|---|---|----------------------|
| onlinearly on current and position. T | d mechanical characteristics of a linear motor or solenoid for e stroke may optionally be limited by mechanical hard stops | |
| positive current i from the electrical arameters | + to - ports results in the force F(i,x) acting from the mecha | anical C to R ports. |
| Magnetic Force Mechanical | | |
| Damping: | 1 | N/(m/s) |
| Plunger mass: | 0.05 | kg 💌 |
| Minimum stroke: | 0 | mm |
| Maximum stroke: | 0.2 | mm |
| Initial plunger position: | 0 | mm |
| Initial plunger velocity: | 0 | mm/s |
| Contact stiffness: | 1e+8 | N/m 💌 |
| Contact damping: | 1e+4 | N/(m/s) |
| | | |
| | | |
| | OK Can | cel Help Apply |

Damping

Linear damping. The default value is 1 N/(m/s). The value can be zero.

Plunger mass

Mass of the moving part, which corresponds to mechanical translational port R. The default value is 0.05 kg. The value can be zero.

Minimum stroke

The stroke at which the lower mechanical end stop is applied. The default value is 0. The value can be -Inf.

| | Maximum stroke The stroke at which the upper mechanical end stop is applied. The default value is 0.2 mm. The value can be Inf. |
|----------|---|
| | Initial plunger position Position of the plunger at the start of the simulation. The default value is 0 mm. |
| | Initial plunger velocity Speed of the plunger at the start of the simulation. The default value is 0 mm/s. |
| | Contact stiffness Contact stiffness between plunger and end stops. The default value is 1e8 N/m. |
| | Contact damping Contact damping between plunger and end stops. The default value is 1e4 N/(m/s). |
| Ports | This block has the following ports: |
| | + Positive electrical conserving port. |
| | - Negative electrical conserving port. |
| | C Mechanical translational conserving port connected to the actuator case. |
| | R Mechanical translational conserving port connected to the plunger. |
| Examples | The Finite Element Parameterized Solenoid example illustrates the use and parameterization options of this block. |
| See Also | FEM-Parameterized Rotary Actuator and Solenoid. |

Purpose Model rotary actuator defined in terms of magnetic flux

Library

Rotational Actuators

Description

ф-ф-ф

The FEM-Parameterized Rotary Actuator block implements a model of a rotary actuator defined in terms of magnetic flux. Use this block to model custom rotary actuators and motors where magnetic flux depends on both rotor angle and current. You parameterize the block using data from a third party Finite Element Magnetic (FEM) package.

The block has two options for the electrical equation. The first, Define in terms of dPhi(i,theta)/dtheta and dPhi(i,theta)/di, defines the current in terms of partial derivatives of the magnetic flux (Φ) with respect to rotor angle (θ) and current (*i*), the equations for which are:

$$\frac{di}{dt} = \left(v - iR - \frac{\partial \Phi}{\partial \theta} \frac{d\theta}{dt}\right) / \frac{\partial \Phi}{\partial i}$$

The second option, Define in terms of Phi(i,theta), defines the voltage across the component directly in terms of the flux, the equation for which is:

$$v = iR + \frac{d}{dt}\Phi(\theta, i)$$

Numerically, defining the electrical equation in terms of flux partial derivatives is better because the back-emf is piecewise continuous. If using the flux directly, using a finer grid size for current and position will improve results, as will selecting cubic or spline interpolation.

In both cases, you specify the torque as a function of current and rotor angle. If the finite element package does not provide torque, then you can calculate it from the flux using the following equation:

$$T = \int_{0}^{i} \frac{\partial \Phi(\theta, i)}{\partial \theta} di$$



See the Finite Element Parameterized Solenoid example model and its initialization file elec_fem_solenoid_ini.m for an example of how to implement this type of integration in MATLAB.

You can define Φ and its partial derivatives for just positive, or positive and negative currents. If defining for just positive currents, then the block assumes that $\Phi(-i,x) = -\Phi(i,x)$. Therefore, if the current vector is positive only:

- The first current value must be zero.
- The flux corresponding to zero current must be zero.
- The partial derivative of flux with respect to rotor angle must be zero for zero current.

To model a rotary motor with a repeated flux pattern, set the **Flux dependence on displacement** parameter to Cyclic. When selecting this option, the torque and flux (or torque and flux partial derivatives depending on the option chosen) must have identical first and last columns.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

Basic Assumptions and Limitations

Dialog

Box and Parameters This block has the following limitations:

- It is imperative that you supply a consistent set of torque and flux data. There is no checking that the torque matrix is consistent with the flux data.
- When driving the FEM-Parameterized Rotary Actuator block via a series inductor, you may need to include a parallel conductance in the inductor component.

Magnetic Force Tab

| is block implements the electrical and me | chanical characteristics of a rotary motor or actuator for which | magnetic flux linkage der |
|--|--|---------------------------|
| onlinearly on current and rotor angle. Th | e angle range may optionally be limited by mechanical hard stop | s. |
| positive current i from the electrical + to | - ports results in the torque T(i,theta) acting from the mechani | cal C to R ports. |
| arameters | | |
| Magnetic Force Mechanical | | |
| Electrical model : | Define in terms of dPhi(i,theta)/dtheta and dPhi(i,theta)/di | 5 |
| | | |
| Current vector, i: | [00.20.40.60.81] | A . |
| Angle vector, theta: | 0 50 60 70 80 90 100 110 120 130 140 150 160 170 180] | deg |
| Flux partial derivative wrt to current, dPhi(i,theta)/di: | 135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002] | Wb/A |
| Flux partial derivative wrt to angle, dPhi(i,theta)/dtheta: | 084 -0.0113 -0.0128 -0.0128 -0.0113 -0.0084 -0.0044 0] | Wb/rad |
| Torque matrix, T(i,theta): | 81 -5.6292 -6.4013 -6.4013 -5.6292 -4.1781 -2.2231 0 | mN*m |
| Flux dependence on displacement: | Cyclic | 2 |
| Interpolation method: | Linear | |
| Winding resistance: | 10 | Ohm |
| | | |

Electrical model

Select one of the following parameterization options, based on the underlying electrical model:

- Define in terms of dPhi(i,theta)/dtheta and dPhi(i,theta)/di Define the current through the block in terms of partial derivatives of the magnetic flux with respect to rotor angle and current. This is the default method.
- Define in terms of Phi(i,theta) Define the voltage across the block terminals directly in terms of the flux.

Current vector, i

Specify a vector of monotonically increasing current values corresponding to your torque-flux data. If you specify positive currents only, the first element must be zero. The default value is $[0\ 0.2\ 0.4\ 0.6\ 0.8\ 1\]$ A.

Angle vector, theta

Specify a vector of monotonically increasing rotor angle values corresponding to your torque-flux data. The default value is [0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180] deg.

Flux partial derivative wrt current, Phi(i,theta)/di

Specify a matrix of the flux partial derivatives with respect to current. This parameter is used if **Electrical model** is set to Define in terms of dPhi(i,theta)/dtheta and dPhi(i,theta)/di. The default value, in Wb/A, is:

[0.002 0.0024 0.0035 0.0052 0.0074 0.0096 0.0118 0.0135 0.0146 ...

0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002;

 $0.002 \ 0.0024 \ 0.0035 \ 0.0052 \ 0.0074 \ 0.0096 \ 0.0118 \ 0.0135 \ 0.0146 \ \ldots$

0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002;

- $0.002 \ 0.0024 \ 0.0035 \ 0.0052 \ 0.0074 \ 0.0096 \ 0.0118 \ 0.0135 \ 0.0146 \ \ldots$
 - 0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002;
- 0.002 0.0024 0.0035 0.0052 0.0074 0.0096 0.0118 0.0135 0.0146 ...

0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002; 0.002 0.0024 0.0035 0.0052 0.0074 0.0096 0.0118 0.0135 0.0146 ...

0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002;

0.002 0.0024 0.0035 0.0052 0.0074 0.0096 0.0118 0.0135 0.0146 ...

0.015 0.0146 0.0135 0.0118 0.0096 0.0074 0.0052 0.0035 0.0024 0.002;]

Flux partial derivative wrt angle, Phi(i,theta)/dtheta

Specify a matrix of the flux partial derivatives with respect to rotor angle. This parameter is used if **Electrical model** is set to Define in terms of dPhi(i,theta)/dtheta and dPhi(i,theta)/di. The default value, in Wb/rad, is:

Flux linkage matrix, Phi(i,theta)

Specify a matrix of the total flux linkage, that is, flux times the number of turns. This parameter is used if **Electrical model** is set to Define in terms of Phi(i,theta). The default value, in Wb, is:

4e-4 4.8e-4 7e-4 0.00105 0.00147 0.00193 0.00235 0.0027 0.00292 ...

0.003 0.00292 0.0027 0.00235 0.00193 0.00147 0.00105 7e-4 4.8e-4 4e-4;

8e-4 9.6e-4 0.00141 0.0021 0.00295 0.00385 0.0047 0.00539 0.00584 ...

0.006 0.00584 0.00539 0.0047 0.00385 0.00295 0.0021 0.00141 9.6e-4 8e-4; 0.0012 0.00144 0.00211 0.00315 0.00442 0.00578 0.00705 0.00809 0.00876 ...

0.009 0.00876 0.00809 0.00705 0.00578 0.00442 0.00315 0.00211 0.00144 0.0012:

0.0016 0.00191 0.00282 0.0042 0.0059 0.0077 0.0094 0.01078 0.01169 ...

0.012 0.01169 0.01078 0.0094 0.0077 0.0059 0.0042 0.00282 0.00191 0.0016;

 $0.002 \ 0.00239 \ 0.00352 \ 0.00525 \ 0.00737 \ 0.00963 \ 0.01175 \ 0.01348 \ 0.01461 \ \ldots$

0.015 0.01461 0.01348 0.01175 0.00963 0.00737 0.00525 0.00352 0.00239 0.002]

Torque matrix, T(i,theta)

Specify a matrix of the electromagnetic torque applied to the rotor. The default value, in mN*m, is:

Flux dependence on displacement

Specify the flux pattern:

- Unique No flux pattern present. This is the default option.
- Cyclic Select this option to model a rotary motor with a repeated flux pattern. The torque and flux (or torque and flux partial derivatives, depending on the **Electrical model** option chosen) must have identical first and last columns.

Interpolation method

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- Linear Uses a bilinear interpolation algorithm, which is an extension of linear interpolation for functions in two variables.
- Cubic Uses the bicubic interpolation algorithm.
- Spline Uses the bicubic spline interpolation algorithm.

For more information on interpolation algorithms, see the PS Lookup Table (2D) block reference page.

Extrapolation method

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- From last 2 points Extrapolates using the linear method (regardless of the interpolation method specified), based on the last two output values at the appropriate end of the range. That is, the block uses the first and second specified output values if the input value is below the specified range, and the two last specified output values if the input value is above the specified range.
- From last point Uses the last specified output value at the appropriate end of the range. That is, the block uses the last specified output value for all input values greater than the last specified input argument, and the first specified output value for all input values less than the first specified input argument.

For more information on extrapolation algorithms, see the PS Lookup Table (2D) block reference page.

This parameter is not available if you set the **Flux dependence** on displacement parameter to Cyclic.

Winding resistance

Total resistance of the electrical winding. The default value is 10 Ohm.

Mechanical Tab

| rameters | | |
|---------------------------|------|-------------|
| Magnetic Force Mechanical | | |
| Damping: | 1e-4 | N*m/(rad/s) |
| Rotor inertia: | 5e-5 | kg*m^2 |
| Minimum rotor angle: | -Inf | deg 💌 |
| Maximum rotor angle: | Inf | deg 💌 |
| Initial rotor angle: | 0 | deg 💌 |
| Initial rotor velocity: | 0 | deg/s 💌 |
| Contact stiffness: | 1e+8 | N*m/rad 💌 |
| Contact damping: | 1e+4 | N*m/(rad/s) |

Damping

Rotary damping. The default value is 1e-4 N*m/(rad/s). The value can be zero.

Rotor inertia

Inertia of the rotor attached to mechanical translational port R. The default value is $5e-5 \text{ kg*m}^2$. The value can be zero.

Minimum rotor angle

The rotor angle at which the lower mechanical end stop is applied. The default value is - Inf.

Maximum rotor angle

The rotor angle at which the upper mechanical end stop is applied. The default value is Inf.

| | Initial rotor position Position of the rotor at the start of the simulation. The default value is 0 deg. |
|----------|---|
| | Initial rotor velocity Angular velocity of the rotor at the start of the simulation. The default value is 0 deg/s. |
| | Contact stiffness Contact stiffness between rotor and end stops. The default value is 1e8 N*m/rad. |
| | Contact damping Contact damping between rotor and end stops. The default value is 1e4 N*m/(rad/s). |
| Ports | This block has the following ports: |
| | + Positive electrical conserving port. |
| | - Negative electrical conserving port. |
| | C Mechanical rotational conserving port connected to the actuator case. |
| | R Mechanical rotational conserving port connected to the rotor. |
| See Also | FEM-Parameterized Linear Actuator and Solenoid. |

Finite-Gain Op-Amp

Purpose Model gain-limited operational amplifier

Library Integrated Circuits

Description

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The Finite-Gain Op-Amp block models a gain-limited operational amplifier. If the voltages at the positive and negative ports are Vp and Vm, respectively, the output voltage is:

$$V_{out} = A(V_p - V_m) - I_{out} * R_{out}$$

where:

- A is the gain.
- R_{out} is the output resistance.
- I_{out} is the output current.

The input current is:

$$\frac{V_p - V_m}{R_{in}}$$

where R_{in} is the input resistance.

The output voltage is limited by the minimum and maximum output values you specify in the block dialog box.

Dialog Box and Parameters

| 🙀 Block Parameters: Fini | te Gain Op-Amp | | × |
|--|---|---|---|
| are denoted Vp and Vm, th where A is the gain, Rout is input current is given by (Vp | nited op-amp. If the voltages at en the output voltage is given b the output resistance and lout -Vm)/Rin where Rin is the inpu imum and maximum values Vmi | y Vout = A*(Vp-Vm)-lout*Rou is the output current. The t resistance. The output | |
| Parameters | | | _ |
| Gain, A: | 1000 | | - |
| Input resistance, Rin: | 1e+06 | Ohm 💌 |] |
| Output resistance, Rout: | 100 | Ohm 💌 |] |
| Minimum output, Vmin: | -15 | V . |] |
| Maximum output, Vmax: | 15 | V - |] |
| | OK Cancel | Help Apply | |

Gain, A

The open-loop gain of the operational amplifier. The default value is 1000.

Input resistance, Rin

The resistance at the input of the operational amplifier that the block uses to calculate the input current. The default value is $1e+06 \Omega$.

Output resistance, Rout

The resistance at the output of the operational amplifier that the block uses to calculate the drop in output voltage due to output current. The default value is 100Ω .

Finite-Gain Op-Amp

| | Minimum output, Vmin The lower limit on the operational amplifier output voltage. The default value is -15 V. |
|----------|--|
| | Maximum output, Vmax The upper limit on the operational amplifier output voltage. The default value is 15 V. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| | OUT Output voltage. |
| See Also | Simscape Op-Amp, Band-Limited Op-Amp, Fully Differential Op-Amp |

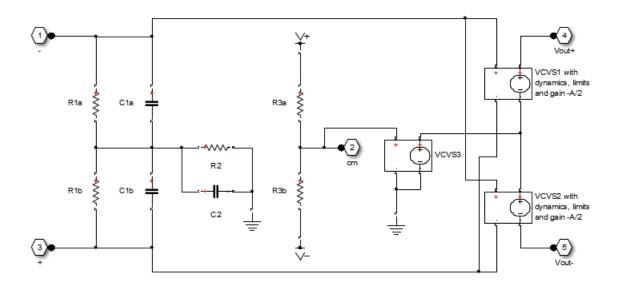
- **Purpose** Model operational amplifier with fully differential output, that is, not referenced to ground
- **Library** Integrated Circuits

Description



The Fully Differential Op-Amp block models a fully differential operational amplifier. Differential signal transmission is better than single-ended transmission due to reduced susceptibility to external noise sources. Applications include data acquisition where inputs are differential, for example, sigma-delta converters.

The following diagram shows the internal representation of the amplifier.



Parameters for the circuit components are derived from the block parameters that you provide. The gain of the two voltage-controlled voltage sources (VCVS1 and VCVS2) is set to half of the differential gain value. Similarly the slew rate of each of the voltage sources is set to half of the differential maximum slew rate value. The voltages of the two output ports Vout+ and Vout- are both limited to be within the minimum and maximum output voltages that you specify.

The output voltage for zero differential input voltage is controlled by the common-mode port, cm. If no current is drawn from the cm port by the external circuit, then the output voltage is set to be the average of the positive and negative supply voltages by the resistor ladder of R3a and R3b. Note that the negative supply voltage can be zero, which corresponds to operation when a split supply is not available. The values for the minimum and maximum output voltages that you provide must be consistent with the values for the supply voltages that you provide. So, for example, the maximum output high voltage will be less than the positive supply voltage, the difference corresponding to the number of p-n junction voltage drops in the circuit.

Note Physical Network block diagrams do not allow unconnected Conserving ports. If you want to leave pin cm open-circuit, connect it to an Open Circuit block from the Simscape Foundation library.

Basic Assumptions and Limitations

This block provides a behavioral model of a fully differential operational amplifier. It does not represent nonlinear effects, such as variation in gain with output voltage amplitude, and the nonlinear nature of the output voltage-current relationship for large load currents.

Dialog Gain Tab Box and Parameters

| 🙀 Block Parameters: Fully Differential Op- | Amp | |
|---|---|---|
| Fully Differential Op-Amp | | |
| port cm. Internal resistors set the non provide for the positive and negative s model equivalent circuit. The Initial differential output voltage of | p-amp. The output common-mode voltage is co ninal output common-mode voltage to be midwa supply voltages. Consult the block reference doc does not take account of the voltage drop due to ct the Start simulation from steady state option i | ay between the values you umentation for an op-amp the output resistance. The |
| Parameters | | |
| Gain Input Impedance Outpu | t Limits Output Bias Initial Conditions | |
| Differential gain: | 1000 | |
| Bandwidth: | 1.5 | GHz 👻 |
| | | |
| | OK Cance | I Help Apply |

Differential gain

The gain applied to a voltage difference between the + and - inputs. The default value is 1000.

Bandwidth

The frequency at which the differential voltage gain drops by 3 dB from its dc value. The default value is 1.5 GHz.

Input Impedance Tab

| 🙀 Block Parameters: Fully Differential Op | -Amp | × |
|---|--|--|
| Fully Differential Op-Amp | | |
| port cm. Internal resistors set the no provide for the positive and negative model equivalent circuit. The Initial differential output voltage | op-amp. The output common-mode voltage is or minal output common-mode voltage to be midv supply voltages. Consult the block reference do does not take account of the voltage drop due t ect the Start simulation from steady state option | vay between the values you cumentation for an op-amp to the output resistance. The |
| Parameters Gain Input Impedance Outp | ut Limits Output Bias Initial Conditions | |
| Differential input resistance: | 1.3 | MOhm - |
| Differential input capacitance: | 1.8 | pF • |
| Common-mode input resistance: | 1 | MOhm 👻 |
| Common-mode input capacitance: | 2.3 | pF • |
| | OK Canc | el Help Apply |

Differential input resistance

The input resistance seen by a voltage source applied across the + and - inputs. The default value is **1.3** MOhm.

Differential input capacitance

The input capacitance seen by a current source applied across the + and - inputs. The default value is 1.8 pF.

Common-mode input resistance

The input resistance seen by a voltage source applied between ground and the + input, or between ground and the - input. The default value is 1 MOhm.

Common-mode input capacitance

The input capacitance seen by a current source applied between ground and the + input, or between ground and the - input. The default value is 2.3 pF.

Output Limits Tab

| 🙀 Block Parameters: Fully Differential Op | -Amp | × |
|---|--|--|
| Fully Differential Op-Amp | | |
| port cm. Internal resistors set the no provide for the positive and negative model equivalent circuit. The Initial differential output voltage | op-amp. The output common-mode voltage is cont minal output common-mode voltage to be midway supply voltages. Consult the block reference docun does not take account of the voltage drop due to th ect the Start simulation from steady state option in | between the values you nentation for an op-amp ne output resistance. The |
| Parameters | | |
| Gain Input Impedance Outp | ut Limits Output Bias Initial Conditions | |
| Output resistance: | 1 | Ohm 👻 |
| Minimum output voltage low: | -1.4 | V • |
| Maximum output voltage high: | 1.4 | V • |
| Differential maximum slew rate: | 5e+3 | V/us 👻 |
| | |] |
| | OK Cancel | Help Apply |

Output resistance

The output resistance of either of the outputs with respect to the common-mode voltage reference. Differential output resistance is therefore twice the value of the output resistance R_out. The default value is 1 Ohm.

Minimum output voltage low

The minimum output voltage for either of the two output pins with respect to ground. The default value is -1.4 V.

Maximum output voltage low

The maximum output voltage for either of the two output pins with respect to ground. The default value is 1.4 V.

Differential maximum slew rate

The maximum slew rate of the differential output voltage. The default value is 5000 V/ $\mu s.$

Output Bias Tab

| Block Parameters: Fully Differ | ntial Op-Amp | × |
|--|---|---|
| Fully Differential Op-Amp | | |
| port cm. Internal resistors se provide for the positive and r model equivalent circuit. The Initial differential output | t the nominal output common-mode volt egative supply voltages. Consult the blo voltage does not take account of the vol | ode voltage is controlled by the common-mode tage to be midway between the values you ck reference documentation for an op-amp tage drop due to the output resistance. The ady state option in the Solver Configuration |
| Parameters Gain Input Impedance | Output Limits Output Bias Initia | al Conditions |
| Guin Input Impedance | | |
| Common-mode port input resistance: | 23 | kOhm 👻 |
| Negative supply voltage: | -5 | V • |
| Positive supply voltage: | 5 | V • |
| | | |
| | 0 | K Cancel Help Apply |

Common-mode port input resistance

The input resistance seen by a voltage source applied between ground and the common mode port. The default value is 23 kOhm.

Negative supply voltage

The value of the negative supply voltage connected to common-mode bias resistor R3b (see diagram). The default value is -5 V.

Positive supply voltage

The value of the positive supply voltage connected to common-mode bias resistor R3a (see diagram). The default value is 5 V.

Initial Conditions Tab

| 🙀 Block Parameters: Fully Differential Op-Amp 🧱 |
|---|
| Fully Differential Op-Amp |
| This block models a fully differential op-amp. The output common-mode voltage is controlled by the common-mode port cm. Internal resistors set the nominal output common-mode voltage to be midway between the values you provide for the positive and negative supply voltages. Consult the block reference documentation for an op-amp model equivalent circuit. The Initial differential output voltage does not take account of the voltage drop due to the output resistance. The initial condition is not used if you select the Start simulation from steady state option in the Solver Configuration |
| block. |
| Parameters |
| Gain Input Impedance Output Limits Output Bias Initial Conditions |
| Initial differential output voltage: 0 V |
| |
| |
| |
| |
| |
| OK Cancel Help Apply |

Initial differential output voltage

The initial differential voltage across the two outputs if the output current is zero. The default value is 0 V. $\,$

Ports The block has the following ports:

| | + |
|------|--|
| | Noninverting input. |
| | - Terredianise d |
| | Inverting input. |
| | cm |
| | Common-mode port. If you want to leave this pin open-circuit, connect a voltage sensor between the cm port and a reference port. |
| | Vout+ |
| | Noninverting output. |
| | Vout- |
| | Inverting output. |
| Also | Simscape Op-Amp, Band-Limited Op-Amp, Finite-Gain Op-Amp |
| | |

See

Fuse

Library Passive Devices

Description The Fuse block breaks the circuit in which it is connected. It does so when the current through the device exceeds the rated current at which the fuse is designed to blow and continues to exceed it for a specified amount of time.

Dialog Box and Parameters

| 🙀 Block Parameters: Fuse | | | | × |
|---|----------------------------|------------------------|----------------------|---------------|
| Fuse | | | | |
| The block represents a fuse. The fuse where T is the Time to fuse parameter | | it exceeds the Rated o | urrent for more that | in T seconds, |
| The Fuse resistance R and Open-circu | t conductance G must be gr | eater than zero. | | |
| Parameters | | | | |
| Rated current: | 1 | | A | • |
| Time to fuse: | 0 | | S | • |
| Fuse resistance R: | 0.01 | | Ohm | • |
| Open-circuit conductance G: | 1e-08 | | 1/0 | ım 💌 |
| | | | | |
| | | OK Can | cel Help | Apply |

Rated current

The current value at which the fuse blows when exceeded for a specified amount of time. The default value is 1 A.

Time to fuse

The time for which the current must exceed the rated current for the fuse to blow. The default value is $0 \, s$.

Fuse resistance R

The fuse resistance. The parameter value must be greater than zero. The default value is 0.01Ω .

Open-circuit conductance G

The open-circuit fuse conductance when the fuse has blown. The parameter value must be greater than zero. The default value is $1e-08 \ 1/\Omega$.

Ports The block has the following ports:

+

-

Positive electrical port.

Negative electrical port.

Generic Battery

| Purpose S | Simple battery model |
|-----------|----------------------|
|-----------|----------------------|

Library Sources

Description

The Generic Battery block represents a simple battery model. If you select Infinite for the **Battery charge capacity** parameter, the block models the battery as a series resistor and a constant voltage source. If you select Finite for the **Battery charge capacity** parameter, the block models the battery as a series resistor and a charge-dependent voltage source whose voltage as a function of charge has the following reciprocal relationship:

$$V = V_0 \left[1 - \left(\frac{\alpha(1-x)}{1 - \beta(1-x)} \right) \right]$$

where:

- *x* is the ratio of the ampere-hours left to the number of ampere-hours, *AH*, for which the battery is rated.
- V_0 is the voltage when the battery is fully charged, as defined by the Nominal voltage, V_nominal parameter.
- The block calculates the constants a and β to satisfy the following battery conditions:
 - The battery voltage is zero when the charge is zero, that is, when x
 = 0.
 - The battery voltage is V1 (the Voltage V1 < V_nominal when charge is AH1 parameter value) when the charge is the Charge AH1 when no-load volts are V1 parameter value, that is, when x = AH1/AH.

The equation defines a reciprocal relationship between voltage and remaining charge. It is an approximation to what happens in a real battery, but it does replicate the increasing rate of voltage drop at low charge values. It also ensures that the battery voltage becomes zero when the charge level is zero. This simple model has the advantage of requiring very few parameters, and these are parameters that are readily available on most datasheets.

Dialog Box and Parameters

| 🙀 Block Parameters: Gene | ric Batte | ery | | | | | | × |
|--|----------------------------|----------------|------------------------|------------------------|-------------------------|-----------------------|---------------|---|
| - Generic Battery | | | | | | | | |
| This block models a generic t parameter, the block models t source. If you select Finite for the battery as a series resistor | the battery r the Batte | yasa xrycha | series re: rge capa | sistor an acity par | d a const ameter, th | ant volt. ie block | age models | 1 |
| $V = V_nominal*(1 - alpha*(1 - x))$ |)/(1-beta*) | (1-x))) | | | | | | |
| where x = (Ampere-Hours rem are calculated to satisfy a use charge. | | | • | | | • | | а |
| Parameters | | | | | | | | |
| Nominal voltage, V_nominal: | 12 | _ | | | | V | • | |
| Internal resistance, R1: | 2 | | | | | Ohn | 1 💌 | |
| Battery charge capacity: | Infinite | | | | | | • | ĺ |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | OK | | Cancel | | Help | | Apply | |

Nominal voltage, V_nominal

The voltage at the output port when the battery is fully charged. The default value is 12 V.

Internal resistance, R1

Internal connection resistance. The default value is 2 Ω .

Battery charge capacity

Select one of the following options for modeling the charge capacity of the battery:

- Infinite The battery voltage is independent of charge drawn from the battery. This is the default option.
- Finite The battery voltage decreases as charge decreases.

Ampere-Hour rating, AH

The maximum battery charge in ampere-hours. This parameter is only visible when you select Finite for the **Battery charge capacity** parameter. The default value is 50 hr*A.

Initial charge

The battery charge at the start of the simulation. This parameter is only visible when you select Finite for the **Battery charge capacity** parameter. The default value is 50 hr*A.

Voltage V1 < V_nominal when charge is AH1

The battery output voltage when the charge level is AH1 hr*A. This parameter is only visible when you select Finite for the **Battery charge capacity** parameter. The default value is 11.5 V.

Charge AH1 when no-load volts are V1

The battery charge level in hr*A when the no-load output voltage is V1. This parameter is only visible when you select Finite for the **Battery charge capacity** parameter. The default value is 25 hr*A.

Self-discharge resistance, R2

Select one of the following options for modeling the self-discharge resistance of the battery:

- Omit Do not include resistance across the battery output terminals in the model.
- Include Include resistance R2 across the battery output terminals in the model.

R2

The resistance across the battery output terminals that represents battery self-discharge. This parameter is only visible when you

| | The default value is $2e+03 \Omega$. |
|----------|--|
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| Examples | For an example of how you can create a detailed battery model, see the Simscape Lead-Acid Battery example. |
| See Also | Simscape DC Voltage Source, Simscape Controlled Voltage Source |

select Include for the Self-discharge resistance, R2 parameter.

Generic Linear Actuator

Purpose Model generic linear actuator driven from DC voltage source or PWM driver

Library

Translational Actuators

Description



The Generic Linear Actuator block implements a model of a generic linear actuator designed to be driven from a DC voltage source or a PWM driver. Define force-speed characteristics in terms of tabulated values for powering the motor at the rated voltage. This functionality enables you to model a motor without referencing an equivalent circuit.

The motor or actuator architecture determines the way in which electrical losses depend on force. For example, a DC motor has losses that are proportional to the square of the current. As force is proportional to current, losses are also proportional to mechanical force. Most motors have an electrical loss term that is proportional to the square of mechanical force. The Generic Linear Actuator block calculates this loss term using the **Motor efficiency (percent)** and **Speed at which efficiency is measured** parameters that you provide.

Some motors also have a loss term that is independent of force. An example is a shunt motor where the field winding draws a constant current regardless of load. The **Force-independent electrical losses** parameter accounts for this effect.

The motor efficiency is the mechanical power divided by the sum of the mechanical power and both electrical loss terms. The block assumes that the speed at which the motor efficiency is defined is in the motoring quadrant and, therefore, positive.

You can operate the block in the reverse direction by changing the sign of the voltage applied. The H-Bridge block, for example, reverses motor direction if the voltage at the REV port is greater than the **Reverse threshold voltage** parameter. However, if you are using the block in reverse, specify the force-speed data for forward operation:

• Positive forces and positive speeds in the motoring quadrant.

- Positive force and negative speeds in the generating counterclockwise quadrant.
- Negative force and positive speed in the generating clockwise quadrant.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

This block has the following limitations:

Basic Assumptions and Limitations

- The force-speed curve data corresponds only to the rated voltage, so the block produces accurate results only when driven by plus or minus the rated voltage.
- The block requires you to provide force-speed data for the full range over which you use the actuator. To use the actuator in the generating and braking regions, provide additional data outside of the normal motoring region.
- Model behavior is sensitive to force-speed data. For example, no-load speed is correctly defined and finite only when the data crosses the speed axis.
- To drive the block from the H-Bridge block:
 - Do not place any other blocks between the H-Bridge and the Generic Linear Actuator blocks.

- In the H-Bridge block dialog box, set the Freewheeling mode to Via one semiconductor switch and one freewheeling diode
 Selecting Via two freewheeling diodes does not set the bridge output voltage to zero when the PWM input signal is low.
- In the H-Bridge, Generic Rotary Actuator, and Controlled PWM block dialog boxes, ensure that the **Simulation mode** is the same for all three blocks.

Electrical Force Tab

| | of tabulated values for when the motor is powered at the rat | |
|--|--|--------------------------------|
| mplitude equal to the rated supply voltage | mode, the applied voltage should either be the rated supply . In Averaged mode, the applied voltage should be the rate | d supply voltage multiplied by |
| | e motor is powered. If driving the block with the H-Bridge blo blocks and also for the Controlled PWM Voltage block if used | |
| lectrical losses are assumed to be the sum | of a force-independent term plus a term proportional to the | square of the force. |
| arameters | | |
| | | |
| Electrical Force Mechanical | | |
| Speed values: | [-15 -10 -5 0 5 10 15 20 25 30] | m/s 💌 |
| Force values: | [43.532.521.510.50-0.5] | N |
| Rated voltage: | 12 | V |
| Motor efficiency (percent): | 70 | |
| Speed at which efficiency is measured: | 20 | m/s |
| | J | |
| Force-independent electrical losses: | 2 | W |
| Simulation mode: | PWM | • |

Speed values

Specify a vector of speeds, including their units, for your force-speed data. The default value is [-15 -10 -5 0 5 10 15 20 25 30] m/s.

Dialog Box and Parameters

Force values

Specify a vector of forces, including their units, for your force-speed data. The default value is [$4\ 3.5\ 3\ 2.5\ 2\ 1.5\ 1\ 0.5\ 0\ -0.5\]$ N.

Rated voltage

Indicate the voltage for which the device you are modeling is rated. The default value is 12 V.

Motor efficiency (percent)

Efficiency that the block uses to calculate force-dependent electrical losses. The default value is **70**.

Speed at which efficiency is measured

Speed that the block uses to calculate force-dependent electrical losses. The default value is 20 m/s.

Force-independent electrical losses

Fixed electrical loss associated with the actuator when the force is zero. The default value is 2 W.

Simulation mode

If you set the **Simulation mode** parameter to PWM, apply a PWM waveform switching between zero and rated volts to the block electrical terminals. The current drawn from the electrical supply is equal to the amount required to deliver the mechanical power and to compensate for electrical losses. If the applied voltage exceeds the rated voltage, the resultant force scales proportionately. However, applying anything other than the rated voltage can provide unrepresentative results. PWM is the default setting.

If you set the ${\bf Simulation\ mode}$ parameter to ${\tt Averaged},$ the force

generated in response to an applied voltage V_{av} is

$$\frac{V_{av}}{V_{rated}} \times F(v)$$

where F(v) is the force value at speed v . The current drawn from

the supply is such that the product of the current and V_{av} is equal to the average power that is consumed.

Mechanical Tab

| 당 Block Parameters: Generic Line | ar Actuator | | × |
|--|--|----------------|--------------|
| speed characteristics are defined in t driven in PWM or Averaged mode. In amplitude equal to the rated supply v the fraction of the PWM period for wi parameter value must be the same for | erms of tabulated values for when the motor i PWM mode, the applied voltage should either oltage. In Averaged mode, the applied voltag | 2 | be e with |
| Electrical Force Mechanical | 0.1 | | _ |
| Linear damping: | 1e-05 | | |
| | | | <u> </u> |
| Initial plunger speed: | 0 | m/s | - |
| | OK | Cancel Help Aj | pply |

Plunger mass

Mass of the moving part of the motor. The default value is 0.1 kg. The value can be zero.

Linear damping

Linear damping. The default value is $1e\,{-}\,05$ N/(m/s). The value can be zero.

Initial plunger speed

Speed of the plunger at the start of the simulation. The default value is 0 m/s.

Generic Linear Actuator

| Ports | This block has the following ports: | | |
|----------|--|--|--|
| | + Positive electrical conserving port. | | |
| | Negative electrical conserving port. | | |
| | C Mechanical translational conserving port connected to the actuator case. | | |
| | R Mechanical translational conserving port connected to the plunger. | | |
| See Also | Generic Rotary Actuator and H-Bridge. | | |

Generic Rotary Actuator

Purpose Model generic rotary actuator driven from DC voltage source or PWM driver

Library

Rotational Actuators

Description



The Generic Rotary Actuator block implements a model of a generic rotary actuator designed to be driven from a DC voltage source or PWM driver. You define torque-speed characteristics in terms of tabulated values for powering the motor at the rated voltage. This functionality allows you to model a motor without referencing an equivalent circuit.

The motor or actuator architecture determines the way in which electrical losses depend on torque. For example, a DC motor has losses that are proportional to the square of the current. As torque is proportional to current, losses are also proportional to mechanical torque. Most motors have an electrical loss term that is proportional to the square of mechanical torque. The Generic Rotary Actuator block calculates this loss term using the **Motor efficiency (percent)** and **Speed at which efficiency is measured** parameters that you provide.

Some motors also have a loss term that is independent of torque. An example is a shunt motor where the field winding draws a constant current regardless of load. The **Torque-independent electrical losses** parameter accounts for this effect.

The motor efficiency is the mechanical power divided by the sum of the mechanical power and both electrical loss terms. The block assumes that the speed at which the motor efficiency is defined is in the motoring quadrant and, therefore, positive.

You can operate the block in the reverse direction by changing the sign of the voltage that you apply. The H-Bridge block, for example, reverses motor direction if the voltage at the REV port is greater than the **Reverse threshold voltage** parameter. However, if you are using the block in reverse, specify the torque-speed data for forward operation:

• Positive torques and positive speeds in the motoring quadrant.

- Positive torque and negative speeds in the generating counterclockwise quadrant.
- Negative torque and positive speed in the generating clockwise quadrant.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

This block has the following limitations:

Basic Assumptions and Limitations

- The torque-speed curve data corresponds only to the rated voltage, so the block produces accurate results only when driven by plus or minus the rated voltage.
- In this block requires, you must provide torque-speed data for the full range over which you use the actuator. To use the actuator in the generating and braking regions, provide additional data outside of the normal motoring region.
- Model behavior is sensitive to torque-speed data. For example, no-load speed is correctly defined and finite only when the data crosses the speed axis.
- To drive the block from the H-Bridge block:
 - Do not place any other blocks between the H-Bridge and the Generic Rotary Actuator blocks.

Dialog

Box and Parameters

- In the H-Bridge block dialog box, set the Freewheeling mode to Via one semiconductor switch and one freewheeling diode
 Selecting Via two freewheeling diodes does not set the bridge output voltage to zero when the PWM input signal is low.
- In the H-Bridge, Generic Rotary Actuator, and Controlled PWM block dialog boxes, ensure that the Simulation mode is the same for all three blocks.

Electrical Torque Tab

| | ary actuator designed to be driven from a DC voltage source on f tabulated values for when the motor is powered at the rated | |
|---|---|---------------------------|
| iven in PWM or Averaged mode. In PWM | mode, the applied voltage should either be the rated supply vo | Itage, or a PWM voltage v |
| e fraction of the PWM period for which th | . In Averaged mode, the applied voltage should be the rated s e motor is powered. If driving the block with the H-Bridge block | |
| | blocks and also for the Controlled PWM Voltage block if used. | |
| ectrical losses are assumed to be the sum | of a torque-independent term plus a term proportional to the s | quare of the torque. |
| arameters | | |
| Electrical Torque Mechanical | | |
| Speed values: | -1000 -500 0 500 1000 1.5e+03 2e+03 2.5e+03 3e+03] | rpm 🔻 |
| Torque values: | 0.040.0350.030.0250.020.0150.010.0050-0.0051 | N*m 🔽 |
| | - | |
| Rated voltage: | 12 | V |
| Motor efficiency (percent): | 80 | |
| Speed at which efficiency is measured: | 2e+03 | rpm 💌 |
| Torque-independent electrical losses: | 0.1 | W |
| Simulation mode: | PWM | ¥ |
| | , | |

Speed values

Specify a vector of speeds, including their units, for your torque-speed data. The default value is [-1.5e+03 -1000 -500 0 500 1000 1.5e+03 2e+03 2.5e+03 3e+03] rpm.

1-200

Torque values

Specify a vector of torques, including their units, for your torque-speed data. The default value is [0.04 0.035 0.03 0.025 0.02 0.015 0.01 0.005 0 -0.005] Nm.

Rated voltage

Indicate the voltage for which the device you are modeling is rated. The default value is 12 V.

Motor efficiency (percent)

The efficiency that the block uses to calculate torque-dependent electrical losses. The default value is 80.

Speed at which efficiency is measured

The speed that the block uses to calculate torque-dependent electrical losses. The default value is 2e+03 rpm.

Torque-independent electrical losses

Fixed electrical loss associated with the actuator when the torque is zero. The default value is 0.1 W.

Simulation mode

If you set the **Simulation mode** parameter to PWM, apply a PWM waveform switching between zero and rated volts to the block electrical terminals. The current drawn from the electrical supply is equal to the amount required to deliver the mechanical power and to compensate for electrical losses. If the applied voltage exceeds the rated voltage, the resultant torque scales proportionately. However, applying anything other than the rated voltage can provide unrepresentative results. PWM is the default setting.

If you set the Simulation mode parameter to Averaged, the

torque generated in response to an applied voltage V_{av} is

$$\frac{V_{av}}{V_{rated}} \times T(\omega)$$

where $T(\omega)$ is the torque value at speed ω . The current drawn

from the supply is such that the product of the current and V_{av} is equal to the average power that is consumed.

Mechanical Tab

| 🙀 Block Parameters: Generic R | otary Actuator | X |
|---|--|--|
| speed characteristics are defined in driven in PWM or Averaged mode, amplitude equal to the rated suppl the fraction of the PWM period for parameter value must be the same | eneric rotary actuator designed to be driven from a DC voltage source or PWM driver. Th terms of tabulated values for when the motor is powered at the rated voltage. The blo In PVM mode, the applied voltage should either be the rated supply voltage. To a PWM · voltage. In Averaged mode, the applied voltage should be the rated supply voltage mu which the motor is powered. If driving the block with the H-Bridge block, the Simulation n for both blocks and also for the Controlled PWM Voltage block if used. the sum of a torque-independent term plus a term proportional to the square of the tor | ck can be voltage with ltiplied by node |
| Parameters Electrical Torque Mechanica Rotor inertia: | 1e-04 ka*m^2 | - |
| Rotor damping: | 1e-08 N*m/(rad/s) | |
| Initial rotor speed: | 0 rpm | <u>×</u> |
| | OK Cancel Help | Apply |

Rotor inertia

Rotor resistance to change in motor motion. The default value is $1e-04 \text{ kg}^*\text{m}^2$. The value can be zero.

Rotor damping

Rotor damping. The default value is 1e-08 N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is 0 rpm.

Generic Rotary Actuator

| Ports | This block has the following ports: | | |
|----------|---|--|--|
| | + Positive electrical conserving port. | | |
| | - Negative electrical conserving port. | | |
| | C Mechanical rotational conserving port. | | |
| | R Mechanical rotational conserving port. | | |
| See Also | Generic Linear Actuator and H-Bridge. | | |

Sensors

Library

Description



The Gyro block implements a behavioral model of a MicroElectroMechanical Systems (MEMS) gyro. The gyro provides an output voltage that is proportional to the angular rotation rate presented at the mechanical rotational physical port R. The output voltage is limited according to the values that you provide for maximum and minimum output voltage.

Optionally, you can model sensor dynamics by setting the **Dynamics** parameter to Model sensor bandwidth. Including dynamics adds a first-order lag between the angular rate presented at port R and the corresponding voltage applied to the electrical + and - ports.

If running your simulation with a fixed-step solver, or generating code for hardware-in-the-loop testing, MathWorks recommends that you set the **Dynamics** parameter to No dynamics Suitable for HIL, because this avoids the need for a small simulation time step if the sensor bandwidth is high.

Gyro

Dialog Box and Parameters

| 🙀 Block Parameters: Gyro | | |
|--|---|------------------------|
| Gyro | | |
| This block represents a gyro. The voltage across the + and - electric | gyro maps the angular rotation rate at mechanical al ports. | rotational port R to a |
| It is recommended that sensor dyn very small time step. | namics be omitted for fixed-step simulation or HIL t | o avoid the need for a |
| Parameters | | |
| Sensitivity: | 12.5 | s*mV/deg |
| Output voltage for zero rotation: | 2.5 | V |
| Maximum output voltage: | 4 | V |
| Minimum output voltage: | 1 | V |
| Dynamics: | No dynamics - Suitable for HIL | |
| | OK Cancel | Help Apply |

Sensitivity

The change in output voltage level per unit change in rotation rate when the output is not being limited. The default value is 12.5 mV/(deg/s).

Output voltage for zero rotation

The output voltage from the sensor when the rotation rate is zero. The default value is **2.5** V.

Maximum output voltage

The maximum output voltage from the sensor, which determines the sensor maximum measured rotational rate. The default value is 4 V.

Minimum output voltage

The minimum output voltage from the sensor, which determines the sensor minimum measured rotational rate. The default value is 1 V.

Dynamics

Select one of the following options for modeling sensor dynamics:

- No dynamics Suitable for HIL Do not model sensor dynamics. Use this option when running your simulation fixed step or generating code for hardware-in-the-loop testing, because this avoids the need for a small simulation time step if the sensor bandwidth is high. This is the default option.
- Model sensor bandwidth Model sensor dynamics with a first-order lag approximation, based on the **Bandwidth** and the **Initial angular rate** parameter values.

Bandwidth

Specifies the 3dB bandwidth for the measured rotational rate assuming a first-order time constant. This parameter is only visible when you select Model sensor bandwidth for the **Dynamics** parameter. The default value is 3 kHz.

Initial angular rate

Determines the initial condition for the lag by specifying the initial output for the sensor, expressed in units of angular rotation rate. This parameter is only visible when you select Model sensor bandwidth for the **Dynamics** parameter. The default value is 0 deg/s.

| Ports | The block has the following ports: | |
|-------|------------------------------------|-----------------------------|
| | R | Mechanical rotational port. |
| | + | Positive electrical port. |
| | - | Negative electrical port. |

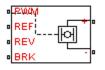
H-Bridge

| Purpose | Model H-bridge motor driver |
|---------|-----------------------------|
|---------|-----------------------------|

Drivers

Library

Description



The H-Bridge block represents an H-bridge motor driver. The block has the following two **Simulation mode** options:

- PWM The H-Bridge output is a controlled voltage that depends on the input signal at the PWM port. If the input signal has a value greater than the **Enable threshold voltage** parameter value, the H-Bridge output is on and has a value equal to the value of the **Output voltage amplitude** parameter. If it has a value less than the **Enable threshold voltage** parameter value, the block maintains the load circuit using one of the following three **Freewheeling mode** options:
 - Via one semiconductor switch and one freewheeling diode
 - Via two freewheeling diodes
 - Via two semiconductor switches and one freewheeling diode

The first and third options are sometimes referred to as synchronous operation.

The signal at the REV port determines the polarity of the output. If the value of the signal at the REV port is less than the value of the **Reverse threshold voltage** parameter, the output has positive polarity; otherwise, it has negative polarity.

- Averaged This mode has two Load current characteristics options:
 - Smoothed
 - Unsmoothed or discontinuous

The Smoothed option assumes that the current is practically continuous due to load inductance. In this case, the H-Bridge output is:

$$\frac{V_O V_{PWM}}{A_{PWM}} - I_{OUT} R_{ON}$$

where:

- V₀ is the value of the **Output voltage amplitude** parameter.
- V_{PWM} is the value of the voltage at the PWM port.
- *A_{PWM}* is the value of the **PWM signal amplitude** parameter.
- *I*_{OUT} is the value of the output current.
- *R*_{ON} is the **Bridge on resistance** parameter.

The current will be smooth if the PWM frequency is large enough. Synchronous operation where freewheeling is via a bridge arm back to the supply also helps smooth the current. For cases where the current is not smooth, or possibly discontinuous (that is, it goes to zero between PWM cycles), use the Unsmoothed or discontinuous option. For this option, you must also provide values for the **Total load series resistance**, **Total load series inductance** and **PWM frequency**. During simulation, the block uses these values to calculate a more accurate value for H-bridge output voltage that achieves the same average current as would be present if simulating in PWM mode.

Set the **Simulation mode** parameter to Averaged to speed up simulations when driving the H-Bridge block with a Controlled PWM Voltage block. You must also set the **Simulation mode** parameter of the Controlled PWM Voltage block to Averaged mode. This applies the average of the demanded PWM voltage to the motor. The accuracy of the Averaged mode simulation results relies on the validity of your assumption about the load current. If you specify that the current is Unsmoothed or discontinuous, then the accuracy also depends on the values you provide for load resistance and inductance being representative. This mode also makes some simplifying assumptions about the underlying equations for the case when current is discontinuous. For typical motor and bridge parameters, accuracy should be within a few percent. To verify Averaged mode accuracy, run the simulation using the PWM mode and compare the results to those obtained from using the Averaged mode.

Braking mode is invoked when the voltage presented at the BRK port is larger than the **Braking threshold voltage**. Regardless of whether in PWM or Averaged mode, when in braking mode the H-bridge is modeled by a series combination of two resistances R1 and R2 where:

- *R1* is the resistance of a single bridge arm, that is, half the value of the **Total bridge on resistance** parameter.
- R2 is the resistance of a single bridge arm in parallel with a diode resistance, that is, $R1 \cdot Rd / (R1 + Rd)$, where Rd is the diode resistance.

The model has the following limitations:

- If you are linearizing your model, set the **Simulation mode** parameter to Averaged and ensure that you have specified the operating point correctly. You can only linearize the H-Bridge block for inputs that are greater than zero and less than the PWM signal amplitude.
- No forward voltage is modeled for the freewheeling diodes. They are approximated as ideal resistances when forward biased, with resistance equal to the **Freewheeling diode on** resistance parameter value.
- In Averaged mode, and with the Unsmoothed or discontinuous choice for Load current characteristics, you must provide representative values for load inductance and resistance. If driving a DC Motor, then the resistance is the armature resistance, and the inductance is the sum of the armature inductance plus series smoothing inductor (if present). For a Universal motor, total resistance is the sum of the armature and field windings, and total inductance is the sum of armature and field inductances plus any series smoothing inductance. For a Shunt Motor, MathWorks recommends that you draw a Thévenin equivalent circuit to determine appropriate values.

Basic Assumptions and Limitations

Dialog Simulation Mode & Load Assumptions Tab Box and Parameters

| 🙀 Block Parameters: H-Bridge | | | | |
|---|---|--|--|--|
| H-Bridge | | | | |
| This block represents an H-bridge mo | tor driver. | | | |
| The block can be driven by the Controlled PWM Voltage block in PWM or Averaged mode. In PWM mode, the motor is powered if the PWM port voltage V is above the Enable threshold voltage. In Averaged mode, the PWM port voltage divided by the PWM signal amplitude parameter defines the ratio of the on-time to the PWM period. Using this ratio and assumptions about the load, the block applies an average voltage to the load that achieves the correct average load current. The Simulation mode parameter value must be the same for the Controlled PWM Voltage and H-Bridge blocks. If the REV port voltage is greater than the Reverse threshold voltage, then the output voltage polarity is reversed. | | | | |
| | the Braking threshold voltage, then the output terminals are short circuited parallel combination of a second bridge arm and a freewheeling diode. | | | |
| | via one bruge ann in series with the parallel combination of a second bruge ann and a neewleeling didde. | | | |
| Voltages at ports PWM, REV and BRK are defined relative to the REF port. | | | | |
| Parameters | | | | |
| Simulation Mode & Load Assumption | ns Input Thresholds Bridge Parameters | | | |
| Simulation mode: | PWM - | | | |
| Freewheeling mode: | Via one semiconductor switch and one freewheeling diode | | | |
| reewieening mode. | Via one semiconductor switch and one neewidening didde | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | OK Cancel Help Apply | | | |

Simulation mode

Select one of the following options for the type of output voltage:

- PWM The output voltage is a pulse-width modulated signal. This is the default option.
- Averaged The output voltage is a constant whose value is equal to the average value of the PWM signal.

Freewheeling mode

Select one of the following options for the type of H-Bridge dissipation circuit:

- Via one semiconductor switch and one freewheeling diode — In this mode, the block controls the load by maintaining one high-side bridge arm permanently on and using the PWM signal to modulate the corresponding low-side bridge arm. This means that the block uses only one of the freewheeling diodes in completing the dissipation circuit when the bridge turns off. This option is the default.
- Via two freewheeling diodes In this mode, all bridge arms are off during the bridge off-state. This means that the block dissipates the load current across the power supply by two freewheeling diodes.
- Via two semiconductor switches and one freewheeling diode — In this mode, the block controls the load by maintaining one high-side bridge arm permanently on and using the PWM signal to toggle between enabling the corresponding low-side bridge arm and the opposite high-side bridge arm. This means that the block uses a freewheeling diode in parallel with a bridge arm, plus another series bridge arm, to complete the dissipation circuit when the bridge turns off.

This parameter is only visible when you select PWM for the **Simulation mode** parameter, or when you select Averaged for the **Simulation mode** parameter and Unsmoothed or discontinuous for the **Load current characteristics** parameter.

Load current characteristics

Select one of the following options for the type of load current:

- Smoothed Assumes that the current is practically continuous due to load inductance. This option is the default.
- Unsmoothed or discontinuous Use this option for cases where the current is not smooth, or possibly discontinuous (that is, it goes to zero between PWM cycles). For this option, you must also provide values for the **Total load series resistance**, **Total load series inductance**, and **PWM frequency** parameters. During simulation, the block uses these values to calculate a more accurate value for H-bridge output voltage that achieves the same average current as would be present if simulating in PWM mode.

This parameter is only visible when you select Averaged for the Simulation mode parameter.

Load total series resistance

The total load series resistance seen by the H-bridge. The default value is 10 $\Omega.$

This parameter is only visible when you select Averaged for the **Simulation mode** parameter and Unsmoothed or discontinuous for the **Load current characteristics** parameter.

Load total series inductance

The total load series inductance seen by the H-bridge. As well as motor inductance, you should include any series inductance added external to the motor to smooth current. The default value is 1e-5 H.

This parameter is only visible when you select Averaged for the **Simulation mode** parameter and Unsmoothed or discontinuous for the **Load current characteristics** parameter.

PWM frequency

The PWM frequency at which the H-bridge is driven. For consistency, this should be the same value as the PWM frequency

specified by the Controlled PWM Voltage block driving the H-Bridge. The default value is 10 kHz.

This parameter is only visible when you select Averaged for the **Simulation mode** parameter and Unsmoothed or discontinuous for the **Load current characteristics** parameter.

Input Thresholds Tab

| 🙀 Block Parameters: H-Bridge | | × | | |
|---|--|-----------------------------|--|--|
| H-Bridge | | | | |
| This block represents an H-bridge me | otor driver. | | | |
| The block can be driven by the Controlled PWM Voltage block in PWM or Averaged mode. In PWM mode, the motor is powered if the PWM port voltage V is above the Enable threshold voltage. In Averaged mode, the PWM port voltage divided by the PWM signal amplitude parameter defines the ratio of the on-time to the PWM period. Using this ratio and assumptions about the load, the block applies an average voltage to the load that achieves the correct average load current. The Simulation mode parameter value must be the same for the Controlled PWM Voltage and H-Bridge blocks. | | | | |
| If the BRK port voltage is greater tha | n the Reverse threshold voltage, then the output vo n the Braking threshold voltage, then the output ter parallel combination of a second bridge arm and a | rminals are short circuited | | |
| Voltages at ports PWM, REV and BRK | are defined relative to the REF port. | | | |
| Parameters | | | | |
| Simulation Mode & Load Assumption | ons Input Thresholds Bridge Parameters | | | |
| Enable threshold voltage: | 2.5 | V • | | |
| PWM signal amplitude: | 5 | V 👻 | | |
| Reverse threshold voltage: | 2.5 | V • | | |
| Braking threshold voltage: | 2.5 | V • | | |
| L | | | | |
| | OK Cancel | Help Apply | | |

Enable threshold voltage

Threshold above which the voltage at the PWM port must rise to enable the H-Bridge output. This parameter is used only when the **Simulation mode** parameter on the **Simulation Mode & Load Assumptions** tab is set to PWM. The default value is 2.5 V.

PWM signal amplitude

The amplitude of the signal at the PWM input. The H-Bridge block uses this parameter only when the **Simulation mode** parameter on the **Simulation Mode & Load Assumptions** tab is set to Averaged. The default value is 5 V.

Reverse threshold voltage

When the voltage at the REV port is greater than this threshold, the output polarity becomes negative. The default value is 2.5 V.

Braking threshold voltage

When the voltage at the BRK port is greater than this threshold, the H-Bridge output terminals are short-circuited via the following series of devices:

- One bridge arm
- One bridge arm in parallel with a conducting freewheeling diode

The default value is 2.5 V.

Bridge Parameters Tab

| 🙀 Block Parameters: H-Bridge | | | — | |
|---|---|--|---------------------|--|
| H-Bridge | | | | |
| This block represents an H-bridge mo | otor driver. | | | |
| The block can be driven by the Controlled PWM Voltage block in PWM or Averaged mode. In PWM mode, the motor is powered if the PWM port voltage V is above the Enable threshold voltage. In Averaged mode, the PWM port voltage divided by the PWM signal amplitude parameter defines the ratio of the on-time to the PWM period. Using this ratio and assumptions about the load, the block applies an average voltage to the load that achieves the correct average load current. The Simulation mode parameter value must be the same for the Controlled PWM Voltage and H-Bridge blocks. | | | | |
| If the REV port voltage is greater tha If the BRK port voltage is greater that via one bridge arm in series with the | n the Braking threshold voltag parallel combination of a sec | ge, then the output terminals cond bridge arm and a freew | are short circuited | |
| Voltages at ports PWM, REV and BRK | are defined relative to the RE | EF port. | | |
| Parameters | | | | |
| Simulation Mode & Load Assumption | ons Input Thresholds B | Bridge Parameters | | |
| Output voltage amplitude: | 12 | V | | |
| Total bridge on resistance: | 0.1 | Ohm | • • | |
| Freewheeling diode on resistance: | 0.05 | Ohm | | |
| | | | | |
| | | | | |
| | | OK Cancel H | Help Apply | |

Output voltage amplitude

The amplitude of the voltage across the H-Bridge output ports when the output is on. The default value is 12 V.

Ports

| Tota | I bridge on resistance The total effective resistance of the two semiconductor switches that connect the load to the two power rails when the voltage at the PWM port is greater than the value of the Enable threshold voltage parameter on the Input Thresholds tab. The default value is 0.1Ω . |
|-------|--|
| Free | wheeling diode on resistance The total resistance in the freewheeling diodes that dissipate the current that flows through the motor when the voltage at the PWM port is less than the value of the Enable threshold voltage parameter on the Input Thresholds tab. This parameter is only visible when you select PWM for the Simulation mode parameter on the Simulation Mode & Load Assumptions tab. The default value is 0.1Ω . |
| The b | block has the following ports: |
| +ref | Positive electrical output voltage. |
| -ref | Negative electrical output voltage. |
| PWM | Pulse-width modulated signal. The voltage is defined relative to the REF port. |
| REF | Floating zero volt reference. |
| REV | Voltage that controls when to reverse the polarity of the H-Bridge output. The voltage is defined relative to the REF port. |
| BRK | Voltage that controls when to short circuit the H-Bridge output. The voltage is defined relative to the REF port. |
| | |

Examples See the Controlled DC Motor, Linear Electrical Actuator (System-Level Model) and Linear Electrical Actuator (Implementation Model) examples.

Incandescent Lamp

Purpose Model incandescent lamp, with resistance depending on temperature

Library Passive Devices

Description

The Incandescent Lamp block models an incandescent lamp, the key characteristic of which is that the resistance increases as the filament warms up.

Under the simplifying assumption that the rate of heat loss from the filament is proportional to temperature difference to ambient, the temperature of the filament is governed by

$$kt_c \frac{dT}{dt} = i^2 R - kT$$

and the filament resistance is governed by the following equation

$$R = R_0 \left(1 + \alpha T \right)$$

where:

- R_0 is the initial resistance at turn-on (when filament is at ambient temperature).
- *T* is the filament temperature relative to ambient temperature.
- α is the resistance temperature coefficient.
- t_c is the thermal time constant.
- *k* is the heat transfer coefficient.
- *R* is the filament resistance.
- i is the filament current.

There are two parameterization options:

| | • If you select Specify resistance values directly, the block uses values that you provide for filament resistance when on and at turn-on to determine the value for the heat transfer coefficient. |
|---------------------------------|--|
| | • If you select Specify currents, the block uses values that you provide for filament current when on and at turn-on to determine the value for the heat transfer coefficient. |
| | Optionally you can specify a simulation time at which the lamp fails by providing a finite value for the Time at which lamp goes open circuit parameter on the Faults tab. When in the open-circuit state, the lamp resistance is set to be the value of the Open-circuit resistance parameter. |
| Dialog Box and Parameters | "Resistance Tab" on page 1-222 "Dynamics Tab" on page 1-224 "Faults Tab" on page 1-225 |
| | |

Resistance Tab

| 🙀 Block Parameters: Incandescent Lamp | | [|
|---------------------------------------|---|----------|
| Incandescent Lamp | | |
| | amp. The resistance is given by R = R0*(1+alpha*d the resistance temperature coefficient and deltaT is | |
| Parameters | | |
| Resistance Dynamics Faults | | |
| Parameterization: | Specify resistance values directly | • |
| Initial resistance at turn-on: | 0.15 | Ohm 🝷 |
| Steady-state resistance when on: | 1 | Ohm 👻 |
| Rated voltage: | 12 | V - |
| Resistance temperature coefficient: | 0.004 | 1/K • |
| | | |
| | OK Cancel | Help App |

Parameterization

Select one of the following methods for block parameterization:

• Specify resistance values directly — Provide the values for filament resistance at turn-on and when on in steady state. The block determines the value for the heat transfer coefficient based on these values. This is the default option.

• Specify currents — Provide the values for filament current at turn-on and when on in steady state. The block determines the value for the heat transfer coefficient based on these values.

Initial resistance at turn-on

The resistance seen by the external circuit when the lamp is initially turned on. This parameter is only visible when you select Specify resistance values directly for the **Parameterization** parameter. The default value is 0.15Ω .

Steady-state resistance when on

The resistance seen by the external circuit when the lamp is on and in steady state. This parameter is only visible when you select Specify resistance values directly for the **Parameterization** parameter. This resistance should be greater than the **Initial resistance at turn-on**. The default value is 1 Ω .

Inrush current at turn-on

The current through the lamp when it is initially turned on. This parameter is only visible when you select Specify currents for the **Parameterization** parameter. The default value is 70 A.

Steady-state current when on

The current through the lamp when it is on and in steady state. This parameter is only visible when you select Specify currents for the **Parameterization** parameter. This current should be less than the **Inrush current at turn-on**. The default value is 10 A.

Rated voltage

The rated voltage for the lamp, and the voltage value for which the resistance or current values are provided in the on and turn-on states. The default value is 12 V.

Resistance temperature coefficient

The fractional increase in resistance per unit increase in temperature. The default value is 0.004 1/K.

Dynamics Tab

| 🙀 Block Parameters: Incandescent Lamp | | |
|---------------------------------------|---|------------|
| Incandescent Lamp | | |
| | amp. The resistance is given by R = R0*(1+alpha the resistance temperature coefficient and delta | |
| Parameters | | |
| Resistance Dynamics Faults | | |
| Thermal time constant: | 25 | ms 💌 |
| Initial lamp state: | Off | • |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cance | I Help App |

Thermal time constant

The first-order thermal time constant for filament temperature when the lamp is turned on or off. The default value is 25 ms.

Initial lamp state

Select between On and Off. The default is Off.

Faults Tab

| 🙀 Block Parameters: Incandescent Lamp | | |
|--|---|------|
| Incandescent Lamp | | |
| | o. The resistance is given by R = R0*(1+alpha ³) resistance temperature coefficient and deltaT | |
| Parameters | | |
| Resistance Dynamics Faults | | |
| Time at which lamp goes open In circuit: | f | S |
| Open-circuit resistance: 16 | e+6 | Ohm |
| | | |
| | OK Cancel | Help |

Time at which lamp goes open circuit

For simulation times greater than this parameter value the filament resistance becomes equal to the **Open-circuit resistance**. The default value is **inf** seconds. Specifying a finite value for this parameter lets you simulate the fault dynamics when the bulb burns out.

Open-circuit resistance

The value of the filament resistance used when the lamp goes open-circuit. The default value is 1e6 Ω .

Ports The block has the following ports:

+

-

Positive electrical port.

Negative electrical port.

Purpose Model device that converts information about angular shaft position into electrical pulses

Library

Sensors

Description



The Incremental Shaft Encoder block represents a device that converts information about the angular position of a shaft into electrical pulses. The block produces N pulses on ports A and B per shaft revolution, where N is the value you specify for the **Pulses per revolution** parameter. Pulses A and B are 90 degrees out of phase. If the shaft rotates in a positive direction, then A leads B. The block produces a single index pulse on port Z once per revolution. The Z pulse positive transition always coincides with an A pulse positive transition. The voltages at output ports A, B, and Z are defined relative to the REF reference port voltage.

Use this block if you need to model the shaft encoder signals, either to support development of a decoding algorithm, or to include the quantization effects. Otherwise, use the Simscape Ideal Rotational Motion Sensor block.

The Incremental Shaft Encoder block has the following limitations:

Basic Assumptions and Limitations

• The Incremental Shaft Encoder block is not linearizable. Use the Simscape Ideal Rotational Motion Sensor block for control design studies where you need to linearize your model.

Dialog Box and Parameters

| 당 Block Parameters: Increme | ntal Shaft Enco | oder | | × |
|--|---|---|--|--|
| _ Incremental Shaft Encoder | | | | |
| This block represents an incremen per shaft revolution, where N is t Pulses A and B are 90 degrees ou leads B. The block produces a sin positive transition always coincide and Z are defined relative to the | the value you spe ut of phase. If th gle index pulse o es with an A puls | ecify for the Pul e shaft rotates n output Z once e positive trans | ses per revolutio in a positive dire e per revolution. | n parameter. ction, then A The Z pulse |
| Parameters | | | | |
| Pulses per revolution: | 2 | | | |
| Output voltage amplitude: | 5 | | V | • |
| Index pulse offset relative to sha angle: | aft initial 0 | | deg | • |
| | | | | |
| | | | (| |
| | ОК | Cancel | Help | Apply |

Pulses per revolution

The number of pulses produced on each of the A and B phases per revolution of the shaft. The default value is 2.

Output voltage amplitude

The amplitude of the shaft encoder output voltage when the output is high. The default value is 5 V.

Index pulse offset relative to shaft initial angle

The offset of the index pulse Z relative to the angle of the shaft at the start of the simulation. This parameter lets you set the initial location of the index pulse. The default value is 0° .

Ports The block has the following ports:

R

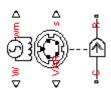
Mechanical rotational conserving port associated with the sensor positive probe.

| | С | Mechanical rotational conserving port associated with the sensor negative (reference) probe. |
|----------|----------|---|
| | A | Encoded electrical output. |
| | B Z | Encoded electrical output. |
| | 2 REF | Index, or synchronization, electrical output. |
| | | Floating zero volt reference. |
| See Also | Sims | cape Ideal Rotational Motion Sensor |

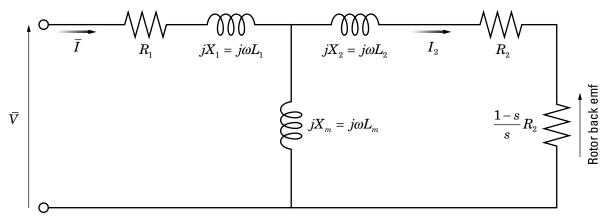
Induction Motor

- Purpose
 Model induction motor powered by ideal AC supply
- Library Rotational Actuators

Description



The Induction Motor block represents the electrical and torque characteristics of an induction motor powered by an ideal AC supply. The following figure shows the equivalent circuit model of the Induction Motor block.



In the figure:

- R₁ is the stator resistance.
- R₂ is the rotor resistance with respect to the stator.
- L_1 is the stator inductance.
- L₂ is the rotor inductance with respect to the stator.
- L_m is magnetizing inductance.
- s is the rotor slip.

• \overline{V} and \overline{I} are the sinusoidal supply voltage and current phasors.

Rotor slip s is defined in terms of the mechanical rotational speed ω_m , the number of pole pairs p, and the electrical supply frequency ω by

$$s = 1 - \frac{p\omega_m}{\omega}$$

This means that the slip is one when starting, and zero when running synchronously with the supply frequency.

For an n-phase induction motor the torque-speed relationship is given by:

$$T = \frac{npR_2}{s\omega} \frac{V_{rms}^2}{\left(R_1 + R_2 + \frac{1 - s}{s}R_2\right)^2 + \left(X_1 + X_2\right)^2}$$

where:

- $V_{\rm rms}$ is the line-neutral supply voltage for a star-configuration induction motor, and the line-to-line voltage for a delta-configuration induction motor.
- *n* is the number of phases.

You can parameterize this block in terms of the preceding equivalent circuit model parameters or in terms of the motor ratings the block uses to derive these parameters.

This block produces a positive torque acting from the mechanical C to R ports.

Thermal Ports

The block has two optional thermal ports, one per winding, hidden by default. To expose the thermal ports, right-click the block in your model, and then from the context menu select **Simscape block choices** >

| | Show thermal port . This action displays the thermal ports on the block icon, and adds the Temperature Dependence and Thermal port tabs to the block dialog box. These tabs are described further on this reference page. |
|--|--|
| | Use the thermal ports to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports in actuator blocks, see "Simulating Thermal Effects in Rotational and Translational Actuators". |
| Basic Assumptions and Limitations | The model is based on the following assumptions:The block does not model the starting mechanism for a single-phase induction motor. |
| | • When you parameterize the block by motor ratings, the block derives the equivalent circuit model parameters by assuming that the effect of the magnetizing inductance L_m is negligible, and the magnetizing inductance is not included in the simulated component. |
| Dialog Box and Parameters | "Electrical Torque Tab" on page 1-233 "Power Supply Tab" on page 1-238 "Mechanical Tab" on page 1-240 "Temperature Dependence Tab" on page 1-241 |
| Dialog Box and | the equivalent circuit model parameters by assuming that the effect of the magnetizing inductance L_m is negligible, and the magnetizing inductance is not included in the simulated component. "Electrical Torque Tab" on page 1-233 "Power Supply Tab" on page 1-238 "Mechanical Tab" on page 1-240 |

• "Thermal Port Tab" on page 1-243

Electrical Torque Tab

| 🙀 Block Parameters: Induction Motor | 📕 Block Parameters: Induction Motor | | |
|---|-------------------------------------|------------|--|
| Induction Motor | | | |
| This block represents the electrical and torque characteristics of an induction motor powered by an ideal AC supply. The block may be parameterized via motor ratings or equivalent circuit parameters expressed with respect to the stator. Physical signal outputs are provided for slip (s), real power (W), imaginary power (VAR) and mechanical speed (wm). If used to model a single-phase induction motor, then the effect of the starting mechanism (e.g. shaded-pole) is not modeled. The block produces a positive torque acting from the mechanical C to R ports. | | | |
| Parameters | | | |
| Electrical Torque Power Supply | Mechanical | | |
| Model parameterization: | By motor ratings | • | |
| Rated mechanical power: | 825 | W - | |
| Rated speed: | 3.5e+3 | rpm 👻 | |
| Rated RMS line-to-line voltage: | 200 | V • | |
| Rated supply frequency: | 60 | Hz 🔻 | |
| Rated RMS line current: | 2.7 | A • | |
| R1 parameterization: | From motor efficiency | • | |
| Motor efficiency (percent): | 95 | | |
| Number of pole pairs: | 1 | | |
| Number of phases: | 3 | | |
| Stator connections: | Star configuration | • | |
| <u>`</u> | | | |
| | OK Cancel | Help Apply | |

Model parameterization

Select one of the following methods for block parameterization:

- By motor ratings Provide electrical torque parameters that the block converts to an equivalent circuit model of the motor assuming that the effect of the magnetizing inductance L_m is negligible. This is the default method.
- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor.

Stator resistance R1

Resistance of the stator winding. The default value is 1 Ω . This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Rotor resistance R2

Resistance of the rotor, specified with respect to the stator. The default value is 1 Ω . This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Stator inductance L1

Inductance of the stator winding. The default value is 0.02 H. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Rotor inductance L2

Inductance of the rotor, specified with respect to the stator. The default value is 0.02 H. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Magnetizing inductance Lm

Magnetizing inductance of the stator. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. Its value is hard to estimate from motor parameters, but the effect is usually small. If you do not know its value, use a typical value of 25 times the **Stator inductance L1** value. The default value is **0.5** H.

Rated mechanical power

Mechanical power the motor delivers when running at the rated speed. The default value is 825 W. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated speed

Speed at which the motor delivers the specified **Rated mechanical power** value. The default value is 3.5e+03 rpm. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated RMS line-to-line voltage

Line-to-line voltage at which the motor ratings are specified. The default value is 200 V. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated supply frequency

Frequency of the AC supply voltage at which the motor ratings are specified. The default value is 60 hertz. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated RMS line current

Line current at which the motor delivers the specified **Rated mechanical power** value. The default value is 2.7 A. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

R1 parameterization

Select one of the following parameterizations for the equivalent circuit resistance, R_1 , of the motor:

• From motor efficiency — Calculate R_1 from the motor efficiency. This is the default method.

- From power factor Calculate \boldsymbol{R}_1 from the motor power factor.
- Use measured stator resistance R1 Measure R_1 directly. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Motor efficiency (percent)

the percentage of input power to the motor that gets delivered to the mechanical load when running at the **Rated speed** value. The default value is 95. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter and From motor efficiency for the **R1 parameterization** parameter.

Motor power factor

The cosine of the angle by which the supply current lags the supply voltage when running at the **Rated mechanical power** value. The default value is 0.93. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter and From power factor for the **R1 parameterization** parameter.

Measured stator resistance R1

the measured stator resistance. The default value is 1 Ω . This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter and Use measured stator resistance R1 for the **R1 parameterization** parameter.

Number of pole pairs

Total number of pole pairs for the motor. The default value is 1.

Number of phases

Number of supply phases. The default value is 3.

Stator connections

Select one of the following motor configurations:

• Delta configuration — Connect the motor stator windings in delta configuration. This is the default method.

• Star configuration — Connect the motor stator windings in star configuration.

Power Supply Tab

| 🙀 Block Parameters: Induction Motor | × |
|---|---|
| Induction Motor | |
| This block represents the electrical and torque characteristics of an induction motor pow The block may be parameterized via motor ratings or equivalent circuit parameters expr stator. Physical signal outputs are provided for slip (s), real power (W), imaginary power speed (wm). If used to model a single-phase induction motor, then the effect of the start shaded-pole) is not modeled. The block produces a positive torque acting from the mechanical C to R ports. | essed with respect to the (VAR) and mechanical |
| Parameters | |
| Electrical Torque Power Supply Mechanical | |
| Supply RMS line-to-line voltage: 200 | V • |
| Supply frequency: 60 | Hz 💌 |
| | |
| OK Cancel | Help Apply |

Supply RMS line-to-line voltage

The line-to-line voltage that supplies the motor. The default value is $200\ \mathrm{V}.$

Supply frequency

Frequency of the AC supply voltage. The default value is 60 hertz.

Mechanical Tab

| 🙀 Block Parameters: Induction Motor | | | × |
|---|--|--|--|
| Induction Motor | | | |
| This block represents the electrical an The block may be parameterized via stator. Physical signal outputs are pro speed (wm). If used to model a single shaded-pole) is not modeled. The block produces a positive torque | notor ratings or equivalent cirr vided for slip (s), real power (1 e-phase induction motor, then t | cuit parameters expressed N), imaginary power (VA the effect of the starting n | d with respect to the R) and mechanical |
| Parameters | | | |
| Electrical Torque Power Supply | Mechanical | | |
| Rotor inertia: | 0.001 | kg | *m^2 • |
| Rotor damping: | 1e-4 | N* | *m/(rad/s) 🔹 |
| Initial rotor speed: | 0 | rp | m 👻 |
| | | | |
| | | K Cancel | Help Apply |

Rotor inertia

Rotor inertia. The default value is $0.1\ \text{kg}^{\star}\text{m}^2.$ The value can be zero.

Rotor damping

Rotor damping. The default value is $2e\,{-}\,06$ N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is $0\ \mathrm{rpm}.$

Temperature Dependence Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| 🙀 Block Parameters: Induction Motor | | | | × |
|---|--|---|---|-----------------------|
| Induction Motor | | | | |
| This block represents the electrical an The block may be parameterized via stator. Physical signal outputs are pro speed (wm). If used to model a single shaded-pole) is not modeled. The block produces a positive torque | motor ratings or vided for slip (s) e-phase inductio | equivalent circuit parameters , real power (W), imaginary p n motor, then the effect of the | expressed with resp ower (VAR) and med | ect to the hanical |
| Parameters | | | · | |
| Electrical Torque Power Supply | Mechanical | Temperature Dependence | Thermal Port | |
| Stator and rotor resistance temperature coefficients, [alpha_1 alpha_2]: | [0.00393 0.003 | 393] | 1/K | - |
| Measurement temperature: | 25 | | с | - |
| | | | | |
| | | | | |
| | | OK Can | cel Help | Apply |

Resistance temperature coefficients, [alpha_1 alpha_2]

A 1 by 2 row vector defining the coefficient α in the equation relating resistance to temperature, as described in "Thermal Model for Actuator Blocks". The first element corresponds to the stator, and the second to rotor. The default value is for copper, and is [0.00393 0.00393] 1/K.

Measurement temperature

The temperature for which motor parameters are defined. The default value is 25 C.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| 🙀 Block Parameters: Induction Motor | | | | — × |
|---|---|--|---------------------------------------|----------------------------|
| Induction Motor | | | | |
| This block represents the electrical a The block may be parameterized via stator. Physical signal outputs are pro speed (wm). If used to model a singl shaded-pole) is not modeled. The block produces a positive torque | motor ratings or ovided for slip (s) le-phase induction | equivalent circuit parameters , real power (W), imaginary po n motor, then the effect of the | expressed with re ower (VAR) and m | spect to the nechanical |
| Parameters | | | | |
| Electrical Torque Power Supply | Mechanical | Temperature Dependence | Thermal Port | |
| Stator and rotor thermal masses, [M_1 M_2]: | [100 100] | | Ј/К | - |
| Stator and rotor initial temperatures, [T_1 T_2]: | [25 25] | | С | • |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | OK Canc | el Help | Apply |

| | Thermal masses, [M_1 M_2] A 1 by 2 row vector defining the thermal mass for the stator and rotor windings. The thermal mass is the energy required to raise the temperature by one degree. The default value is [100 100] J/K. |
|------------|--|
| | <pre>Initial temperatures, [T_A T_B] A 1 by 2 row vector defining the temperature of the stator and rotor thermal ports at the start of simulation. The default value is [25 25] C.</pre> |
| Ports | The block has the following ports: |
| | W Real power. |
| | wm Mechanical speed. |
| | VAR Imaginary power. |
| | s Motor slip. |
| | C Mechanical rotational conserving port. |
| | R Mechanical rotational conserving port. |
| | H1 Stator thermal port. For more information, see "Thermal Ports" on page 1-897. |
| | H2 Rotor thermal port. For more information, see "Thermal Ports" on page 1-897. |
| References | [1] S.E. Lyshevski. <i>Electromechanical Systems, Electric Machines, and</i> <i>Applied Mechatronics</i> , CRC, 1999. |

See Also DC Motor, Servomotor, Shunt Motor, and Universal Motor.

Light-Emitting Diode

Purpose Model light-emitting diode as exponential diode and current sensor in series

Library

Sensors

Description



The Light-Emitting Diode block represents a light-emitting diode as an exponential diode in series with a current sensor. The optical power presented at the signal port W is equal to the product of the current flowing through the diode and the **Optical power per unit current** parameter value.

The exponential diode model provides the following relationship between the diode current I and the diode voltage V:

$$I = IS \cdot \left(e^{\frac{qV}{NkT_{m1}}} - 1 \right)$$

where:

- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e–23 J/K).
- *N* is the emission coefficient.
- *IS* is the saturation current.
- T_{m1} is the temperature at which the diode parameters are specified, as defined by the **Measurement temperature** parameter value.

When $(qV/NkT_{m1}) > 80$, the block replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV/NkT_{m1} - 79)e^{80}$, which matches the gradient of the diode current at $(qV/NkT_{m1}) = 80$ and extrapolates linearly. When $(qV/NkT_{m1}) < -79$, the block

replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV / NkT_{m1} + 80)e^{-79}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not

reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

When you select Use parameters IS and N for the **Parameterization** parameter, you specify the diode in terms of the **Saturation current IS** and **Emission coefficient N** parameters. When you select Use I-V curve data points for the **Parameterization** parameter, you specify two voltage and current measurement points on the diode I-V curve and the block derives the *IS* and *N* values. When you specify current and voltage measurements, the block calculates *IS* and *N* as follows:

- $N = ((V_1 V_2) / V_t) / (\log(I_1) \log(I_2))$
- IS = $(I_1 / (\exp(V_1 / (NV_t)) 1) + I_2 / (\exp(V_2 / (NV_t)) 1)))/2$

where:

- $V_{\rm t} = kT_{\rm m1} / q$.
- V₁ and V₂ are the values in the Voltages [V1 V2] vector.
- I_1 and I_2 are the values in the **Currents** [I1 I2] vector.

The exponential diode model provides the option to include a junction capacitance:

- When you select Fixed or zero junction capacitance for the **Junction capacitance** parameter, the capacitance is fixed.
- When you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter, the block uses the coefficients *CJO*, *VJ*, *M*, and *FC* to calculate a junction capacitance that depends on the junction voltage.
- When you select Use C-V curve data points for the **Junction** capacitance parameter, the block uses three capacitance values on the C-V capacitance curve to estimate *CJO*, *VJ*, and *M* and uses these values with the specified value of *FC* to calculate a

junction capacitance that depends on the junction voltage. The block calculates *CJO*, *VJ*, and *M* as follows:

- $CJ0 = C_1((V_{R2} V_{R1})/(V_{R2} V_{R1}(C_2/C_1)^{-1/M}))^M$
- $VJ = -(-V_{R2}(C_1/C_2)^{-1/M} + V_{R1})/(1 (C_1/C_2)^{-1/M})$
- $M = \log(C_3 / C_2) / \log(V_{R2} / V_{R3})$ where:
- V_{R1}, V_{R2}, and V_{R3} are the values in the Reverse bias voltages [VR1 VR2 VR3] vector.
- C₁, C₂, and C₃ are the values in the Corresponding capacitances
 [C1 C2 C3] vector.

It is not possible to estimate FC reliably from tabulated data, so you must specify its value using the **Capacitance coefficient FC** parameter. In the absence of suitable data for this parameter, use a typical value of 0.5.

The reverse bias voltages (defined as positive values) should satisfy $V_{R3} > V_{R2} > V_{R1}$. This means that the capacitances should satisfy $C_1 > C_2 > C_3$ as reverse bias widens the depletion region and hence reduces capacitance. Violating these inequalities results in an error. Voltages V_{R2} and V_{R3} should be well away from the Junction potential VJ. Voltage V_{R1} should be less than the Junction potential VJ, with a typical value for V_{R1} being 0.1 V.

The voltage-dependent junction is defined in terms of the capacitor charge storage Q_i as:

• For $V < FC \cdot VJ$:

$$Q_{i} = CJ0 \cdot (VJ / (M - 1)) \cdot ((1 - V / VJ)^{1 - M} - 1)$$

• For $V \ge FC \cdot VJ$:

$$Q_{j} = CJ0 \cdot F_{1} + (CJ0/F_{2}) \cdot (F_{3} \cdot (V - FC \cdot VJ) + 0.5(M/VJ) \cdot (V^{2} - (FC \cdot VJ))$$

where:

- $F_1 = (VJ / (1 M)) \cdot (1 (1 FC)^{1 M}))$
- $F_2 = (1 FC)^{1+M})$
- $F_3 = 1 FC \cdot (1 + M)$

These equations are the same as used in [2], except that the temperature dependence of VJ and FC is not modeled. This model does not include the diffusion capacitance term that affects performance for high frequency switching applications.

The Light-Emitting Diode block contains several options for modeling the dependence of the diode current-voltage relationship on the temperature during simulation. Temperature dependence of the junction capacitance is not modeled, this being a much smaller effect. For details, see the Diode reference page.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

| Basic | The Light-Emitting Diode block has the following limitations: |
|-----------------------------------|---|
| Assumptions and Limitations | • When you select Use I-V curve data points for the Parameterization parameter, choose a pair of voltages near the diode turn-on voltage. Typically this is in the range from 0.05 to 1 Volt. Using values outside of this region may lead to numerical issues and poor estimates for <i>IS</i> and <i>N</i> . |
| | • You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the |

simulation may run faster with these values set to zero.

Dialog Main Tab Box and Parameters

| 🙀 Block Parameters: Light-Emitting Di | ode | | × |
|--|-------------------------|------------------------|------------|
| Light-Emitting Diode | | | |
| This block represents a light-emitti sensor. The optical power presente diode and the Optical power per un | ed at the signal port W | | |
| Parameters | | | |
| Main Ohmic Resistance J | Junction Capacitance | Temperature Dependence | |
| Optical power per unit current: | 0.005 | | W/A 🔹 |
| Parameterization: | Use I-V curve data | points | • |
| Currents [I1 I2]: | [0.0017 0.003] | | A • |
| Voltages [V1 V2]: | [0.9 1.05] | | V • |
| Measurement temperature: | 25 | | C • |
| | | |] |
| | | OK Cancel | Help Apply |

Optical power per unit current

The amount of optical power the light-emitting diode generates per unit of current flowing through the diode. The default value is 0.005 W/A.

Parameterization

Select one of the following methods for model parameterization:

• Use I-V curve data points — Specify measured data at two points on the diode I-V curve. This is the default method.

 \bullet Use parameters IS and N- Specify saturation current and emission coefficient.

Currents [I1 I2]

A vector of the current values at the two points on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select Use I-V curve data points for the **Parameterization** parameter. The default value is [0.0017 0.003] A.

Voltages [V1 V2]

A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use I-V curve data points for the **Parameterization** parameter. The default value is [0.9 1.05] V.

Saturation current IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Use parameters IS and N for the **Parameterization** parameter. The default value is 5e-5 A.

Measurement temperature

The temperature at which IS or the I-V curve was measured. The default value is 25 C.

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Use parameters IS and N for the **Parameterization** parameter. The default value is 10.

Ohmic Resistance Tab

| 🙀 Block Parameters: Light-Emitting | j Diode | | |
|--|----------------------------|------------------------|------------|
| Light-Emitting Diode | | | |
| This block represents a light-en sensor. The optical power prese diode and the Optical power per | ented at the signal port W | | |
| Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Ohmic resistance, RS: | 0.1 | | Ohm |
| | | OK Cancel | Help Apply |

Ohmic resistance RS

The series diode connection resistance. The default value is $0.1\,\Omega$

Junction Capacitance Tab

| 🙀 Block Parameters: Light-Emitting Dioc | le | | × |
|---|----------------------|--------------------------------|------------|
| Light-Emitting Diode | | | |
| This block represents a light-emitting sensor. The optical power presented diode and the Optical power per unit | at the signal port W | is equal to the product of the | |
| Parameters | | | |
| Main Ohmic Resistance Jun | nction Capacitance | Temperature Dependence | |
| Junction capacitance: | Fixed or zero junct | tion capacitance | _ |
| Zero-bias junction capacitance, CJ0: | 20 | | pF 🔻 |
| | | | |
| | | | |
| | | | |
| [` | | | |
| | | OK Cancel | Help Apply |

Junction capacitance

Select one of the following options for modeling the junction capacitance:

- Fixed or zero junction capacitance Model the junction capacitance as a fixed value.
- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 20 pF.

Reverse bias voltages [VR1 VR2 VR3]

A vector of the reverse bias voltage values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [0.1 10 100] V.

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate CJ0, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [15 10 2] pF.

Junction potential VJ

The junction potential. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 1 V.

Grading coefficient M

The grading coefficient. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Capacitance coefficient FC

Fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Use C-V curve data points or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Temperature Dependence Tab

| 🙀 Block Parameters: Light-Emitting Diode 🧮 |
|---|
| Light-Emitting Diode |
| This block represents a light-emitting diode. Structurally it consists of an exponential diode in series with a current sensor. The optical power presented at the signal port W is equal to the product of the current flowing through the diode and the Optical power per unit current parameter. |
| Parameters |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature - |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified by the **Measurement temperature** parameter on the **Main** tab). This is the default method.
- Use an I-V data point at second measurement temperature T2 If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and the current

and voltage values at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.

- Specify saturation current at second measurement temperature T2 If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and saturation current value at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify the energy gap EG Specify the energy gap value directly.

Current I1 at second measurement temperature

Specify the diode current I1 value when the voltage is V1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 0.0034 A.

Voltage V1 at second measurement temperature

parameter. The default value is 1.8e-4 A.

Specify the diode voltage V1 value when the current is I1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 1.05 V.

Saturation current, IS, at second measurement temperature Specify the saturation current *IS* value at the second measurement temperature. This parameter is only visible when you select Specify saturation current at second measurement temperature T2 for the **Parameterization**

Second measurement temperature

Specify the value for the second measurement temperature. This parameter is only visible when you select either Use an I-V data point at second measurement temperature T2 $\,$

or Specify saturation current at second measurement temperature T2 for the **Parameterization** parameter. The default value is 125 C.

Energy gap parameterization

This parameter is only visible when you select Specify the energy gap EG for the **Parameterization** parameter. It lets you select a value for the energy gap from a list of predetermined options, or specify a custom value:

- Use nominal value for silicon (EG=1.11eV) This is the default.
- Use nominal value for 4H-SiC silicon carbide (EG=3.23eV)
- Use nominal value for 6H-SiC silicon carbide (EG=3.00eV)
- Use nominal value for germanium (EG=0.67eV)
- Use nominal value for gallium arsenide (EG=1.43eV)
- Use nominal value for selenium (EG=1.74eV)
- Use nominal value for Schottky barrier diodes (EG=0.69eV)
- Specify a custom value If you select this option, the **Energy gap, EG** parameter appears in the dialog box, to let you specify a custom value for *EG*.

Energy gap, EG

Specify a custom value for the energy gap, EG. This parameter is only visible when you select Specify a custom value for the **Energy gap parameterization** parameter. The default value is 1.11 eV.

Saturation current temperature exponent parameterization Select one of the following options to specify the saturation current temperature exponent value:

| | Use nominal value for pn-junction diode (XTI=3) — This is the default. |
|------------|--|
| | Use nominal value for Schottky barrier diode (XTI=2) |
| | • Specify a custom value — If you select this option, the Saturation current temperature exponent, XTI parameter appears in the dialog box, to let you specify a custom value for <i>XTI</i> . |
| | Saturation current temperature exponent, XTI Specify a custom value for the saturation current temperature exponent, XTI. This parameter is only visible when you select Specify a custom value for the Saturation current temperature exponent parameterization parameter. The default value is 3. |
| | Device simulation temperature Specify the value for the temperature T_s , at which the device is to be simulated. The default value is 25 C. |
| Ports | The block has the following ports: |
| | W Optical output power. |
| | + Electrical conserving port associated with the diode positive terminal. |
| | - Electrical conserving port associated with the diode negative terminal. |
| References | [1] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984. |
| | [2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. |

Light-Emitting Diode

See Also Diode, Optocoupler, Photodiode

Purpose Model integrated circuit multiplier

Integrated Circuits

Description

Library

The Multiplier block models an integrated circuit multiplier. The block implements the following equation, which defines the voltage applied to the output port:

$$V_{out} = A\left(\frac{(X_1 - X_2)(Y_1 - Y_2)}{K} - (Z_1 - Z_2)\right)$$

where $X_1, X_2, Y_1, Y_2, Z_1, Z_2$ are the voltages presented at the input ports, A is the gain, and K is the scale factor.

In a typical multiplication circuit, the output is fed back into input Z1, which results in the following gain (assuming that A is large):

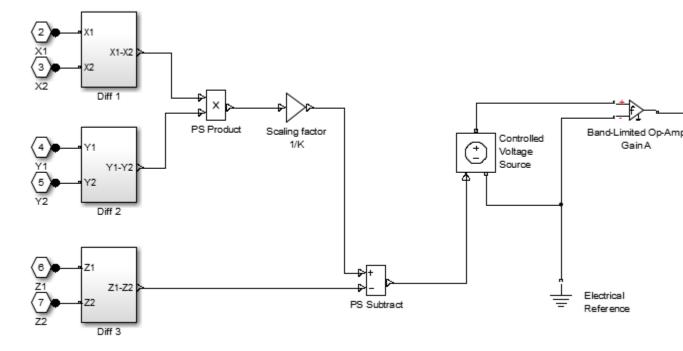
$$V_{out} = \left(\frac{(X_1 - X_2)(Y_1 - Y_2)}{K} + Z_2\right)$$

The value of the scale factor K is usually altered by an external resistor bias network. The Multiplier block implements K as an internal gain, and the external bias network is not necessary for system simulation. A typical value for K is 10, with a typical adjustment down to 3.

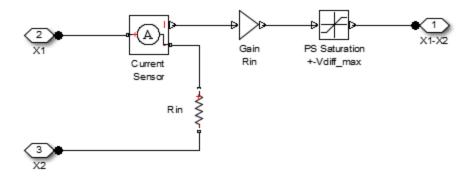
You can use the Multiplier block to implement a number of other functions, as well as multiplication. Examples include division, squares, and square roots. For example circuits, consult manufacturer datasheets.

The following figure shows the internal model structure of the Multiplier block. It includes the Band-Limited Op-Amp block to model finite bandwidth and slew-rate limiting.

Multiplier



The next figure shows one of the differential subsystem blocks. All three differential subsystem blocks are identical in structure.



Basic Assumptions and Limitations

The Multiplier block has the following limitations:

- Only differential limiting of the inputs is implemented. You must ensure that the absolute values of the inputs you use keep the actual device operating in its linear region.
- Output current is such that the integrated circuit is operating in the linear I-V region, which can be approximated by a voltage source plus a series output resistance.
- Input offset voltage is not modeled, and the input voltage-current relationship is treated as linear within the differential signal voltage range.

Dialog Box and Parameters

Main Tab

| Vout = A*((X1-X2)*(Y1-Y2)/K - (| iplier. The block implements the fol | | | to the output port: |
|---|--------------------------------------|----|-------------|---------------------|
| Main Inputs Outputs Scaling factor, K: Gain, A: | 10 3e+3 | | V | × |
| <u> </u> | | ОК | Cancel Help | Apply |

Scaling factor, K

The scaling factor K in the equation that defines output voltage. Datasheets sometimes refer to it as the scale factor, or SF. The default value is 10 V.

Gain, A

The gain of the internal operational amplifier, corresponding to the gain A in the equation that defines output voltage. The default value is 3e3.

Inputs Tab

| Block Parameters: Multiplier Multiplier Models an integrated circuit multiplier. The Vout = A*((X1-X2)*(Y1-Y2)/K - (Z1-Z2)) where X1, X2, Y1, Y2, Z1, Z2 are the volt Parameters Main Inputs Outputs | | | | | e output port: |
|--|----|----|--------|----------|----------------|
| Differential resistance, Rin: Differential signal voltage range: | 10 | | | Ohm V | Y |
| | | ОК | Cancel | Help | Apply |

Differential resistance, Rin

Each of the differential inputs is approximated as a linear resistor with value Rin. Set this value to the datasheet value for differential resistance. The default value is $1e7 \Omega$.

Differential signal voltage range

This value, *Vdiff_max*, is used to limit the magnitude of each of the three differential input voltages. Set this value to the datasheet value for differential signal voltage range. The default value is 10 V.

Outputs Tab

| 🙀 Block Parameters: Multiplier | | | | | × |
|---|---------------------------|---------------------------|--------------------|--------------------|----------------|
| -Multiplier | | | | | |
| Models an integrated circuit multiplier. Th | he block implements the f | ollowing equation which | defines the volta | age applied to the | e output port: |
| Vout = A*((X1-X2)*(Y1-Y2)/K - (Z1-Z2) |) | | | | |
| where X1, X2, Y1, Y2, Z1, Z2 are the vo | oltages presented at the | input ports, A is the gai | n and K is the sca | le factor. | |
| Parameters | | | | | |
| Main Inputs Outputs | | | | | 1 |
| Output resistance, Rout: | 0.1 | | | Ohm | • |
| Minimum output, Vmin: | -11 | | | ۷ | - |
| Maximum output, Vmax: | 11 | | | ۷ | - |
| Maximum slew rate, Vdot: | 20 | | | V/us | • |
| Bandwidth, f: | 1 | | | MHz | |
| Initial output voltage, VO: | 0 | | | ٧ | - |
| | | | | | |
| | | ок | Cancel | Help | Apply |
| | | | Carleer | | - Alden |

Output resistance, Rout

The multiplier output stage is modeled as a voltage source plus series resistor inside the Band-Limited Op-Amp block. This parameter specifies the value of this series resistor. The default value is 0.1Ω .

Minimum output, Vmin

The lower limit of the output voltage. The default value is -11 V.

Maximum output, Vmax

The upper limit of the output voltage. The default value is 11 V.

Multiplier

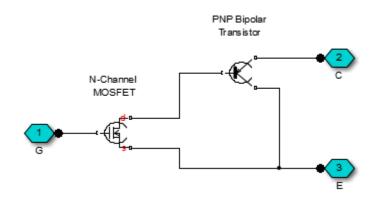
| | Maximum slew rate, Vdot The maximum positive or negative rate of change of output voltage magnitude. The default value is 20 V/µs. |
|-------|--|
| | Bandwidth, f The bandwidth of the Band-Limited Op-Amp block. The default value is 1 MHz. |
| | Initial output voltage, V0 The value of the initial Multiplier block output if the Start simulation from steady-state option is not selected in the Solver block. The default value is 0 V. |
| Ports | The block has six electrical conserving ports that serve as signal input ports and one electrical conserving port that outputs the multiplied signal. |

Purpose Model N-Channel IGBT

Library Semiconductor Devices

Description

The N-Channel IGBT block models a PNP Bipolar transistor driven by an N-Channel MOSFET, as shown in the following figure:



The MOSFET source is connected to the bipolar transistor collector, and the MOSFET drain is connected to the bipolar transistor base. The MOSFET uses the equations shown in the N-Channel MOSFET block reference page. The bipolar transistor uses the equations shown in the PNP Bipolar Transistor block reference page, but with the addition of an emission coefficient parameter N that scales kT/q.

The N-Channel IGBT block uses the on and off characteristics you specify in the block dialog box to estimate the parameter values for the underlying N-Channel MOSFET and PNP bipolar transistor.

The block uses the off characteristics to calculate the base-emitter voltage, $V_{\rm he}$, and the saturation current, $I_{\rm S}$.

When the transistor is off, the gate-emitter voltage is zero and the IGBT base-collector voltage is large, so the PNP base and collector current equations simplify to:

$$I_{b} = 0 = -I_{s} \left[\frac{1}{\beta_{F}} \left(e^{-qV_{be}/(NkT)} - 1 \right) - \frac{1}{\beta_{R}} \right]$$
$$I_{c} = -I_{s} \left[e^{-qV_{be}/(NkT)} \left(1 + \frac{V_{bc}}{V_{AF}} \right) + \frac{1}{\beta_{R}} \right]$$

where N is the **Emission coefficient**, N parameter value, V_{AF} is the forward Early voltage, and I_c and I_b are defined as positive flowing into the collector and base, respectively. See the PNP Bipolar Transistor reference page for definitions of the remaining variables. The first equation can be solved for V_{be} .

The base current is zero in the off-condition, and hence $I_c = -I_{ces}$, where I_{ces} is the Zero gate voltage collector current. The base-collector voltage, V_{bc} , is given by $V_{bc} = V_{ces} + V_{ces}$, where V_{ces} is the voltage at which I_{ces} is measured. Hence we can rewrite the second equation as follows:

$$I_{ces} = I_s \left[e^{-qV_{be}/(NkT)} \left(1 + \frac{V_{ces} + V_{be}}{V_{AF}} \right) + \frac{1}{\beta_R} \right]$$

The block sets β_R and β_F to typical values of 1 and 50, so these two equations can be used to solve for V_{be} and I_S :

$$V_{be} = \frac{-NkT}{q} \log\left(1 + \frac{\beta_F}{\beta_R}\right)$$
$$I_s = \frac{I_c}{e^{-qV_{be}/(NkT)} + \frac{1}{\beta_R}}$$

Note The block does not require an exact value for β_F because it can adjust the MOSFET gain *K* to ensure the overall device gain is correct.

The block parameters Collector-emitter saturation voltage, Vce(sat) and Collector current at which Vce(sat) is defined are used to determine $V_{be(sat)}$ by solving the following equation:

$$I_{ce(sat)} = I_s \left[e^{-qV_{be(sat)}/(NkT)} \left(1 + \frac{V_{ce(sat)} + V_{be(sat)}}{V_{AF}} \right) + \frac{1}{\beta_R} \right]$$

Given this value, the block calculates the MOSFET gain, K, using the following equation:

$$I_{ds} = I_{b} = K \left[(V_{GE(sat)} - V_{th}) V_{ds} - \frac{V_{ds}^{2}}{2} \right]$$

where V_{th} is the **Gate-emitter threshold voltage**, Vge(th) parameter value and $V_{GE(sat)}$ is the **Gate-emitter voltage at which Vce(sat) is defined** parameter value.

 V_{ds} is related to the transistor voltages as $V_{ds} = V_{ce} - V_{be}$. The block substitutes this relationship for V_{ds} , sets the base-emitter voltage and base current to their saturated values, and rearranges the MOSFET equation to give

$$K = \frac{I_{b(sat)}}{\left[(V_{GE(sat)} - V_{th}) \left(V_{be(sat)} + V_{ce(sat)} \right) - \frac{\left(V_{be(sat)} + V_{ce(sat)} \right)^2}{2} \right]}$$

where $V_{ce(sat)}$ is the Collector-emitter saturation voltage, Vce(sat) parameter value.

These calculations ensure the zero gate voltage collector current and collector-emitter saturation voltage are exactly met at these two specified conditions. However, the current-voltage plots are very sensitive to the emission coefficient N and the precise value of V_{th} . If

the manufacturer datasheet gives current-voltage plots for different $V_{\rm GE}$ values, then the N and $V_{\rm th}$ can be tuned by hand to improve the match.

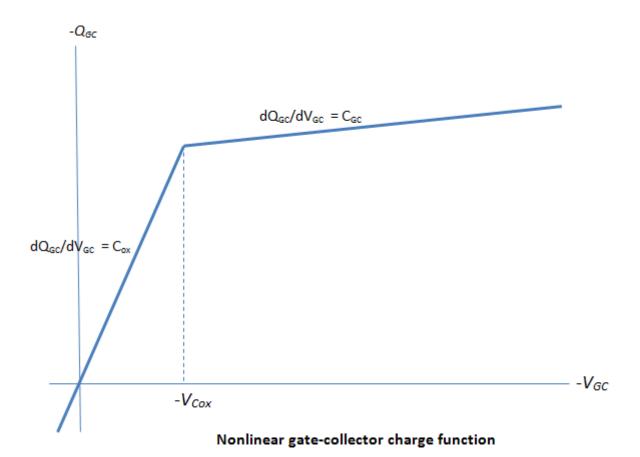
Charge Model

The block models gate junction capacitance as a fixed gate-emitter capacitance $C_{\rm GE}$ and either a fixed or a nonlinear gate-collector capacitance $C_{\rm GC}.$

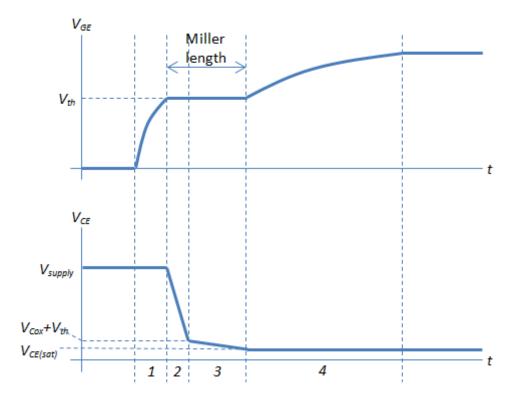
If you select Specify using equation parameters directly for the **Parameterization** parameter in the **Junction Capacitance** tab, you specify the **Gate-emitter junction capacitance** and **Gate-collector junction capacitance** parameters directly. Otherwise, the block derives them from the **Input capacitance Cies** and **Reverse transfer capacitance Cres** parameter values. The two parameterizations are related as follows:

- $C_{GE} = Cres$
- $C_{GC} = Cies Cres$

If you select the Gate-collector charge function is nonlinear option for the **Charge-voltage linearity** parameter, then the gate-collector charge relationship is defined by the piecewise-linear function shown in the following figure.



With this nonlinear capacitance, the gate-emitter and collector-emitter voltage profiles take the form shown in the next figure, where the collector-emitter voltage fall has two regions (labeled 2 and 3) and the gate-emitter voltage has two time-constants (before and after the threshold voltage $V_{\rm th}$):



You can determine the capacitor values for *Cies*, *Cres*, and C_{ox} as follows, assuming that the IGBT gate is driven through an external resistance R_{G} :

- **1** Set *Cies* to get correct time-constant for $V_{\rm GE}$ in Region 1. The time constant is defined by the product of *Cies* and $R_{\rm G}$. Alternatively, you can use a datasheet value for *Cies*.
- **2** Set *Cres* so as to achieve the correct $V_{\rm CE}$ gradient in Region 2. The gradient is given by $(V_{\rm GE} V_{\rm th})/(Cres \cdot R_{\rm G})$.

- **3** Set $V_{\rm Cox}$ to the voltage at which the $V_{\rm CE}$ gradient changes minus the threshold voltage Vth.
- **4** Set C_{ox} to get correct Miller length and time constant in Region 4.

Because the underlying model is a simplification of an actual charge distribution, some iteration of these four steps may be required to get a best overall fit to measured data. The collector current tail when the IGBT is turned off is determined by the **Total forward transit time** parameter.

Fine-Tuning the Current-Voltage Characteristics

Use the parameters on the **Advanced** tab to fine-tune the current-voltage characteristics of the modeled device. To use these additional parameters effectively, you will need a manufacturer datasheet that provides plots of the collector current versus collector-emitter voltage for different values of gate-emitter voltage. The parameters on the **Advanced** tab have the following effects:

- The **Emission coefficient**, **N** parameter controls the shape of the current-voltage curves around the origin.
- The **Collector resistance**, **RC** and **Emitter resistance**, **RE** parameters affect the slope of the current-voltage curve at higher currents, and when fully turned on by a high gate-emitter voltage.
- The Forward Early voltage, VAF parameter affects the shape of the current-voltage curves for gate-emitter voltages around the Gate-emitter threshold voltage, Vge(th).

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect. Temperature dependence is modeled by the temperature dependence of the constituent components. See the N-Channel MOSFET and PNP Bipolar Transistor block reference pages for further information on the defining equations.

Some datasheets do not provide information on the zero gate voltage collector current, *Ices*, at a higher measurement temperature. In this case, you can alternatively specify the energy gap, EG, for the device, using a typical value for the semiconductor type. For silicon, the energy gap is usually 1.11 eV.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The model is based on the following assumptions:

Basic Assumptions and Limitations

- This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.
- You may need to use nonzero junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.
- The block does not account for temperature-dependent effects on the junction capacitances.

Dialog Main Tab Box and Parameters

| | | | nderlying model is based on a PNP bipolar tra ne IGBT datasheet parameters. It is assumed | |
|-------------------|---|--------------------|--|------|
| | | | e diode, and reverse breakdown is not mode | |
| ramet | ers | | | |
| Main | Junction Capacitance A | dvanced | Temperature Dependence | |
| Zero g Ices: | ate voltage collector current, | 2 | | mA 👻 |
| Voltag | e at which Ices is defined: | 600 | | V • |
| Gate-e Vge(th | mitter threshold voltage,): | 6 | | V · |
| Collect Vce(sa | or-emitter saturation voltage it): | ^e , 2.6 | | V - |
| Collect define | or current at which Vce(sat) d: | is 400 | | Α - |
| | mitter voltage at which t) is defined: | 10 | | V - |
| Measu | rement temperature: | 25 | | C - |
| | | | | |

Zero gate voltage collector current, Ices

The collector current that flows when the gate-emitter voltage is set to zero, and a large collector-emitter voltage is applied, that is, the device is in the off-state. The value of the large collector-emitter voltage is defined by the parameter **Voltage at which Ices is defined**. The default value is 2 mA.

Voltage at which Ices is defined

The voltage used when measuring the **Zero gate voltage** collector current, Ices. The default value is 600 V.

Gate-emitter threshold voltage, Vge(th)

The threshold voltage used in the MOSFET equations. The default value is 6 V.

Collector-emitter saturation voltage, Vce(sat)

The collector-emitter voltage for a typical on-state as specified by the manufacturer. The default value is 2.8 V.

Collector current at which Vce(sat) is defined

The collector-emitter current when the gate-emitter voltage is $V_{\rm ge(sat)}$ and collector-emitter voltage is $V_{\rm ce(sat)}$. The default value is 400 A.

Gate-emitter voltage at which Vce(sat) is defined

The gate voltage used when measuring $V_{\rm ce(sat)}$ and $I_{\rm ce(sat)}.$ The default value is 10 V.

Measurement temperature

The temperature for which the parameters are quoted. The default value is 25 C.

Junction Capacitance Tab

| Main Junction Capacitance Adv | anced Temperature Dependence | |
|-------------------------------------|--|------|
| Parameterization: | Specify from a datasheet | • |
| Input capacitance, Cies: | 26.4 | nF 👻 |
| Reverse transfer capacitance, Cres: | 2.7 | nF 👻 |
| Charge-voltage linearity: | Gate-collector capacitance is constant | • |
| Total forward transit time: | 0 | us 🔻 |
| | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance, Cies

The gate-emitter capacitance with the collector shorted to the source. This parameter is only visible when you select Specify from a datasheet for the Model junction capacitance parameter. The default value is 26.4 nF.

Reverse transfer capacitance, Cres

The collector-gate capacitance with the emitter connected to ground. This parameter is only visible when you select Specify from a datasheet for the Model junction capacitance parameter. The default value is 2.7 nF.

Gate-emitter junction capacitance

The value of the capacitance placed between the gate and the emitter. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction** capacitance parameter. The default value is 23.7 nF.

Gate-collector junction capacitance

The value of the capacitance placed between the gate and the collector. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction capacitance** parameter. The default value is 2.7 nF.

Charge-voltage linearity

Select whether gate-drain capacitance is fixed or nonlinear:

- Gate-collector capacitance is constant The capacitance value is constant and defined according to the selected parameterization option, either directly or derived from a datasheet. This is the default method.
- Gate-collector charge function is nonlinear The gate-collector charge relationship is defined according to the piecewise-nonlinear function described in "Charge Model" on page 1-270. Two additional parameters appear to let you define the gate-collector charge function.

Gate-collector oxide capacitance

The gate-collector capacitance when the device is on and the collector-gate voltage is small. This parameter is only visible when you select Gate-collector charge function is nonlinear for the **Charge-voltage linearity** parameter. The default value is 20 nF.

Collector-gate voltage below which oxide capacitance becomes active

The collector-gate voltage at which the collector-gate capacitance switches between off-state ($C_{\rm GC}$) and on-state ($C_{\rm ox}$) capacitance values. This parameter is only visible when you select Gate-collector charge function is nonlinear for the Charge-voltage linearity parameter. The default value is -5 V.

Total forward transit time

The forward transit time for the PNP transistor used as part of the underlying IGBT model. It affects how quickly charge is removed from the channel when the IGBT is turned off. The default value is $0 \mu s$.

Advanced Tab

| 🛅 Block Parameters: N-Channel IGBT | | × |
|--|------------------------------|------------|
| N-Channel IGBT | | |
| This block represents an N-channel IGBT. The underlying model is based on a PNP bipolar transistor plus an N-channel MOSFET whose parameters are derived from the IGBT datasheet parameters. It is assumed that both the MOSFET gate resistance is infinite. There is no integral reverse diode, and reverse breakdown is not modeled. | | |
| Parameters | | |
| Main Junction Capacitance Adv | anced Temperature Dependence | |
| Emission coefficient, N: | 1 | |
| Forward Early voltage, VAF: | 200 | V • |
| Collector resistance, RC: | 0.001 | Ohm 👻 |
| Emitter resistance, RE: | 0.001 | Ohm 👻 |
| Forward current transfer ratio, BF: | 50 | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel | Help Apply |

Emission coefficient, N

The emission coefficient or ideality factor of the bipolar transistor. The default value is 1.

Forward Early voltage, VAF

The forward Early voltage for the PNP transistor used in the IGBT model. See the PNP Bipolar Transistor block reference page for more information. The default value is 200 V.

Collector resistance, RC

Resistance at the collector. The default value is 0.001 Ohm.

Emitter resistance, RE

Resistance at the emitter. The default value is 0.001 Ohm.

Forward current transfer ratio BF

Ideal maximum forward current gain for the PNP transistor used in the IGBT model. See the PNP Bipolar Transistor block reference page for more information. The default value is 50.

Temperature Dependence Tab

| Block Parameters: N-Channel IGBT | | |
|--|--|--|
| N-Channel IGBT | | |
| This block represents an N-channel IGBT. The underlying model is based on a PNP bipolar transistor plus an N-channel MOSFET whose parameters are derived from the IGBT datasheet parameters. It is assumed that both the MOSFET gate resistance is infinite. There is no integral reverse diode, and reverse breakdown is not modeled. | | |
| Parameters | | |
| Main Junction Capacitance Advanced Temperature Dependence | | |
| Parameterization: None - Simulate at parameter measurement temperature | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| OK Cancel Help Apply | | |

Parameterization

Select one of the following methods for temperature dependence parameterization:

• None Simulate at parameter measurement temperature — Temperature dependence is not modeled, and none of the other parameters on this tab are visible. This is the default method.

- Specify Ices and Vce(sat) at second measurement temperature Model temperature-dependent effects by providing values for the zero gate voltage collector current, *Ices*, and collector-emitter voltage, $V_{\rm ce(sat)}$, at the second measurement temperature.
- Specify Vce(sat) at second measurement temperature plus the energy gap, EG Use this option when the datasheet does not provide information on the zero gate voltage collector current, *Ices*, at a higher measurement temperature.

Energy gap, EG

Energy gap value. This parameter is only visible when you select Specify Vce(sat) at second measurement temperature plus the energy gap, EG for the **Parameterization** parameter. The default value is 1.11 eV.

Zero gate voltage collector current, Ices, at second measurement temperature

The zero gate collector current value at the second measurement temperature. This parameter is only visible when you select Specify Ices and Vce(sat) at second measurement temperature for the **Parameterization** parameter. The default value is 100 mA.

Collector-emitter saturation voltage, Vce(sat), at second measurement temperature

The collector-emitter saturation voltage value at the second measurement temperature, and when the collector current and gate-emitter voltage are as defined by the corresponding parameters on the **Main** tab. The default value is 3 V.

Second measurement temperature

Second temperature $T_{\rm m2}$ at which Zero gate voltage collector current, Ices, at second measurement temperature and Collector-emitter saturation voltage, Vce(sat), at second measurement temperature are measured. The default value is 125 C.

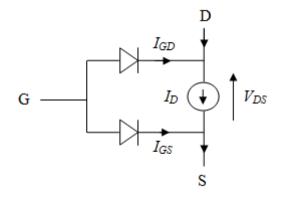
| | Saturation current temperature exponent, XTI The saturation current exponent value for your device type. If you have graphical data for the value of <i>Ices</i> as a function of temperature, you can use it to fine-tune the value of <i>XTI</i> . The default value is 3 . |
|-------|---|
| | Mobility temperature exponent, BEX Mobility temperature coefficient value. You can use the default value for most devices. If you have graphical data for $V_{ce(sat)}$ at different temperatures, you can use it to fine-tune the value of <i>BEX</i> . The default value is -1.5. |
| | Device simulation temperature Temperature $T_{\rm s}$ at which the device is simulated. The default value is 25 C. |
| Ports | The block has the following ports: |
| | C Electrical conserving port associated with the PNP emitter terminal. |
| | G Electrical conserving port associated with the MOSFET gate terminal. |
| | E Electrical conserving port associated with the PNP collector terminal. |

- Purpose Model N-Channel JFET
- Library Semiconductor Devices

Description

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The N-Channel JFET block uses the Shichman and Hodges equations to represent an N-Channel JFET using a model with the following structure:



G is the transistor gate, D is the transistor drain, and S is the transistor source. The drain current, $I_{\rm D}$, depends on the region of operation and whether the transistor is operating in normal or inverse mode.

• In normal mode ($V_{\rm DS} \ge 0$), the block provides the following relationship between the drain current $I_{\rm D}$ and the drain-source voltage $V_{\rm DS}$.

| Region | Applicable Range of V _{GS} and V _{DS} Values | Corresponding I _D Equation |
|-----------|--|---|
| Off | $V_{\rm GS}-V_{\rm t0} \le 0$ | $I_{\rm D} = 0$ |
| Linear | $0 < V_{\rm DS} < V_{\rm GS} - V_{\rm t0}$ | $I_{\rm D} = \beta V_{\rm DS} (2(V_{\rm GS} - V_{\rm t0}) - V_{\rm DS}) (1 + \lambda V_{\rm DS})$ |
| Saturated | $0 < V_{\rm GS} - V_{\rm t0} \leq V_{\rm DS}$ | $I_{\rm D} = \beta \; (V_{\rm GS} - V_{\rm t0})^2 \; (1 + \lambda V_{\rm DS})$ |

• In inverse mode ($V_{\rm DS} < 0$), the block provides the following relationship between the drain current $I_{\rm D}$ and the drain-source voltage $V_{\rm DS}$.

| Region | Applicable Range of V _{GS} and V _{DS} Values | Corresponding I _D Equation |
|-----------|--|---|
| Off | $V_{\rm GS}-V_{\rm t0} \leq 0$ | $I_{\rm D} = 0$ |
| Linear | $0 < -V_{\rm DS} < V_{ m GS} - V_{ m t0}$ | $I_{\rm D} = \beta V_{\rm DS} (2(V_{\rm GD} - V_{\rm t0}) + V_{\rm DS}) (1 - \lambda V_{\rm DS})$ |
| Saturated | $0 < V_{\rm GS} - V_{\rm t0} \leq -V_{\rm DS}$ | $I_{\rm D} = \beta \; (V_{\rm GD} - V_{\rm t0})^2 \; (1 - \lambda V_{\rm DS})$ |

In the preceding equations:

- V_{GS} is the gate-source voltage.
- $V_{\rm GD}$ is the gate-drain voltage.
- $V_{\rm t0}$ is the threshold voltage. If you select Specify using equation parameters directly for the **Parameterization** parameter, $V_{\rm t0}$ is the **Threshold voltage** parameter value. Otherwise, the block calculates $V_{\rm t0}$ from the datasheet parameters you specify.
- β is the transconductance parameter. If you select Specify using equation parameters directly for the **Parameterization** parameter, β is the **Transconductance parameter** parameter value. Otherwise, the block calculates β from the datasheet parameters you specify.
- λ is the channel-length modulation parameter. If you select Specify using equation parameters directly for the Parameterization parameter, λ is the Channel-length modulation parameter value. Otherwise, the block calculates λ from the datasheet parameters you specify.

The currents in each of the diodes satisfy the exponential diode equation

$$I_{GD} = IS \cdot \left(e^{\frac{qV_{GD}}{kT_{m1}}} - 1 \right)$$
$$I_{GS} = IS \cdot \left(e^{\frac{qV_{GS}}{kT_{m1}}} - 1 \right)$$

where:

- *IS* is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, *IS* is the **Saturation current** parameter value. Otherwise, the block calculates *IS* from the datasheet parameters you specify.
- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e–23 J/K).
- T_{m1} is the measurement temperature. The value comes from the **Measurement temperature** parameter.

The block models gate junction capacitance as a fixed gate-drain capacitance C_{GD} and a fixed gate-source capacitance C_{GS} . If you select Specify using equation parameters directly for the **Parameterization** parameter, you specify these values directly using the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = Ciss Crss$

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The measurement temperature value, $T_{\rm m1}$, is replaced with the simulation temperature, $T_{\rm s}$. The transconductance, β , and the threshold voltage, $V_{\rm t0}$, become a function of temperature according to the following equations:

$$\beta_{Ts} = \beta_{Tm1} \left(\frac{T_s}{T_{m1}} \right)^{BEX}$$

 $V_{\rm t0s} = V_{\rm t01} + a \ (\ T_{\rm s} - T_{\rm m1})$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- $T_{\rm s}$ is the simulation temperature.
- β_{Tm1} is JFET transconductance at the measurement temperature.
- β_{Ts} is JFET transconductance at the simulation temperature. This is the transconductance value used in the JFET equations when temperature dependence is modeled.
- V_{t01} is the threshold voltage at measurement temperature.
- $V_{\rm t0s}$ is the threshold voltage at simulation temperature. This is the threshold voltage value used in the JFET equations when temperature dependence is modeled.

- *BEX* is the mobility temperature exponent. A typical value of *BEX* is -1.5.
- *a* is the gate threshold voltage temperature coefficient, $dV_{\rm th}/dT$.

For most JFETS, you can use the default value of -1.5 for *BEX*. Some datasheets quote the value for a, but most typically they provide the temperature dependence for the saturated drain current, I_dss . Depending on the block parameterization method, you have two ways of specifying a:

- If you parameterize the block from a datasheet, you have to provide I_dss at a second measurement temperature. The block then calculates the value for *a* based on this data.
- If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

If you have more data comprising drain current as a function of gate-source voltage for fixed drain-source voltage plotted at more than one temperature, then you can also use Simulink Design Optimization software to help tune the values for a and *BEX*.

In addition, the saturation current term, *IS*, in the gate-drain and gate-source current equations depends on temperature

$$IS_{Ts} = IS_{Tm1} \cdot (T_s / T_{m1})^{XTI} \cdot \exp\left(-\frac{EG}{kT_s} (1 - T_s / T_{m1})\right)$$

where:

- IS_{Tm1} is the saturation current at the measurement temperature.
- IS_{Ts} is the saturation current at the simulation temperature. This is the saturation current value used in the bipolar transistor equations when temperature dependence is modeled.
- *EG* is the energy gap.

- k is the Boltzmann constant (1.3806503e-23 J/K).
- *XTI* is the saturation current temperature exponent.

Similar to *a*, you have two ways of specifying *EG* and *XTI*:

- If you parameterize the block from a datasheet, you have to specify the gate reverse current, *I_gss*, at a second measurement temperature. The block then calculates the value for *EG* based on this data and assuming a p-n junction nominal value of 3 for *XTI*.
- If you parameterize by specifying equation parameters, you have to provide the values for EG and XTI directly. This option gives you most flexibility to match device behavior, for example, if you have a graph of I_gss as a function of temperature. With this data you can use Simulink Design Optimization software to help tune the values for EG and XTI.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The model is based on the following assumptions:

Basic Assumptions and Limitations

• This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.

- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.
- The block does not account for temperature-dependent effects on the junction capacitances.
- When you specify I_dss at a second measurement temperature, it must be quoted for the same working point (that is, the same drain current and gate-source voltage) as for the I_dss value on the **Main** tab. Inconsistent values for I_dss at the higher temperature will result in unphysical values for a and unrepresentative simulation results.
- You may need to tune the value of *BEX* to replicate the $I_{\rm D}$ - $V_{\rm GS}$ relationship (if available) for a given device. The value of *BEX* affects whether the $I_{\rm D}$ - $V_{\rm GS}$ curves for different temperatures cross each other, or not, for the ranges of $I_{\rm D}$ and $V_{\rm GS}$ considered.

Dialog Main Tab Box and Parameters

| 🙀 Block Parameters: N-Channel JFET | | — | | |
|--|--|---------------------------|--|--|
| N-Channel JFET | | | | |
| This block represents an N-Channel JFET. The drain current Id for positive Vds (normal operation) is given by: | | | | |
| Id = 0 if Vgs-Vt0 < 0 (off) | | | | |
| Id = B*Vds*[2*(Vgs - Vt0) - Vds]*(: | 1+L* Vds) if 0 < Vds < Vgs - Vt0] (linear region) | | | |
| Id = B*(Vgs - Vt0)^2*(1+L* Vds) i | f 0 < Vgs - Vt0 < Vds (saturated region) | | | |
| where B is the Transconductance particular the gate-source voltage and Vds is | rameter, Vt0 is the Threshold voltage, L is the Chanr s the drain-source voltage. | el-length modulation, Vgs | | |
| Parameters | | | | |
| Main Ohmic Resistance Jur | nction Capacitance Temperature Dependence | | | |
| Parameterization: | Specify from a datasheet | • | | |
| Gate reverse current, I_gss: | -1 | nA 🔻 | | |
| Saturated drain current, I_dss: | 3 | mA 👻 | | |
| I_dss measurement point, [V_gs V_ds]: | [015] | V • | | |
| Small-signal parameters, [g_fs g_os]: | [3e+3 10] | uS 👻 | | |
| Small-signal measurement point, [V_gs V_ds]: | [015] | V • | | |
| Measurement temperature: | 25 | C • | | |
| | | | | |
| | OK Cancel | Help Apply | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to equations that describe the transistor. This is the default method.
- Specify using equation parameters directly Provide equation parameters β , *IS*, V_{t0} , and λ .

Gate reverse current, I_gss

The reverse current that flows in the diode when the drain and source are short-circuited and a large negative gate-source voltage is applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -1 nA.

Saturated drain current, I_dss

The current that flows when a large positive drain-source voltage is applied for a specified gate-source voltage. For a depletion-mode device, this gate-source voltage may be zero, in which case I_dss may be referred to as the zero-gate voltage drain current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 3 mA.

I_dss measurement point, [V_gs V_ds]

A vector of the values of $V_{\rm GS}$ and $V_{\rm DS}$ at which I_dss is measured. Normally $V_{\rm GS}$ is zero. $V_{\rm DS}$ should be greater than zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 15] V.

Small-signal parameters, [g_fs g_os]

A vector of the values of g_fs and g_os . g_fs is the forward transfer conductance, that is, the conductance for a fixed drain-source voltage. g_os is the output conductance, that is, the conductance for a fixed gate-source voltage. This parameter is only visible when you select Specify from a datasheet for the

Parameterization parameter. The default value is [3e+03 10] uS.

Small-signal measurement point, [V_gs V_ds]

A vector of the values of $V_{\rm GS}$ and $V_{\rm DS}$ at which g_fs and g_os are measured. $V_{\rm DS}$ should be greater than zero. For depletion-mode devices, $V_{\rm GS}$ is typically zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 15] V.

Transconductance parameter

The derivative of drain current with respect to gate voltage. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is $1e-04 \text{ A/V}^2$.

Saturation current

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 1e-14 A.

Threshold voltage

The gate-source voltage above which the transistor produces a nonzero drain current. For an enhancement device, Vt0 should be positive. For a depletion mode device, Vt0 should be negative. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is -2 V.

Channel-length modulation

The channel-length modulation. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 0 1/V.

Measurement temperature

The temperature for which the datasheet parameters are quoted. The default value is 25 C.

Ohmic Resistance Tab

| 🙀 Block Parameters: N-Channel JFE | T | |
|---|--|---|
| -N-Channel JFET | | |
| This block represents an N-Cha | nnel JFET. The drain current Id for positive | Vds (normal operation) is given by: |
| Id = 0 if Vgs-Vt0 < 0 (off) | | |
| Id = B*Vds*[2*(Vgs - Vt0) - Vc | ls]*(1+L* Vds) if 0 < Vds < Vgs - Vt0] (li | inear region) |
| Id = B*(Vgs - Vt0)^2*(1+L* Ve | ds) if 0 < Vgs - Vt0 < Vds (saturated regio | on) |
| where B is the Transconductance is the gate-source voltage and V | e parameter, Vt0 is the Threshold voltage, /ds is the drain-source voltage. | L is the Channel-length modulation, Vgs |
| Parameters | | |
| Main Ohmic Resistance | Junction Capacitance Temperature D | ependence |
| Source ohmic resistance: | 1e-4 | Ohm 👻 |
| Drain ohmic resistance: | 0.01 | Ohm 👻 |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | ОК | Cancel Help Apply |

Source ohmic resistance

The transistor source resistance. The default value is $1e-4 \Omega$. The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is 0.01Ω . The value must be greater than or equal to 0.

Junction Capacitance Tab

| N-Channel JFET | | | |
|---|-------------------------|---------------------------------|------------------------|
| This block represents an N-Channe | el JFET. The drain curr | ent Id for positive Vds (normal | operation) is given by |
| td = 0 if Vgs-Vt0 < 0 (off) | | | |
| id = B*Vds*[2*(Vgs - Vt0) - Vds] | *(1+L* Vds) if 0 < V | ds < Vgs - Vt0] (linear region) | |
| Id = B*(Vqs - Vt0)^2*(1+L* Vds |) if 0 < Vas - Vt0 < Va | ls (saturated region) | |
| | | | |
| where B is the Transconductance is the gate-source voltage and Vds | | | nei-length modulation |
| Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Parameterization: | Specify from a dat | achoot | |
| | | asileet | |
| Input capacitance, Ciss: | 4.5 | | pF |
| Reverse transfer capacitance, Crss: | 1.5 | | pF |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| < | | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance, Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 4.5 pF.

Reverse transfer capacitance, Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 1.5 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the Model junction capacitance parameter. The default value is 3 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction** capacitance parameter. The default value is 1.5 pF.

Temperature Dependence Tab

| 🙀 Block Parameters: N-Channel JFET 💽 |
|--|
| N-Channel JFET |
| This block represents an N-Channel JFET. The drain current Id for positive Vds (normal operation) is given by: |
| Id = 0 if Vgs-Vt0 < 0 (off) |
| $Id = B*Vds*[2*(Vgs - Vt0) - Vds]*(1+L* Vds) \ if \ 0 < Vds < Vgs - Vt0] \ (linear \ region)$ |
| $Id = B^{*}(Vgs - Vt0)^{2^{*}(1+L^{*} Vds)} \text{ if } 0 < Vgs - Vt0 < Vds (saturated region)$ |
| where B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-length modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. |
| Parameters |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature |
| |
| |
| |
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| |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled. This is the default method.
- Model temperature dependence Model temperature-dependent effects. You also have to provide a set of additional parameters depending on the block parameterization method. If you parameterize the block from a datasheet, you have to provide values for *I_gss* and *I_dss* at second measurement temperature. If you parameterize by directly specifying equation parameters, you have to provide the values for *EG*, *XTI*, and the gate threshold voltage temperature coefficient, dV_{t0}/dT . Regardless of the block parameterization method, you also have to provide values for *BEX* and for the simulation temperature, T_s .

$Gate\ reverse\ current, I_gss, at\ second\ measurement\ temperature$

The value of the gate reverse current, *I_gss*, at the second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted for the same working point (drain current and gate-source voltage) as the **Drain-source on resistance**, **R_DS(on)** parameter on the **Main** tab. The default value is -200 nA.

Saturated drain current, I_dss, at second measurement temperature

The value of the saturated drain current, I_dss , at the second measurement temperature, and when the I_dss measurement point is the same as defined by the **I**_dss measurement point, **[V_gs V_ds]** parameter on the **Main** tab. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 2.5 mA.

Second measurement temperature

Second temperature T_{m2} at which **Gate reverse current**, **I**_gss, at second measurement temperature and **Saturated drain** current, **I**_dss, at second measurement temperature are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Energy gap, EG

Energy gap value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 1.11 eV.

Saturation current temperature exponent, XTI

Saturation current temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 3.

Gate threshold voltage temperature coefficient, dVt0/dT

The rate of change of gate threshold voltage with temperature. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is -6 mV/K.

Mobility temperature exponent, BEX

Mobility temperature coefficient value. You can use the default value for most JFETs. See the "Basic Assumptions and Limitations" on page 1-290 section for additional considerations. The default value is -1.5.

Device simulation temperature

Temperature $T_{\rm s}$ at which the device is simulated. The default value is 25 C.

Ports The block has the following ports:

| | G Electrical conserving port associated with the transistor gate terminal. |
|------------|---|
| | D Electrical conserving port associated with the transistor drain terminal. |
| | S Electrical conserving port associated with the transistor source terminal. |
| References | [1] H. Shichman and D. A. Hodges, <i>Modeling and simulation of insulated-gate field-effect transistor switching circuits</i> . IEEE J. Solid State Circuits, SC-3, 1968. |
| | [2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2. |
| See Also | P-Channel JFET |

N-Channel MOSFET

Library

Purpose Model N-Channel MOSFET using Shichman-Hodges equation

Semiconductor Devices

Description The N-Channel MOSFET block uses the Shichman and Hodges equations [1] for an insulated-gate field-effect transistor to represent an N-Channel MOSFET.

The drain-source current, I_{DS} , depends on the region of operation:

• In the off region ($V_{\rm GS} < V_{\rm th}$) the drain-source current is:

$$I_{DS} = 0$$

• In the linear region (0 < $V_{\rm DS}$ < $V_{\rm GS}$ – $V_{\rm th}$) the drain-source current is:

$$I_{DS} = K \left((V_{GS} - V_{th}) V_{DS} - V_{DS}^{2} / 2 \right) \left(1 + \lambda | V_{DS} | \right)$$

- In the saturated region (0 < $V_{\rm GS}$ – $V_{\rm th}$ < $V_{\rm DS})$ the drain-source current is:

$$I_{DS} = (K/2)(V_{GS} - V_{th})^2 (1 + \lambda |V_{DS}|)$$

In the preceding equations:

- *K* is the transistor gain.
- $V_{\rm DS}$ is the positive drain-source voltage.
- $V_{\rm GS}$ is the gate-source voltage.
- $V_{\rm th}$ is the threshold voltage.
- λ is the channel modulation.

Charge Model

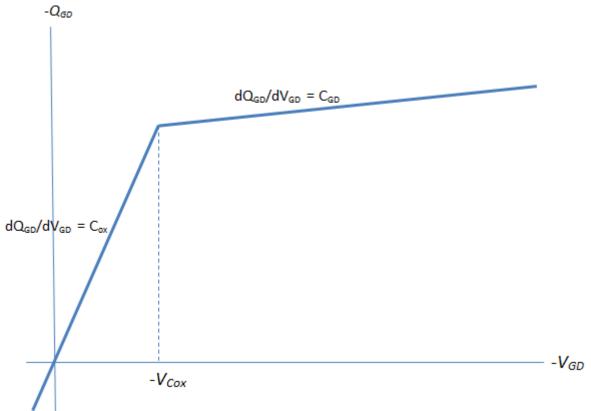
The block models gate junction capacitance as a fixed gate-source capacitance $C_{\rm GS}$ and either a fixed or a nonlinear gate-drain capacitance $C_{\rm GD}.$

If you select Specify using equation parameters directly for the **Parameterization** parameter in the **Junction Capacitance** tab, you specify the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters directly. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{\rm GD} = Crss$
- $C_{GS} = Ciss Crss$

If you select the Gate-drain charge function is nonlinear option for the **Charge-voltage linearity** parameter, then the gate-drain charge relationship is defined by the piecewise-linear function shown in the following figure.

N-Channel MOSFET



Nonlinear gate-drain charge function

For instructions on how to map a time response to device capacitance values, see the N-Channel IGBT block reference page. However, this mapping is only approximate because the Miller voltage typically varies more from the threshold voltage than in the case for the IGBT.

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide

block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The gain, K, and the threshold voltage, $V_{\rm th}$, become a function of temperature according to the following equations:

$$K_{Ts} = K_{Tm1} \left(\frac{T_s}{T_{m1}}\right)^{BEX}$$
$$V_{ths} = V_{th1} + a (T_s - T_{m1})$$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_{s} is the simulation temperature.
- K_{Tm1} is the transistor gain at the measurement temperature.
- K_{Ts} is the transistor gain at the simulation temperature. This is the transistor gain value used in the MOSFET equations when temperature dependence is modeled.
- + $V_{\rm th1}$ is the threshold voltage at the measurement temperature.
- $V_{\rm ths}$ is the threshold voltage at the simulation temperature. This is the threshold voltage value used in the MOSFET equations when temperature dependence is modeled.
- *BEX* is the mobility temperature exponent. A typical value of *BEX* is -1.5.
- *a* is the gate threshold voltage temperature coefficient, $dV_{\rm th}/dT$.

For most MOSFETS, you can use the default value of -1.5 for *BEX*. Some datasheets quote the value for a, but most typically they provide the temperature dependence for drain-source on resistance, $R_{DS}(on)$. Depending on the block parameterization method, you have two ways of specifying a:

- If you parameterize the block from a datasheet, you have to provide $R_{DS}(on)$ at a second measurement temperature. The block then calculates the value for a based on this data.
- If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

If you have more data comprising drain current as a function of gate-source voltage for more than one temperature, then you can also use Simulink Design Optimization software to help tune the values for a and *BEX*.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

When modeling temperature dependence, consider the following:

Basic Assumptions and Limitations

- The block does not account for temperature-dependent effects on the junction capacitances.
- When you specify $R_{DS}(on)$ at a second measurement temperature, it must be quoted for the same working point (that is, the same drain current and gate-source voltage) as for the other $R_{DS}(on)$ value.

Inconsistent values for $R_{DS}(on)$ at the higher temperature will result in unphysical values for a and unrepresentative simulation results. Typically $R_{DS}(on)$ increases by a factor of about 1.5 for a hundred degree increase in temperature.

• You may need to tune the values of *BEX* and threshold voltage, $V_{\rm th}$, to replicate the $V_{\rm DS}$ - $V_{\rm GS}$ relationship (if available) for a given device. Increasing $V_{\rm th}$ moves the $V_{\rm DS}$ - $V_{\rm GS}$ plots to the right. The value of *BEX* affects whether the $V_{\rm DS}$ - $V_{\rm GS}$ curves for different temperatures cross each other, or not, for the ranges of $V_{\rm DS}$ and $V_{\rm GS}$ considered. Therefore, an inappropriate value can result in the different temperature curves appearing to be reordered. Quoting $R_{DS}(on)$ values for higher currents, preferably close to the current at which it will operate in your circuit, will reduce sensitivity to the precise value of *BEX*.

N-Channel MOSFET

Dialog Box and Parameters

Main Tab

| his bloc | k represents an N-channe | el MOSFET (or IGFET) | . The drain-source current Ids f | or positive Vds is given by |
|------------------|---------------------------------|------------------------|----------------------------------|-----------------------------|
| ds = 0 if | f Vqs < Vth (off) | | | |
| | |)/2]*/14 * \/dc \ if 0 | < Vds < Vgs - Vth] (linear regio | 20) |
| | | | 5 5 5 | лт <i>)</i> |
| ds = (K/ | '2)*(Vgs - Vth)^2*(1+L* | Vds) if 0 < Vgs - Vtł | n < Vds (saturated region) | |
| | | | the channel modulation, Vgs is | the gate-source voltage |
| nd Vds | is the drain-source voltag | e. | | |
| aramet | ers | | | |
| Main | Ohmic Resistance J | unction Capacitance | Temperature Dependence | |
| Param | eterization: | Specify from a da | tasheet | • |
| Drain-s R_DS(| source on resistance, on): | 0.025 | | Ohm 👻 |
| Drain o | current, Ids, for R_DS(on) | : 6 | | Α 🗸 |
| Gate-s R_DS(| ource voltage, Vgs, for on): | 10 | | V - |
| Gate-s Vth: | ource threshold voltage, | 1.7 | | V • |
| Chann | el modulation, L: | 0 | | 1/V - |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide the drain-source on resistance and the corresponding drain current and gate-source voltage. The block calculates the transistor gain for the Shichman and Hodges equations from this information. This is the default method.
- Specify using equation parameters directly Provide the transistor gain.

Drain-source on resistance, R_DS(on)

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage. $R_{DS}(on)$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.025 Ω .

Drain current, Ids, for R_DS(on)

The drain current the block uses to calculate the value of the drain-source resistance. $I_{\rm DS}$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 6 A.

Gate-source voltage, Vgs, for R_DS(on)

The gate-source voltage the block uses to calculate the value of the drain-source resistance. $V_{\rm GS}$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 10 V.

Gain K

Positive constant gain coefficient for the Shichman and Hodges equations. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 5 A/V^2 .

Gate-source threshold voltage Vth

Gate-source threshold voltage $V_{\rm th}$ in the Shichman and Hodges equations. For an enhancement device, $V_{\rm th}$ should be positive. For a depletion mode device, $V_{\rm th}$ should be negative. The default value is 1.7 V.

Channel modulation, L

The channel-length modulation, usually denoted by the mathematical symbol λ . When in the saturated region, it is the rate of change of drain current with drain-source voltage. The effect on drain current is typically small, and the effect is neglected if calculating transistor gain K from drain-source

on-resistance, $R_{DS}(on)$. A typical value is 0.02, but the effect can be ignored in most circuit simulations. However, in some circuits a small nonzero value may help numerical convergence. The default value is 0 1/V.

Measurement temperature

Temperature $T_{\rm m1}$ at which **Drain-source on resistance**, **R_DS(on)** is measured. This parameter is only visible when you select Model temperature dependence for the **Parameterization** parameter on the **Temperature Dependence** tab. The default value is 25 C.

Ohmic Resistance Tab

| 눰 Block Parameters: N-Channel MOSFET | r | | × |
|---|-----------------------|-----------------------------------|-----------------------------|
| N-Channel MOSFET | | | |
| This block represents an N-channel N | MOSFET (or IGFET) | . The drain-source current Ids fo | r positive Vds is given by: |
| Ids = 0 if $Vgs < Vth (off)$ | | | |
| Ids = K*[(Vgs - Vth)*Vds - Vds^2/2 |]*(1+L* Vds) if 0 | < Vds < Vgs - Vth] (linear region | n) |
| Ids = (K/2)*(Vgs - Vth)^2*(1+L* Vd | ds) if 0 < Vgs - Vtl | h < Vds (saturated region) | |
| where K is a constant, Vth is the Thr and Vds is the drain-source voltage. | eshold voltage, L is | the channel modulation, Vgs is t | he gate-source voltage |
| Parameters | | | |
| Main Ohmic Resistance June | ction Capacitance | Temperature Dependence | |
| Source ohmic resistance: | 1e-4 | | Ohm 👻 |
| Drain ohmic resistance: | 0.01 | | Ohm 👻 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | OK Cancel | Help Apply |

Source ohmic resistance

The transistor source resistance. The default value is $1e-4~\Omega.$ The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is $0.001~\Omega.$ The value must be greater than or equal to 0.

Junction Capacitance Tab

| 🔁 Block Parameters: N-Channel MOSFE | T | — | | |
|--|---|-----------------------------|--|--|
| N-Channel MOSFET | | | | |
| This block represents an N-channel | MOSFET (or IGFET). The drain-source current Ids fo | r positive Vds is given by: | | |
| Ids = 0 if Vgs < Vth (off) | | | | |
| Ids = K*[(Vgs - Vth)*Vds - Vds^2/2 | $2^{1+L^{*} Vds }$ if $0 < Vds < Vgs - Vth]$ (linear region | n) | | |
| Ids = (K/2)*(Vgs - Vth)^2*(1+L* V | ds() if 0 < Vgs - Vth < Vds (saturated region) | | | |
| | where K is a constant, Vth is the Threshold voltage, L is the channel modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. | | | |
| Parameters | | | | |
| Main Ohmic Resistance Jun | ction Capacitance Temperature Dependence | | | |
| Parameterization: | Specify from a datasheet | • | | |
| Input capacitance, Ciss: | 350 | pF 🔻 | | |
| Reverse transfer capacitance, Crss: | 80 | pF 🗸 | | |
| Charge-voltage linearity: | Gate-drain capacitance is constant | • | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | OK Cancel | Help Apply | | |

Parameterization

Select one of the following methods for capacitance parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 350 pF.

Reverse transfer capacitance Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 80 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 270 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 80 pF.

Charge-voltage linearity

Select whether gate-drain capacitance is fixed or nonlinear:

- Gate-drain capacitance is constant The capacitance value is constant and defined according to the selected parameterization option, either directly or derived from a datasheet. This is the default method.
- Gate-drain charge function is nonlinear The gate-drain charge relationship is defined according to the

piecewise-nonlinear function described in "Charge Model" on page 1-303. Two additional parameters appear to let you define the gate-drain charge function.

Gate-drain oxide capacitance

The gate-drain capacitance when the device is on and the drain-gate voltage is small. This parameter is only visible when you select Gate-drain charge function is nonlinear for the **Charge-voltage linearity** parameter. The default value is 200 pF.

Drain-gate voltage at which oxide capacitance becomes active

The drain-gate voltage at which the drain-gate capacitance switches between off-state ($C_{\rm GD}$) and on-state ($C_{\rm ox}$) capacitance values. This parameter is only visible when you select Gate-drain charge function is nonlinear for the Charge-voltage linearity parameter. The default value is -0.5 V.

N-Channel MOSFET

Temperature Dependence Tab

| Block Parameters: N-Channel MOSFET |
|---|
| N-Channel MOSFET |
| This block represents an N-channel MOSFET (or IGFET). The drain-source current Ids for positive Vds is given by: |
| Ids = 0 if Vgs < Vth (off) |
| $Ids = K^*[(Vgs - Vth)^*Vds - Vds^2/2]^*(1+L^* Vds) \text{ if } 0 < Vds < Vgs - Vth] \text{ (linear region)}$ |
| $Ids = (K/2)^{*}(Vgs - Vth)^{2^{*}(1+L^{*} Vds)} \text{ if } 0 < Vgs - Vth < Vds \text{ (saturated region)}$ |
| where K is a constant, Vth is the Threshold voltage, L is the channel modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. |
| Parameters |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature |
| |
| |
| |
| |
| |
| |
| |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled. This is the default method.
- Model temperature dependence Model temperature-dependent effects. Provide a value for simulation temperature, T_s , a value for *BEX*, and a value for the measurement temperature T_{m1} (using the **Measurement temperature** parameter on the **Main** tab). You also have to provide a value for *a* using one of two methods, depending on the value of the **Parameterization** parameter on the **Main** tab. If you parameterize the block from a datasheet, you have to provide $R_{DS}(on)$ at a second measurement temperature, and the block will calculate *a* based on that. If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

Drain-source on resistance, R_DS(on), at second measurement temperature

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage at second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted for the same working point (drain current and gate-source voltage) as the **Drain-source on resistance**, **R_DS(on)** parameter on the **Main** tab. The default value is 0.037Ω .

Second measurement temperature

Second temperature T_{m2} at which **Drain-source on resistance**, **R_DS(on)**, at second measurement temperature is measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Gate threshold voltage temperature coefficient, dVth/dT

The rate of change of gate threshold voltage with temperature. This parameter is only visible when you select Specify using

| | equation parameters directly for the Parameterization parameter on the Main tab. The default value is -6 mV/K. | | |
|------------|--|--|--|
| | Mobility temperature exponent, BEX Mobility temperature coefficient value. You can use the default value for most MOSFETs. See the "Basic Assumptions and Limitations" on page 1-306 section for additional considerations. The default value is -1.5. | | |
| | Device simulation temperature Temperature T_s at which the device is simulated. The default value is 25 C. | | |
| Ports | The block has the following ports: | | |
| | G Electrical conserving port associated with the transistor gate terminal. | | |
| | D Electrical conserving port associated with the transistor drain terminal. | | |
| | S Electrical conserving port associated with the transistor source terminal. | | |
| References | [1] H. Shichman and D. A. Hodges. "Modeling and simulation of insulated-gate field-effect transistor switching circuits." IEEE J. Solid State Circuits, SC-3, 1968. | | |
| See Also | P-Channel MOSFET | | |

- **Purpose** Model ideal negative supply rail
- Library Sources

Description
The Negative Supply Rail block represents an ideal negative supply rail. Use this block instead of the Simscape DC Voltage Source block to define the output voltage relative to the Simscape Electrical Reference block that must appear in each model.

Note Do not attach more than one Negative Supply Rail block to any connected line.

Dialog Box and Parameters

| 🙀 Block Parameters: Negative Supply Rail | | | | |
|---|----|-----------|------------|--|
| Negative Supply Rail | | | | |
| This block represents an ideal negative supply rail. It can be used in place of the Foundation Library DC Voltage Source. The output voltage is defined relative to the Electrical Reference block. Use the Constant voltage parameter to specify the output voltage value. | | | | |
| Do not attach more than one Negative Supply Rail block to any connected line. | | | | |
| Parameters | | | | |
| Constant voltage: | -1 | | V • | |
| | | OK Cancel | Help Apply | |

Constant voltage

The voltage at the output port relative to the Electrical Reference block ground port. The default value is -1 V.

Negative Supply Rail

| Ports | The block has the following ports: | | |
|----------|--|--|--|
| | - Negative electrical voltage. | | |
| See Also | Simscape DC Voltage Source, Positive Supply Rail | | |

Purpose Model inductor with nonideal core

Library Passive Devices

Description

ofn.

The Nonlinear Inductor block represents an inductor with a nonideal core. A core may be nonideal due to its magnetic properties and dimensions. The block provides the following parameterization options:

- Single inductance (linear)
- Single saturation point
- Magnetic flux versus current characteristic
- Magnetic flux density versus magnetic field strength characteristic

Single Inductance (Linear)

The relationships between voltage, current and flux are defined by the following equations:

$$i = i_L + vG_p$$
$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = \frac{L}{N_w} i_L$$

where:

- v is the terminal voltage.
- i is the terminal current.
- $i_{\rm L}$ is the current through inductor.
- G_{p} is the parasitic parallel conductance.
- $N_{\rm w}$ is the number of winding turns.

- Φ is the magnetic flux.
- *L* is the unsaturated inductance.

Single Saturation Point

The relationships between voltage, current and flux are defined by the following equations:

$$\begin{split} &i = i_{L} + vG_{p} \\ &v = N_{w} \frac{d\Phi}{dt} \\ &\Phi = \frac{L}{N_{w}} i_{L} \text{ (for unsaturated)} \\ &\Phi = \frac{L_{sat}}{N_{w}} i_{L} \pm \Phi_{offset} \text{ (for saturated)} \end{split}$$

where:

- *v* is the terminal voltage.
- *i* is the terminal current.
- $i_{\rm L}$ is the current through inductor.
- $G_{\rm p}$ is the parasitic parallel conductance.
- $N_{\rm w}$ is the number of winding turns.
- Φ is the magnetic flux.
- + $\varPhi_{\rm offset}$ is the magnetic flux saturation offset.
- *L* is the unsaturated inductance.
- $L_{\rm sat}$ is the saturated inductance.

Magnetic Flux Versus Current Characteristic

The relationships between voltage, current and flux are defined by the following equations:

$$i = i_L + vG_p$$
$$v = N_w \frac{d\Phi}{dt}$$

 $\Phi = f(i_L)$

where:

- v is the terminal voltage.
- *i* is the terminal current.
- $i_{\rm L}$ is the current through inductor.
- G_{p} is the parasitic parallel conductance.
- $N_{\rm w}$ is the number of winding turns.
- Φ is the magnetic flux.

Magnetic flux is determined by one-dimensional table lookup, based on the vector of current values and the vector of corresponding magnetic flux values that you provide. You can construct these vectors using either negative and positive data, or positive data only. If using positive data only, the vector must start at 0, and the negative data will be automatically calculated by rotation about (0,0).

Magnetic Flux Density Versus Magnetic Field Strength Characteristic

The relationships between voltage, current and flux are defined by the following equations:

 $i = i_L + vG_p$ $v = N_w \frac{d\Phi}{dt}$ $\Phi = B \cdot A_e$ B = f(H) $H = \frac{N_w}{l_e} i_L$

where:

- *v* is the terminal voltage.
- i is the terminal current.
- $i_{\rm L}$ is the current through inductor.
- G_{p} is the parasitic parallel conductance.
- $N_{\rm w}$ is the number of winding turns.
- Φ is the magnetic flux.
- *H* is the magnetic field strength.
- *B* is the magnetic flux density.
- l_e is the effective core length.
- A_{e} is the effective core cross-sectional area.

Magnetic flux density is determined by one-dimensional table lookup, based on the vector of magnetic field strength values and the vector of corresponding magnetic flux density values that you provide. You can construct these vectors using either negative and positive data, or positive data only. If using positive data only, the vector must start at 0, and the negative data will be automatically calculated by rotation about (0,0).

Nonlinear Inductor

Dialog Box and Parameters

- "Main Tab" on page 1-324
- "Initial Conditions Tab" on page 1-328

Main Tab

🙀 Block Parameters: Nonlinear Inductor

Nonlinear Inductor

Represents a nonlinear inductor. The inductor can be modeled with varying levels of nonlinearity. These range fro a linear representation to specification of the magnetic flux density (B) versus magnetic field strength (H) characteristic.

The Initial current or Initial magnetic flux parameter is used to set the initial magnetic flux of the inductor. Note this value is not used if the solver configuration is set to Start simulation from steady state.

The Parasitic parallel conductance represents small parasitic effects. A small parallel conductance may be requir for the simulation of some circuit topologies.

Parameters Main Initial Conditions

| Parameterized by: | Single saturation point | |
|---------------------------------|-------------------------|-------|
| Number of turns: | 10 | |
| Unsaturated inductance: | 2e-4 | Н |
| Saturated inductance: | 1e-4 | Н |
| Saturation magnetic flux: | 1.3e-5 | Wb |
| Parasitic parallel conductance: | 1e-9 | 1/Ohm |

Parameterized by

Select one of the following methods for block parameterization:

- Single inductance (linear) Provide the values for number of turns, unsaturated inductance, and parasitic parallel conductance.
- Single saturation point Provide the values for number of turns, unsaturated and saturated inductances, saturation magnetic flux, and parasitic parallel conductance. This is the default option.
- Magnetic flux versus current characteristic In addition to the number of turns and the parasitic parallel conductance value, provide the current vector and the magnetic flux vector, to populate the magnetic flux versus current lookup table.
- Magnetic flux density versus magnetic field strength characteristic — In addition to the number of turns and the parasitic parallel conductance value, provide the values for effective core length and cross-sectional area, as well as the magnetic field strength vector and the magnetic flux density vector, to populate the magnetic flux density versus magnetic field strength lookup table.

Number of turns

The total number of turns of wire wound around the inductor core. The default value is 10.

Unsaturated inductance

The value of inductance used when the inductor is operating in its linear region. This parameter is only visible when you select Single inductance (linear) or Single saturation point for the **Parameterized by** parameter. The default value is 2e-4 H.

Saturated inductance

The value of inductance used when the inductor is operating beyond its saturation point. This parameter is only visible when you select Single saturation point for the **Parameterized by** parameter. The default value is 1e-4 H.

Saturation magnetic flux

The value of magnetic flux at which the inductor saturates. This parameter is only visible when you select Single saturation point for the **Parameterized by** parameter. The default value is 1.3e-5 Wb.

Current, i

The current data used to populate the magnetic flux versus current lookup table. This parameter is only visible when you select Magnetic flux versus current characteristic for the **Parameterized by** parameter. The default value is [0 0.64 1.28 1.92 2.56 3.20] A.

Magnetic flux vector, phi

The magnetic flux data used to populate the magnetic flux versus current lookup table. This parameter is only visible when you select Magnetic flux versus current characteristic for the **Parameterized by** parameter. The default value is [0 1.29 2.00 2.27 2.36 2.39].*1e-5 Wb.

Magnetic field strength vector, H

The magnetic field strength data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Parameterized by** parameter. The default value is [0 200 400 600 800 1000] A/m.

Magnetic flux density vector, B

The magnetic flux density data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Parameterized by** parameter. The default value is [0 0.81 1.25 1.42 1.48 1.49] T.

Effective length

The effective core length, that is, the average distance of the magnetic path. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Parameterized by** parameter. The default value is 0.032 m.

Effective cross-sectional area

The effective core cross-sectional area, that is, the average area of the magnetic path. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Parameterized by** parameter. The default value is $1.6e-5 \text{ m}^2$.

Parasitic parallel conductance

Use this parameter to represent small parasitic effects. A small parallel conductance may be required for the simulation of some circuit topologies. The default value is $1e-9 \ 1/\Omega$.

Interpolation option

The lookup table interpolation option. This parameter is only visible when you select Magnetic flux versus current characteristic or Magnetic flux density versus magnetic field strength characteristic for the **Parameterized by** parameter. Select one of the following interpolation methods:

- Linear Uses a linear interpolation function.
- Cubic Uses the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP).

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

Initial Conditions Tab

| 🙀 Block Parameters: Nonlinear Inducto | r | | | | (|
|---|---------|-----------------------|------------------|---------------|--------------|
| Nonlinear Inductor | | | | | |
| Represents a nonlinear inductor. The a linear representation to specificate characteristic. | | | | | |
| The Initial current or Initial magnet this value is not used if the solver o | | | | | tor. Note ti |
| The Parasitic parallel conductance for the simulation of some circuit to | | rasitic effects. A sm | all parallel cor | nductance may | / be requir |
| Parameters | | | | | |
| Main Initial Conditions | | | | | |
| Specify initial state by: | Current | | | | • |
| Initial current: | 0 | | | Α | - |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | ОК | Cancel | Help | Appl |

Specify initial state by

Select the appropriate initial state specification option:

- Current Specify the initial state of the inductor by the initial current through the inductor (i_1) . This is the default option.
- Magnetic flux Specify the initial state of the inductor by the magnetic flux.

Initial current

The initial current value used to calculate the value of magnetic flux at time zero. This is the current passing through the inductor. Component current consists of current passing through the inductor and current passing through the parasitic parallel conductance. This parameter is only visible when you select Current for the **Specify initial state by** parameter. The default value is 0 A.

Initial magnetic flux

The value of magnetic flux at time zero. This parameter is only visible when you select Magnetic flux for the Specify initial state by parameter. The default is 0 Wb.

Examples For comparison of nonlinear inductor behavior with different parameterization options, see the Nonlinear Inductor Characteristics example.

Ports The block has the following ports:

- + Positive electrical port. -Negative electrical port.
- See Also Simscape Inductor

Nonlinear Transformer

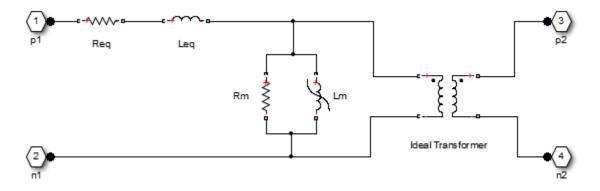
- Purpose
 Model transformer with nonideal core
- **Library** Passive Devices

Description

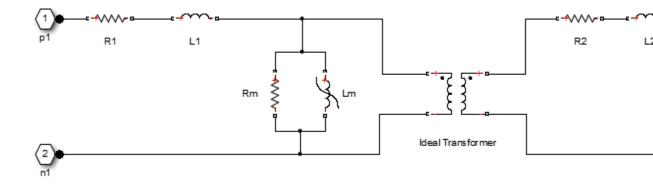


The Nonlinear Transformer block represents a transformer with a nonideal core. A core may be nonideal due to its magnetic properties and dimensions. The equivalent circuit topology depends upon which of the two winding leakage parameterization options you select:

• Combined primary and secondary values



• Separate primary and secondary values



where:

- *Req* is the combined leakage resistance.
- *Leq* is the combined leakage inductance.
- *R1* is the primary leakage resistance.
- *L1* is the primary leakage inductance.
- *R2* is the secondary leakage resistance.
- *L2* is the secondary leakage inductance.
- *Rm* is the magnetization resistance.
- *Lm* is the magnetization inductance.

The block provides the following parameterization options for the nonlinear magnetization inductance:

- Single inductance (linear)
- Single saturation point
- Magnetic flux versus current characteristic

• Magnetic flux density versus magnetic field strength characteristic

For more information, see the Nonlinear Inductor block reference page.

• "Main Tab" on page 1-333

Dialog Box and Parameters

- "Magnetization Tab" on page 1-336
- "Initial Conditions Tab" on page 1-340
- "Parasitics Tab" on page 1-343

Main Tab

Combined leakage inductance:

| ł | Block Parameters: Nonlinear Transform | ier | | |
|---|---|---|-----------|-------------------|
| | Nonlinear Transformer | | | |
| | | The transformer can be modeled with varying specification of the magnetic flux density (B) | | |
| | | ons tab are used to set the initial current or flu the solver configuration is set to Start simula | | |
| | The parallel conductances on the Par be required for the simulation of som | asitics tab represent small parasitic effects. S e circuit topologies. | mall para | illel conductance |
| | Parameters | | | |
| | Main Magnetization Initial Co | onditions Parasitics | | |
| | Primary number of turns: | 100 | | |
| | Secondary number of turns: | 200 | | |
| | Winding parameterized by: | Combined primary and secondary values | | |
| | Combined leakage resistance: | 0.01 | (| Dhm |

1e-4

Help

Н

Cancel

OK

Primary number of turns

The number of turns of wire on the primary winding of the transformer. The default value is 100.

Secondary number of turns

The number of turns of wire on the secondary winding of the transformer. The default value is 200.

Winding parameterized by

Select one of the following methods for the winding leakage parameterization:

- Combined primary and secondary values Use the lumped resistance and inductance values representing the combined leakage in the primary and secondary windings. This is the default option.
- Separate primary and secondary values Use separate resistances and inductances to represent leakages in the primary and secondary windings.

Combined leakage resistance

The lumped equivalent resistance Req, which represents the combined power loss of the primary and secondary windings. This parameter is only visible when you select Combined primary and secondary values for the **Winding parameterized by** parameter. The default value is 0.01 Ω .

Combined leakage inductance

The lumped equivalent inductance *Leq*, which represents the combined magnetic flux loss of the primary and secondary windings. This parameter is only visible when you select Combined primary and secondary values for the **Winding parameterized by** parameter. The default value is 1e-4 H.

Primary leakage resistance

The resistance R1, which represents the power loss of the primary winding. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter. The default value is 0.01 Ω .

Primary leakage inductance

The inductance L1, which represents the magnetic flux loss of the primary winding. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter. The default value is 1e-4 H.

Secondary leakage resistance

The resistance R2, which represents the power loss of the secondary winding. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter. The default value is 0.01 Ω .

Secondary leakage inductance

The inductance L2, which represents the magnetic flux loss of the secondary winding. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter. The default value is 1e-4 H.

Magnetization Tab

| 🙀 Block Parameters: Nonlinear Transform | mer | [|
|--|--|--------------------------|
| Nonlinear Transformer | | |
| | The transformer can be modeled with varying level o specification of the magnetic flux density (B) versu | |
| Note that these values are not used | ions tab are used to set the initial current or flux for if the solver configuration is set to Start simulation f | from steady state. |
| The parallel conductances on the Pa be required for the simulation of son | rasitics tab represent small parasitic effects. Small ne circuit topologies. | parallel conductances ma |
| Parameters | | |
| Main Magnetization Initial C | Conditions Parasitics | |
| Magnetization resistance: | 100 | Ohm 👻 |
| Magnetization inductance parameterized by: | Single saturation point | T |
| Unsaturated inductance: | 0.04 | H 👻 |
| Saturated inductance: | 0.01 | H – |
| Saturation magnetic flux: | 1.6e-4 | Wb 👻 |
| | | |
| | OK Cancel | Help Appl |

Magnetization resistance

The resistance Rm, which represents the magnetic losses in the transformer core. The default value is 100 Ω .

Magnetization inductance parameterized by

Select one of the following methods for the nonlinear magnetization inductance parameterization:

- Single inductance (linear) Provide the unsaturated inductance value.
- Single saturation point Provide the values for the unsaturated and saturated inductances, as well as saturation magnetic flux. This is the default option.
- Magnetic flux versus current characteristic Provide the current vector and the magnetic flux vector, to populate the magnetic flux versus current lookup table.
- Magnetic flux density versus magnetic field strength characteristic — Provide the values for effective core length and cross-sectional area, as well as the magnetic field strength vector and the magnetic flux density vector, to populate the magnetic flux density versus magnetic field strength lookup table.

Unsaturated inductance

The value of inductance used when the magnetization inductance Lm is operating in its linear region. This parameter is only visible when you select Single inductance (linear) or Single saturation point for the **Magnetization inductance** parameterized by parameter. The default value is 0.04 H.

Saturated inductance

The value of inductance used when the magnetization inductance Lm is operating beyond its saturation point. This parameter is only visible when you select Single saturation point for the **Magnetization inductance parameterized by** parameter. The default value is 0.01 H.

Saturation magnetic flux

The value of magnetic flux at which the magnetization inductance Lm saturates. This parameter is only visible when you select Single saturation point for the **Magnetization inductance parameterized by** parameter. The default value is 1.6e-4 Wb.

Current, i

The current data used to populate the magnetic flux versus current lookup table. This parameter is only visible when you select Magnetic flux versus current characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 0.4 0.8 1.2 1.6 2.0] A.

Magnetic flux vector, phi

The magnetic flux data used to populate the magnetic flux versus current lookup table. This parameter is only visible when you select Magnetic flux versus current characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 0 0.161 0.25 0.284 0.295 0.299].*1e-3 Wb.

Magnetic field strength vector, H

The magnetic field strength data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 200 400 600 800 1000] A/m.

Magnetic flux density vector, B

The magnetic flux density data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 0.81 1.25 1.42 1.48 1.49] T.

Effective length

The effective core length, that is, the average distance of the magnetic path around the transformer core. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is 0.2 m.

Effective cross-sectional area

The effective core cross-sectional area, that is, the average area of the magnetic path around the transformer core. This parameter is only visible when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is 2e-4 m².

Interpolation option

The lookup table interpolation option. This parameter is only visible when you select Magnetic flux versus current characteristic or Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. Select one of the following interpolation methods:

- Linear Uses a linear interpolation function.
- Cubic Uses the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP).

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

Initial Conditions Tab

| 🙀 Block Parameters: Nonlinear Transfor | rmer | | | (|
|---|----------------------|--------------------------|------------------------|-------------|
| Nonlinear Transformer | | | | |
| Represents a nonlinear transformer range from a linear representation ((H) characteristic. | | | | |
| The parameters on the Initial Condi Note that these values are not used | | | | |
| The parallel conductances on the Pa be required for the simulation of so | | small parasitic effects. | . Small parallel condu | ictances ma |
| Parameters | | | | |
| Main Magnetization Initial | Conditions Parasitic | S | | |
| Combined leakage inductance initial current: | 0 | | A | • |
| Specify magnetization inductance initial state by: | Current | | | • |
| Magnetization inductance initial current: | 0 | | A | • |
| | | | | |
| | | | | |
| | | | | |
| | | ОК С | Cancel Help | Appl |

Combined leakage inductance initial current

The value of current through the combined leakage inductance *Leq* at time zero. This parameter is only visible when you select Combined primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Primary leakage inductance initial current

The value of current through the primary leakage inductance L1 at time zero. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Secondary leakage inductance initial current

The value of current through the secondary leakage inductance L2 at time zero. This parameter is only visible when you select Separate primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Specify magnetization inductance initial state by

Select the appropriate initial state specification option:

- Current Specify the initial state of the magnetization inductance *Lm* by the initial current. This is the default option.
- Magnetic flux Specify the initial state of the magnetization inductance *Lm* by the magnetic flux.

Magnetization inductance initial current

The initial current value used to calculate the value of magnetic flux within the magnetization inductance Lm at time zero. This is the current passing through the magnetization inductance Lm. Total magnetization current consists of current passing through the magnetization resistance Rm and current passing through the magnetization inductance Lm. This parameter is only visible when you select Current for the **Specify magnetization** inductance initial state by parameter. The default value is 0 A.

Magnetization inductance initial magnetic flux

The value of the magnetic flux in the magnetization inductance Lm at time zero. This parameter is only visible when you select Magnetic flux for the **Specify magnetization inductance** initial state by parameter. The default is 0 Wb.

Parasitics Tab

| 🙀 Block Parameters: Nonlinear Transformer | |
|--|---------------------|
| Nonlinear Transformer | |
| Represents a nonlinear transformer. The transformer can be modeled with varying levels range from a linear representation to specification of the magnetic flux density (B) versus (H) characteristic. | |
| The parameters on the Initial Conditions tab are used to set the initial current or flux for Note that these values are not used if the solver configuration is set to Start simulation for | |
| The parallel conductances on the Parasitics tab represent small parasitic effects. Small p be required for the simulation of some circuit topologies. | arallel conductance |
| Parameters | |
| Main Magnetization Initial Conditions Parasitics | |
| Combined leakage inductance parasitic parallel conductance: 1e-9 | 1/Ohm |
| | |
| | |
| | |
| | |
| | |
| OK Cancel | Help |

| | Combined leakage inductance parasitic parallel conductance Use this parameter to represent small parasitic effects in parallel to the combined leakage inductance Leq. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is only visible when you select Combined primary and secondary values for the Winding parameterized by parameter on the Main tab. The default value is 1e-9 $1/\Omega$. |
|----------|---|
| | Primary leakage inductance parasitic parallel conductance Use this parameter to represent small parasitic effects in parallel to the primary leakage inductance $L1$. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is only visible when you select Separate primary and secondary values for the Winding parameterized by parameter on the Main tab. The default value is 1e-9 $1/\Omega$. |
| | Secondary leakage inductance parasitic parallel conductance Use this parameter to represent small parasitic effects in parallel to the secondary leakage inductance L2. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is only visible when you select Separate primary and secondary values for the Winding parameterized by parameter on the Main tab. The default value is 1e-9 $1/\Omega$. |
| Examples | For comparison of nonlinear transformer behavior with different parameterization options, see the Nonlinear Transformer Characteristics example. |
| Ports | The block has four electrical conserving ports. Polarity is indicated by the + and - signs. |
| See Also | Simscape Ideal Transformer, Nonlinear Inductor |

Purpose Model NPN bipolar transistor using enhanced Ebers-Moll equations

Semiconductor Devices

Description



Library

The NPN Bipolar Transistor block uses a variant of the Ebers-Moll equations to represent an NPN bipolar transistor. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. The NPN Bipolar Transistor block provides the following enhancements to that model:

- Early voltage effect
- Optional base, collector, and emitter resistances.
- Optional fixed base-emitter and base-collector capacitances.

The collector and base currents are:

$$\begin{split} I_{C} &= IS \Bigg[\left(e^{qV_{BE}/(kT_{m1})} - e^{qV_{BC}/(kT_{m1})} \right) \Bigg(1 - \frac{V_{BC}}{V_{A}} \Bigg) - \frac{1}{\beta_{R}} \Big(e^{qV_{BC}/(kT_{m1})} - 1 \Big) \Bigg] \\ I_{B} &= IS \Bigg[\frac{1}{\beta_{F}} \Big(e^{qV_{BE}/(kT_{m1})} - 1 \Big) + \frac{1}{\beta_{R}} \Big(e^{qV_{BC}/(kT_{m1})} - 1 \Big) \Bigg] \end{split}$$

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- *IS* is the saturation current.
- V_{BE} is the base-emitter voltage and V_{BC} is the base-collector voltage.
- $\beta_{\rm F}$ is the ideal maximum forward current gain BF
- $\beta_{\rm R}$ is the ideal maximum reverse current gain BR
- V_A is the forward Early voltage VAF
- q is the elementary charge on an electron (1.602176e–19 Coulombs).

- k is the Boltzmann constant (1.3806503e-23 J/K).
- T_{m1} is the transistor temperature, as defined by the **Measurement** temperature parameter value.

You can specify the transistor behavior using datasheet parameters that the block uses to calculate the parameters for these equations, or you can specify the equation parameters directly.

If $qV_{\rm BC} / (kT_{\rm m1}) > 40$ or $qV_{\rm BE} / (kT_{\rm m1}) > 40$, the corresponding exponential terms in the equations are replaced with $(qV_{\rm BC} / (kT_{\rm m1}) - 39)e^{40}$ and $(qV_{\rm BE} / (kT_{\rm m1}) - 39)e^{40}$, respectively. This helps prevent numerical issues associated with the steep gradient of the exponential function $e^{\rm x}$ at large values of x. Similarly, if $qV_{\rm BC} / (kT_{\rm m1}) < -39$ or $qV_{\rm BE} / (kT_{\rm m1}) < -39$ then the corresponding exponential terms in the equations are replaced with $(qV_{\rm BC} / (kT_{\rm m1}) < -39$ then the quations are replaced with $(qV_{\rm BC} / (kT_{\rm m1}) + 40)e^{-39}$ and $(qV_{\rm BE} / (kT_{\rm m1}) + 40)e^{-39}$.

Optionally, you can specify parasitic fixed capacitances across the base-emitter and base-collector junctions. You also have the option to specify base, collector, and emitter connection resistances.

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The measurement temperature value, $T_{\rm m1}$, is replaced with the simulation temperature, $T_{\rm s}$. The saturation current, *IS*, and the forward and reverse gains (β_F and β_R) become a function of temperature according to the following equations:

$$IS_{T_{s}} = IS_{T_{m1}} \cdot (T_{s} / T_{m1})^{XTI} \cdot \exp\left(-\frac{EG}{kT_{s}}(1 - T_{s} / T_{m1})\right)$$

$$\beta_{Fs} = \beta_{Fm1} \left(\frac{T_s}{T_{m1}}\right)^{XTB}$$
$$\beta_{Rs} = \beta_{Rm1} \left(\frac{T_s}{T_{m1}}\right)^{XTB}$$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_{s} is the simulation temperature.
- IS_{Tm1} is the saturation current at the measurement temperature.
- IS_{Ts} is the saturation current at the simulation temperature. This is the saturation current value used in the bipolar transistor equations when temperature dependence is modeled.
- $\beta_{\rm Fm1}$ and $\beta_{\rm Rm1}$ are the forward and reverse gains at the measurement temperature.
- $\beta_{\rm Fs}$ and $\beta_{\rm Rs}$ are the forward and reverse gains at the simulation temperature. These are the values used in the bipolar transistor equations when temperature dependence is modeled.
- *EG* is the energy gap for the semiconductor type measured in Joules. The value for silicon is usually taken to be 1.11 eV, where 1 eV is 1.602e-19 Joules.
- *XTI* is the saturation current temperature exponent.
- *XTB* is the forward and reverse gain temperature coefficient.
- k is the Boltzmann constant (1.3806503e-23 J/K).

Appropriate values for XTI and EG depend on the type of transistor and the semiconductor material used. In practice, the values of XTI, EG, and XTB need tuning to model the exact behavior of a particular transistor. Some manufacturers quote these tuned values in a SPICE Netlist, and you can read off the appropriate values. Otherwise you can determine values for *XTI*, *EG*, and *XTB* by using a datasheet-defined data at a higher temperature $T_{\rm m2}$. The block provides a datasheet parameterization option for this.

You can also tune the values of *XTI*, *EG*, and *XTB* yourself, to match lab data for your particular device. You can use Simulink Design Optimization software to help tune the values.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The NPN Bipolar Transistor model has the following limitations:

Basic Assumptions and Limitations

- The block does not account for temperature-dependent effects on the junction capacitances.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.

Dialog Main Tab Box and Parameters

| Block Parameters: NPN Bipolar Transis IPN Bipolar Transistor | | | | |
|---|---|---|---|--------------|
| his block represents an NPN transis quations are based on two exponer dds the Early voltage effect, and giv mitter and base-collector capacitan arameters can either be specified d | tial diodes es the option ces. For full | plus two current-controlled cur on to include base, emitter and details of the equations, consi | rrent sources. In addition, this t d emitter resistances plus fixed sult the documentation. The equ | block bas |
| arameters | | | | |
| Main Ohmic Resistance Ca | pacitance | Temperature Dependence | | |
| Parameterization: | Specify fro | om a datasheet | | • |
| Forward current transfer ratio, h_fe: | 100 | | | |
| Output admittance, h_oe: | 5e-5 | | 1/Ohm | • |
| Collector current at which h- parameters are defined: | 1 | | mA | • |
| Collector-emitter voltage at which h-parameters are defined: | 5 | | V | • |
| Voltage Vbe: | 0.55 | | V | • |
| Current Ib for voltage Vbe: | 0.5 | | mA | • |
| Reverse current transfer ratio, BR: | 1 | | | |
| Measurement temperature: | 25 | | С | • |
| | | | | |
| | | ОК | Cancel Help | \pp |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to equations that describe the transistor. The block calculates the forward Early voltage VAF as Ic/h_oe , where Ic is the Collector current at which h-parameters are defined parameter value, and h_oe is the Output admittance h_oe parameter value [1]. The block sets BF to the small-signal Forward current transfer ratio h_fe value. The block calculates the saturation current IS from the specified Voltage Vbe value and the corresponding Current Ib for voltage Vbe value when Ic is zero. This is the default method.
- Specify using equation parameters directly Provide equation parameters *IS*, *BF*, and *VAF*.

Forward current transfer ratio h_fe

Small-signal current gain. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 100.

Output admittance h_oe

Derivative of the collector current with respect to the collector-emitter voltage for a fixed base current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is $5e-05 1/\Omega$.

Collector current at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 1 mA.

Collector-emitter voltage at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector-emitter voltage. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 5 V.

Voltage Vbe

Base-emitter voltage when the base current is Ib. The [Vbe Ib] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.55 V.

Current Ib for voltage Vbe

Base current when the base-emitter voltage is *Vbe*. The [*Vbe Ib*] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.5 mA.

Forward current transfer ratio BF

Ideal maximum forward current gain. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 100.

Saturation current IS

Transistor saturation current. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 1e-14 A.

Forward Early voltage VAF

In the standard Ebers-Moll equations, the gradient of the *Ic* versus *Vce* curve is zero in the normal active region. The additional forward Early voltage term increases this gradient. The intercept on the *Vce*-axis is equal to -VAF when the linear region is extrapolated. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 200 V.

Reverse current transfer ratio BR

Ideal maximum reverse current gain. This value is often not quoted in manufacturer datasheets, because it is not significant when the transistor is biased to operate in the normal active region. When the value is not known and the transistor is not to be operated on the inverse region, use the default value of 1.

Measurement temperature

Temperature $\hat{T}_{\rm m1}$ at which Vbe and Ib, or IS, are measured. The default value is 25 C.

Ohmic Resistance Tab

| 🙀 Block Parameters: NPN Bipolar Transistor | | | | | |
|---|------------|--|--|--|--|
| NPN Bipolar Transistor | | | | | |
| This block represents an NPN transistor modeled using a variant of the Ebers-Moll equations. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. In addition, this block adds the Early voltage effect, and gives the option to include base, emitter and emitter resistances plus fixed base-emitter and base-collector capacitances. For full details of the equations, consult the documentation. The equation parameters can either be specified directly, or are derived from standard datasheet parameters. | | | | | |
| Parameters | | | | | |
| Main Ohmic Resistance Capacitance Temperature Dependence | | | | | |
| Collector resistance, RC: 0.01 | Ohm 👻 | | | | |
| Emitter resistance, RE: 1e-4 | Ohm 👻 | | | | |
| Zero bias base resistance, RB: 1 | Ohm 👻 | | | | |
| | | | | | |
| OK Cancel | Help Apply | | | | |

Collector resistance RC

Resistance at the collector. The default value is $0.01~\Omega.$

Emitter resistance RE

Resistance at the emitter. The default value is $1e-4 \Omega$.

Zero bias base resistance RB

Resistance at the base at zero bias. The default value is 1 $\Omega.$

Capacitance Tab

| ase-collector junction | Capacitance Temperature Dependence | <u>۵</u> |
|-------------------------------------|------------------------------------|----------|
| ase-collector junction | | . |
| apacitance: | 5 | pF |
| ase-emitter junction apacitance: | 5 | pF |
| otal forward transit time: | 0 | us |
| otal reverse transit time: | 0 | us |
| | | |
| | | |
| | | |
| | | |
| | | |

Base-collector junction capacitance

Parasitic capacitance across the base-collector junction. The default value is 5 pF.

Base-emitter junction capacitance

Parasitic capacitance across the base-emitter junction. The default value is 5 pF.

Total forward transit time

Represents the mean time for the minority carriers to cross the base region from the emitter to the collector, and is often denoted by the parameter TF [1]. The default value is $0 \ \mu s$.

Total reverse transit time

Represents the mean time for the minority carriers to cross the base region from the collector to the emitter, and is often denoted by the parameter TR [1]. The default value is $0\mu s$.

Temperature Dependence Tab

| Block Parameters: NPN Bipolar Transistor |
|---|
| NPN Bipolar Transistor |
| This block represents an NPN transistor modeled using a variant of the Ebers-Moll equations. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. In addition, this block adds the Early voltage effect, and gives the option to include base, emitter and emitter resistances plus fixed base-emitter and base-collector capacitances. For full details of the equations, consult the documentation. The equation parameters can either be specified directly, or are derived from standard datasheet parameters. |
| Parameters |
| Main Ohmic Resistance Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature |
| |
| |
| |
| |
| |
| |
| |
| |
| |
| |
| |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified by the **Measurement temperature** parameter on the **Main** tab). This is the default method.
- Model temperature dependence Provide a value for simulation temperature, to model temperature-dependent effects. You also have to provide a set of additional parameters depending on the block parameterization method. If you parameterize the block from a datasheet, you have to provide values for a second [*Vbe Ib*] data pair and *h_fe* at second measurement temperature. If you parameterize by directly specifying equation parameters, you have to provide the values for *XTI*, *EG*, and *XTB*.

Forward current transfer ratio, h_{fe} , at second measurement temperature

Small-signal current gain at the second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted at the same collector-emitter voltage and collector current as for the **Forward current transfer ratio** h_fe parameter on the **Main** tab. The default value is 125.

Voltage Vbe at second measurement temperature

Base-emitter voltage when the base current is Ib and the temperature is set to the second measurement temperature. The $[Vbe \ Ib]$ data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 0.45 V.

Current Ib for voltage Vbe at second measurement temperature

Base current when the base-emitter voltage is *Vbe* and the temperature is set to the second measurement temperature. The [*Vbe Ib*] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 0.5 mA.

Second measurement temperature

Second temperature $T_{\rm m2}$ at which h_{fe} , *Vbe*, and *Ib* are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Current gain temperature coefficient, XTB

Current gain temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 0.

Energy gap, EG

Energy gap value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 1.11 eV.

Saturation current temperature exponent, XTI

Saturation current temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 3.

Device simulation temperature

Temperature $T_{\rm s}$ at which the device is simulated. The default value is 25 C.

Ports The block has the following ports:

| | B Electrical conserving port associated with the transistor base terminal. | |
|------------|--|--|
| | C Electrical conserving port associated with the transistor collector terminal. | |
| | E Electrical conserving port associated with the transistor emitter terminal. | |
| Examples | See the NPN Bipolar Transistor Characteristics example. | |
| References | Ces [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling</i> with SPICE. 2nd Edition, McGraw-Hill, 1993. | |
| | [2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984. | |
| See Also | Diode, PNP Bipolar Transistor | |

Purpose Model behavioral representation of operational transconductance amplifier

Integrated Circuits

Description

Library



The Operational Transconductance Amplifier block provides a behavioral representation of an operational transconductance amplifier. A transconductance amplifier converts an input voltage into an output current. Applications include variable frequency oscillators, variable gain amplifiers and current-controlled filters. These applications exploit the fact that the transconductance gain is a function of current flowing into the control current pin.

To support faster simulation, the behavioral representation does not model the detailed transistor implementation. Therefore, the model is only valid when operating in the linear region, that is, where the device input resistance, output resistance, and transconductance gain all depend linearly on the control current, and are independent of input signal amplitude. The dynamics are approximated by a first-order lag, based on the value you specify for the block parameter **Bandwidth**.

Control Current

The control current pin C is maintained at the voltage that you specify for the **Minimum output voltage**. In practice, the **Minimum output voltage** equals the negative supply voltage plus the transistor collector-emitter voltage drop. For example, if the **Minimum output voltage** for a supply voltage of +-15V is -14.5, then to achieve a control current of 500µA, a resistor connected between the +15V rail and the control current pin must have a value of (15 - (-14.5)) / 500e-6 = 59kOhm.

Transconductance

The relationship between input voltage, v, and transconductance current, $i_{\rm gm}$, is:

$$v = v_{+} - v_{-}$$
$$i_{gm} = g_{m} \cdot v$$
$$g_{m} = \frac{g_{m0} \cdot i_{c}}{i_{c0}}$$

where:

- v_+ is the voltage presented at the block + pin.
- v_{-} is the voltage presented at the block pin.
- $g_{\rm m}$ is the transconductance.
- i_c is the control current flowing into the control current pin C.
- i_{c0} is the reference control current, that is, the control current at which transconductance is quoted on the datasheet.
- $g_{\rm m0}$ is the transconductance measured at the reference control current $i_{\rm c0}$.

Therefore, increasing control current increases the transconductance.

Output Resistance and Determining Output Current

The output resistance, R_{out} , is defined by:

$$i_{gm} + i_o = \frac{v_o}{R_{out}}$$
$$R_{out} = \frac{R_{out0} \cdot i_{c0}}{i_c}$$

where:

- i_{gm} is the transconductance current.
- i_{o} is the output current, defined as positive if flowing into the transconductance amplifier output pin.
- $i_{\rm c}$ is the control current flowing into the control current pin C.

- i_{c0} is the reference control current, that is, the control current at which output resistance is quoted on the datasheet.
- R_{out0} is the output resistance measured at the reference control current i_{c0} .

Therefore, increasing control current reduces output resistance.

Input Resistance

The relationship between input voltage, v, across the + and - pins and the current flowing, i, is:

$$\frac{v}{i} = R_{in}$$
$$R_{in} = \frac{R_{in0} \cdot i_{c0}}{i_c}$$

where:

- i_c is the control current flowing into the control current pin C.
- $R_{\rm in}$ is the input resistance for the current control current value, $i_{\rm c}$.
- i_{c0} is the reference control current, that is, the control current at which input resistance is quoted on the datasheet.
- $R_{\rm in0}$ is the input resistance measured at the reference control current $i_{\rm c0}$

Therefore, increasing control current reduces input resistance.

Limits

Because of the physical construction of an operational transconductance amplifier based on current mirrors, the transconductance current $i_{\rm gm}$ cannot exceed the control current. Hence the value of $i_{\rm gm}$ is limited by:

$$-i_{\rm c} \leq i_{\rm gm} \leq i_{\rm c}$$

The output voltage is also limited by the supply voltage:

$$V_{\min} \le v_{o} \le V_{\max}$$

where V_{\min} is the **Minimum output voltage**, and V_{\max} is the **Maximum output voltage**. Output voltage limiting is implemented by adding a low resistance to the output when the voltage limit is exceeded. The value of this resistance is set by the **Additional output resistance at voltage swing limits** parameter.

The transconductance current is also slew-rate limited, a value for slew rate limiting typically being given on datasheets:

$$-\mu \leq \frac{di_{gm}}{dt} \leq \mu$$

where μ is the Maximum current slew rate.

Dialog Nominal Measurements Tab Box and Parameters

| 🙀 Block Parameters: Operational Trans | conductance Amplifier | | |
|---|-----------------------|--------|--|
| Operational Transconductance Amplifier | | | |
| This block represents a behavioral model of an operational transconductance amplifier such as the LM13700 main simplifying assumption is that the input stage is linear. Input and output resistance are assumed to scalinearly with the ratio of the Reference control current to the control current flowing into port C. Conversely, transconductance is assumed to scale linearly with one over this ratio. | | | |
| Parameters | | | |
| Nominal Measurements Dynam | nics Limits | | |
| Transconductance: | 9.6e+3 | uS | |
| Input resistance: | 25 | kOhm | |
| Output resistance: | 3 | MOhm | |
| Reference control current: | 500 | uA | |
| | | | |
| | | | |
| | OK Cancel | Help A | |

Transconductance

The transconductance, g_m , when the control current is equal to the **Reference control current**. This is the ratio of the transconductance current, i_{gm} , to the voltage difference, v, across the + and - pins. The default value is 9600 µS.

Input resistance

The input resistance, R_{in} , when the control current is equal to the **Reference control current**. The input resistance is the ratio of the voltage difference, v, across the + and - pins to the current flowing from the + to the - pin. The default value is 25 kOhm.

Output resistance

The output resistance, R_{out} , when the control current is equal to the **Reference control current**. See above for the equation defining output resistance. The default value is 3 MOhm.

Reference control current

The control current at which the **Transconductance**, **Input resistance**, and **Output resistance** are quoted. The default value is $500 \mu A$.

Operational Transconductance Amplifier

Dynamics Tab

| 1 | Block Parameters: Operational Transconductance Amplifier |
|---|---|
| | Operational Transconductance Amplifier |
| | This block represents a behavioral model of an operational transconductance amplifier such as the LM13700 main simplifying assumption is that the input stage is linear. Input and output resistance are assumed to scal linearly with the ratio of the Reference control current to the control current flowing into port C. Conversely, transconductance is assumed to scale linearly with one over this ratio. |
| | Parameters |
| | Nominal Measurements Dynamics Limits |
| | |
| | Dynamics: No lag |
| | |
| | |
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| | |
| | |
| | OK Cancel Help A |

Dynamics

Select one of the following options:

- No lag Do not model the dynamics of the relationship between output current and input voltage. This is the default.
- Finite bandwidth with slew rate limiting Model the dynamics of the relationship between output current and input voltage using a first-order lag. If you select this option, the

Bandwidth, Maximum current slew rate, and Initial current parameters appear on the Dynamics tab.

Bandwidth

The bandwidth of the first-order lag used to model the dynamics of the relationship between output current and input voltage. The default value is 2 MHz.

Maximum current slew rate

The maximum rate-of-change of transconductance current when there is no feedback around the device. Note that datasheets sometimes quote slew rate as a maximum rate of change of voltage. In this case, the value depends on the particular test circuit. To get an accurate value for **Maximum current slew rate**, reproduce the test circuit in a SimElectronics[®] model, and tune the parameter value to match the datasheet value. If the test circuit is open-loop, and the load resistance is quoted, you can obtain an approximate value for the **Maximum current slew rate** by dividing the voltage slew rate by the load resistance. The default value is 2 A/µs.

Initial current

The initial transconductance current (note, not the initial output current). This is the transconductance current sinking to both the internal output resistance, $R_{\rm out}$, and the output pin. The default value is 0 A.

Limits Tab

Block Parameters: Operational Transconductance Amplifier

Operational Transconductance Amplifier

This block represents a behavioral model of an operational transconductance amplifier such as the LM13700 main simplifying assumption is that the input stage is linear. Input and output resistance are assumed to scal linearly with the ratio of the Reference control current to the control current flowing into port C. Conversely, transconductance is assumed to scale linearly with one over this ratio.

| Minimum output voltage: | -15 | V |
|---|-------|-----|
| Maximum output voltage: | 15 | V |
| Additional output resistance at oltage swing limits: | 1 | Ohm |
| Minimum control current for simulation: | 0.001 | uA |

Minimum output voltage

The output voltage is limited to be greater than the value of this parameter. The default value is -15 V.

Maximum output voltage

The output voltage is limited to be less than the value of this parameter. The default value is 15 V.

Operational Transconductance Amplifier

| | Additional output resistance at voltage swing limits To limit the output voltage swing, an additional output resistance is applied between output and the power rail when the output voltage exceeds the limit. The value of this resistance should be low compared to the output resistance and circuit load resistance. The default value is 1 Ohm. | | |
|----------|--|--|--|
| | Minimum control current for simulation The control current measured at the control current pin C is limited to be greater than the value of this parameter. This prevents a potential divide-by-zero when calculating input and output resistance values based on the value of the control current The default value is 0.001 µA. | | |
| Ports | The block has the following ports: | | |
| | + Positive electrical voltage. - Negative electrical voltage. | | |
| | C Control current. | | |
| | OUT Output current. | | |
| See Also | Simscape Op-Amp, Band-Limited Op-Amp, Finite-Gain Op-Amp | | |

Purpose Model optocoupler as LED, current sensor, and controlled current source

Semiconductor Devices

Description

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Library

This block represents an optocoupler using a model that consists of the following components:

- An exponential light-emitting diode in series with a current sensor on the input side
- A controlled current source on the output side

The output-side current flows from the collector junction to the emitter junction. It has a value of $CTR \cdot I_d$, where CTR is the **Current transfer ratio** parameter value and I_d is the diode current.

Use the Optocoupler block to interface two electrical circuits without making a direct electrical connection. A common reason for doing this is that the two circuits work at very different voltage levels.

Note Each electrical circuit must have its own Electrical Reference block.

If the output circuit is a phototransistor, typical values for the **Current transfer ratio** parameter are 0.1 to 0.5. If the output stage consists of a Darlington pair, the parameter value can be much higher than this. The **Current transfer ratio** value also varies with the light-emitting diode current, but this effect is not modeled by the Photodiode block.

Some manufacturers provide a maximum data rate for optocouplers. In practice, the maximum data rate depends on the following factors:

- The capacitance of the photodiode and the type of the driving circuit
- The construction of the phototransistor and its associated capacitance

The Optocoupler block only lets you define the capacitance on the light-emitting diode. You can use the **Junction capacitance** parameter to add your own capacitance across the collector and emitter connections.

The Optocoupler block lets you model temperature dependence of the underlying diode. For details, see the Diode reference page.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The Optocoupler block has the following limitations:

Basic Assumptions and Limitations

- The output side is modeled as a controlled current source. As such, it only correctly approximates a bipolar transistor operating in its normal active region. To create a more detailed model, connect the Optocoupler output directly to the base of an NPN Bipolar Transistor block, and set the parameters to maintain a correct overall value for the current transfer ratio. If you need to connect optocouplers in series, use this approach to avoid the invalid topology of two current sources in series.
- The temperature dependence of the forward current transfer ratio is not modeled. Typically the temperature dependence of this parameter is much less than that of the optical diode I-V characteristic.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.

Dialog Main Tab Box and Parameters

| Į | Block Pa | arameters: Optocoupler | | | X |
|---|---|------------------------|----------------------|------------------------|------------|
| | Optocoup | oler | | | |
| | This block represents a simplified implementation of an optocoupler. Structurally the model consists of an exponential diode in series with a current sensor on the input-side, and a controlled current source on the output side. The output side current flows from the collector to emitter junction, and is equal to CTR*Id where Id is the diode current and CTR is the Current Transfer Ratio. | | | | |
| | Paramete | ers | | | |
| | Main | Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| | Curren | t transfer ratio: | 0.2 | | |
| | Diode p | parameterization: | Use I-V curve data | points | • |
| | Currents [I1 I2]: | | [0.001 0.015] | [0.001 0.015] | |
| | Voltage | es [V1 V2]: | [0.9 1.05] | | V |
| | Measu | rement temperature: | 25 | | C • |
| | <u> </u> | | | | 1 |
| | | | | OK Cancel | Help Apply |

Current transfer ratio

The output current flowing from the transistor collector to emitter junctions is equal to the product of the current transfer ratio and the current flowing the light-emitting diode. The default value is 0.2.

Diode parameterization

Select one of the following methods for model parameterization:

- Use I-V curve data points Specify measured data at two points on the diode I-V curve. This is the default method.
- \bullet Use parameters IS and N- Specify saturation current and emission coefficient.

Currents [I1 I2]

A vector of the current values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use I-V curve data points for the **Diode parameterization** parameter. The default value is [0.001 0.015] A.

Voltages [V1 V2]

A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use I-V curve data points for the **Diode parameterization** parameter. The default value is [0.9 1.05] V.

Saturation current IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Use parameters IS and N for the **Diode parameterization** parameter. The default value is 1e-10 A.

Measurement temperature

The temperature at which IS or the I-V curve was measured. The default value is 25 °C.

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Use parameters IS and N for the **Diode parameterization** parameter. The default value is 2.

Ohmic Resistance Tab

| 🙀 Block Parameters: Optocoupler | | | × |
|---|----------------------|------------------------|------------|
| Optocoupler | | | |
| This block represents a simplified implementation of an optocoupler. Structurally the model consists of an exponential diode in series with a current sensor on the input-side, and a controlled current source on the output side. The output side current flows from the collector to emitter junction, and is equal to CTR*Id where Id is the diode current and CTR is the Current Transfer Ratio. | | | |
| Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Ohmic resistance, RS: | 0.1 | | Ohm |
| | | OK Cancel | Help Apply |

Ohmic resistance RS

The series diode connection resistance. The default value is 0.1 $\Omega.$

Junction Capacitance Tab

| Block Parameters: Optocoupler | | | | |
|---|--|--|--|--|
| Optocoupler | | | | |
| This block represents a simplified implementation of an optocoupler. Structurally the model consists of an exponential diode in series with a current sensor on the input-side, and a controlled current source on the output side. The output side current flows from the collector to emitter junction, and is equal to CTR*Id where Id is the diode current and CTR is the Current Transfer Ratio. | | | | |
| Parameters | | | | |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence | | | | |
| Junction capacitance: Fixed or zero junction capacitance | | | | |
| Zero-bias junction capacitance, 5 pF 🔹 | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| OK Cancel Help Apply | | | | |

Junction capacitance

Select one of the following options for modeling the diode junction capacitance:

- Fixed or zero junction capacitance Model the junction capacitance as a fixed value.
- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 5 pF.

Junction potential VJ

The junction potential. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 1 V.

Grading coefficient M

The coefficient that quantifies the grading of the junction. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Reverse bias voltages [VR1 VR2 VR3]

A vector of the reverse bias voltage values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [0.1 10 100] V.

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [3.5 1 0.4] pF.

Capacitance coefficient FC

Fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Use C-V curve data points or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Temperature Dependence Tab

| 🙀 Block Parameters: Optocoupler | | | × |
|---|----------------------|------------------------------|------------|
| Optocoupler | | | |
| This block represents a simplified implementation of an optocoupler. Structurally the model consists of an exponential diode in series with a current sensor on the input-side, and a controlled current source on the output side. The output side current flows from the collector to emitter junction, and is equal to CTR*Id where Id is the diode current and CTR is the Current Transfer Ratio. | | | |
| Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Parameterization: | None - Simulate | at parameter measurement ter | mperature |
| | | |] |
| | | OK Cancel | Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified by the **Measurement temperature** parameter on the **Main** tab). This is the default method.
- Use an I-V data point at second measurement temperature T2 If you select this option, you specify

a second measurement temperature $T_{\rm m2},$ and the current and voltage values at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.

- Specify saturation current at second measurement temperature T2 If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and saturation current value at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify the energy gap EG Specify the energy gap value directly.

Current I1 at second measurement temperature

Specify the diode current I1 value when the voltage is V1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 0.029 A.

Voltage V1 at second measurement temperature

Specify the diode voltage V1 value when the current is I1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 1.05 V.

Saturation current, IS, at second measurement temperature

Specify the saturation current *IS* value at the second measurement temperature. This parameter is only visible when you select Specify saturation current at second measurement temperature T2 for the **Parameterization** parameter. The default value is 1.8e-8 A.

Second measurement temperature

Specify the value for the second measurement temperature. This parameter is only visible when you select either Use an I-V data point at second measurement temperature T2 or Specify saturation current at second measurement temperature T2 for the **Parameterization** parameter. The default value is 125 C.

Energy gap parameterization

This parameter is only visible when you select Specify the energy gap EG for the **Parameterization** parameter. It lets you select a value for the energy gap from a list of predetermined options, or specify a custom value:

- Use nominal value for silicon (EG=1.11eV) This is the default.
- Use nominal value for 4H-SiC silicon carbide (EG=3.23eV)
- Use nominal value for 6H-SiC silicon carbide (EG=3.00eV)
- Use nominal value for germanium (EG=0.67eV)
- Use nominal value for gallium arsenide (EG=1.43eV)
- Use nominal value for selenium (EG=1.74eV)
- Use nominal value for Schottky barrier diodes (EG=0.69eV)
- Specify a custom value If you select this option, the **Energy gap, EG** parameter appears in the dialog box, to let you specify a custom value for *EG*.

Energy gap, EG

Specify a custom value for the energy gap, EG. This parameter is only visible when you select Specify a custom value for the **Energy gap parameterization** parameter. The default value is 1.11 eV.

Saturation current temperature exponent parameterization Select one of the following options to specify the saturation current temperature exponent value:

| | Use nominal value for pn-junction diode (XTI=3) — This is the default. |
|-------|--|
| | Use nominal value for Schottky barrier diode (XTI=2) |
| | • Specify a custom value — If you select this option, the Saturation current temperature exponent, XTI parameter appears in the dialog box, to let you specify a custom value for <i>XTI</i> . |
| | Saturation current temperature exponent, XTI Specify a custom value for the saturation current temperature exponent, XTI. This parameter is only visible when you select Specify a custom value for the Saturation current temperature exponent parameterization parameter. The default value is 3. |
| | Device simulation temperature Specify the value for the temperature T_s , at which the device is to be simulated. The default value is 25 C. |
| Ports | The block has the following ports: |
| | + Electrical conserving port associated with the diode positive terminal. |
| | - Electrical conserving port associated with the diode negative terminal. |
| | C Electrical conserving port associated with the transistor collector terminal. |
| | E Electrical conserving port associated with the transistor emitter terminal. |

Optocoupler

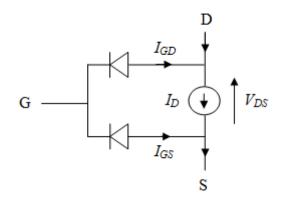
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. | |
|------------|--|--|
| | [2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984. | |
| See Also | Diode, NPN Bipolar Transistor, Simscape Controlled Current Source | |

Purpose Model P-Channel JFET

Library Semiconductor Devices

Description

The P-Channel JFET block uses the Shichman and Hodges equations to represent a P-Channel JFET using a model with the following structure:



G is the transistor gate, D is the transistor drain and S is the transistor source. The drain current, $I_{\rm D}$, depends on the region of operation and whether the transistor is operating in normal or inverse mode.

• In normal mode ($-V_{DS} \ge 0$), the block provides the following relationship between the drain current $I_{\rm D}$ and the drain-source voltage $V_{\rm DS}$.

| Region | Applicable Range of V _{GS} and V _{DS} Values | Corresponding I _D Equation |
|-----------|--|---|
| Off | $-V_{\rm GS} < -V_{\rm t0}$ | $I_{\rm D} = 0$ |
| Linear | $0 < -V_{\rm DS} < -V_{\rm GS} + V_{\rm t0}$ | $I_{ds} = \beta V_{ds} \left(2(-V_{gs} + V_{t0}) + V_{ds} \right) (1 - \lambda V_{ds}) I_{\rm D} = \beta V_{\rm DS} (2(-V_{\rm GS} + V_{t0}) + V_{\rm DS}) (1 - \lambda V_{\rm DS})$ |
| Saturated | $\begin{array}{l} 0 < -V_{\rm GS} + V_{\rm t0} < \\ -V_{\rm DS} \end{array}$ | $I_{ds} = -\beta (-V_{gs} + V_{t0})^2 (1 - \lambda V_{ds}) I_{\rm D} = -\beta (-V_{\rm GS} + V_{t0})^2 (1 - \lambda V_{\rm DS})$ |

• In inverse mode (– $V_{DS} < 0$), the block provides the following relationship between the drain current $I_{\rm D}$ and the drain-source voltage $V_{\rm DS}$.

| Region | Applicable Range of V _{GS} and V _{DS} Values | Corresponding I _D Equation |
|-----------|--|---|
| Off | $-V_{\rm GD} \leq -V_{\rm t0}$ | $I_{\rm D} = 0$ |
| Linear | $\begin{array}{l} 0 < V_{DS} < - \ V_{\rm GD} + \\ V_{\rm t0} \end{array}$ | $I_{\rm D} = \beta V_{\rm DS} (2(-V_{\rm GD} + V_{\rm t0}) - V_{\rm DS})(1 + \lambda V_{\rm DS})$ |
| Saturated | $\begin{array}{l} 0 < -V_{\rm GD} + V_{\rm t0} < \\ V_{DS} \end{array}$ | $I_{\rm D} = \beta \; (-V_{\rm GD} + V_{\rm t0})^2 \; (1 + \lambda V_{\rm DS})$ |

In the preceding equations:

- $V_{\rm GS}$ is the gate-source voltage.
- $V_{\rm GD}$ is the gate-drain voltage.
- $V_{\rm t0}$ is the threshold voltage. If you select Specify using equation parameters directly for the Parameterization parameter, $V_{\rm t0}$

is the **Threshold voltage** parameter value. Otherwise, the block calculates $V_{\rm t0}$ from the datasheet parameters you specify.

- β is the transconductance parameter. If you select Specify using equation parameters directly for the **Parameterization** parameter, β is the **Transconductance parameter** parameter value. Otherwise, the block calculates β from the datasheet parameters you specify.
- λ is the channel-length modulation parameter. If you select Specify using equation parameters directly for the Parameterization parameter, λ is the Channel-length modulation parameter value. Otherwise, the block calculates λ from the datasheet parameters you specify.

The currents in each of the diodes satisfy the exponential diode equation

$$egin{aligned} I_{GD} &= -IS \cdot \left(e^{-qV_{GD}/kT_{m1}} - 1
ight) \ &I_{GS} &= -IS \cdot \left(e^{-qV_{GS}/kT_{m1}} - 1
ight) \end{aligned}$$

where:

- *IS* is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, *IS* is the **Saturation current** parameter value. Otherwise, the block calculates *IS* from the datasheet parameters you specify.
- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e–23 J/K).
- T_{m1} is the measurement temperature. The value comes from the **Measurement temperature** parameter.

The block models gate junction capacitance as a fixed gate-drain capacitance C_{GD} and a fixed gate-source capacitance C_{GS} . If you select Specify using equation parameters directly for the

Parameterization parameter, you specify these values directly using the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = Ciss Crss$

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The measurement temperature value, $T_{\rm m1}$, is replaced with the simulation temperature, $T_{\rm s}$. The transconductance, β , and the threshold voltage, $V_{\rm t0}$, become a function of temperature according to the following equations:

$$\beta_{Ts} = \beta_{Tm1} \left(\frac{T_s}{T_{m1}}\right)^{BEX}$$
$$V_{t0s} = V_{t01} + a (T_s - T_{m1})$$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_s is the simulation temperature.
- + $\beta_{\rm Tm1}$ is JFET transconductance at the measurement temperature.

- β_{Ts} is JFET transconductance at the simulation temperature. This is the transconductance value used in the JFET equations when temperature dependence is modeled.
- V_{t01} is the threshold voltage at measurement temperature.
- $V_{\rm t0s}$ is the threshold voltage at simulation temperature. This is the threshold voltage value used in the JFET equations when temperature dependence is modeled.
- *BEX* is the mobility temperature exponent. A typical value of *BEX* is -1.5.
- *a* is the gate threshold voltage temperature coefficient, $dV_{\rm th}/dT$.

For most JFETS, you can use the default value of -1.5 for *BEX*. Some datasheets quote the value for a, but most typically they provide the temperature dependence for the saturated drain current, I_dss . Depending on the block parameterization method, you have two ways of specifying a:

- If you parameterize the block from a datasheet, you have to provide I_dss at a second measurement temperature. The block then calculates the value for a based on this data.
- If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

If you have more data comprising drain current as a function of gate-source voltage for fixed drain-source voltage plotted at more than one temperature, then you can also use Simulink Design Optimization software to help tune the values for a and *BEX*.

In addition, the saturation current term, *IS*, in the gate-drain and gate-source current equations depends on temperature

$$IS_{Ts} = IS_{Tm1} \cdot (T_s / T_{m1})^{XTI} \cdot \exp\left(-\frac{EG}{kT_s}(1 - T_s / T_{m1})\right)$$

where:

- IS_{Tm1} is the saturation current at the measurement temperature.
- IS_{Ts} is the saturation current at the simulation temperature. This is the saturation current value used in the bipolar transistor equations when temperature dependence is modeled.
- *EG* is the energy gap.
- k is the Boltzmann constant (1.3806503e-23 J/K).
- *XTI* is the saturation current temperature exponent.

Similar to *a*, you have two ways of specifying *EG* and *XTI*:

- If you parameterize the block from a datasheet, you have to specify the gate reverse current, *I_gss*, at a second measurement temperature. The block then calculates the value for *EG* based on this data and assuming a p-n junction nominal value of 3 for *XTI*.
- If you parameterize by specifying equation parameters, you have to provide the values for EG and XTI directly. This option gives you most flexibility to match device behavior, for example, if you have a graph of I_gss as a function of temperature. With this data you can use Simulink Design Optimization software to help tune the values for EG and XTI.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

Basic Assumptions and Limitations

The model is based on the following assumptions:

- This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.
- The block does not account for temperature-dependent effects on the junction capacitances.
- When you specify *I_dss* at a second measurement temperature, it must be quoted for the same working point (that is, the same drain current and gate-source voltage) as for the *I_dss* value on the **Main** tab. Inconsistent values for *I_dss* at the higher temperature will result in unphysical values for *a* and unrepresentative simulation results.
- You may need to tune the value of *BEX* to replicate the $I_{\rm D}$ - $V_{\rm GS}$ relationship (if available) for a given device. The value of *BEX* affects whether the $I_{\rm D}$ - $V_{\rm GS}$ curves for different temperatures cross each other, or not, for the ranges of $I_{\rm D}$ and $V_{\rm GS}$ considered.

Dialog Main Tab Box and Parameters

| 🙀 Block Parameters: P-Channel JFET | Block Parameters: P-Channel JFET | | | | | | | |
|--|---|------------|--|--|--|--|--|--|
| P-Channel JFET | | | | | | | | |
| This block represents a P-Channel JFET. The drain current Id for negative Vds (normal operation) is given by: | | | | | | | | |
| Id = 0 if -Vgs-Vt0 < 0 (off) | | | | | | | | |
| $Id = -B*Vds*[2*(-Vgs - Vt0) + Vds]*(1+L* Vds) \ if \ 0 < -Vds < -Vgs - Vt0] \ (linear \ region)$ | | | | | | | | |
| Id = -B*(-Vgs - Vt0)^2*(1+L* Vds) if 0 < -Vgs - Vt0 < -Vds (saturated region) | | | | | | | | |
| where B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-length modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. | | | | | | | | |
| Parameters | | | | | | | | |
| Main Ohmic Resistance Ju | nction Capacitance Temperature Dependence | | | | | | | |
| Parameterization: | Specify from a datasheet | | | | | | | |
| Gate reverse current, I_gss: | 5 | nA 🔻 | | | | | | |
| Saturated drain current, I_dss: | -3 | mA 👻 | | | | | | |
| I_dss measurement point, [V_gs V_ds]: | [0-15] | V • | | | | | | |
| Small-signal parameters, [g_fs g_os]: | [2.5e+3 75] | uS 🔹 | | | | | | |
| Small-signal measurement point, [V_gs V_ds]: | [0-15] | V • | | | | | | |
| Measurement temperature: | 25 | C • | | | | | | |
| L | | | | | | | | |
| | OK Cancel | Help Apply | | | | | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to equations that describe the transistor. This is the default method.
- Specify using equation parameters directly Provide equation parameters β , *IS*, V_{t0} , and λ .

Gate reverse current, I_gss

The reverse current that flows in the diode when the drain and source are short-circuited and a large positive gate-source voltage is applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 5 nA.

Saturated drain current, I_dss

The current that flows when a large negative drain-source voltage is applied for a specified gate-source voltage. For a depletion-mode device, this gate-source voltage may be zero, in which case I_{dss} may be referred to as the zero-gate voltage drain current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -3 mA.

I_dss measurement point, [V_gs V_ds]

A vector of the values of $V_{\rm GS}$ and $V_{\rm DS}$ at which I_dss is measured. Normally $V_{\rm GS}$ is zero. $V_{\rm DS}$ should be greater than zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 -15] V.

Small-signal parameters, [g_fs g_os]

A vector of the values of g_fs and g_os . g_fs is the forward transfer conductance, that is, the conductance for a fixed drain-source voltage. g_os is the output conductance, that is, the conductance for a fixed gate-source voltage. This parameter is only visible when you select Specify from a datasheet for the

Parameterization parameter. The default value is [2.5e+3 75] uS.

Small-signal measurement point [V_gs V_ds]

A vector of the values of $V_{\rm GS}$ and $V_{\rm DS}$ at which g_fs and g_os are measured. $V_{\rm DS}$ should be greater than zero. For depletion-mode devices, $V_{\rm GS}$ is typically zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 -15] V.

Transconductance parameter

The derivative of drain current with respect to gate voltage. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is $1e-04 \text{ A/V}^2$.

Saturation current

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 1e-14 A.

Threshold voltage

The gate-source voltage above which the transistor produces a nonzero drain current. For an enhancement device, Vt0 should be negative. For a depletion mode device, Vt0 should be positive. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 2 V.

Channel-length modulation

The channel-length modulation. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 0 1/V.

Measurement temperature

The temperature for which the datasheet parameters are quoted. The default value is 25 C.

Ohmic Resistance Tab

| 🙀 Block Parameters: P-Channel JFE | Т | | X |
|---|---------------------------|---------------------------------|----------------------------|
| P-Channel JFET | | | |
| This block represents a P-Chan | nel JFET. The drain curre | nt Id for negative Vds (normal | operation) is given by: |
| Id = 0 if -Vgs-Vt0 < 0 (off) | | | |
| Id = -B*Vds*[2*(-Vgs - Vt0) + | Vds]*(1+L* Vds) | -Vds < -Vgs - Vt0] (linear regi | ion) |
| Id = -B*(-Vgs - Vt0)^2*(1+L*) | Vds) if 0 < -Vgs - Vt0 < | -Vds (saturated region) | |
| where B is the Transconductance is the gate-source voltage and V | | | nel-length modulation, Vgs |
| Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Source ohmic resistance: | 1e-4 | | Ohm 👻 |
| Drain ohmic resistance: | 0.01 | | Ohm 👻 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | OK Cancel | Help Apply |

Source ohmic resistance

The transistor source resistance. The default value is $1e-4 \Omega$. The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is 0.01Ω . The value must be greater than or equal to 0.

Junction Capacitance Tab

| Reverse transfer capacitance, 1 | is block represents a P-Channel | JFET. The drain curre | nt Id for negative Vds (normal o | operation) is given b |
|---|---------------------------------|-------------------------|----------------------------------|-----------------------|
| = -B*(-Vgs - Vt0)^2*(1+L* Vds) if 0 < -Vgs - Vt0 < -Vds (saturated region) ere B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-length modulation the gate-source voltage and Vds is the drain-source voltage. rameters Main Ohmic Resistance Junction Capacitance Temperature Dependence Parameterization: Specify from a datasheet hput capacitance, Ciss: 5 Reverse transfer capacitance, 1 | = 0 if -Vgs-Vt0 < 0 (off) | | | |
| ere B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-length modulation the gate-source voltage and Vds is the drain-source voltage. rameters Main Ohmic Resistance Junction Capacitance Temperature Dependence Parameterization: Specify from a datasheet input capacitance, Ciss: 5 Reverse transfer capacitance, 1 | = -B*Vds*[2*(-Vgs - Vt0) + Vd | s]*(1+L* Vds) if 0 < | -Vds < -Vgs - Vt0] (linear regi | on) |
| the gate-source voltage and Vds is the drain-source voltage. rameters Main Ohmic Resistance Junction Capacitance Temperature Dependence Parameterization: Specify from a datasheet Input capacitance, Ciss: 5 pF Reverse transfer capacitance, 1 pF | = -B*(-Vgs - Vt0)^2*(1+L* Vd | s) if 0 < -Vgs - Vt0 < | -Vds (saturated region) | |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence Parameterization: Specify from a datasheet Pressure Input capacitance, Ciss: 5 PF Reverse transfer capacitance, 1 PF | | | | nel-length modulatio |
| Parameterization: Specify from a datasheet Parameterization: 5 PF Reverse transfer capacitance, 1 PF | rameters | | | |
| Input capacitance, Ciss: 5 pF | Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | |
| Reverse transfer canacitance | Parameterization: | Specify from a dat | asheet | |
| | ínput capacitance, Ciss: | 5 | | pF |
| Lrss: | | 1 | | pF |
| | urss: | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance, Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 4.5 pF.

Reverse transfer capacitance, Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 1.5 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction** capacitance parameter. The default value is 3 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction capacitance** parameter. The default value is 1.5 pF.

Temperature Dependence Tab

| 🙀 Block Parameters: P-Channel JFET |
|--|
| P-Channel JFET |
| This block represents a P-Channel JFET. The drain current Id for negative Vds (normal operation) is given by: |
| Id = 0 if -Vgs-Vt0 < 0 (off) |
| Id = -B*Vds*[2*(-Vgs - Vt0) + Vds]*(1+L* Vds) if 0 < -Vds < -Vgs - Vt0] (linear region) |
| $Id = -B^{*}(-Vgs - Vt0)^{2^{*}(1+L^{*} Vds)} \text{ if } 0 < -Vgs - Vt0 < -Vds \text{ (saturated region)}$ |
| where B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-length modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. |
| Parameters |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature - |
| |
| |
| |
| |
| |
| |
| |
| OK Cancel Help Apply |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled. This is the default method.
- Model temperature dependence Model temperature-dependent effects. You also have to provide a set of additional parameters depending on the block parameterization method. If you parameterize the block from a datasheet, you have to provide values for *I_gss* and *I_dss* at second measurement temperature. If you parameterize by directly specifying equation parameters, you have to provide the values for *EG*, *XTI*, and the gate threshold voltage temperature coefficient, dV_{t0}/dT . Regardless of the block parameterization method, you also have to provide values for *BEX* and for the simulation temperature, T_{s} .

Gate reverse current, I_gss, at second measurement temperature

The value of the gate reverse current, *I_gss*, at the second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted for the same working point (drain current and gate-source voltage) as the **Drain-source on resistance**, **R_DS(on)** parameter on the **Main** tab. The default value is 950 nA.

Saturated drain current, I_dss, at second measurement temperature

The value of the saturated drain current, I_dss , at the second measurement temperature, and when the I_dss measurement point is the same as defined by the **I**_dss measurement point, **[V_gs V_ds]** parameter on the **Main** tab. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is -2.3 mA.

Second measurement temperature

Second temperature T_{m2} at which **Gate reverse current**, **I**_gss, at second measurement temperature and **Saturated drain** current, **I**_dss, at second measurement temperature are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Energy gap, EG

Energy gap value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 1.11 eV.

Saturation current temperature exponent, XTI

Saturation current temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 3.

Gate threshold voltage temperature coefficient, dVt0/dT

The rate of change of gate threshold voltage with temperature. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 1 mV/K.

Mobility temperature exponent, BEX

Mobility temperature coefficient value. You can use the default value for most JFETs. See the "Basic Assumptions and Limitations" on page 1-389 section for additional considerations. The default value is -1.5.

Device simulation temperature

Temperature $T_{\rm s}$ at which the device is simulated. The default value is 25 C.

Ports The block has the following ports:

| | G Electrical conserving port associated with the transistor gate terminal. |
|------------|---|
| | D Electrical conserving port associated with the transistor drain terminal. |
| | S Electrical conserving port associated with the transistor source terminal. |
| References | [1] H. Shichman and D. A. Hodges, <i>Modeling and simulation of insulated-gate field-effect transistor switching circuits</i> . IEEE J. Solid State Circuits, SC-3, 1968. |
| | [2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2. |
| See Also | N-Channel JFET |

P-Channel MOSFET

Library

Purpose Model P-Channel MOSFET using Shichman-Hodges equation

Semiconductor Devices

Description The P-Channel MOSFET block uses the Shichman and Hodges equations [1] for an insulated-gate field-effect transistor to represent a P-Channel MOSFET.

The drain-source current, I_{DS} , depends on the region of operation:

• In the off region $(-V_{GS} < -V_{th})$ the drain-source current is:

$$I_{DS} = 0$$

• In the linear region (0 < – $V_{\rm DS}$ < – $V_{\rm GS}$ + $V_{\rm th}$) the drain-source current is:

$$I_{DS} = -K \left((V_{GS} - V_{th}) V_{DS} - V_{DS}^{2} / 2 \right) \left(1 + \lambda |V_{DS}| \right)$$

- In the saturated region (0 < $-V_{\rm GS}$ + $V_{\rm th}$ < $-V_{\rm DS})$ the drain-source current is:

$$I_{DS} = -(K/2)(V_{GS} - V_{th})^2 (1 + \lambda |V_{DS}|)$$

In the preceding equations:

- *K* is the transistor gain.
- $V_{\rm DS}$ is the positive drain-source voltage.
- $V_{\rm GS}$ is the gate-source voltage.
- V_{th} is the threshold voltage.
- λ is the channel modulation.

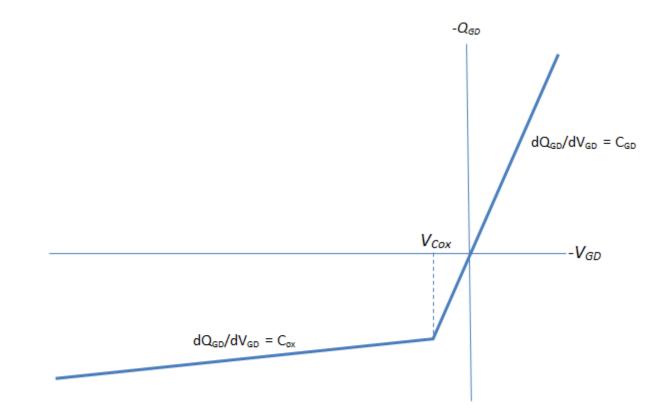
Charge Model

The block models gate junction capacitance as a fixed gate-source capacitance $C_{\rm GS}$ and either a fixed or a nonlinear gate-drain capacitance $C_{\rm GD}.$

If you select Specify using equation parameters directly for the **Parameterization** parameter in the **Junction Capacitance** tab, you specify the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters directly. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{\rm GD} = Crss$
- $C_{GS} = Ciss Crss$

If you select the Gate-drain charge function is nonlinear option for the **Charge-voltage linearity** parameter, then the gate-drain charge relationship is defined by the piecewise-linear function shown in the following figure.



Nonlinear gate-drain charge function

For instructions on how to map a time response to device capacitance values, see the N-Channel IGBT block reference page. However, this mapping is only approximate because the Miller voltage typically varies more from the threshold voltage than in the case for the IGBT.

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The gain, K, and the threshold voltage, $V_{\rm th}$, become a function of temperature according to the following equations:

$$K_{Ts} = K_{Tm1} \left(\frac{T_s}{T_{m1}}\right)^{BEX}$$
$$V_{ths} = V_{th1} + a (T_s - T_{m1})$$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_{s} is the simulation temperature.
- K_{Tm1} is the transistor gain at the measurement temperature.
- K_{Ts} is the transistor gain at the simulation temperature. This is the transistor gain value used in the MOSFET equations when temperature dependence is modeled.
- + $V_{\rm th1}$ is the threshold voltage at the measurement temperature.
- $V_{\rm ths}$ is the threshold voltage at the simulation temperature. This is the threshold voltage value used in the MOSFET equations when temperature dependence is modeled.
- *BEX* is the mobility temperature exponent. A typical value of *BEX* is -1.5.
- *a* is the gate threshold voltage temperature coefficient, $dV_{\rm th}/dT$.

For most MOSFETS, you can use the default value of -1.5 for *BEX*. Some datasheets quote the value for a, but most typically they provide the temperature dependence for drain-source on resistance, $R_{DS}(on)$. Depending on the block parameterization method, you have two ways of specifying a:

- If you parameterize the block from a datasheet, you have to provide $R_{DS}(on)$ at a second measurement temperature. The block then calculates the value for a based on this data.
- If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

If you have more data comprising drain current as a function of gate-source voltage for more than one temperature, then you can also use Simulink Design Optimization software to help tune the values for a and *BEX*.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

When modeling temperature dependence, consider the following:

Basic Assumptions and Limitations

- The block does not account for temperature-dependent effects on the junction capacitances.
- When you specify $R_{DS}(on)$ at a second measurement temperature, it must be quoted for the same working point (that is, the same drain current and gate-source voltage) as for the other $R_{DS}(on)$ value.

Inconsistent values for $R_{DS}(on)$ at the higher temperature will result in unphysical values for a and unrepresentative simulation results. Typically $R_{DS}(on)$ increases by a factor of about 1.5 for a hundred degree increase in temperature.

• You may need to tune the values of *BEX* and threshold voltage, $V_{\rm th}$, to replicate the $V_{\rm DS}$ - $V_{\rm GS}$ relationship (if available) for a given device. Increasing $V_{\rm th}$ moves the $V_{\rm DS}$ - $V_{\rm GS}$ plots to the right. The value of *BEX* affects whether the $V_{\rm DS}$ - $V_{\rm GS}$ curves for different temperatures cross each other, or not, for the ranges of $V_{\rm DS}$ and $V_{\rm GS}$ considered. Therefore, an inappropriate value can result in the different temperature curves appearing to be reordered. Quoting $R_{DS}(on)$ values for higher currents, preferably close to the current at which it will operate in your circuit, will reduce sensitivity to the precise value of *BEX*.

P-Channel MOSFET

Dialog Box and Parameters

Main Tab

| his bloc | k represents a P-channel | MOSFET (or IGFET). | The drain-source current Ids fo | r negative Vds is given by: |
|--|---|-------------------------|---------------------------------|-----------------------------|
| ds = 0 i | f -Vqs < -Vth (off) | | | |
| | 5 | ·2/2]*(1+L* Vdsl) if 0 | < -Vds < -Vqs + Vth] (linear r | egion) |
| | | | 5 10 | 59.017 |
| 15 = -(K | /2)~(Vgs - Vtn)^2~(1+L* | " vas) ir u < -vgs + v | /th < -Vds (saturated region) | |
| | is a constant, Vth is the T is the drain-source voltag | | the channel modulation, Vgs is | the gate-source voltage |
| | | | | |
| aramet | | | | |
| Main | Ohmic Resistance J | unction Capacitance | Temperature Dependence | |
| Param | eterization: | Specify from a dat | tasheet | • |
| Drain-: R_DS(| source on resistance, on): | 0.167 | | Ohm 👻 |
| Drain current, Ids, for R_DS(on): - | |): -2.5 | | Α 🔹 |
| Gate-source voltage, Vgs, for R_DS(on): | | -4.5 | -4.5 | |
| Gate-source threshold voltage, Vth: | | | V | |
| Chann | el modulation, L: | 0 | | 1/V • |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide the drain-source on resistance and the corresponding drain current and gate-source voltage. The block calculates the transistor gain for the Shichman and Hodges equations from this information. This is the default method.
- Specify using equation parameters directly Provide the transistor gain.

Drain-source on resistance, R_DS(on)

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage. $R_{DS}(on)$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.167 Ω .

Drain current, Ids, for R_DS(on)

The drain current the block uses to calculate the value of the drain-source resistance. I_{DS} should have a negative value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -2.5 A.

Gate-source voltage, Vgs, for R_DS(on)

The gate-source voltage the block uses to calculate the value of the drain-source resistance. V_{GS} should have a negative value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -4.5 V.

Gain K

Positive constant gain coefficient for the Shichman and Hodges equations. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 2 A/V^2 .

Gate-source threshold voltage Vth

Gate-source threshold voltage V_{th} in the Shichman and Hodges equations. For an enhancement device, V_{th} should be negative. For a depletion mode device, V_{th} should be positive. The default value is -1.4 V.

Channel modulation, L

The channel-length modulation, usually denoted by the mathematical symbol λ . When in the saturated region, it is minus the rate of change of drain current with drain-source voltage. The effect on drain current is typically small, and the effect is neglected if calculating transistor gain *K* from drain-source

on-resistance, $R_{DS}(on)$. A typical value is 0.02, but the effect can be ignored in most circuit simulations. However, in some circuits a small nonzero value may help numerical convergence. The default value is 0 1/V.

Measurement temperature

Temperature $T_{\rm m1}$ at which **Drain-source on resistance**, **R_DS(on)** is measured. This parameter is only visible when you select Model temperature dependence for the **Parameterization** parameter on the **Temperature Dependence** tab. The default value is 25 C.

Ohmic Resistance Tab

| Block Parameters: P-Channel MOSFET | r | | |
|---|-----------------------|------------------------------------|---------------------------|
| P-Channel MOSFET | | | |
| This block represents a P-channel M | OSFET (or IGFET). | The drain-source current Ids for | negative Vds is given by: |
| Ids = 0 if -Vgs < -Vth (off) | | | |
| Ids = -K*[(Vgs - Vth)*Vds - Vds^2/ | 2]*(1+L* Vds) if (|) < -Vds < -Vgs + Vth] (linear reg | gion) |
| Ids = -(K/2)*(Vgs - Vth)^2*(1+L* \ | /ds) if 0 < -Vgs + ' | Vth < -Vds (saturated region) | |
| where K is a constant, Vth is the Thr and Vds is the drain-source voltage. | | the channel modulation, Vgs is t | he gate-source voltage |
| Parameters | | | |
| Main Ohmic Resistance Jun | ction Capacitance | Temperature Dependence | |
| Source ohmic resistance: | 1e-4 | | Ohm 👻 |
| Drain ohmic resistance: | 0.01 | | Ohm 👻 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
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| | | OK Cancel | Help Apply |

Source ohmic resistance

The transistor source resistance. The default value is $1e-4~\Omega.$ The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is 0.001Ω . The value must be greater than or equal to 0.

Junction Capacitance Tab

| Block Parameters: P-Channel MOSFE | г | | — | | |
|---|------------------------------|-----------------------------------|---------------------------|--|--|
| P-Channel MOSFET | | | | | |
| This block represents a P-channel M | OSFET (or IGFET). | The drain-source current Ids for | negative Vds is given by: | | |
| Ids = 0 if -Vgs < -Vth (off) | Ids = 0 if -Vgs < -Vth (off) | | | | |
| Ids = -K*[(Vgs - Vth)*Vds - Vds^2/ | 2]*(1+L* Vds) if (|) < -Vds < -Vgs + Vth] (linear re | gion) | | |
| Ids = -(K/2)*(Vgs - Vth)^2*(1+L*) | /ds) if 0 < -Vgs + ' | Vth < -Vds (saturated region) | | | |
| where K is a constant, Vth is the Thi and Vds is the drain-source voltage. | | the channel modulation, Vgs is t | the gate-source voltage | | |
| Parameters | | | | | |
| Main Ohmic Resistance Jun | ction Capacitance | Temperature Dependence | | | |
| Parameterization: | Specify from a da | tasheet | • | | |
| Input capacitance, Ciss: | 270 | | pF 🔹 | | |
| Reverse transfer capacitance, Crss: | 45 | | pF 🔹 | | |
| Charge-voltage linearity: | Gate-drain capaci | tance is constant | • | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | OK Cancel | Help Apply | | |

Parameterization

Select one of the following methods for capacitance parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 270 pF.

Reverse transfer capacitance Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 45 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 225 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 45 pF.

Charge-voltage linearity

Select whether gate-drain capacitance is fixed or nonlinear:

- Gate-drain capacitance is constant The capacitance value is constant and defined according to the selected parameterization option, either directly or derived from a datasheet. This is the default method.
- Gate-drain charge function is nonlinear The gate-drain charge relationship is defined according to the

piecewise-nonlinear function described in "Charge Model" on page 1-401. Two additional parameters appear to let you define the gate-drain charge function.

Gate-drain oxide capacitance

The gate-drain capacitance when the device is on and the drain-gate voltage is small. This parameter is only visible when you select Gate-drain charge function is nonlinear for the **Charge-voltage linearity** parameter. The default value is 200 pF.

Drain-gate voltage at which oxide capacitance becomes active

The drain-gate voltage at which the drain-gate capacitance switches between off-state ($C_{\rm GD}$) and on-state ($C_{\rm ox}$) capacitance values. This parameter is only visible when you select Gate-drain charge function is nonlinear for the Charge-voltage linearity parameter. The default value is -0.5 V.

P-Channel MOSFET

Temperature Dependence Tab

| Block Parameters: P-Channel MOSFET |
|---|
| P-Channel MOSFET |
| This block represents a P-channel MOSFET (or IGFET). The drain-source current Ids for negative Vds is given by: |
| Ids = 0 if -Vgs < -Vth (off) |
| $Ids = -K^*[(Vgs - Vth)^*Vds - Vds^2/2]^*(1+L^* Vds) \text{ if } 0 < -Vds < -Vgs + Vth] \text{ (linear region)}$ |
| $Ids = -(K/2)^*(Vgs - Vth)^2^*(1+L^* Vds) \text{ if } 0 < -Vgs + Vth < -Vds \text{ (saturated region)}$ |
| where K is a constant, Vth is the Threshold voltage, L is the channel modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage. |
| Parameters |
| Main Ohmic Resistance Junction Capacitance Temperature Dependence |
| Parameterization: None - Simulate at parameter measurement temperature |
| |
| |
| |
| |
| |
| |
| |
| OK Cancel Help Apply |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled. This is the default method.
- Model temperature dependence Model temperature-dependent effects. Provide a value for simulation temperature, T_s , a value for *BEX*, and a value for the measurement temperature T_{m1} (using the **Measurement temperature** parameter on the **Main** tab). You also have to provide a value for *a* using one of two methods, depending on the value of the **Parameterization** parameter on the **Main** tab. If you parameterize the block from a datasheet, you have to provide $R_{DS}(on)$ at a second measurement temperature, and the block will calculate *a* based on that. If you parameterize by specifying equation parameters, you have to provide the value for *a* directly.

Drain-source on resistance, R_DS(on), at second measurement temperature

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage at second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted for the same working point (drain current and gate-source voltage) as the **Drain-source on resistance**, **R_DS(on)** parameter on the **Main** tab. The default value is 0.25 Ω .

Second measurement temperature

Second temperature T_{m2} at which **Drain-source on resistance**, **R_DS(on)**, at second measurement temperature is measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Gate threshold voltage temperature coefficient, dVth/dT

The rate of change of gate threshold voltage with temperature. This parameter is only visible when you select Specify using

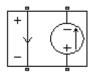
| | equation parameters directly for the Parameterization parameter on the Main tab. The default value is 2 mV/K. |
|------------|--|
| | Mobility temperature exponent, BEX Mobility temperature coefficient value. You can use the default value for most MOSFETs. See the "Basic Assumptions and Limitations" on page 1-404 section for additional considerations. The default value is -1.5. |
| | Device simulation temperature Temperature T_s at which the device is simulated. The default value is 25 C. |
| Ports | The block has the following ports: |
| | G Electrical conserving port associated with the transistor gate terminal. |
| | D Electrical conserving port associated with the transistor drain terminal. |
| | S Electrical conserving port associated with the transistor source terminal. |
| References | [1] H. Shichman and D. A. Hodges. "Modeling and simulation of insulated-gate field-effect transistor switching circuits." IEEE J. Solid State Circuits, SC-3, 1968. |
| See Also | N-Channel MOSFET |

Purpose Model polynomial current-controlled current source

SPICE-Compatible Components/Sources

Description

Library



The PCCCS (Polynomial Current-Controlled Current Source) block represents a current source whose output current value is a polynomial function of the current through the input ports. The following equations describe the current through the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

$$I_{out} = p(0) + p(1) * I_{in} + \dots + p(n-1) * I_{in}^{n-1} + p(n) * I_{in}^{n}$$

• If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$I_{out} = p * I_{in}$$

where:

- I_{in} is the current through the input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| 🙀 Block Parameters: PC | CCS | | | X | |
|--|---|------------------|---------------------|-----------|--|
| PCCCS | | | | | |
| The Polynomial Current-Co waveform, Iout, by evalu current, Iin. Iin is the time | ating a polynon | nial function fo | r a single controll | ing input | |
| If you specify a vector of | If you specify a vector of polynomial coefficients, p, in ascending order, the output is: | | | | |
| $Iout = p(0) + p(1)^*Iin + .$ | + p(n-1)*Iin | ^(n-1) + p(n) | *Iin^n | | |
| If you specify a scalar coefficient, p, the block creates a linearly dependent output current. | | | | | |
| Iout = p * Iin | | | | | |
| | | | | | |
| Parameters | | | | | |
| Polynomial coefficients: | [01] | | | | |
| | | | | | |
| | | | | | |
| | ОК | Cancel | Help | Apply | |

Polynomial coefficients

The polynomial coefficients that relate the input current to the output current, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

Positive electrical output voltage.

Ports

N-Negative electrical output voltage.

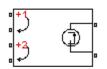
See Also , PCCCS2PCCVS, PVCCS, and PVCVS

PCCCS2

Purpose Model polynomial current-controlled current source with two controlling inputs

Library SPICE-Compatible Components/Sources

Description



The PCCCS2 (Two-Input Polynomial Current-Controlled Current Source) block represents a current source whose output current value is a polynomial function of the currents through the pairs of controlling input ports. The following equations describes the current through the source as a function of time:

$$I_{out} = p_1 + p_2 * I_{in1} + p_3 * I_{in2} + p_4 * I_{in1}^2 + p_5 I_{in1} * I_{in2} + p_6 * I_{in2}^2 + \dots$$

where:

- *I*_{*in1*} is the current across the first pair of input ports.
- I_{in2} is the current across the second pair of input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e–12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| 🙀 Block Parameters: PCCCS2 | | | | | |
|--|-------------------------|-------------------|------------------|-------------------|--------------------|
| PCCCS2 The Polynomial Current-Controlled polynomial function for two control | ling input currents, Ii | n1 and Iin2. Iin1 | and Iin2 are the | e time-dependent | t currents flowing |
| through the input terminals. If you p(1) + p(2)*Iin1 + p(3)*Iin2 + p(4) | | | | ending order, the | output is: Iout = |
| -Parameters | | | | | |
| Polynomial coefficients: | [011] | | | | |
| | | | | | |

Polynomial coefficients

The polynomial coefficients that relate the input current to the output current, as described in the preceding section. The default value is $[0\ 1\ 1]$.

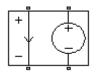
| Ports | The block has the following ports: | | | |
|----------|------------------------------------|---|--|--|
| | +1 | Positive electrical input voltage of first controlling source. | | |
| | - 1 | Negative electrical input voltage of first controlling source. | | |
| | +2 | Positive electrical input voltage of second controlling source. | | |
| | -2 | Negative electrical input voltage of second controlling source. | | |
| | N+ | Positive electrical output voltage. | | |
| | N - | Negative electrical output voltage. | | |
| See Also | PCC | CS, PCCVS2, PVCCS2, and PVCVS2 | | |

PCCVS

Purpose Model polynomial current-controlled voltage source

Library SPICE-Compatible Components/Sources

Description



The PCCVS (Polynomial Current-Controlled Voltage Source) block represents a voltage source whose output voltage value is a polynomial function of the current through the input ports. The following equations describe the voltage across the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

$$V_{out} = p(0) + p(1) * I_{in} + ... + p(n-1) * I_{in}^{n-1} + p(n) * I_{in}^{n}$$

• If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$V_{out} = p * I_{in}$$

where:

- I_{in} is the current through the input ports.
- *p* is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters

| 🙀 Block Parameters: PCC¥S 🛛 🗙 | | | |
|--|--|--|--|
| -PCCVS | | | |
| The Polynomial Current-Controlled Voltage Source (PCCVS) block generates a voltage waveform, Vout, by evaluating a polynomial function for a single controlling input current, Iin. Iin is the time-dependent current flowing through the input terminals. | | | |
| If you specify a vector of polynomial coefficients, p, in ascending order, the output is: | | | |
| $Vout = p(0) + p(1)*Iin + + p(n-1)*Iin^{(n-1)} + p(n)*Iin^{n}$ | | | |
| If you specify a scalar coefficient, $p,$ the block creates a linearly dependent output voltage. | | | |
| Vout = p * Iin | | | |
| Parameters | | | |
| Polynomial coefficients: [0 1] | | | |
| | | | |
| | | | |
| OK Cancel Help Apply | | | |

Polynomial coefficients

The polynomial coefficients that relate the input current to the output voltage, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Ports

Positive electrical input voltage.

- Negative electrical input voltage.
- N+

+

-

Positive electrical output voltage.

N -

Negative electrical output voltage.

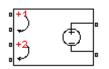
See Also PCCCS, PCCVS2, PVCCS, and PVCVS

Purpose Model polynomial current-controlled voltage source with two controlling inputs

SPICE-Compatible Components/Sources

Description

Library



The PCCVS2 (Two-Input Polynomial Current-Controlled Voltage Source) block represents a voltage source whose output voltage value is a polynomial function of the currents through the pairs of controlling input ports. The following equations describes the voltage across the source as a function of time:

 $V_{out} = p_1 + p_2 * I_{in1} + p_3 * I_{in2} + p_4 * I_{in1}^2 + p_5 I_{in1} * I_{in2} + p_6 * I_{in2}^2 + \dots$

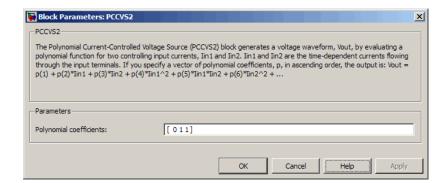
where:

- *I*_{*in1*} is the current across the first pair of input ports.
- I_{in2} is the current across the second pair of input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e–12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters



Polynomial coefficients

The polynomial coefficients that relate the input current to the output voltage, as described in the preceding section. The default value is $[0\ 1\ 1]$.

| Ports | The b | e block has the following ports: | |
|----------|-----------------------------------|---|--|
| | +1 | Positive electrical input voltage of first controlling source. | |
| | - 1 | Negative electrical input voltage of first controlling source. | |
| | +2 | Positive electrical input voltage of second controlling source. | |
| | -2 | Negative electrical input voltage of second controlling source. | |
| | N+ | Positive electrical output voltage. | |
| | N - | Negative electrical output voltage. | |
| See Also | PCCCS2, PCCVS, PVCCS2, and PVCVS2 | | |

Purpose Model photodiode as parallel controlled current source and exponential diode

Library

Sensors

Description



The Photodiode block represents a photodiode as a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current I_p that is proportional to the radiant flux density:

$I_{\rm p} = DeviceSensitivity \cdot RadiantFluxDensity$

where:

- *DeviceSensitivity* is the ratio of the current produced to the incident radiant flux density.
 - If you select Specify measured current for given flux density for the Sensitivity parameterization parameter, the block calculates this variable by converting the Measured current parameter value to units of amps and dividing it by the Flux density parameter values.
 - If you select Specify current per unit flux density for the Sensitivity parameterization parameter, this variable is defined by the Device sensitivity parameter value.
- *RadiantFluxDensity* is the incident radiant flux density.

To model dynamic response time, use the **Junction capacitance** parameter to include the diode junction capacitance in the model.

The exponential diode model provides the following relationship between the diode current I and the diode voltage V:

$$I = IS \cdot \left(e^{\frac{qV}{NkT_{m1}}} - 1 \right)$$

where:

- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e-23 J/K).
- *N* is the emission coefficient.
- *IS* is the saturation current, which is equal to the **Dark current** parameter value.
- T_{m1} is the temperature at which the diode parameters are specified, as defined by the **Measurement temperature** parameter value.

When $(qV / NkT_{m1}) > 80$, the block replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV / NkT_{m1} - 79)e^{80}$, which matches the gradient of the diode current at $(qV / NkT_{m1}) = 80$ and extrapolates linearly. When $(qV / NkT_{m1}) < -79$, the block

replaces $e^{\frac{qV}{NkT_{m1}}}$ with $(qV / NkT_{m1} + 80)e^{-79}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

When you select Use dark current and N for the **Diode parameterization** parameter, you specify the diode in terms of the **Dark current** and **Emission coefficient** N parameters. When you select Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter, you specify the **Dark current** parameter and a voltage and current measurement point on the diode I-V curve. The block calculates N from these values as follows:

$$N = V_F / (V_t \log(I_F / IS + 1))$$

where:

- V_F is the Forward voltage VF parameter value.
- $V_{\rm t} = kT_{\rm m1} / q$.

• *I_F* is the **Current IF at forward voltage VF** parameter value.

The exponential diode model provides the option to include a junction capacitance:

- When you select Fixed or zero junction capacitance for the **Junction capacitance** parameter, the capacitance is fixed.
- When you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter, the block uses the coefficients CJO, VJ, M, and FC to calculate a junction capacitance that depends on the junction voltage.
- When you select Use C-V curve data points for the Junction capacitance parameter, the block uses three capacitance values on the C-V capacitance curve to estimate CJO, VJ, and M and uses these values with the specified value of FC to calculate a junction capacitance that depends on the junction voltage. The block calculates CJO, VJ, and M as follows:
 - $CJ0 = C_1((V_{R2} V_{R1})/(V_{R2} V_{R1}(C_2/C_1)^{-1/M}))^M$
 - $VJ = -(-V_{R2}(C_1/C_2)^{-1/M} + V_{R1})/(1 (C_1/C_2)^{-1/M})$
 - $M = \log(C_3 / C_2) / \log(V_{R2} / V_{R3})$ where:
 - V_{R1}, V_{R2}, and V_{R3} are the values in the Reverse bias voltages [VR1 VR2 VR3] vector.
 - C₁, C₂, and C₃ are the values in the Corresponding capacitances [C1 C2 C3] vector.

It is not possible to estimate FC reliably from tabulated data, so you must specify its value using the **Capacitance coefficient FC** parameter. In the absence of suitable data for this parameter, use a typical value of 0.5.

The reverse bias voltages (defined as positive values) should satisfy $V_{R3} > V_{R2} > V_{R1}$. This means that the capacitances should satisfy

 $C_1 > C_2 > C_3$ as reverse bias widens the depletion region and hence reduces capacitance. Violating these inequalities results in an error. Voltages V_{R2} and V_{R3} should be well away from the Junction potential VJ. Voltage V_{R1} should be less than the Junction potential VJ, with a typical value for V_{R1} being 0.1 V.

The voltage-dependent junction is defined in terms of the capacitor charge storage Q_i as:

• For $V < FC \cdot VJ$:

$$Q_i = CJ0 \cdot (VJ / (M - 1)) \cdot ((1 - V / VJ)^{1 - M} - 1)$$

• For $V \ge FC \cdot VJ$:

$$Q_{i} = CJ0 \cdot F_{1} + (CJ0/F_{2}) \cdot (F_{3} \cdot (V - FC \cdot VJ) + 0.5(M/VJ) \cdot (V^{2} - (FC \cdot VJ)^{2}))$$

where:

- $F_1 = (VJ / (1 M)) \cdot (1 (1 FC)^{1 M}))$
- $F_2 = (1 FC)^{1+M})$
- $F_3 = 1 FC \cdot (1 + M)$

These equations are the same as used in [2], except that the temperature dependence of VJ and FC is not modeled. This model does not include the diffusion capacitance term that affects performance for high frequency switching applications.

The Photodiode block contains several options for modeling the dependence of the diode current-voltage relationship on the temperature during simulation. Temperature dependence of the junction capacitance is not modeled, this being a much smaller effect. For details, see the Diode reference page.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The Photodiode block has the following limitations:

- When you select Use dark current plus a forward bias I-V curve data point for the **Diode parameterization** parameter, choose a voltage near the diode turn-on voltage. Typically this will be in the range from 0.05 to 1 Volt. Using a value outside of this region may lead to a poor estimate for *N*.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.

Basic Assumptions and Limitations

Dialog Main Tab Box and Parameters

| 🙀 Block Parameters: Photodiode | | | X | |
|---|---------------------|---------------------------------|------------|--|
| Photodiode | | | | |
| This block represents a photodiode. Structurally it consists of a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current Ip that is proportional to the Radiant flux density presented at the physical signal port D: | | | | |
| Ip = Device sensitivity * Radiant flux density | | | | |
| In order to model dynamic response time, the diode junction capacitance can be set to a suitable value. | | | | |
| Parameters | | | | |
| Main Ohmic Resistance Jur | nction Capacitance | Temperature Dependence | | |
| Sensitivity parameterization: | Specify measured | current for given flux density | • | |
| Measured current: | 25 | | uA 🔻 | |
| Flux density: | 5 | | W/m^2 - | |
| Diode parameterization: | Use dark current pl | us a forward bias I-V data poir | nt 🔹 | |
| Current IF at forward voltage VF: | 0.1 | | A • | |
| Forward voltage VF: | 1.3 | | V • | |
| Dark current: | 5e-9 | | A • | |
| Measurement temperature: | 25 | | C • | |
| | | | | |
| | | OK Cancel | Help Apply | |

Sensitivity parameterization

Select one of the following methods for sensitivity parameterization:

- Specify measured current for given flux density Specify the measured current and the corresponding flux density. This is the default method.
- Specify current per unit flux density Specify the device sensitivity directly.

Measured current

The current the block uses to calculate the device sensitivity. This parameter is only visible when you select Specify measured current for given flux density for the **Sensitivity parameterization** parameter. The default value is 25μ A.

Flux density

The flux density the block uses to calculate the device sensitivity. This parameter is only visible when you select Specify measured current for given flux density for the **Sensitivity parameterization** parameter. The default value is 5 W/m².

Device sensitivity

The current per unit flux density. This parameter is only visible when you select Specify current per unit flux density for the **Sensitivity parameterization** parameter. The default value is $5e-06 \text{ m}^{2*}\text{A/W}$.

Diode parameterization

Select one of the following methods for diode model parameterization:

- Use dark current plus a forward bias I-V data point — Specify the dark current and a point on the diode I-V curve. This is the default method.
- \bullet Use dark current and N Specify dark current and emission coefficient.

Current IF at forward voltage VF

The current at the forward-biased point on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter. The default value is 0.1 A.

Forward voltage VF

The corresponding voltage at the forward-biased point on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select and Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter. The default value is 1.3 V.

Dark current

The current through the diode when it is not exposed to light. The default value is 5e-9 A.

Measurement temperature

The temperature at which the I-V curve or dark current was measured. The default value is $25 \ ^{\circ}C$.

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Use dark current and N for the **Diode parameterization** parameter. The default value is 3.

Ohmic Resistance Tab

| 🙀 Block Parameters: Photodiode | | | X | |
|---|---------------------------|--------------------------------|-------------------|--|
| Photodiode | | | | |
| This block represents a photodiode. Structurally it consists of a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current Ip that is proportional to the Radiant flux density presented at the physical signal port D: | | | | |
| Ip = Device sensitivity * Radiant flux density | | | | |
| In order to model dynamic resp | onse time, the diode junc | tion capacitance can be set to | a suitable value. | |
| Parameters | | | | |
| Main Ohmic Resistance | Junction Capacitance | Temperature Dependence | | |
| Ohmic resistance, RS: | 0.1 | | Ohm 👻 | |
| | | | | |
| | | | | |
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| [. | | | | |
| | | OK Cancel | Help Apply | |

Ohmic resistance RS

The series diode connection resistance. The default value is $0.1\,\Omega$

Junction Capacitance Tab

| 🙀 Block Parameters: Photodiode | | | × | | |
|---|---------------------|------------------------|------------|--|--|
| Photodiode | | | | | |
| This block represents a photodiode. Structurally it consists of a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current Ip that is proportional to the Radiant flux density presented at the physical signal port D: Ip = Device sensitivity * Radiant flux density | | | | | |
| In order to model dynamic response time, the diode junction capacitance can be set to a suitable value. | | | | | |
| Parameters | | _ | | | |
| Main Ohmic Resistance Jun | nction Capacitance | Temperature Dependence | | | |
| Junction capacitance: | Fixed or zero junct | ion capacitance | • | | |
| Zero-bias junction capacitance, CJ0: | 60 | | pF 👻 | | |
| | | | | | |
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| | | OK Cancel | Help Apply | | |

Junction capacitance

Select one of the following options for modeling the junction capacitance:

- Fixed or zero junction capacitance Model the junction capacitance as a fixed value.
- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 60 pF. When you select Fixed or zero junction capacitance for the **Junction capacitance** parameter, a value of zero omits junction capacitance.

Reverse bias voltages [VR1 VR2 VR3]

A vector of the reverse bias voltage values at the three points on the diode C-V curve that the block uses to calculate CJO, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [0.1 10 100] V.

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate CJ0, VJ, and M. This parameter is only visible when you select Use C-V curve data points for the **Junction capacitance** parameter. The default value is [45 30 6] pF.

Junction potential VJ

The junction potential. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 1 V.

Grading coefficient M

The grading coefficient. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Capacitance coefficient FC

Fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Use C-V curve data points or Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Temperature Dependence Tab

| 뒑 Block Pa | Block Parameters: Photodiode | | | | |
|---|--|---------------------------|--------------------------------|-------------------|--|
| Photodiode | | | | | |
| This block represents a photodiode. Structurally it consists of a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current Ip that is proportional to the Radiant flux density presented at the physical signal port D: | | | | | |
| Ip = Device sensitivity * Radiant flux density | | | | | |
| In order t | to model dynamic resp | onse time, the diode junc | tion capacitance can be set to | a suitable value. | |
| Paramete | ers | | | | |
| Main | Ohmic Resistance | Junction Capacitance | Temperature Dependence | | |
| Param | Parameterization: None - Simulate at parameter measurement temperature | | | | |
| | | | | | |
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| | | | OK Cancel | Help Apply | |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified by the **Measurement temperature** parameter on the **Main** tab). This is the default method.
- Use an I-V data point at second measurement temperature T2 If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and the current and voltage values at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify saturation current at second measurement temperature T2 If you select this option, you specify a second measurement temperature $T_{\rm m2}$, and saturation current value at this temperature. The model uses these values, along with the parameter values at the first measurement temperature $T_{\rm m1}$, to calculate the energy gap value.
- Specify the energy gap EG Specify the energy gap value directly.

Current I1 at second measurement temperature

Specify the diode current I1 value when the voltage is V1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 0.07 A.

Voltage V1 at second measurement temperature

Specify the diode voltage V1 value when the current is I1 at the second measurement temperature. This parameter is only visible when you select Use an I-V data point at second measurement temperature T2 for the **Parameterization** parameter. The default value is 1.3 V.

Saturation current, IS, at second measurement temperature

Specify the saturation current *IS* value at the second measurement temperature. This parameter is only visible when you select Specify saturation current at second measurement temperature T2 for the **Parameterization** parameter. The default value is 2.5e-7 A.

Second measurement temperature

Specify the value for the second measurement temperature. This parameter is only visible when you select either Use an I-V data point at second measurement temperature T2 or Specify saturation current at second measurement temperature T2 for the **Parameterization** parameter. The default value is 125 C.

Energy gap parameterization

This parameter is only visible when you select Specify the energy gap EG for the **Parameterization** parameter. It lets you select a value for the energy gap from a list of predetermined options, or specify a custom value:

- Use nominal value for silicon (EG=1.11eV) This is the default.
- Use nominal value for 4H-SiC silicon carbide (EG=3.23eV)
- Use nominal value for 6H-SiC silicon carbide (EG=3.00eV)
- Use nominal value for germanium (EG=0.67eV)
- Use nominal value for gallium arsenide (EG=1.43eV)
- Use nominal value for selenium (EG=1.74eV)
- Use nominal value for Schottky barrier diodes (EG=0.69eV)
- Specify a custom value If you select this option, the **Energy gap, EG** parameter appears in the dialog box, to let you specify a custom value for *EG*.

Energy gap, EG

Specify a custom value for the energy gap, EG. This parameter is only visible when you select Specify a custom value for the **Energy gap parameterization** parameter. The default value is 1.11 eV.

Saturation current temperature exponent parameterization

Select one of the following options to specify the saturation current temperature exponent value:

- Use nominal value for pn-junction diode (XTI=3) This is the default.
- Use nominal value for Schottky barrier diode (XTI=2)
- Specify a custom value If you select this option, the Saturation current temperature exponent, XTI parameter appears in the dialog box, to let you specify a custom value for *XTI*.

Saturation current temperature exponent, XTI

Specify a custom value for the saturation current temperature exponent, XTI. This parameter is only visible when you select Specify a custom value for the Saturation current temperature exponent parameterization parameter. The default value is 3.

Device simulation temperature

Specify the value for the temperature $T_{\rm s},$ at which the device is to be simulated. The default value is 25 C.

Ports The block has the following ports:

D

Physical port representing incident flux.

+

Electrical conserving port associated with the diode positive terminal.

Photodiode

Electrical conserving port associated with the diode negative terminal.

References [1] MH. Ahmed and P.J. Spreadbury. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

[2] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993.

See Also Diode, Light-Emitting Diode, Optocoupler

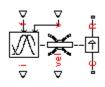
Piezo Linear Motor

Purpose Model force-speed characteristics of linear piezoelectric traveling wave motor

Library

Translational Actuators

Description



The Piezo Linear Motor block represents the force-speed characteristics of a linear piezoelectric traveling wave motor. The block represents the force-speed relationship of the motor at a level that is suitable for system-level modeling. To simulate the motor, the block uses the following models:

- "Mass and Friction Model for Unpowered Motor" on page 1-442
- "Resonant Circuit Model for Powered Motor" on page 1-442

Mass and Friction Model for Unpowered Motor

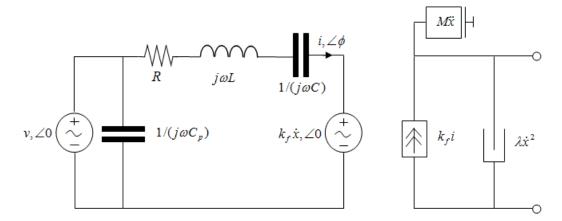
The motor is unpowered when the physical signal input v is zero. This corresponds to applying zero RMS volts to the motor. In this scenario, the block models the motor using the following elements:

- An mass whose value is the **Plunger mass** parameter value.
- A friction whose characteristics you specify using the parameter values in the **Motor-Off Friction** tab.

The block uses a Simscape Translational Friction block to model the friction component. For detailed information about the friction model, see the Translational Friction block reference page.

Resonant Circuit Model for Powered Motor

When the motor is active, Piezo Linear Motor block represents the motor characteristics using the following equivalent circuit model.



In the preceding figure:

- The AC voltage source represents the block's physical signal input of frequency *f* and magnitude *v*.
- The resistor R provides the main electrical and mechanical damping term.
- The inductor *L* represents the rotor vibration inertia.
- The capacitor C represents the piezo crystal stiffness.
- The capacitor C_p represents the phase capacitance. This is the electrical capacitance associated with each of the two motor phases.
- The force constant k_i relates the RMS current i to the resulting mechanical force.
- The quadratic mechanical damping term, $\lambda \dot{x}^2$, shapes the force-speed curve predominantly at speeds close to maximum RPM. \dot{x} is the linear speed.
- The term $M\dot{x}$ represents the plunger inertia.

At model initialization, the block calculates the model parameters R, L, C, k_i and λ to ensure that the steady-state force-speed curve matches the values for the following user-specified parameters:

- Rated force
- Rated speed
- No-load maximum speed
- Maximum (stall) force

These parameter values are defined for the **Rated RMS voltage** and **Motor natural frequency** (or rated frequency) parameter values.

The quadratic mechanical damping term produces a quadratic force-speed curve. Piezoelectric motors force-speed curves can typically be approximated more accurately using a quadratic function than a linear one because the force-speed gradient becomes steeper as the motor approaches the maximum speed.

If the plunger mass M is not specified on the datasheet, you can select a value that provides a good match to the quoted response time. The response time is often defined as the time for the rotor to reach maximum speed when starting from rest, under no-load conditions.

The quality factor that you specify using the **Resonance quality factor** parameter relates to the equivalent circuit model parameters as follows:

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

This term is not usually provided on a datasheet. You can calculate its value by matching the sensitivity of force to driving frequency.

To reverse the motor direction of operation, make the physical signal input v negative.

Basic Assumptions and Limitations

The block has the following limitations:

- When the motor is powered, the model is valid only between zero and maximum speed, for the following reasons:
 - Datasheets do not provide information for operation outside of normal range.
 - Piezoelectric motors are not designed to operate in the powered braking and generating regions.

The block behaves as follows outside the valid operating region:

- Below zero speed, the model maintains a constant force with a zero speed value. The zero speed value is the Maximum (stall) force parameter value if the RMS input voltage equals the Rated RMS voltage parameter value, and the frequency input equals the Motor natural frequency parameter value.
- Above maximum speed, the model produces the negative force predicted by the equivalent circuit model, but limits the absolute value of the force to the zero-speed maximum force.
- The force-speed characteristics are most representative when operating the model close to the rated voltage and resonant frequency.

Piezo Linear Motor

Dialog Box and Parameters

Electrical Force Tab

| | the Rated RMS voltage. If the voltage v i model the holding force behavior. The dire | | |
|---|---|-----------------------------|--------------------------|
| value for v. | model the holding force behavior. The diff | ection of operation is reve | i seu by providing a rie |
| For positive v, the block produces a po | sitive force acting from the mechanical C t | o R ports. | |
| Parameters | | | |
| Electrical Force Mechanical I | lotor-Off Friction | | |
| Motor natural frequency: | 92 | | kHz |
| Rated RMS voltage: | 5.7 | | V |
| Rated force: | 0.1 | | N |
| Rated speed: | 50 | | mm/s |
| No-load maximum speed: | 150 | | mm/s |
| Maximum (stall) force: | 0.15 | | N |
| Resonance quality factor: | 100 | | |
| Capacitance per phase: | 5 | | nF |

Motor natural frequency

Frequency at which the piezoelectric crystal naturally resonates. For most applications, set the input signal at port f to this frequency. To slow down the motor, for example in a closed-loop speed control, use a frequency slightly less than the motor natural frequency. The default value is 92 kHz.

Rated RMS voltage

Voltage at which the motor is designed to operate. The default value is 5.7 V.

Rated force

Force the motor delivers at the rated RMS voltage. The default value is $0.1\ \mathrm{N}.$

Rated speed

Motor speed when the motor drives a load at the rated force. The default value is 50 mm/s.

No-load maximum speed

Motor speed when driving no load and powered at the rated voltage and driving frequency. The default value is 150 mm/s.

Maximum (stall) force

Maximum force the motor delivers when actively driving a load and powered at the rated voltage and frequency. The default value is 0.15 N.

Note The **Holding force** parameter value, the load force the motor holds when stationary, may be greater than the **Maximum** (stall) force parameter value.

Resonance quality factor

Quality factor Q that specifies how force varies as a function of driving frequency. Increasing the quality factor results in a much more rapid decrease in force as driving frequency is moved away from the natural frequency. The default value is 100.

Capacitance per phase

Electrical capacitance associated with each of the two motor phases. The default value is 5 nF.

Mechanical Tab

| 🙀 Block Parameters: Piezo Linea | Motor | | X |
|--|--|--|---|
| Piezo Linear Motor | | | |
| This block provides a simple represent inputs are driving frequency f (Hz) are frequency, and the RMS voltage set Friction component is used internally value for v. For positive v, the block produces a p | nd RMS voltage v (Volts). The drivin to the Rated RMS voltage. If the vo to model the holding force behavior | g frequency should normally oltage v is zero, then the Fou . The direction of operation is | be set to the motor natural Indation Library Translational |
| Parameters Electrical Force Mechanical | Motor-Off Friction | | |
| Plunger mass: | 0.3 | | g 💌 |
| Initial rotor speed: | 0 | | mm/s |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | [| OK Cancel | Help Apply |

Plunger mass

Mass of the moving part of the motor. The default value is **0.3** g.

Initial rotor speed

Rotor speed at the start of the simulation. The default value is $0\,$ mm/s.

Motor-Off Friction Tab

| Friction component is used internally to m value for v. | | | Foundation Library Translational on is reversed by providing a neg | |
|--|--------------------------------|-----------------------|---|---|
| For positive v, the block produces a posit | ive force acting from the mech | hanical C to R ports. | | |
| Parameters Electrical Force Mechanical Mo | tor-Off Friction | | | |
| Holding force: | 0.3 | | N | • |
| Coulomb friction force: | 0.15 | | N | • |
| Viscous friction coefficient: | 1e-05 | | s*N/mm | • |
| Transition approximation coefficient: | 0.1 | | s/mm | • |
| Linear region velocity threshold: | 0.1 | | mm/s | • |
| | | | | |
| | | | | |
| | | | | |

Holding force

The sum of the Coulomb and the static frictions. It must be greater than or equal to the **Coulomb friction force** parameter value. The default value is **0.3** N.

Coulomb friction force

The friction that opposes rotation with a constant force at any velocity. The default value is 0.15 N.

| Viscous fr | riction co | oefficient |
|------------|------------|------------|
|------------|------------|------------|

Proportionality coefficient between the friction force and the relative velocity. The parameter value must be greater than or equal to zero. The default value is $1e-05 \text{ s}^*\text{N/mm}$.

Transition approximation coefficient

The parameter sets the coefficient value that is used to approximate the transition between the static and the Coulomb frictions. For detailed information about the coefficient, c_v , see the Simscape Translational Friction block reference page. The default value is 0.1 s/mm.

Linear region velocity threshold

The parameter sets the small vicinity near zero velocity, within which friction force is considered to be linearly proportional to the relative velocity. MathWorks recommends that you use values between 1e-6 and 1e-4 mm/s. The default value is 0.1 mm/s.

Ports

The block has the following ports:

f

Physical signal input value specifying the motor driving frequency in Hz.

v

Physical signal input magnitude specifying the RMS supply voltage, and sign specifying the direction of rotation. If v is positive, then a positive force acts from port C to port R.

i

Physical signal output value that is the RMS phase current.

vel

Physical signal output value that is the linear speed of the rotor.

С

Mechanical translational conserving port.

R

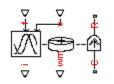
Mechanical translational conserving port.

Purpose Model torque-speed characteristics of rotary piezoelectric traveling wave motor

Library

Rotational Actuators

Description



The Piezo Rotary Motor block represents the torque-speed characteristics of a piezoelectric traveling wave motor. The block represents the torque-speed relationship of the motor at a level that is suitable for system-level modeling. To simulate the motor, the block uses the following models:

- "Inertia and Friction Model for Unpowered Motor" on page 1-451
- "Resonant Circuit Model for Powered Motor" on page 1-451

Inertia and Friction Model for Unpowered Motor

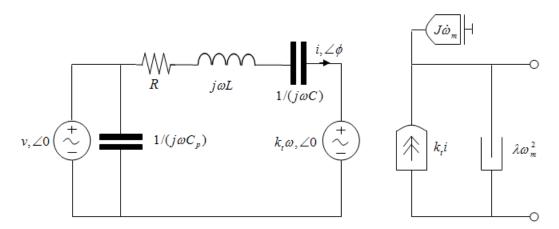
The motor is unpowered when the physical signal input v is zero. This corresponds to applying zero RMS volts to the motor. In this scenario, the block models the motor using the following elements:

- An inertia whose value is the **Rotor inertia** parameter value.
- A friction whose characteristics are determined by the parameter values in the **Motor-Off Friction** tab.

The block uses a Simscape Rotational Friction block to model the friction component. For detailed information about the friction model, see the Rotational Friction block reference page.

Resonant Circuit Model for Powered Motor

When the motor is active, Piezo Rotary Motor block represents the motor characteristics using the following equivalent circuit model.



In the preceding figure:

- The AC voltage source represents the block's physical signal input of frequency *f* and magnitude *v*.
- The resistor R provides the main electrical and mechanical damping term.
- The inductor *L* represents the rotor vibration inertia.
- The capacitor *C* represents the piezo crystal stiffness.
- The capacitor C_p represents the phase capacitance. This is the electrical capacitance associated with each of the two motor phases.
- The torque constant k_t relates the RMS current i to the resulting mechanical torque.
- The quadratic mechanical damping term, $\lambda \omega_m^2$, shapes the torque-speed curve predominantly at speeds close to maximum RPM. ω_m is the mechanical rotational speed.
- The term $J\dot{\omega}_m$ represents the rotor inertia.

At model initialization, the block calculates the model parameters R, L, C, k_i and λ to ensure that the steady-state torque-speed curve matches the values of the following user-specified parameter values:

- Rated torque
- Rated rotational speed
- No-load maximum rotational speed
- Maximum torque

These parameter values are defined for the **Rated RMS voltage** and **Motor natural frequency** (or rated frequency) parameter values.

The quadratic mechanical damping term produces a quadratic torque-speed curve. Piezoelectric motors torque-speed curves can typically be approximated more accurately using a quadratic function than a linear one because the torque-speed gradient becomes steeper as the motor approaches the maximum speed.

If the rotor inertia J is not specified on the datasheet, you can select a value that provides a good match to the quoted response time. The response time is often defined as the time for the rotor to reach maximum speed when starting from rest, under no-load conditions.

The quality factor that you specify using the **Resonance quality factor** parameter relates to the equivalent circuit model parameters as follows:

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

This term is not usually provided on a datasheet. You can calculate its value by matching the sensitivity of torque to driving frequency.

To reverse the motor direction of operation, make the physical signal input v negative.

Piezo Rotary Motor

| Basic | The block has the following limitations: |
|-----------------------------------|---|
| Assumptions and Limitations | When the motor is powered, the model is valid only between zero and maximum speed, for the following reasons: Datasheets do not provide information for operation outside of normal range. |

 Piezoelectric motors are not designed to operate in the powered braking and generating regions.

The block behaves as follows outside the valid operating region:

- Below zero speed, the model maintains a constant torque that is the zero rpm torque value. The zero rpm torque value is the Maximum torque parameter value if the RMS input voltage equals the Rated RMS voltage parameter value, and the frequency input equals the Motor natural frequency parameter value.
- Above maximum speed, the model produces the negative torque predicted by the equivalent circuit model, but limits the absolute value of the torque to the zero-speed maximum torque.
- The torque-speed characteristics are most representative when operating the model close to the rated voltage and resonant frequency.

Dialog Box and Parameters

Electrical Torque Tab

| component is used internally to model the | | | n the Foundation Library Ro | |
|--|----------------------------|----------------------------|-----------------------------|---------|
| for v. | induing torque benavior. | The direction of operation | ris reversed by providing a | megauve |
| For positive v, the block produces a posit | ive torque acting from the | e mechanical C to R ports. | | |
| Parameters | | | | |
| Electrical Torque Mechanical M | otor-Off Friction | | | |
| Motor natural frequency: | 40 | | kHz | |
| Rated RMS voltage: | 130 | | V | |
| Rated torque: | 0.5 | | N*m | |
| Rated rotational speed: | 100 | | rpm | |
| No-load maximum rotational speed: | 160 | | rpm | |
| Maximum torque: | 1 | | N*m | |
| Resonance quality factor: | 100 | | | |
| Capacitance per phase: | 5 | | InF | |

Motor natural frequency

Frequency at which the piezoelectric crystal naturally resonates. For most applications, set the input signal at port f to this frequency. To slow down the motor, for example in a closed-loop speed control, use a frequency slightly less than the motor natural frequency. The default value is 40 kHz.

Rated RMS voltage

Voltage at which the motor is designed to operate. The default value is 130 V.

Rated torque

Torque the motor delivers at the rated RMS voltage. The default value is 0.5 N*m.

Rated rotational speed

Motor speed when the motor drives a load at the rated torque. The default value is 100 rpm.

No-load maximum rotational speed

Motor rotational speed when driving no load and powered at the rated voltage and driving frequency. The default value is 160 rpm.

Maximum torque

Maximum torque that the motor delivers when actively driving a load and powered at the rated voltage and frequency. The default value is 1 N*m.

Note The **Holding torque** parameter value, the load torque the motor holds when stationary, may be greater than the **Maximum torque** parameter value.

Resonance quality factor

Quality factor Q that specifies how torque varies as a function of driving frequency. Increasing the quality factor results in a much more rapid decrease in torque as driving frequency is moved away from the natural frequency. The default value is 100.

Capacitance per phase

Electrical capacitance associated with each of the two motor phases. The default value is 5 nF.

Mechanical Tab

| 🙀 Block Parameters: Piezo Rotary Motor | X |
|--|--|
| Piezo Rotary Motor | |
| signal inputs are driving frequency f (Hz) and RMS voltage v (Vo frequency, and the RMS voltage set to the Rated RMS voltage. | characteristics of a rotary piezoelectric or ultrasonic motor. Physical lts). The driving frequency should normally be set to the motor natural If the voltage v is zero, then the Foundation Library Rotational Friction ior. The direction of operation is reversed by providing a negative value the mechanical C to R ports. |
| -Parameters | |
| Electrical Torque Mechanical Motor-Off Friction | |
| Rotor inertia: | g*cm^2 |
| Initial rotor speed: 0 | rpm |
| | |
| | OK Cancel Help Apply |

Rotor inertia

Rotor resistance to change in motor motion. The default value is $200 \text{ g}^*\text{cm}^2$.

Initial rotor speed

Rotor speed at the start of the simulation. The default value is $0\ \mbox{rpm}.$

Motor-Off Friction Tab

| 🚺 Block Parameters: Piezo Rotary Mot | or | × | | |
|--|-----------------|-------------------|--|--|
| Piezo Rotary Motor This block provides a simple representation of the torque-speed characteristics of a rotary piezoelectric or ultrasonic motor. Physical signal inputs are driving frequency f (Hz) and RMS voltage v (Volts). The driving frequency should normally be set to the motor natural frequency, and the RMS voltage set to the Rated RMS voltage. If the voltage v is zero, then the Foundation Library Rotational Friction component is used internally to model the holding torque behavior. The direction of operation is reversed by providing a negative value for v. For positive v, the block produces a positive torque acting from the mechanical C to R ports. | | | | |
| Parameters Electrical Torque Mechanical Mot | or-Off Friction | 1 | | |
| Holding torque: | 1.5 | N*m 💌 | | |
| Coulomb friction torque: | 1 | N*m 💌 | | |
| Viscous friction coefficient: | 0.001 | N*m/(rad/s) | | |
| Transition approximation coefficient: | 10 | s/rad 💌 | | |
| Linear region velocity threshold: | 1e-04 | rad/s | | |
| | | | | |
| | ок | Cancel Help Apply | | |

Holding torque

The sum of the Coulomb and the static frictions. It must be greater than or equal to the **Coulomb friction torque** parameter value. The default value is 1.5 N*m.

Coulomb friction torque

The friction that opposes rotation with a constant torque at any velocity. The default value is $1 N^*m$.

Viscous friction coefficient

Proportionality coefficient between the friction torque and the relative angular velocity. The parameter value must be greater than or equal to zero. The default value is 0.001 N*m/(rad*s).

Transition approximation coefficient

The parameter sets the coefficient value that is used to approximate the transition between the static and the Coulomb frictions. For detailed information about the coefficient, c_v , see the Simscape Rotational Friction block reference. The default value is 10 s/rad.

Linear region velocity threshold

The parameter sets the small vicinity near zero velocity, within which friction torque is considered to be linearly proportional to the relative velocity. MathWorks recommends that you use values in the range between 1e-5 and 1e-3 rad/s. The default value is 1e-04 rad/s.

Ports The block has the following ports:

f

Physical signal input value specifying the motor driving frequency in Hz.

۷

Physical signal input magnitude specifying the RMS supply voltage, and sign specifying the direction of rotation. If v is positive, then a positive torque acts from port C to port R.

i

Physical signal output value that is the RMS phase current.

wm

Physical signal output value that is the rotational speed of the rotor.

С

Mechanical rotational conserving port.

Piezo Rotary Motor

R

Mechanical rotational conserving port.

Purpose Model electrical and force characteristics of piezoelectric stacked actuator

Library Translational Actuators

Description

The Piezo Stack block represents the electrical and force characteristics of a piezoelectric stacked actuator using the following equations:

$$S = s^{E}T + d^{T}E$$
$$D = dT + \varepsilon^{T}E$$

where

- S is the strain tensor.
- *T* is the stress tensor.
- *E* is the electric field vector.
- *D* is the electric displacement vector.
- s^E is the elastic compliance matrix when subjected to a constant electric field.
- *d* is the piezoelectric constant matrix.
- ε^T is the permittivity measured at a constant stress.

Note The block models one-dimensional lumped parameter behavior, so *S*, *T*, *E* and *D* are all scalar values.

You can specify the block parameters that determine static force using either datasheet parameters or material properties, as determined by the value of the **Parameterization** parameter on the **Static Force** tab of the block dialog box.

The **Dynamic Forces** tab of the block dialog box lets you include optional effective mass and mechanical damping effects.



| | • If you specify a nonzero value for the Effective mass parameter or a finite value for the Resonant frequency at constant field parameter, the block attaches a lumped mass to the mechanical R port. When you specify a finite resonant frequency, the block calculates the effective mass to achieve the correct resonant frequency. |
|--|--|
| | • If you specify a nonzero value for the Damping parameter or a finite value for the Mechanical quality factor parameter, the block adds a damping term across the R and C mechanical ports. When you specify a mechanical quality factor, Q_m , the block calculates the |
| | damping from this parameter value as \sqrt{Mk}/Q_m , where k is the short-circuit device stiffness, or equivalently the stiffness at constant field. |
| | A positive voltage across the electrical + to – ports creates a positive displacement acting from the mechanical C to R ports. |
| Basic Assumptions and Limitations | The model does not include hysteresis effects. |

Piezo Stack

Dialog Box and Parameters

| Static Force Tab | Static | Force | Tab |
|-------------------------|---------------|-------|-----|
|-------------------------|---------------|-------|-----|

| positive voltage across the electrical + | to - ports results in a positive displacement acting from th | e mechanical C to R ports. |
|--|--|----------------------------|
| rameters | | |
| Static Force Dynamic Forces I | nitial Conditions | |
| Parameterization: | Specify from a datasheet | |
| Stack area: | 100 | mm^2 |
| Stack length: | 36 | mm |
| No-load displacement at V0 volts: | 0.038 | mm |
| Blocking force at V0 volts: | 3.8e+03 | N |
| Test voltage V0: | 120 | V |
| Capacitance: | 13 | uF |

Parameterization

Select one of the following methods for static force parameterization:

- Specify from a datasheet Provide datasheet parameters that the block converts to static force values. This is the default method.
- Specify material properties Provide material properties that the block converts to static force values.

Stack area

Cross-sectional area of the stack. The default value is 100 mm^2 .

Stack length

Stack length when no load and no electrical potential are applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 36 mm.

No-load displacement at V0 volts

Unconstrained displacement of the stack when a voltage of V0 volts is applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.038 mm.

Blocking force at V0 volts

Force the stack produces when a voltage of V0 volts is applied and the stack is physically prevented from expanding. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 3.8e+03 N.

Test voltage V0

Voltage used to determine the no-load displacement and blocking force. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 120 V.

Capacitance

This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 13 uF.

Piezo layer thickness

Thickness of each layer in the piezo stack. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0.3 mm.

Number of layers

Number of layers in the piezo stack. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 50.

Piezoelectric charge constant

Mechanical strain per unit electric field applied. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 5e-10 m/V.

Dielectric constant

Permittivity or dielectric displacement per unit electric field measured at constant stress. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 2.124e-08 F/m.

Elastic compliance

Strain produced in a piezoelectric material per unit of stress applied. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is $1.9e-11 \text{ m}^2/\text{N}$.

Dynamic Forces Tab

| ezo Stack inis block implements the electrical and force characteristics of a piezoelectric stacked actuator. Effective mass and mere amping effects may also be optionally included. positive voltage across the electrical + to - ports results in a positive displacement acting from the mechanical C to R p arameters Static Force Dynamic Forces Initial Conditions Parameterization: Specify from a datasheet Resonant frequency at constant field: Inf Mechanical quality factor: Inf | |
|---|----------|
| Static Force Dynamic Forces Initial Conditions Parameterization: Specify from a datasheet Resonant frequency at constant field: Inf | _ |
| Resonant frequency at constant field: Inf | - |
| Mechanical quality factor: | • |
| | |
| | |
| | |
| OK Cancel Help | App |

Parameterization

Select one of the following methods for dynamic force parameterization:

- Specify from a datasheet Provide datasheet parameters that the block converts to dynamic force values. This is the default method.
- Specify material properties Provide material properties that the block converts to dynamic force values.

Resonant frequency at constant field

Frequency at which the actuator naturally resonates if mechanically perturbed with the electrical ports shorted. This parameter is only visible when you select Specify from a datasheet for the ${\bf Parameterization}$ parameter. The default value is Inf kHz.

Mechanical quality factor

Factor that affects the damping across the R and C mechanical ports. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is Inf.

Damping

Translational damping term. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0 N/(m/s).

Effective mass

Mass that approximates the distributed dynamics of the device and causes the stack to resonate at the correct frequency when attached to the mechanical R port. This mass is usually about one third of the actual stack mass. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0 g.

Initial Conditions Tab

| damping effects may also be optional | d force characteristics of a piezoelectric stacked actuator. Effective mass and mechanical y included. |
|---|---|
| Static Force Dynamic Forces | Initial Conditions |
| Initial stack deflection: Initial voltage: | 0 mm ¥ 0 V ¥ |
| | OK Cancel Help Apply |

Initial stack deflection

Stack deflection at time zero. If you have an external Ideal Translational Motion Sensor block attached across the Piezo Stack block, you must use the same initial deflection parameter for both blocks. The default value is 0 mm.

Initial voltage

Stack voltage at time zero. The default value is 0 V.

Ports The block has the following ports:

+

Positive electrical port.

Negative electrical port.

- Mechanical translational conserving port.
- R

-

С

Mechanical translational conserving port.

PNP Bipolar Transistor

| Purpose | Model PNP big | oolar transistor | using enhance | d Ebers-Moll equations |
|---------|---------------|------------------|---------------|------------------------|
| | | | | |

Library Semiconductor Devices

DescriptionThe PNP Bipolar Transistor block uses a variant of the Ebers-Moll equations to represent an PNP bipolar transistor. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. The PNP Bipolar Transistor block provides the following enhancements to that model:

- Early voltage effect
- Optional base, collector, and emitter resistances.
- Optional fixed base-emitter and base-collector capacitances.

The collector and base currents are [1]:

$$I_{C} = -IS\left[\left(e^{-qV_{BE}/(kT_{m1})} - e^{-qV_{BC}/(kT_{m1})}\right)\left(1 + \frac{V_{BC}}{V_{A}}\right) - \frac{1}{\beta_{R}}\left(e^{-qV_{BC}/(kT_{m1})} - 1\right)\right]$$
$$I_{B} = -IS\left[\frac{1}{\beta_{F}}\left(e^{-qV_{BE}/(kT_{m1})} - 1\right) + \frac{1}{\beta_{R}}\left(e^{-qV_{BC}/(kT_{m1})} - 1\right)\right]$$

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- *IS* is the saturation current.
- V_{BE} is the base-emitter voltage and V_{BC} is the base-collector voltage.
- β_F is the ideal maximum current gain BF
- β_R is the ideal maximum current gain BR
- V_A is the forward Early voltage VAF
- q is the elementary charge on an electron (1.602176e-19 Coulombs).

- k is the Boltzmann constant (1.3806503e-23 J/K).
- T_{m1} is the transistor temperature, as defined by the **Measurement** temperature parameter value.

You can specify the transistor behavior using datasheet parameters that the block uses to calculate the parameters for these equations, or you can specify the equation parameters directly.

If $-qV_{\rm BC} / (kT_{\rm m1}) > 40$ or $-qV_{\rm BE} / (kT_{\rm m1}) > 40$, the corresponding exponential terms in the equations are replaced with $(-qV_{\rm BC} / (kT_{\rm m1}) - 39)e^{40}$ and $(-qV_{\rm BE} / (kT_{\rm m1}) - 39)e^{40}$, respectively. This helps prevent numerical issues associated with the steep gradient of the exponential function $e^{\rm x}$ at large values of x. Similarly, if $-qV_{\rm BC} / (kT_{\rm m1}) < -39$ or $-qV_{\rm BE} / (kT_{\rm m1}) < -39$ then the corresponding exponential terms in the equations are replaced with $(-qV_{\rm BC} / (kT_{\rm m1}) < -39$ or $-qV_{\rm BE} / (kT_{\rm m1}) < -39$ then the corresponding exponential terms in the equations are replaced with $(-qV_{\rm BC} / (kT_{\rm m1}) + 40)e^{-39}$ and $(-qV_{\rm BE} / (kT_{\rm m1}) + 40)e^{-39}$.

Optionally, you can specify parasitic fixed capacitances across the base-emitter and base-collector junctions. You also have the option to specify base, collector, and emitter connection resistances.

Modeling Temperature Dependence

The default behavior is that dependence on temperature is not modeled, and the device is simulated at the temperature for which you provide block parameters. You can optionally include modeling the dependence of the transistor static behavior on temperature during simulation. Temperature dependence of the junction capacitances is not modeled, this being a much smaller effect.

When including temperature dependence, the transistor defining equations remain the same. The measurement temperature value, $T_{\rm m1}$, is replaced with the simulation temperature, $T_{\rm s}$. The saturation current, *IS*, and the forward and reverse gains (β_F and β_R) become a function of temperature according to the following equations:

$$IS_{Ts} = IS_{Tm1} \cdot (T_s / T_{m1})^{XTI} \cdot \exp\left(-\frac{EG}{kT_s}(1 - T_s / T_{m1})\right)$$

$$\beta_{Fs} = \beta_{Fm1} \left(\frac{T_s}{T_{m1}} \right)^{XTB}$$

$$\beta_{Rs} = \beta_{Rm1} \left(\frac{T_s}{T_{m1}} \right)^{XTB}$$

where:

- T_{m1} is the temperature at which the transistor parameters are specified, as defined by the **Measurement temperature** parameter value.
- T_{s} is the simulation temperature.
- IS_{Tm1} is the saturation current at the measurement temperature.
- IS_{Ts} is the saturation current at the simulation temperature. This is the saturation current value used in the bipolar transistor equations when temperature dependence is modeled.
- $\beta_{\rm Fm1}$ and $\beta_{\rm Rm1}$ are the forward and reverse gains at the measurement temperature.
- $\beta_{\rm Fs}$ and $\beta_{\rm Rs}$ are the forward and reverse gains at the simulation temperature. These are the values used in the bipolar transistor equations when temperature dependence is modeled.
- *EG* is the energy gap for the semiconductor type measured in Joules. The value for silicon is usually taken to be 1.11 eV, where 1 eV is 1.602e-19 Joules.
- *XTI* is the saturation current temperature exponent.
- *XTB* is the forward and reverse gain temperature coefficient.
- k is the Boltzmann constant (1.3806503e-23 J/K).

Appropriate values for XTI and EG depend on the type of transistor and the semiconductor material used. In practice, the values of XTI, EG, and XTB need tuning to model the exact behavior of a particular transistor. Some manufacturers quote these tuned values in a SPICE Netlist, and you can read off the appropriate values. Otherwise you can determine values for *XTI*, *EG*, and *XTB* by using a datasheet-defined data at a higher temperature $T_{\rm m2}$. The block provides a datasheet parameterization option for this.

You can also tune the values of *XTI*, *EG*, and *XTB* yourself, to match lab data for your particular device. You can use Simulink Design Optimization software to help tune the values.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The PNP Bipolar Transistor model has the following limitations:

Basic Assumptions and Limitations

- The block does not account for temperature-dependent effects on the junction capacitances.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation issues, but the simulation may run faster with these values set to zero.

PNP Bipolar Transistor

Dialog Main Tab Box and Parameters

| - C | lar Transistor k represents a PNP transist | or modeled | using a variant of the Ebers-Moll equ | ations. The Ebers-Moll |
|---------------------------------|--|---|---|--|
| quations Ids the nitter a | are based on two exponent Early voltage effect, and gind nd base-collector capacitar | ntial diodes ves the opti nces. For ful | olus two current-controlled current so in to include base, emitter and emitte details of the equations, consult the re derived from standard datasheet p | ources. In addition, this bloc er resistances plus fixed bas documentation. The equati |
| aramete | ers | | | |
| Main | Ohmic Resistance Ca | pacitance | Temperature Dependence | |
| Parame | eterization: | Specify fr | m a datasheet | • |
| Forwar h_fe: | d current transfer ratio, | 100 | | |
| Output | admittance, h_oe: | 5e-5 | | 1/Ohm 👻 |
| | or current at which h- eters are defined: | -1 | | mA 👻 |
| | or-emitter voltage at n-parameters are defined: | -5 | | V |
| Voltage | e Vbe: | -0.55 | | V - |
| Curren | t Ib for voltage Vbe: | -0.5 | | mA 👻 |
| Revers BR: | e current transfer ratio, | 1 | | |
| Measur | rement temperature: | 25 | | C - |
| | | | | |

Parameterization

Select one of the following methods for block parameterization:

- Specify from a datasheet Provide parameters that the block converts to equations that describe the transistor. The block calculates the forward Early voltage VAF as Ic/h_oe, where Ic is the Collector current at which h-parameters are defined parameter value, and h_oe is the Output admittance h_oe parameter value [2]. The block sets BF to the small-signal Forward current transfer ratio h_fe value. The block calculates the saturation current IS from the specified Voltage Vbe value and the corresponding Current Ib for voltage Vbe value when Ic is zero. This is the default method.
- Specify using equation parameters directly Provide equation parameters *IS*, *BF*, and *VAF*.

Forward current transfer ratio h_fe

Small-signal current gain. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 100.

Output admittance h_oe

Derivative of the collector current with respect to the collector-emitter voltage for a fixed base current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is $5e-5 1/\Omega$.

Collector current at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -1 mA.

Collector-emitter voltage at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector-emitter voltage. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -5 V.

Voltage Vbe

Base-emitter voltage when the base current is Ib. The [Vbe Ib] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -0.55 V.

Current Ib for voltage Vbe

Base current when the base-emitter voltage is *Vbe*. The [*Vbe Ib*] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -0.5 mA.

Forward current transfer ratio BF

Ideal maximum forward current gain. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 100.

Saturation current IS

Transistor saturation current. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 1e-14 A.

Forward Early voltage VAF

In the standard Ebers-Moll equations, the gradient of the *Ic* versus *Vce* curve is zero in the normal active region. The additional forward Early voltage term increases this gradient. The intercept on the *Vce*-axis is equal to -VAF when the linear region is extrapolated. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 200 V.

Reverse current transfer ratio BR

Ideal maximum reverse current gain. This value is often not quoted in manufacturer datasheets because it is not significant when the transistor is biased to operate in the normal active region. When the value is not known and the transistor is not to be operated on the inverse region, use the default value of 1.

Measurement temperature

Temperature $\hat{T}_{\rm m1}$ at which Vbe and Ib, or IS, are measured. The default value is 25 C.

Ohmic Resistance Tab

| 🙀 Block Parameters: PNP Bipolar Transistor | | | | | | |
|--|-----|----------|------------------------|--------|------|------|
| PNP Bipolar Transistor | | | | | | |
| This block represents a PNP transistor modeled using a variant of the Ebers-Moll equations. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. In addition, this block adds the Early voltage effect, and gives the option to include base, emitter and emitter resistances plus fixed base-emitter and base-collector capacitances. For full details of the equations, consult the documentation. The equation parameters can either be specified directly, or are derived from standard datasheet parameters. | | | | | | |
| Parameters | | | | | | |
| Main Ohmic Resistance | Сар | acitance | Temperature Dependence | | | |
| Collector resistance, RC: | | 0.01 | | | Ohm | • |
| Emitter resistance, RE: 1e-4 | | | | | Ohm | • |
| Zero bias base resistance, RB: 1 | | | Ohm | - | | |
| | | | | | | |
| | | | ОК | Cancel | Help | pply |

Collector resistance RC

Resistance at the collector. The default value is 0.01Ω .

Emitter resistance RE

Resistance at the emitter. The default value is $1e-4 \Omega$.

Zero bias base resistance RB

Resistance at the base at zero bias. The default value is 1 $\boldsymbol{\Omega}.$

Capacitance Tab

| mitter and base-collector capa | citances. For full | n to include base, emitter and emitt details of the equations, consult the re derived from standard datasheet | e documentation. The equation |
|---|--------------------|---|-------------------------------|
| Main Ohmic Resistance | Capacitance | Temperature Dependence | |
| Base-collector junction capacitance: | 5 | | pF 🗸 |
| Base-emitter junction capacitance: | 5 | | pF 🗸 |
| Total forward transit time: | 0 | | us 🔻 |
| Total reverse transit time: | 0 | | us 🔻 |
| | | | |
| | | | |

Base-collector junction capacitance

Parasitic capacitance across the base-collector junction. The default value is 5 $\rm pF.$

Base-emitter junction capacitance

Parasitic capacitance across the base-emitter junction. The default value is 5 pF.

Total forward transit time

Represents the mean time for the minority carriers to cross the base region from the emitter to the collector, and is often denoted by the parameter TF [1]. The default value is $0 \ \mu s$.

Total reverse transit time

Represents the mean time for the minority carriers to cross the base region from the collector to the emitter, and is often denoted by the parameter TR [1]. The default value is $0\mu s$.

Temperature Dependence Tab

| 🙀 Block Parameters: PNP Bipolar Transistor | × |
|--|-----|
| PNP Bipolar Transistor | |
| This block represents a PNP transistor modeled using a variant of the Ebers-Moll equations. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. In addition, this block adds the Early voltage effect, and gives the option to include base, emitter and emitter resistances plus fixed base emitter and base-collector capacitances. For full details of the equations, consult the documentation. The equation parameters can either be specified directly, or are derived from standard datasheet parameters. | e- |
| Parameters | |
| Main Ohmic Resistance Capacitance Temperature Dependence | |
| Parameterization: None - Simulate at parameter measurement temperature | וור |
| | |
| OK Cancel Help Apply | / |

Parameterization

Select one of the following methods for temperature dependence parameterization:

- None Simulate at parameter measurement temperature Temperature dependence is not modeled, or the model is simulated at the measurement temperature $T_{\rm m1}$ (as specified by the **Measurement temperature** parameter on the **Main** tab). This is the default method.
- Model temperature dependence Provide a value for simulation temperature, to model temperature-dependent effects. You also have to provide a set of additional parameters depending on the block parameterization method. If you parameterize the block from a datasheet, you have to provide values for a second [*Vbe Ib*] data pair and *h_fe* at second measurement temperature. If you parameterize by directly specifying equation parameters, you have to provide the values for *XTI*, *EG*, and *XTB*.

Forward current transfer ratio, h_{fe} , at second measurement temperature

Small-signal current gain at second measurement temperature. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. It must be quoted at the same collector-emitter voltage and collector current as for the **Forward current transfer ratio** h_fe parameter on the **Main** tab. The default value is 125.

Voltage Vbe at second measurement temperature

Base-emitter voltage when the base current is Ib and the temperature is set to the second measurement temperature. The [Vbe Ib] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is -0.45 V.

Current Ib for voltage Vbe at second measurement temperature

Base current when the base-emitter voltage is *Vbe* and the temperature is set to the second measurement temperature. The [*Vbe Ib*] data pair must be quoted for when the transistor is in the normal active region, that is, not in the saturated region. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is -0.5 mA.

Second measurement temperature

Second temperature T_{m2} at which h_fe,Vbe , and Ib are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter on the **Main** tab. The default value is 125 C.

Current gain temperature coefficient, XTB

Current gain temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 0.

Energy gap, EG

Energy gap value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 1.11 eV.

Saturation current temperature exponent, XTI

Saturation current temperature coefficient value. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter on the **Main** tab. The default value is 3.

Device simulation temperature

Temperature $T_{\rm s}$ at which the device is simulated. The default value is 25 C.

Ports The block has the following ports:

| | B Electrical conserving port associated with the transistor base terminal. |
|------------|--|
| | C Electrical conserving port associated with the transistor collector terminal. |
| | E Electrical conserving port associated with the transistor emitter terminal. |
| Examples | See the PNP Bipolar Transistor Characteristics example. |
| References | [1] G. Massobrio and P. Antognetti. Semiconductor Device Modeling with SPICE. 2nd Edition, McGraw-Hill, 1993. |
| | [2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984. |
| See Also | Diode, NPN Bipolar Transistor |

Positive Supply Rail

| Purpose | Model ideal positive supply rail |
|------------------------|---|
| Library | Sources |
| Description ↓+ Ţ | The Positive Supply Rail block represents an ideal positive supply rail. Use this block instead of the Simscape DC Voltage Source block to define the output voltage relative to the Simscape Electrical Reference block that must appear in each model. |

Note Do not attach more than one Positive Supply Rail block to any connected line.

Dialog Box and Parameters

| 🙀 Block Parameters: Positive Suppl | y Rail | | × | | | |
|---|--------|-----------|------------|--|--|--|
| Positive Supply Rail | | | | | | |
| This block represents an ideal positive supply rail. It can be used in place of the Foundation Library DC Voltage Source. The output voltage is defined relative to the Electrical Reference block. Use the Constant voltage parameter to specify the output voltage value. | | | | | | |
| Do not attach more than one Positive Supply Rail block to any connected line. | | | | | | |
| Parameters | | | | | | |
| Constant voltage: | 1 | | V • | | | |
| | | OK Cancel | Help Apply | | | |

Constant voltage

The voltage at the output port relative to the Electrical Reference block ground port. The default value is 1 V. $\,$

| Ports | The block has the following ports: | |
|----------|--|--|
| | + Positive electrical voltage. | |
| See Also | Simscape DC Voltage Source, Negative Supply Rail | |

Potentiometer

Purpose Model rotary or linear-travel potentiometer controlled by physical signal

Library Passive Devices

Description

▫┶∽╱╱╲╸╄╺╹ ▫₩─┘ × ◁ The Potentiometer block represents a rotary or linear-travel potentiometer, with the wiper position controlled by the input physical signal.

If the potentiometer resistance changes linearly based on wiper position, then the resistance between the wiper position and port L is:

$$R_{WL} = \frac{R_0}{x_{\max} - x_{\min}} (x - x_{\min})$$

where

- R_{WL} is the resistance between the wiper position and port L.
- R_o is the total resistance between ports L and R.
- *x* is the wiper position.
- x_{min} is the value of the wiper position when the wiper is at port L.
- x_{max} is the value of the wiper position when the wiper is at port R.

If you specify LOG for the potentiometer resistance **Taper** parameter, then the resistance between the wiper position and port L is:

 $R_{WL} = egin{cases} A\left(e^{\lambda(x-x_{\min})}-1
ight) & ext{if resistance gradient is higher at R} \ R_{WL} = egin{cases} A\left(e^{\lambda(x_{\max}-x)}-1
ight) & ext{if resistance gradient is higher at L} \end{cases}$

where A and λ are chosen such that R_{WL} at x_{max} is R_0 , and R_{WL} at $x = (x_{max} + x_{min}) / 2$ is equal to R_{av} , the resistance when the wiper is centered.

Note Potentiometers widely described as LOG or logarithmic taper are, in fact, exponential taper. That is, the gradient of the resistance between wiper and left-hand port increases as the resistance increases. The Potentiometer block implements this behavior.

For both linear and logarithmic tapers, the resistance between the wiper position and port R is:

$$R_{WR} = R_0 - R_{WL}$$

where

Dialog Box and Parameters

- $R_{W\!R}$ is the resistance between the wiper position and port R.
- R_0 is the total resistance between ports L and R.
- R_{WL} is the resistance between the wiper position and port L.

| This block represents a potentio between the L and R electrical p greater than the residual resista | orts is equal to the total | resistance parameter val | | |
|---|----------------------------|--------------------------|-----|---|
| Parameters | | | | |
| Total resistance: | 1000 | | Ohm | |
| Residual resistance: | 1 | | Ohm | _ |
| PS input for wiper at L: | 0 | | | |
| PS input for wiper at R: | 1 | | | |
| Taper: | LIN | | | |

Total resistance

The resistance between port L and port R when port W is open-circuit. The default value is 1000Ω .

Residual resistance

The lower limit placed on the resistance between the wiper and the two end ports. It must be greater than zero. A typical value is 5e-3 times the total resistance. The default value is 1Ω .

Resistance when centered

This parameter is available only if you select LOG for the **Taper** parameter. If you select Higher at R for the **Resistance** gradient parameter, then **Resistance when centered** is the resistance between port L and port W when the wiper is centered. Otherwise, if you select Higher at R for the **Resistance** gradient parameter, then **Resistance when centered** is the resistance between port R and port W when the wiper is centered. Because the resistance taper is exponential in shape, the value of the **Resistance when centered** parameter must be less than half of the **Total resistance** parameter value. The default value is 200Ω .

PS input for wiper at L

The value of the input physical signal at port x that corresponds to the wiper being located at port L. The default value is **0**.

PS input for wiper at R

The value of the input physical signal at port x that corresponds to the wiper being located at port R. The default value is 1.

Taper

Specifies the potentiometer resistance taper behavior: LIN (linear) or LOG (logarithmic). The default value is LIN.

Resistance gradient

Specifies whether the potentiometer resistance varies more rapidly at the left or the right end: Higher at L or Higher at R. This parameter is available only if you select LOG for the **Taper** parameter. The default value is Higher at R.

Ports The block has the following ports:

| See Also | Simscape Variable Resistor |
|----------|---|
| | x Physical signal input port controlling the wiper position. |
| | Electrical port representing the wiper pin. |
| | W |
| | R Electrical port representing the right pin. |
| | L Electrical port representing the left pin. |

Power Sensor

| Purpose | Measure instantaneous or cycle-average power |
|---------|--|
|---------|--|

Sensors

Library

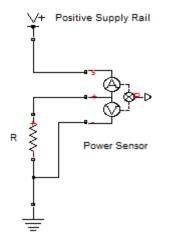
Description



The Power Sensor block calculates the power taken by the load connected across the + and - terminals under the assumption that only the load is connected to the + terminal. Refer to the block icon for the arrangement of internal current and voltage sensors.

The sensor can return either instantaneous power, or power averaged over a fixed time period. Use the latter option for periodic current and voltage waveforms such as those associated with PWM control.

The following figure shows how you connect the block to measure power dissipated in a resistor.



For an alternative workflow using data logging to view component powers, see the Synchronous Buck Converter example.

Power Sensor

Dialog Box and Parameters

Ports

| 😺 Block Parameters: Power Se | nsor 🔀 |
|------------------------------|--|
| Power Sensor | |
| | wer taken by the load connected across the + and - terminals under the ad is connected to the + terminal. Refer to the block icon for the rrent and voltage sensors. |
| | er instantaneous power, or power averaged over a fixed time period. The odic current and voltage waveforms such as those associated with PWM |
| Parameters | |
| Measurement type: | Instantaneous power |
| | OK Cancel Help Apply |

Measurement type

Select whether you want to measure Instantaneous power or Average power over a specified period. The default value is Instantaneous power.

Averaging period

The fixed period of time for measuring the average power. This parameter is only visible when you select Average power over a specified period for the **Measurement type** parameter. The default value is 1e-4 s.

The block has the following ports:

S

Electrical conserving port connected to the positive supply rail.

+

Electrical conserving port connected to the positive terminal of the load.

Power Sensor

Electrical conserving port connected to the negative terminal of the load.

Ρ

_

Physical signal port that outputs the measured power.

Purpose Model generic pressure transducer that turns pressure measurement into voltage

Library

Sensors

Description



The Pressure Transducer block models a generic pressure transducer that turns a pressure measurement into a voltage. The output voltage is linearly proportional to the pressure, and the block outputs zero volts if the pressure is less than zero. An input pressure equal to the **Pressure range** parameter value results in an output voltage equal to the **Full-scale deflection** parameter value. For higher pressures, the output voltage remains at this **Full-scale deflection** value.

You have three choices of operation mode, which let you select between vacuum, atmospheric pressure, or sealed-gauge reference pressure as the reference point for the pressure measurement.

Optionally, if you set the **Dynamics** parameter to Model transducer bandwidth, then the dynamics of the sensor are approximated by a first-order lag. The lag is determined by the **Bandwidth** parameter. If you select this option, you must also specify an initial condition for the lag by using the **Initial pressure** parameter.

If running your simulation with a fixed-step solver, or generating code for hardware-in-the-loop testing, MathWorks recommends that you set the **Dynamics** parameter to No dynamics Suitable for HIL, because this avoids the need for a small simulation time step if the sensor bandwidth is high.

Pressure Transducer

Dialog Box and Parameters

| 📜 Block Parameters: Pressure Transo | lucer | × | |
|--|---|--------------------------|--|
| Pressure Transducer | | | |
| This block represents an absolute, gauge or sealed-gauge pressure transducer. The transducer maps the pressure at pneumatic port A to a voltage across the electrical ports p and n. | | | |
| It is recommended that transduc a very small time step. | er dynamics be omitted for fixed-step simulation or H | IL to avoid the need for | |
| Parameters | | | |
| Pressure range: | 1e+6 | Pa 💌 | |
| Operation mode: | Absolute | • | |
| Full-scale deflection: | 5 | V - | |
| Output resistance: | 200 | Ohm 👻 | |
| Dynamics: | No dynamics - Suitable for HIL | • | |
| | OK Cancel | Help Apply | |

Pressure range

The maximum pressure that the sensor can measure. The default value is 1e6 Pa.

Operation mode

Select one of the following options to define the reference point for the pressure measurement:

- Absolute The pressure measurement is with respect to zero absolute pressure, that is, vacuum. This is the default option.
- Gauge The pressure measurement is with respect to atmospheric pressure. Atmospheric pressure is defined by the Gas Properties block in the Simscape Foundation library.
- Sealed-Gauge The pressure measurement is referenced to an internal sealed chamber. If you select this option, use the **Reference pressure** parameter to specify the reference point for pressure measurement.

Reference pressure

The reference pressure in the internal sealed chamber. This parameter is only visible when you select Sealed-Gauge for the **Operation mode** parameter. The default value is 1.01325e5 Pa.

Full-scape deflection

The output voltage when the measured pressure is equal to, or greater than, the **Pressure range** parameter value. The default value is 5 V.

Output resistance

The output resistance of the transducer. The default value is 200 $\Omega_{\rm \cdot}$

Dynamics

Select one of the following options for modeling sensor dynamics:

- No dynamics Suitable for HIL Do not model sensor dynamics. Use this option when running your simulation fixed step or generating code for hardware-in-the-loop testing, because this avoids the need for a small simulation time step if the sensor bandwidth is high. This is the default option.
- Model transducer bandwidth Model sensor dynamics with a first-order lag approximation, based on the **Bandwidth** and the **Initial pressure** parameter values.

| | Bandwidth Determines the value of the sensor lag. This parameter is only visible when you select Model transducer bandwidth for the Dynamics parameter. The default value is 5 kHz. |
|-------|--|
| | Initial pressure Determines the initial condition for the lag. This parameter is only visible when you select Model transducer bandwidth for the Dynamics parameter. The default value is 0 Pa. |
| Ports | The block has the following ports: |
| | A Pneumatic port. + |
| | Positive electrical port. |
| | - Negative electrical port. |

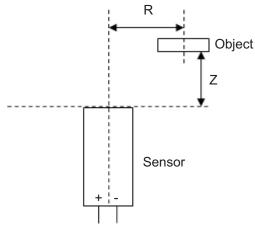
- Purpose
 Model simple distance sensor
- Library

Sensors

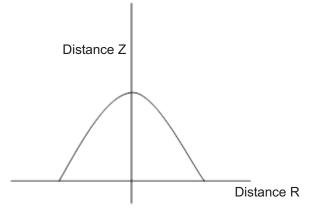
Description



The Proximity Sensor block represents a simple proximity sensor. The sensing distance Z is defined as the distance normal to the sensor surface at which the sensor detects an object for a given radial offset R, as shown in the following figure.



A typical sensing distance curve is shown in the following figure.



The output is modeled by an electrical switch which can either be Normally Open (N.O.) or Normally Closed (N.C.) when no object is detected.

Dialog Box and Parameters

| Block Parameters: Proximity Sensor Proximity Sensor This block implements a simple representation of a proximity sensor. The sensing | | | | |
|--|--|-------|--|--|
| distance Z is defined as the distance normal to the sensor surface at which an object is detected for a given radial offset R. For an explanatory diagram see the documentation. The output is modeled by an electrical switch which can either be Normally Open (N.O.) or Normally Closed (N.C.) when no object is detected. | | | | |
| Parameters | | | | |
| Vector of radial offset distances R: | [-25 -20 -15 -10 -5 0 5 10 15 20 25] | mm | | |
| Corresponding sensing distances Z: | [00589.5109.58500] | mm | | |
| Output when not detected: | Normally Open (N.O.) | • | | |
| Closed resistance R_closed: | 0.01 | Ohm 💌 | | |
| Open conductance G_open | 1e-08 | 1/0hm | | |
| | | | | |
| | | | | |
| _ | | | | |
| | OK Cancel Help | Apply | | |

Vector of radial offset distances R

Vector of distances from the sensor to the object resolved into a plane tangential to the sensor head. The default value is [-25 -20 -15 -10 -5 0 5 10 15 20 25] mm.

Corresponding sensing distances Z

Vector of distances from the sensor to the object resolved with respect to a normal vector at the sensor head. The default value is $[0\ 0\ 5\ 8\ 9.5\ 10\ 9.5\ 8\ 5\ 0\ 0\]$ mm.

Output when not detected

Indicates whether the output is Normally Open (N.O.), meaning the output becomes closed only when the object is detected, or Normally Closed (N.C.), meaning the output becomes open

| | only when the object is detected. The default value is Normally Open (N.O.). |
|-------|--|
| | Closed resistance R_closed The resistance between the + and - ports when the output contacts are closed. The default value is 0.01 Ω . |
| | Open conductance G_open The conductance between the + and - ports when the output contacts are open. The default value is $1e-08 \ 1/\Omega$. |
| Ports | The block has the following ports: |
| | R Radial distance to the sensor. |
| | Z Perpendicular distance to the sensor. |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |

Purpose Model generic linear sensor

Library

Sensors

Description



The PS Sensor block represents a generic linear sensor. The block converts the physical signal input U into an electrical output Y across the + and - ports. The **Output type** parameter value determines which of the following electrical outputs the block produces:

- Output voltage
- Output current
- Output resistance

Y is related to *U* as $Y = \max(\min(A * U + B, Y_{\max}), Y_{\min})$ where Y_{\min} and Y_{\max} are minimum and maximum limits on the output, respectively.

PS Sensor

Dialog Box and Parameters

| 😼 Block Parameters: PS S | ensor 🛛 🗶 | | |
|--|----------------------|--|--|
| PS Sensor | | | |
| This block implements a generic linear sensor. The physical signal input U is converted into an electrical output voltage Y, output current Y or resistance Y across the + and - ports, depending on the selected Output type. Y is related to U with the following equation: | | | |
| Y = max(min(A*U + B,Ymax),Ymin) | | | |
| where Ymin and Ymax are limits on the output voltage in volts, current in amps or resistance in ohms, depending on the selected Output type. If the Output type is set to Variable resistance, then the minimum resistance Ymin must be greater than zero. | | | |
| Parameters | | | |
| Output type: | Variable voltage | | |
| Sensor gain, A: | 1 | | |
| Sensor offset, B: | 0 | | |
| Maximum output, Ymax: | 5 | | |
| Minimum output, Ymin: | 0.01 | | |
| | | | |
| | | | |
| | | | |
| | OK Cancel Help Apply | | |

Output type

Indicates whether the sensor output is a Variable voltage of Y V, a Variable current of Y A, or Variable resistor with a value of $Y \Omega$. The default value is Variable voltage.

Sensor gain, A

The sensitivity of the output Y with respect to the input U, dY/dU. The default value is 1.

Sensor offset, B

The output when the input U is zero. The output does not exceed the limits Y_{max} and Y_{min} . The default value is **0**.

Maximum output, Ymax

The upper limit on the sensor output. The following table shows the units of this parameter, which depend on the selected value of the **Output type** parameter.

| Output type | Units |
|-------------------|-------|
| Variable voltage | V |
| Variable current | А |
| Variable resistor | Ω |

The default value is 5.

Minimum output, Ymin

The lower limit on the sensor output. The following table shows the units of this parameter, which depend on the selected value of the **Output type** parameter.

| Output type | Units |
|-------------------|-------|
| Variable voltage | V |
| Variable current | А |
| Variable resistor | Ω |

The default value is 0.01.

If you select Variable resistance for the Output type parameter, the minimum resistance $Y_{\rm min}$ must be greater than zero.

Ports The block has the following ports:

U

Physical input signal.

+

Positive electrical voltage.

Negative electrical voltage.

_

See Also Simscape Controlled Voltage Source, Simscape Controlled Current Source, and Simscape Variable Resistor

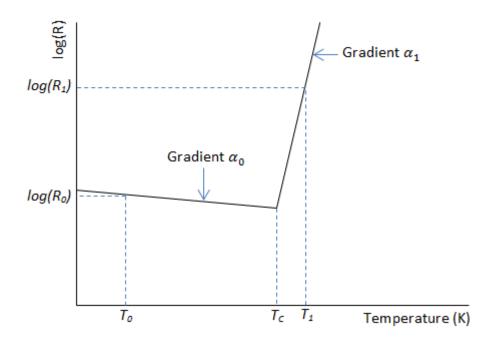
Purpose Model switching type positive temperature coefficient (PTC) thermistor

Library Sensors

Description



The PTC Thermistor block represents a switching type PTC thermistor. This type of thermistor has a decreasing resistance with temperature increasing up to the Curie temperature. Above the Curie temperature the resistance increases very rapidly with increasing temperature, as shown in the following plot. The region to the right of the Curie temperature is called the Positive Temperature Coefficient (PTC) regime. To represent a non-switching linear PTC thermistor, use the Thermal Resistor block.



For a switching type PTC thermistor, the resistance ${\cal R}$ at temperature ${\cal T}$ is given by

$$R = \begin{cases} R_0 e^{\alpha_0 (T-T_0)} & \text{for } T < T_c \\ R_1 e^{\alpha_1 (T-T_1)} & \text{for } T \ge T_c \end{cases}$$
$$T_c = \frac{\log(R_1) - \log(R_0) + \alpha_0 T_0 - \alpha_1 T_1}{\alpha_0 - \alpha_1}$$

where:

- $T_{\rm c}$ is the Curie temperature.
- R_0 is the resistance at nominal temperature T_0 .
- R_1 is the resistance at reference temperature T_1 .
- T_0 is the nominal temperature at which the resistance is quoted, usually room temperature. T_0 is less than the Curie temperature T_c .
- T_1 is the reference temperature, equal or greater than the Curie temperature T_c , which means that at this temperature the PTC regime is in force.
- a_0 is the temperature coefficient at nominal temperature T_0 .
- a_1 is the temperature coefficient at reference temperature T_1 .

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt}$$

where:

- *Q* is the net heat flow into port A.
- $K_{\rm d}$ is the **Dissipation factor** parameter value.
- *t_c* is the **Thermal time constant** parameter value.
- dT/dt is the rate of change of the temperature.

Dialog Electrical Tab Box and Parameters

| 🙀 Block Parameters: PTC Thermisto |
|-----------------------------------|
|-----------------------------------|

PTC Thermistor

This block represents a switching type PTC thermistor. The resistance R at temperature T is defined by $log(R_0) + alpha0^*(T-T_0)$ below the Curie temperature Tc, and by $log(R) = log(R_1) + alpha1^*(T-T_1)$ above Tc where alpha0 < 0 and alpha1 > 0 are resistance temperature coefficients, [T0, R0] is a data point for T < Tc [T1, R1] is a data point for T > Tc.

The thermistor temperature is governed by the equation $m^*c^*dT/dt = Q$ where Q is the net heat flow into p m is the mass and c is the lumped specific heat capacity. The thermal mass m^*c is calculated from the Ther time constant t_c and the Dissipation factor K_d using the equation $m^*c = K_d^*t_c$.

| Nominal resistance R0 at T0: | 1000 | Ohm |
|--|--------|-----|
| Temperature coefficient alpha0 at T0: | -0.01 | 1/K |
| Iominal temperature T0: | 298.15 | К |
| Reference resistance R1 at T1: | 1e+4 | Ohm |
| emperature coefficient alpha1 at 1: | 1 | 1/K |
| Reference temperature T1: | 398.15 | К |

Nominal resistance R0 at T0

The nominal resistance of the thermistor at the nominal temperature. Many datasheets quote the nominal resistance at 25°C and list it as R25. The default value is 1000 Ω .

Temperature coefficient alpha0 at T0

The temperature coefficient at the nominal temperature. The value must be less than zero. The default value is -0.01 l/K.

Nominal temperature T0

The temperature at which the nominal resistance is measured. The default value is **298.15** K.

Reference resistance R1 at T1

The reference resistance of the thermistor at the reference temperature. The default value is 10000 Ω .

Temperature coefficient alpha1 at T1

The temperature coefficient at the reference temperature. The value must be greater than zero. The default value is 1 1/K.

Reference temperature T1

The temperature at which the reference resistance is measured. This temperature must be in the PTC regime. The default value is **398.15** K.

Thermal Tab

| Block Parameters: PTC Thermistor | | |
|-------------------------------------|--|-----------------------|
| PTC Thermistor | | |
| log(R0) + alpha0*(T-T0) below the | pe PTC thermistor. The resistance R at temperatur Curie temperature Tc, and by log(R) = log(R1) + al re resistance temperature coefficients, [T0, R0] is | lpha1*(T-T1) above To |
| m is the mass and c is the lumped s | rned by the equation m*c*dT/dt = Q where Q is th specific heat capacity. The thermal mass m*c is cal n factor K_d using the equation m*c = K_d*t_c. | |
| Parameters | | |
| Electrical Thermal | | |
| Thermal time constant: | 5 | S |
| Dissipation factor: | 7.5e-4 | W/K |
| Initial temperature: | 298.15 | К |
| | OK Cancel | Help |
| | | |

| | Thermal time constant The time it takes the sensor temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 5 s. |
|----------|---|
| | Dissipation factor The thermal power required to raise the thermistor temperature by one K. The default value is 7.5e-4 W/K. |
| | Initial temperature The temperature of the thermistor at the start of the simulation. The default value is 298.15 K. |
| Ports | The block has the following ports: |
| | A Thermal port. |
| | + Positive electrical port. |
| | - Negative electrical port. |
| See Also | Thermal Resistor |
| | Thermistor |

Purpose Model periodic square pulse current source

Library SPICE-Compatible Components/Sources

Description

The Pulse Current Source block represents a current source whose output current value is a periodic square pulse as a function of time and is independent of the voltage across the terminals of the source. The following equations describe the current through the source as a function of time:

$$I_{out} (0) = I1$$

$$I_{out} (TD) = I1$$

$$I_{out} (TD + TR) = I2$$

$$I_{out} (TD + TR + PW) = I2$$

$$I_{out} (TD + TR + PW + TF) = I1$$

$$I_{out} (TD + PER) = I1$$

where:

- *I1* is the **Initial value**, **I1** parameter value.
- 12 is the Pulse value, I2 parameter value.
- *TD* is the **Pulse delay time, TD** parameter value.
- *TR* is the **Pulse rise time, TR** parameter value.
- *TF* is the **Pulse fall time, TF** parameter value.
- *PW* is the **Pulse width**, **PW** parameter value.
- *PER* is the **Pulse period**, **PER** parameter value.

The block determines the values at intermediate time points by linear interpolation.

The specified values for PW and PER have the following effect on the block output:

- If both *PW* and *PER* are infinite, the block produces a step response at time *TD*.
- If *PER* is infinite and *PW* is finite, the block produces a single pulse of width *PW* and infinite period.
- If *PW* is infinite and *PER* is finite, the block produces a step response with pulses of width *TR* to a value *I1* every *PER* seconds.
- If *PW* > *PER*, the block produces a step response with pulses of width *TR* to a value *I1* every *PER* seconds.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the + and - ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| 🙀 Block Parameters: F | Pulse Current S | ource | × | |
|--|-----------------|--------|------------|--|
| -Pulse Current Source | | | | |
| The Pulse Current Source block maintains a pulsed current through its terminals, independent of the voltage across its terminals. The following table describes the current through the block as a function of time: | | | | |
| Iout(0) = I1 | Iout(0) = I1 | | | |
| Iout(TD) = I1 | | | | |
| Iout(TD+TR) = I2 | | | | |
| Iout(TD+TR+PW) = I2 | | | | |
| Iout(TD+TR+PW+TF) = | = I1 | | | |
| Iout(TD+PER) = I1 | | | | |
| The block determines the values at intermediate time points by linear interpolation. TD is the delay time. TR is the rise time. TF is the fall time. PW is the pulse width. | | | | |
| The default values for TR, TF, PW and PER differ from SPICE. The default rise and fall times are one nanosecond (1e-9), and the values of TR and TF can be set to zero. | | | | |
| Parameters | | | | |
| Initial value, I1: | 0 | | A | |
| Pulse value, I2: | 0 | | A | |
| Pulse delay time, TD: | 0 | | s 💌 | |
| Pulse rise time, TR: | 1e-09 | | s 💌 | |
| Pulse fall time, TF: | 1e-09 | | s 💌 | |
| Pulse width, PW: | Inf | | s 💌 | |
| Pulse period, PER: | Inf | | 5 💌 | |
| | | | | |
| | | | | |
| | ОК | Cancel | Help Apply | |

Initial value, I1

The value of the output current at time zero. The default value is $0\ \rm A.$

| | Pulse value, I2 The value of the output current when the output is high. The default value is 0 A. |
|----------|--|
| | Pulse delay time, TD The time at which the pulse first starts. The default value is 0 s. |
| | Pulse rise time, TR The time it takes the output current to rise from the Initial value, I1 value to the Pulse value, I2 value. The default value is 1e-09 s. The value must be greater than or equal to 0. |
| | Pulse fall time, TF The time it takes the output current to fall from the Pulse value, I2 value to the Initial value, I1 value. The default value is 1e-09 s. The value must be greater than or equal to 0. |
| | Pulse width, PW The time width of the output pulse. The default value is Inf s. The value must be greater than 0. |
| | Pulse period, PER The period of the output pulse. The default value is Inf s. This value means that the block produces a single pulse with an infinite period. The value must be greater than 0. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | Pulse Voltage Source |

Purpose Model periodic square pulse voltage source

Library SPICE-Compatible Components/Sources

Description

The Pulse Voltage Source block represents a voltage source whose output voltage value is a periodic square pulse as a function of time and is independent of the current through the source. The following equations describe the output voltage as a function of time:

$$V_{out} (0) = V1$$

$$V_{out} (TD) = V1$$

$$V_{out} (TD + TR) = V2$$

$$V_{out} (TD + TR + PW) = V2$$

$$V_{out} (TD + TR + PW + TF) = V1$$

$$V_{out} (TD + PER) = V1$$

where:

- V1 is the Initial value, V1 parameter value.
- V2 is the Pulse value, V2 parameter value.
- *TD* is the **Pulse delay time, TD** parameter value.
- *TR* is the **Pulse rise time, TR** parameter value.
- *TF* is the **Pulse fall time**, **TF** parameter value.
- *PW* is the **Pulse width**, **PW** parameter value.
- *PER* is the **Pulse period**, **PER** parameter value.

The block determines the values at intermediate time points by linear interpolation.

The specified values for PW and PER have the following effect on the block output:

- If both *PW* and *PER* are infinite, the block produces a step response at time *TD*.
- If *PER* is infinite and *PW* is finite, the block produces a single pulse of width *PW* and infinite period.
- If *PW* is infinite and *PER* is finite, the block produces a step response with pulses of width *TR* to a value *V1* every *PER* seconds.
- If *PW* > *PER*, the block produces a step response with pulses of width *TR* to a value *V1* every *PER* seconds.

Dialog Box and **Parameters**

| 🙀 Block Parameters: I | Pulse Voltage Source | X | | |
|---|----------------------|------------|--|--|
| Pulse Voltage Source | | | | |
| The Pulse Voltage Source block maintains a pulsed voltage across its terminals, independent of the current through its terminals. The following table describes the voltage across the block as a function of time: | | | | |
| Vout(0) = V1 | Vout(0) = V1 | | | |
| Vout(TD) = V1 | | | | |
| Vout(TD+TR) = V2 | | | | |
| Vout(TD+TR+PW) = V2 | : | | | |
| Vout(TD+TR+PW+TF) | = V1 | | | |
| Vout(TD+PER) = V1 | | | | |
| The block determines the values at intermediate time points by linear interpolation. TD is the delay time. TR is the rise time. TF is the fall time. PW is the pulse width. | | | | |
| The default values for TR, TF, PW and PER differ from SPICE. The default rise and fall times are one nanosecond (1e-9), and the values of TR and TF can be set to zero. | | | | |
| Parameters | | | | |
| Initial value, V1: | 0 | V | | |
| Pulse value, V2: | 0 | V | | |
| Pulse delay time, TD: | 0 | s 💌 | | |
| Pulse rise time, TR: | 1e-09 | 5 | | |
| Pulse fall time, TF: | 1e-09 | 5 | | |
| Pulse width, PW: | Inf | 5 | | |
| Pulse period, PER: | Inf | s 💌 | | |
| | | | | |
| | | | | |
| | OK Cancel | Help Apply | | |

Initial value, V1

The value of the output voltage at time zero. The default value is 0 V.

| | Pulse value, V2 The value of the output voltage when the output is high. The default value is 0 V. |
|----------|--|
| | Pulse delay time, TD The time at which the pulse first starts. The default value is 0 s. |
| | Pulse rise time, TR The time it takes the output voltage to rise from the Initial Value, I1 value to the Pulse Value, V2 value. The default value is 1e-09 s. The value must be greater than or equal to 0. |
| | Pulse fall time, TF The time it takes the output voltage to fall from the Pulse Value, V2 value to the Initial Value, V1 value. The default value is 1e-09 s. The value must be greater than or equal to 0. |
| | Pulse width, PW The time width of the output pulse. The default value is Inf s. |
| | Pulse period, PER The period of the output pulse. The default value is Inf s. This value means that the block produces a single pulse with an infinite period. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | Pulse Current Source |

Purpose Represent CMOS complementary output stage behaviorally

Library

Integrated Circuits

Description

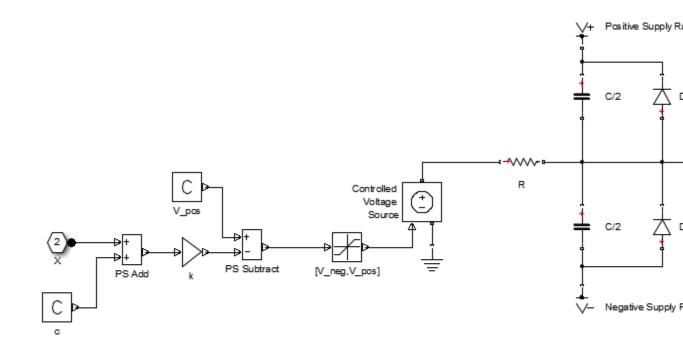


The Push-Pull Output block represents a CMOS complementary output stage behaviorally. To improve simulation speed, the block does not model all the internal individual MOSFET devices that make up the gate. You can use this block to create a representative output current-voltage relationship when defining an integrated circuit model behavior with Physical Signal blocks from the Simscape Foundation library.

You can choose between are two output current-voltage relationships:

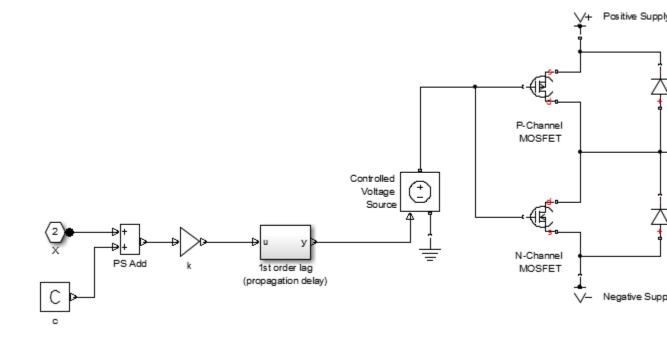
• Linear — The block represents the output as a voltage source plus series resistance and parallel capacitance, as shown in the following figure. The value you specify for the **Output resistance** parameter is assigned to the series resistance, and the capacitance values are determined by matching the RC time constant to the **Propagation delay** parameter value.

Push-Pull Output



The input to the Controlled Voltage Source block is limited to be between the supply rails, and it is also inverted by subtraction from the supply voltage. The inversion makes it behave like a complementary output stage, with a high gate-source voltage resulting in a low output.

• Quadratic — The output stage is modeled by the two MOSFETs that constitute the complementary pair. The MOSFET parameters are derived from the output resistance values and short-circuit currents that you specify as mask parameters. The gate input demand is lagged to approximate the **Propagation delay** parameter value.



Both Linear and Quadratic output models add an offset and scale the physical input X so that the gate voltage is given by:

$$Vg = k \cdot (X + c)$$

where

- k is the input signal scaling.
- *c* is the input signal offset.

The offset and scaling can be used, for example, to match logical values for X (that is, range [0,1]) to [V-, V+] at the output pin. For example,

| | if V+ = 10V and V- = 0, then to match the signal logical values to this voltage range, set $c = -1$ and $k = -10$. For both Linear and Quadratic output models, the protection diodes |
|-----------------------------|---|
| | D1 and D2 act to limit the output voltage range. These diodes are Diode blocks from the Simscape Foundation library, that is, piecewise linear diodes defined by their forward voltage and on resistance. If the voltage across D1 rises above the forward voltage, then the diode starts to conduct, and provided that the on resistance is low, it effectively prevents the output rising above V+ plus the diode forward voltage drop. An equivalent behavior results if the output voltage drops too low. |
| | The output model is very similar to that used for the logic blocks. For a plot of a typical output V-I characteristic when using the Quadratic output model, see Selecting the Output Model for Logic Blocks. |
| Basic Assumptions and | The Push-Pull Output block has the following limitations:The block does not accurately model dynamic response. |
| Limitations | • The Quadratic output model does not model any output capacitance effects. Add output capacitance externally to the block if required. |

Dialog Input Scaling Tab Box and Parameters

| D | Block Parameters | s: Push-Pull Output | | | | | | | | |
|-----|---|---------------------|--------|----------------|--------------------|------|------|--|--|--|
| | Push-Pull Output | | | | | | | | | |
| . 1 | The block implements a CMOS push-pull output stage. The gates of the complementary pair are connected together, and the gate voltage is given by $Vg = k^*(X+c)$ where X is the physical signal input value. Use this b interface integrated circuit behaviors, defined in Simulink(R) or by physical signal blocks, to an electrical network | | | | | | | | | |
| C | Parameters | | | | | | | | | |
| | Input Scaling | Output Character | istics | Supply Voltage | Initial Conditions |] | | | | |
| | Input signal scaling, k: Input signal offset, c: | | 1 | | | | ٧ | | | |
| | | | 0 | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | (| OK Car | ncel | Help | | | |

Input signal scaling, k

The input physical signal X is mapped to the gate voltage by $Vg = k \cdot (X + c)$, where k is the input signal scaling. Use this parameter in conjunction with the **Input signal offset**, c to map

the range of X to the voltage range defined by the power supply. The default value is 1 V. $\,$

Input signal offset, c

The input physical signal X is mapped to the gate voltage by $Vg = k \cdot (X + c)$, where *c* is the input signal offset. Use this parameter in conjunction with the **Input signal scaling**, **k** to map the range of X to the voltage range defined by the power supply. The default value is **0**.

Output Characteristics Tab

| • | Block Parameter | s: Push-Pull Output | | | | | |
|---|---|---------------------|----------------|----------------|--------------------|------|--|
| | Push-Pull Output | | | | | | |
| 1 | The block implements a CMOS push-pull output stage. The gates of the complementary pair are connected together, and the gate voltage is given by $Vg = k^*(X+c)$ where X is the physical signal input value. Use the interface integrated circuit behaviors, defined in Simulink(R) or by physical signal blocks, to an electrical product of the second states of the second | | | | | | |
| ſ | Parameters | | | | | | |
| | Input Scaling | Output Character | istics | Supply Voltage | Initial Conditions | | |
| | Output current-voltage relationship: | | Linea | r | | | |
| | Output resistance: Propagation delay: Protection diode on resistance: Protection diode forward voltage: | | 25 | | | Ohm | |
| | | | 25 5 0.6 | | | ns | |
| | | | | | | Ohm | |
| | | | | | | V | |
| | L | | | | | | |
| | | | | | OK Car | Help | |

Block Parameters: Push-Pull Output

Push-Pull Output

The block implements a CMOS push-pull output stage. The gates of the complementary pair are connected together, and the gate voltage is given by $Vg = k^*(X+c)$ where X is the physical signal input value. Use this block interface integrated circuit behaviors, defined in Simulink(R) or by physical signal blocks, to an electrical network

Parameters

| Input Scaling Output Character | istics | Supply Voltage | Initial Conditions | | | |
|---|--------|----------------|--------------------|------|------|-----|
| Output current-voltage relationship: | | ratic | | | | • |
| Power rail voltages, [V- V+], used for measurements: | [05 |] | | | ۷ | • |
| Output resistance values at zero output current and at I_OH when Vg=V-: | [25 2 | 250] | | | Ohm | - |
| Output current I_OH when output is shorted to V- and Vg=V-: | 63 | | | | mA | • |
| Output resistance values at zero output current and at I_OL when Vg=V+: | [30 8 | 300] | | | Ohm | - |
| Output current I_OL when output is shorted to V+ and Vg=V+: | -45 | | | | mA | • |
| Propagation delay: | 25 | | | | ns | • |
| Protection diode on resistance: | 5 | | | | Ohm | • |
| Protection diode forward voltage: | 0.6 | | | | V | • |
| | | | | | | |
| | | | OK Ca | ncel | Help | Арр |

Output current-voltage relationship

Select the output model, Linear or Quadratic output model options. If Linear, the output voltage drops linearly with output current. If you select Quadratic, then the output voltage dependency on output current is defined by the quadratic I-V characteristics of the two output MOSFET devices. The default value is Linear.

Output resistance

Defines one over the slope of the output I-V characteristic. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter. The default value is 25Ω .

Power rail voltages, [V-V+], used for measurements

Defines the rail voltages for which mask data output resistances and currents are defined. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter. The default value is [0 5] V.

Output resistance values at zero output current and at I_OH when Vg=V- $\ensuremath{\mathsf{Vg}}$

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 complementary pair output is HIGH (Vg=V-) and there is no output current. The second value R_OH2 is the gradient of the output voltage-current relationship when the output is HIGH and the output current is I_OH. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter. The default value is [25 250] Ω .

Output current I_OH when output is shorted to V- and Vg=V-

The resulting current when the output is HIGH (Vg=V-), but the load forces the output voltage to the negative supply rail. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter. The default value is 63 mA.

Output resistance values at zero output current and at I_OL when Vg=V+

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 complementary pair output is LOW (Vg=V+) and there is no output current. The second value R_OL2 is the gradient of the output voltage-current relationship when the output is LOW and the output current is I_OL. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter. The default value is [30 800] Ω .

Output current I_OL when output is shorted to V+ and Vg=V+ The resulting current when the output is LOW (Vg=V+), but the load forces the output voltage to the positive supply voltage. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter. The default value is -45 mA.

Propagation delay

Time it takes for the output to reach 63.2% of its final value following a step change in the input, X. 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.

Supply Voltage Tab

| 당 Block Parameters: Push-Pu | ull Output | | | | | | | | |
|--|-------------------|----------------|--------------------|------|--|--|--|--|--|
| - Push-Pull Output | | | | | | | | | |
| The block implements a CMOS push-pull output stage. The gates of the complementary pair are connect together, and the gate voltage is given by $Vg = k^*(X+c)$ where X is the physical signal input value. Use t interface integrated circuit behaviors, defined in Simulink(R) or by physical signal blocks, to an electrical | | | | | | | | | |
| Parameters | | | | | | | | | |
| Input Scaling Output | t Characteristics | Supply Voltage | Initial Conditions | | | | | | |
| Negative power rail volt | tage, V-: 0 | | | V | | | | | |
| Positive power rail volta | age, V+: 5 | | V | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | OK Can | Help | | | | | |

Negative power rail voltage, V-

Negative power supply voltage applied to the N-channel MOSFET source pin. The default value is 0 V.

Positive power rail voltage, V+

Positive power supply voltage applied to the P-channel MOSFET source pin. The default value is 5 V.

Initial Conditions Tab

| Į | Block Parameters | s: Push-Pull Output | | | | | | | (| |
|---|---|---------------------|--------|----------------|--------------------|------|------|--|------|--|
| | Push-Pull Output | | | | | | | | | |
| | The block implements a CMOS push-pull output stage. The gates of the complementary pair are connected together, and the gate voltage is given by $Vg = k^*(X+c)$ where X is the physical signal input value. Use this block interface integrated circuit behaviors, defined in Simulink(R) or by physical signal blocks, to an electrical network | | | | | | | | | |
| | Parameters | | | | | | | | | |
| | Input Scaling | Output Character | istics | Supply Voltage | Initial Conditions |] | | | | |
| | Initial output voltage: | | 0 | | | | V | | • | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | ОК Са | ncel | Help | | Appl | |

Initial output voltage

This parameter is visible when you select the Linear option for the **Output current-voltage relationship** parameter on the **Output Characteristics** tab. The parameter is used to set the voltage on the output capacitors so that the output voltage is initialized to the parameter's value. The default value is 0 V.

Initial input signal

This parameter is visible when you select the Quadratic option for the **Output current-voltage relationship** parameter on the **Output Characteristics** tab. The parameter is used to initialize the propagation delay first-order lag such that there is no transient at time zero. The default value is 0 V.

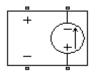
Ports The block has one input physical signal port X and one electrical conserving port that outputs the resulting voltage.

PVCCS

Purpose Model polynomial voltage-controlled current source

Library SPICE-Compatible Components/Sources

Description



The PVCCS (Polynomial Voltage-Controlled Current Source) block represents a current source whose output current value is a polynomial function of the voltage across the input ports. The following equations describe the current through the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

$$I_{out} = p(0) + p(1) * V_{in} + \dots + p(n-1) * V_{in}^{n-1} + p(n) * V_{in}^{n}$$

• If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$I_{out} = p * V_{in}$$

where:

- V_{in} is the voltage across the input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

Ports

| 🙀 Block Parameters: PVCCS 🛛 🗙 |
|---|
| -PVCCS |
| The Polynomial Voltage-Controlled Current Source (PVCCS) block generates a current waveform, Iout, by evaluating a polynomial function for a single controlling input voltage, Vin. Vin is the time-dependent voltage across its input terminals. |
| If you specify a vector of polynomial coefficients, p, in ascending order, the output is: |
| $Iout = p(0) + p(1)*Vin + + p(n-1)*Vin^{(n-1)} + p(n)*Vin^n$ |
| If you specify a scalar coefficient, p, the block creates a linearly dependent output current. |
| Iout = p * Vin |
| Parameters |
| Polynomial coefficients: |
| |
| OK Cancel Help Apply |

Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output current, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

_

Positive electrical output voltage.

N -

Negative electrical output voltage.

See Also PCCCS, PCCVS, PVCCS2, and PVCVS

Purpose Model polynomial voltage-controlled current source with two controlling inputs

Library SPICE-Compatible Components/Sources

Description

+1

The PVCCS2 (Two-Input Polynomial Voltage-Controlled Current Source) block represents a current source whose output current value is a polynomial function of the voltages across the pairs of controlling input ports. The following equations describes the current through the source as a function of time:

 $I_{out} = p_1 + p_2 * V_{in1} + p_3 * V_{in2} + p_4 * V_{in1}^2 + p_5 V_{in1} * V_{in2} + p_6 * V_{in2}^2 + \dots$

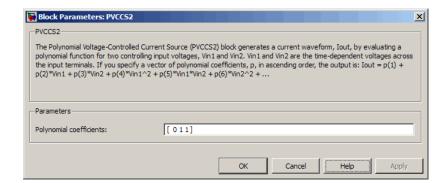
where:

- V_{in1} is the voltage across the first pair of input ports.
- V_{in2} is the voltage across the second pair of input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters



Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output current, as described in the preceding section. The default value is $[0\ 1\ 1]$.

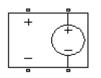
| Ports | The block has the following ports: | | |
|----------|------------------------------------|---|--|
| | +1 | Positive electrical input voltage of first controlling source. | |
| | - 1 | Negative electrical input voltage of first controlling source. | |
| | +2 | Positive electrical input voltage of second controlling source. | |
| | -2 | Negative electrical input voltage of second controlling source. | |
| | N+ | Positive electrical output voltage. | |
| | N - | Negative electrical output voltage. | |
| See Also | PCCO | CS2, PCCVS2, PVCCS, and PVCVS2 | |

Purpose Model polynomial voltage-controlled voltage source

SPICE-Compatible Components/Sources

Description

Library



The PVCVS (Polynomial Voltage-Controlled Voltage Source) block represents a voltage source whose output voltage value is a polynomial function of the voltage across the input ports. The following equations describe the voltage across the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

$$V_{out} = p(0) + p(1) * V_{in} + ... + p(n-1) * V_{in}^{n-1} + p(n) * V_{in}^{n}$$

• If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$V_{out} = p * V_{in}$$

where:

- V_{in} is the voltage across the input ports.
- *p* is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters

| 🙀 Block Parameters: PVCV5 🛛 🔍 🗙 |
|---|
| PVCV5 |
| The Polynomial Voltage-Controlled Voltage Source (PVCVS) block generates a voltage waveform, Vout, by evaluating a polynomial function for a single controlling input voltage, Vin. Vin is the time-dependent voltage across its input terminals. |
| If you specify a vector of polynomial coefficients, p, in ascending order, the output is: |
| $Vout = p(0) + p(1)*Vin + + p(n-1)*Vin^{n-1} + p(n)*Vin^{n-1}$ |
| If you specify a scalar coefficient, $p,$ the block creates a linearly dependent output voltage. |
| Vout = p * Vin |
| Parameters |
| Polynomial coefficients: [0 1] |
| |
| |
| OK Cancel Help Apply |

Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output voltage, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

Positive electrical output voltage.

N -

Negative electrical output voltage.

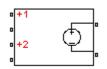
Ports

See Also PCCCS, PCCVS, PVCCS, and PVCVS2

Purpose Model polynomial voltage-controlled voltage source with two controlling inputs

Library SPICE-Compatible Components/Sources

Description



The PVCVS2 (Two-Input Polynomial Voltage-Controlled Voltage Source) block represents a voltage source whose output voltage value is a polynomial function of the voltages across the pairs of controlling input ports. The following equations describes the voltage across the source as a function of time:

$$V_{out} = p_1 + p_2 * V_{in1} + p_3 * V_{in2} + p_4 * V_{in1}^2 + p_5 V_{in1} * V_{in2} + p_6 * V_{in2}^2 + \dots$$

where:

- V_{in1} is the voltage across the first pair of input ports.
- V_{in2} is the voltage across the second pair of input ports.
- *p* is the **Polynomial coefficients** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the output ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| PVCVS2- The Polynomial Voltage-Controlled Voltage Source (PVCVS2) block generates a voltage waveform, Vout, by evaluating a polynomial function for two controlling input voltages, Vin1 and Vin2. Vin1 and Vin2 are the time-dependent voltages act the input terminals. If you specify a vector of polynomial coefficients, p, in ascending order, the output is: Vout = p(1) - p(2)*Vin1 + p(3)*Vin2 + p(4)*Vin1^2 + p(5)*Vin1*Vin2 + p(6)*Vin2^2 + Parameters Polynomial coefficients: | | | | | | | arameters: PVCV52 | Block Pa |
|--|----------|----------------|------------------|---|-----------------------|---------------------------------------|---|--|
| | s across | pendent voltag | 2 are the time-d | d Vin2. Vin1 and ficients, p, in asc | , Vin 1 a mial coe | ng input voltages vector of polyno | al function for two contro terminals. If you specify | The Polyno polynomial the input te |
| Polynomial coefficients: [011] | | | | | | | ers | Parameters |
| | | | | | | [011] | al coefficients: | Polynomial |

Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output voltage, as described in the preceding section. The default value is $[0\ 1\ 1]$.

| Ports | The | block has the following ports: |
|----------|-----|---|
| | +1 | Positive electrical input voltage of first controlling source. |
| | - 1 | Negative electrical input voltage of first controlling source. |
| | +2 | Positive electrical input voltage of second controlling source. |
| | -2 | Negative electrical input voltage of second controlling source. |
| | N+ | Positive electrical output voltage. |
| | N - | Negative electrical output voltage. |
| See Also | PCC | CS2, PCCVS2, PVCCS2, and PVCVS |

PWL Current Source

| Purpose | Model lookup table current source |
|-------------|---|
| Library | SPICE-Compatible Components/Sources |
| Description | The PWL Current Source block represents a current source that you specify in lookup table form using a vector of time values and a vector of the corresponding current values. You must specify at least four time-current value pairs. The block generates a time-dependent current based on these time-current values using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods. The output current is independent of the voltage across the terminals of the source. The block uses a small conductance internally to prevent numerical |
| | simulation issues. The conductance connects the + and - ports of the |

device and has a conductance GMIN:

• By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e–12.

• To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| 🙀 Block Parameters: F | WL Current Source | × |
|--|---|--|
| PWL Current Source- | | |
| (Time, Current) to speci equivalent, this source determine output currer | urrent Source (PWL) block uses fy a time dependent current wa can use linear, cubic or spline int it values at intermediate time po nts method for extrapolation. | veform. Like its SPICE terpolation methods to |
| Parameters | | |
| Time specification: | [01234] | 5 |
| Current at specified time: | [00000] | A |
| Interpolation method: | Linear | ▼ . |
| Extrapolation method: | Last point value | _ |
| | | |
| | OK Cancel | Help Apply |

Time specification

The vector of time values as a tabulated 1-by-n array. The time values vector must be strictly monotonically increasing. The values can be non-uniformly spaced. The default value is $\begin{bmatrix} 0 \\ 1 & 2 & 3 \end{bmatrix}$ s.

Current at specified time

The vector of current values as a tabulated 1-by-n array. The current values vector must be the same size as the time values vector. The default value is $[0\ 0\ 0\ 0\ 0]$ A.

Interpolation method

Select the method the block uses determine the output current values at intermediate time points that are not specified in the preceding vectors:

• Linear — Use a linear function. This is the default method.

| | • Cubic — Use the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP). For more information, see [1] and the pchip MATLAB function. |
|------------|--|
| | • Spline — Use the cubic spline interpolation algorithm described in [2]. |
| | Extrapolation method Select the method the block uses determine the output current values at time points that are outside the time range specified in the preceding vectors: |
| | • Last point value — Use the last specified current value at the appropriate end of the range. That is, use the last specified current value for all time values greater than the last specified time argument, and the first specified current value for all time values less than the first specified time argument. This is the default method. |
| | • Last 2 points — Extrapolate using the linear method (regardless of the interpolation method specified), based on the last two current values at the appropriate end of the range. That is, use the first and second specified current values if the time value is below the specified range, and the two last specified current values if the time value is the time value is above the specified range. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| References | [1] D. Kahaner, Cleve Moler, and Stephen Nash <i>Numerical Methods and Software</i> Prentice Hall, 1988. |

[2] W.H. Press, B.P. Flannery, S.A. Teulkolsky, and W.T. Wetterling *Numerical Recipes in C: The Art of Scientific Computing* Cambridge University Press, 1992.

See Also PWL Voltage Source

PWL Voltage Source

| Purpose | Model lookup table voltage source |
|---------|-----------------------------------|
|---------|-----------------------------------|

Library SPICE-Compatible Components/Sources

Description

The PWL Voltage Source block represents a voltage source that you specify in lookup table form using a vector of time values and a vector of the corresponding voltage values. You must specify at least four time-current value pairs. The block generates a time-dependent voltage based on these time-voltage values using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods. The output voltage is independent of the current through the source.

Dialog Box and Parameters

| (Time, Voltage) to speci equivalent, this source determine output voltag | oltage Source (PWL) block uses time-voltage pairs of the form fy a time dependent voltage waveform. Like its SPICE can use linear, cubic or spline interpolation methods to ge values at intermediate time points. The block can use either ints method for extrapolation. |
|--|--|
| - Parameters | |
| Time specification: | [01234] s |
| Voltage at specified time: | [00000] V V |
| Interpolation method: | Linear |
| Extrapolation method: | Last point value |
| | |
| | OK Cancel Help Apply |

Time specification

The vector of time values as a tabulated 1-by-n array. The time values vector must be strictly monotonically increasing. The values can be non-uniformly spaced. The default value is $\begin{bmatrix} 0 \\ 1 & 2 & 3 \end{bmatrix}$ s.

Voltage at specified time

The vector of voltage values as a tabulated 1-by-n array. The voltage values vector must be the same size as the time values vector. The default value is $[0\ 0\ 0\ 0\ 0]$ V.

Interpolation method

Select the method the block uses determine the output voltage values at intermediate time points that are not specified in the preceding vectors:

- Linear Use a linear function. This is the default method.
- Cubic Use the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP). For more information, see [1] and the pchip MATLAB function.
- Spline Use the cubic spline interpolation algorithm described in [2].

Extrapolation method

Select the method the block uses determine the output voltage values at time points that are outside the time range specified in the preceding vectors:

- Last point value Use the last specified voltage value at the appropriate end of the range. That is, use the last specified voltage value for all time values greater than the last specified time argument, and the first specified voltage value for all time values less than the first specified time argument. This is the default method.
- Last 2 points Extrapolate using the linear method (regardless of the interpolation method specified), based on the last two voltage values at the appropriate end of the range. That is, use the first and second specified voltage values if the time value is below the specified range, and the two last specified voltage values if the time value is above the specified range.

Ports The block has the following ports:

Positive electrical voltage.

Negative electrical voltage.

References [1] D. Kahaner, Cleve Moler, and Stephen Nash *Numerical Methods and Software* Prentice Hall, 1988.

[2] W.H. Press, B.P. Flannery, S.A. Teulkolsky, and W.T. Wetterling *Numerical Recipes in C: The Art of Scientific Computing* Cambridge University Press, 1992.

See Also PWL Current Source

+

Purpose Model switching and associated delay of relay

Library

Passive Devices

Description



The Relay block models a relay controlled by an external physical signal. In the steady state, the relay behaves as follows:

- When the physical signal input PS rises above the **Threshold** parameter, the relay is *energized* (meaning closed). The common port C connects to the normally open port S2.
- When the physical signal input PS falls below the **Threshold** parameter, the relay is *not energized* (meaning open). The common port C connects to the normally closed port S1.

During switching, the relay behaves as follows:

- When the relay closes, the C to S1 connection breaks open after delay **Time-to-break C-S1 connection**. The C to S2 connection closes after delay **Time-to-make C-S2 connection**.
- When the relay opens, the C to S2 connection breaks open after delay **Time-to-break C-S2 connection**. The C to S1 connection closes after delay **Time-to-make C-S1 connection**.

You can specify break delays that are longer than the close delays to implement a make-before-break behavior.

Basic Assumptions and Limitations If the PS input changes during the switching process, the block behavior can be inaccurate. The switching delay occurs due to both mechanical inertia and the fact that modeling inertia as a delay requires approximation.

Relay

Dialog Box and Parameters

| 🙀 Block Parameters: Relay | | × |
|----------------------------------|--|------------|
| | en the physical signal input PS rises above the thresh inal S2. When PS falls below the threshold, then the | |
| The Connected resistance R and C | Open-circuit conductance G must be greater than zero | D. |
| Parameters | | |
| Time-to-break C-S1 connection: | 0 | s • |
| Time-to-make C-S1 connection: | 0 | s • |
| Time-to-break C-S2 connection: | 0 | s • |
| Time-to-make C-S2 connection: | 0 | s • |
| Connected resistance R: | 0.01 | Ohm 👻 |
| Open-circuit conductance G: | 1e-8 | 1/Ohm 👻 |
| Threshold: | 0 | |
| Initial connection: | C to S1 closed, C to S2 open | • |
| | OK Cancel | Help Apply |

Time-to-break C-S1 connection

Time it takes the connection between ports C and S1 to break apart when the relay is energized. The default value is 0 s.

Time-to-make C-S1 connection

Time it takes the connection between ports C and S1 to close when the relay is not energized. The default value is **0** s.

Time-to-break C-S2 connection

Time it takes the connection between ports C and S2 to break apart when the relay is not energized. The default value is 0 s.

Time-to-make C-S2 connection

Time it takes the connection between ports C and S2 to close when the relay is not energized. The default value is **0** s.

| | must be greater than zero. The default value is 0.01 sz. |
|----------|--|
| | Open-circuit conductance G Conductance across open relay contacts. The parameter value must be greater than zero. The default value is $1e-08 \ 1/\Omega$. |
| | Threshold If the physical signal input rises above this value, the relay is energized. Conversely, if the physical signal input falls below this value, the relay is de-energized. The default value is 0. |
| | Initial connection For the initial state of the relay, select one of the following options: |
| | • C to S1 closed, C to S2 open — The common port C connects to the S1 contact. This is the default option. |
| | • C to S1 open, C to S2 closed — The common port C connects to the S2 contact. |
| Ports | This block has the following ports: |
| | PS Physical signal that energizes and de-energizes the relay. |
| | C Common electrical port. |
| | S1 Normally-closed electrical port. |
| | S2 Normally-open electrical port. |
| See Also | Simscape Switch |

Resistance across closed relay contacts. The parameter value must be greater than zero. The default value is $0.01~\Omega.$

Connected resistance R

Resistor

| Purpose | Model linear resistor with optional noise |
|-------------|---|
| Library | Passive Devices |
| Description | The Resistor block models a linear resistor, described with the following equation: |
| | i = v/R |
| | 1 |

where:

- *i* is the current.
- v is the voltage.
- *R* is the resistance.

Optionally, the Resistor block can generate thermal noise current. If you set the **Noise mode** parameter to **Enabled**, then the defining equations are augmented by a discrete variable i_N to represent thermal noise:

 $i = v/R + i_N$

If the sampling time is h, then the thermal noise is given by:

$$i_N = \sqrt{2kT/R} \, rac{N(0,1)}{\sqrt{h}}$$

where:

- k is the Boltzmann constant, 1.3806504e-23 J/K.
- *T* is the temperature.
- *R* is the resistance.
- *N* is a Gaussian random number with zero mean and standard deviation of one.

• 2kT/R is the double-sided thermal noise power distribution (the single-sided equivalent is 4kT/R).

If you set the **Noise mode** parameter to **Disabled**, then no noise is added, and the component behavior is identical to the Simscape Foundation library Resistor block.

Noise Options

The block generates Gaussian noise by using the Random Number source in the Simscape Foundation library. You can control the random number seed by setting the **Repeatability** parameter:

• Not repeatable — Every time you simulate your model, the block resets the random seed using the MATLAB random number generator:

seed = $randi(2^{32-1});$

- Repeatable The block uses a hidden parameter, called auto_seed, to always start the simulation with the same random number. The value of auto_seed is set whenever you copy the Resistor block from the block library to the model, or when you make a new copy of the Resistor block from an existing one in a model. The block sets the value using the MATLAB random number generator command shown above.
- Specify seed If you select this option, the additional Seed parameter lets you directly specify the random number seed value.

Basic Assumptions and Limitations Simulating with noise enabled slows down simulation. Choose the sample time (h) so that noise is generated only at frequencies of interest, and not higher.

Dialog Main Tab Box and Parameters

| 🚹 Block Parameters: Resistor | | |
|------------------------------|------------------------|--|
| Resistor | | |
| | ne Boltzmann constant, | bise. Thermal noise is assumed to have a power spectral T is the temperature and R is the resistance value. The ing. |
| Parameters | | |
| Main Noise | | |
| Resistance: | 1 | Ohm 👻 |
| | | |
| | | OK Cancel Help Apply |

Resistance

The resistance value. The default value is 1 Ω .

Noise Tab

| 🚹 Block Parameters: Resistor | | 3 |
|------------------------------|--|---|
| Resistor | | |
| | ional thermal noise. Thermal noise is assumed to have a power spectral mann constant, T is the temperature and R is the resistance value. The discrete sampling. | |
| Parameters | | |
| Main Noise | | 1 |
| Noise mode: | Disabled | |
| | OK Cancel Help Apply | |

Noise mode

Select the noise option:

- Disabled No noise is produced by the resistor. This is the default.
- Enabled Resistor generates thermal noise current, and the associated parameters become visible on the **Noise** tab.

Device simulation temperature

The temperature of the thermal resistor at the start of the simulation. The default value is $25 \, ^{\circ}$ C.

Sample time

Defines the rate at which the noise source is sampled. Choose it to reflect the frequencies of interest in your model. Making the sample time too small will unnecessarily slow down your simulation. The default value is 1e-3 s.

Repeatability

Select the noise control option:

Resistor

| | Not repeatable — The random sequence used for noise generation is not repeatable. This is the default. Repeatable — The random sequence used for noise generation is repeatable, with a system-generated seed. |
|----------|---|
| | Specify seed — The random sequence used for noise generation is repeatable, and you control the seed by using the Seed parameter. |
| | Seed Random number seed used by the noise random number generator. This parameter is visible only if you select Specify seed for the Repeatability parameter. The default value is 0. |
| Ports | The block has the following ports: |
| | + Positive electrical port. |
| | Negative electrical port. |
| See Also | Current Source, Voltage Source. |

Purpose Model rotary transformer that measures motor rotation angle

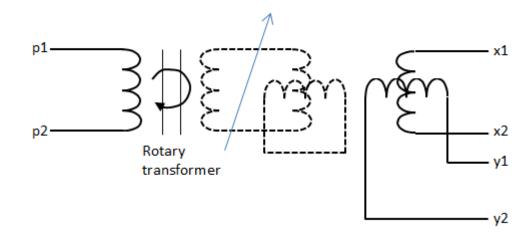
Sensors

Description

Library



The Resolver block models a generic resolver, which consists of a rotary transformer that couples an AC voltage applied to the primary winding to two secondary windings. These secondary windings are physically oriented at 90 degrees to each other. As the rotor angle changes, the relative coupling between the primary and the two secondary windings varies. In the Resolver block model, the first secondary winding is oriented such that peak coupling occurs when the rotor is at zero degrees, and therefore the second secondary winding has minimum coupling when the rotor is at zero degrees.



Without loss of generality, it is assumed that the transformer between primary and rotor circuit is ideal with a ratio of 1:1. This results in the rotor current and voltage being equivalent to the primary current and voltage.

You have two options for defining the block equations:

- Omit the dynamics by neglecting the transformer inductive terms. This model is only valid if the sensor is driven by a sine wave because any DC component on the primary side will pass to the output side.
- Include the inductive terms, thereby capturing voltage amplitude loss and phase differences. This model is valid for any input waveform. Within this option, you can either specify the inductances and the peak coupling coefficient directly, or specify the transformation ratio and measured impedances, in which case the block uses these values to determine the inductive terms.

Equations when Omitting Dynamics

The equations are based on the superposition of two ideal transformers, both with coupling coefficients that depend on rotor angle. The two ideal transformers have a common primary winding. See the Simscape Ideal Transformer block reference page for more information on modeling ideal transformers. The equations are:

$$\begin{split} K_{\rm x} &= R\,\cos(N\,\varTheta)\\ K_{\rm y} &= R\,\sin(N\,\varTheta)\\ v_{\rm x} &= K_{\rm x}v_{\rm p}\\ v_{\rm y} &= K_{\rm y}v_{\rm p}\\ i_{\rm p} &= -K_{\rm x}i_{\rm x} - K_{\rm y}i_{\rm y} \end{split}$$

where:

- $v_{\rm p}$ and $i_{\rm p}$ are the rotor (or equivalently primary) voltage and current, respectively.
- $v_{\rm x}$ and $i_{\rm x}$ are the first secondary voltage and current, respectively.
- $v_{\rm v}$ and $i_{\rm v}$ are the second secondary voltage and current, respectively.
- K_x is the coupling coefficient for the first secondary winding.

- $K_{\rm v}$ is the coupling coefficient for the second secondary winding.
- *R* is the transformation ratio.
- *N* is the number of pole pairs.
- Θ is the rotor angle.

Equations when Including Dynamics

The equations are based on the superposition of two mutual inductors, both with coupling coefficients that depend on rotor angle. The two mutual inductors have a common primary winding. See the Simscape Mutual Inductor block reference page for more information on modeling mutual inductors. The equations are:

$$v_{p} = R_{p}i_{p} + L_{p}\frac{di_{p}}{dt} + \sqrt{L_{p}L_{s}}k\left(\cos(N\theta)\frac{di_{x}}{dt} + \sin(N\theta)\frac{di_{y}}{dt}\right)$$
$$v_{x} = R_{s}i_{x} + L_{s}\frac{di_{x}}{dt} + \sqrt{L_{p}L_{s}}k\cos(N\theta)\frac{di_{p}}{dt}$$
$$v_{y} = R_{s}i_{y} + L_{s}\frac{di_{y}}{dt} + \sqrt{L_{p}L_{s}}k\sin(N\theta)\frac{di_{p}}{dt}$$

where:

- $v_{\rm p}$ and $i_{\rm p}$ are the rotor (or equivalently primary) voltage and current, respectively.
- $v_{\rm x}$ and $i_{\rm x}$ are the first secondary voltage and current, respectively.
- $v_{\rm v}$ and $i_{\rm v}$ are the second secondary voltage and current, respectively.
- $R_{\rm p}$ is the rotor (or primary) resistance.
- L_{p} is the rotor (or primary) inductance.
- $R_{\rm s}$ is the stator (or secondary) resistance.
- L_{s} is the stator (or secondary) inductance.

Resolver

- *N* is the number of pole pairs.
- k is the coefficient of coupling.
- Θ is the rotor angle.

It is assumed that coupling between the two secondary windings is zero.

Datasheets typically do not quote the coefficient of coupling and inductance parameters, but instead give the transformation ratio R and measured impedances. If you select Specify transformation ratio and measured impedances for the **Parameterization** parameter, then the values you provide are used to determine values for the equation coefficients, as defined above.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The resolver draws no torque between the mechanical rotational ports R and C.
- The transformer between primary and rotor circuit is ideal with a ratio of 1:1.
- The coupling between the two secondary windings is zero.

Dialog Box and Parameters

| 뒑 Block Parameters: Resolver | | |
|--------------------------------------|--|--------------------|
| Resolver | | |
| the AC excitation voltage is applied | e resolver. Ports p1 and p2 represent the primary (d. Port pairs [x1 x2] and [y1 y2] represent the two anical rotational ports corresponding to rotor and s | secondary (stator) |
| Parameters | | |
| Parameterization: | Specify transformation ratio and omit dynamics | |
| Transformation ratio: | 0.5 | |
| Number of pole pairs: | 1 | |
| Initial rotor angle: | 0 | deg |
| | OK Cancel | Help Apply |

Parameterization

Select one of the following methods for block parameterization:

• Specify transformation ratio and omit dynamics — Provide values for transformation ratio, number of pole pairs, and initial rotor angle only. This model neglects the transformer inductive terms, and is only valid if the sensor is driven by a sine wave. The equations are based on the superposition of two ideal transformers, both with coupling coefficients that depend on rotor angle. For more information, see "Equations when Omitting Dynamics" on page 1-560. This is the default option.

- Specify transformation ratio and measured impedances — Provide additional values to determine the transformer inductive terms, to model the voltage amplitude loss and phase differences. This model is valid for any input waveform. The equations are based on the superposition of two mutual inductors, both with coupling coefficients that depend on rotor angle. For more information, see "Equations when Including Dynamics" on page 1-561.
- Specify equation parameters directly Model the dynamics, but provide values for rotor and stator inductances and the peak coefficient of coupling, instead of transformation ratio and measured impedances. For more information, see "Equations when Including Dynamics" on page 1-561. This model is valid for any input waveform.

Transformation ratio

The ratio between peak output voltage and peak input voltage assuming negligible secondary voltage drop due to resistance and inductance. This parameter is only visible when you select Specify transformation ratio and omit dynamics or Specify transformation ratio and measured impedances for the **Parameterization** parameter. If you select Specify transformation ratio and measured impedances for the **Parameterization** parameter, then the transformation ratio takes into account the voltage drop due to primary winding resistance. The default value is **0.5**.

Rotor resistance

This is the rotor (or equivalently the primary) ohmic resistance. This parameter is only visible when you select Specify transformation ratio and measured impedances or Specify equation parameters directly for the **Parameterization** parameter. The default value is 70 Ω .

Stator resistance

This is the secondary winding ohmic resistance. It is assumed that both secondaries have the same resistance. This parameter is only visible when you select Specify transformation ratio and measured impedances or Specify equation parameters directly for the **Parameterization** parameter. The default value is 180 Ω .

Rotor reactance

This is the rotor (or equivalently the primary) reactance with the secondary windings open-circuit. This parameter is only visible when you select Specify transformation ratio and measured impedances for the **Parameterization** parameter. The default value is 100 Ω .

Stator reactance

This is the stator (or equivalently the secondary) reactance with the primary winding open-circuit. This parameter is only visible when you select Specify transformation ratio and measured impedances for the **Parameterization** parameter. The default value is 300 Ω .

Frequency at which reactances and transformation ratio are specified

This is the frequency of the sinusoidal source used when measuring the reactances. This parameter is only visible when you select Specify transformation ratio and measured impedances for the **Parameterization** parameter. The default value is 10 kHz.

Rotor inductance

This is the rotor (or equivalently the primary) inductance $L_{\rm p}$. This parameter is only visible when you select Specify equation parameters directly for the **Parameterization** parameter. The default value is 0.0016 H.

Stator inductance

This is the stator (or equivalently the secondary) inductance $L_{\rm s}.$ This parameter is only visible when you select Specify equation

Resolver

| | parameters directly for the Parameterization parameter. The default value is 0.0048 H. |
|-------|--|
| | Peak coefficient of coupling This is the peak coefficient of coupling between the primary and secondary windings. The parameter value should be greater than zero and less than one. This parameter is only visible when you select Specify equation parameters directly for the Parameterization parameter. The default value is 0.35. |
| | Number of pole pairs The number of pole pairs on the rotor. The default value is 1. |
| | Initial rotor angle The initial angle of the rotor, Θ . The default value is 0 degrees. |
| Ports | The block has the following ports: |
| | p1, p2 Electrical ports of the primary winding. |
| | x1, x2 Electrical ports of the first secondary winding. |
| | y1, y2 Electrical ports of the second secondary winding. |
| | R, C Mechanical rotational ports. |
| | |

Purpose Model an S-R Latch behaviorally

Library Logic

Description



The S-R Latch block is an abstracted behavioral model of a set-reset latch. It does not model the internal individual MOSFET devices (see "Basic Assumptions and Limitations" on page 1-568 for details). Therefore, the block runs quickly during simulation but retains the correct I/O behavior.

If the gate voltage is greater than the threshold voltage V_{TH} , then the input taken is 1 (HIGH). Otherwise, the input is zero (LOW). The

gate threshold voltage $V_{T\!H}$ is halfway between the ${\bf Low}~{\bf level~input}$

voltage (V_{IL}) and High level input voltage (V_{IH}) parameters.

The block output logic level is either HIGH or LOW, according to the logic levels of the gate inputs and the S-R latch truth table.

| S | R | Q |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output offers a selection of two models: Linear and Quadratic. For more information, see "Selecting the Output Model for Logic Blocks". Use the **Output current-voltage relationship** parameter to specify the output model.
- You can specify propagation delay for both output models. For Linear output, the block sets the value of the gate output capacitor such that

the resistor-capacitor time constant equals the **Propagation delay** parameter value. For Quadratic output, the gate input demand is lagged to approximate the **Propagation delay** parameter value.

The block output voltage depends on the output model selected:

- For Linear model, output high is the **High level output voltage** parameter value, and output low is the **Low level output voltage** parameter value.
- For Quadratic model, the output voltage for High and Low states is a function of the output current, as explained in "Quadratic Model Output and Parameters". For zero load current, output high is Vcc (the **Supply voltage** parameter value), and output low is zero volts.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate (except for the final MOSFET pair if you select the Quadratic option for the **Output current-voltage relationship** parameter). This limitation has the following implications:

- The behavior of this block is abstracted. In particular, response to input noise and inputs that are around the logic threshold voltage can be inaccurate. Also, dynamic response is approximate.
- The linear drop in output voltage as a function of output current is an approximation to the MOSFET or bipolar output behavior.
- Modeling of the output as a controlled voltage source is representative of a totem-pole or push-pull output stage. To model a device with an open-collector:
 - **1** Connect the output pin to the base of an NPN Bipolar Transistor or PNP Bipolar Transistor block.
 - 2 Set the **Output resistance** parameter to a suitable value.

Dialog Box and Parameters

| In | puts | Tab |
|----|------|-----|
| | P013 | IMN |

| Inputs Outputs Initial Cor | nditions | | | |
|----------------------------|----------|--|----|---|
| Low level input voltage: | 2 | | V | • |
| High level input voltage: | 3 | | V | • |
| Average input capacitance: | 5 | | pF | • |
| | | | | |

Low level input voltage

Voltage value less than which the block interprets the input voltage as LOW. The default value is 2 V.

High level input voltage

Voltage value greater than which the block interprets the input voltage as HIGH. The default value is 3 V.

Average input capacitance

Fixed capacitance that approximates the input capacitance for a MOSFET gate. You can usually find this capacitance value on a manufacturer datasheet. The default value is 5 pF. Setting this value to zero can result in faster simulation times.

Outputs Tab

| Block Parameters: S-R Latch | | | | | > |
|---|--------|----|----------------|---------------------|--------------|
| -S-R Latch | | | | | |
| This block implements a simplified model of supply voltage used. Default values are ty | | | output low and | l output high volta | iges for the |
| Parameters | | | | | |
| Inputs Outputs Initial Conditio | ns | | | | |
| Output current-voltage relationship: | Linear | | | | • |
| Low level output voltage: | 0 | | | ۷ | - |
| High level output voltage: | 5 | | | V | • |
| Output resistance: | 25 | | | Ohm | - |
| Propagation delay: | 25 | | | ns | • |
| | | | | | |
| | | | | | |
| | | ОК | Cancel | Help | Apply |

| ameters | | |
|--|------------|----------|
| Inputs Outputs Initial Condition | 5 | |
| Output current-voltage relationship: | Quadratic | • |
| Supply voltage: | 5 | V |
| Measurement voltage: | 5 | V |
| Logic HIGH output resistance at zero current and at I_OH: | [25 250] | Ohm 💌 |
| Logic HIGH output current I_OH when shorted to ground: | 63 | mA |
| Logic LOW output resistance at zero current and at I_OL: | [30 800] | Ohm |
| Logic LOW output current I_OL when shorted to Vcc: | -45 | mA |
| Propagation delay: | 25 | ns |
| Protection diode on resistance: | 5 | Ohm 💌 |
| Protection diode forward voltage: | 0.6 | V • |

Output current-voltage relationship

Select the output model, Linear or Quadratic. The default value is Linear.

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 25 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current. This parameter is available when you select the Linear option for the **Output current-voltage relationship** parameter.

Supply voltage

Supply voltage value applied to the gate in your circuit. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Measurement voltage

The gate supply voltage for which mask data output resistances and currents are defined. The default value is 5 V. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

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. This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. 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 . This parameter is available when you select the Quadratic option for the **Output current-voltage relationship** parameter.

Protection diode forward voltage

The voltage above which the protection diode is turned on. The default value is 0.6 V. This parameter is available when you select the Quadratic option for the **Output current-voltage** relationship parameter.

Initial Conditions Tab

| Block Parameters: S-I | R Latch | | 2 |
|-----------------------|--------------------|---|---|
| | | -reset latch. Set the input low, input high, output for a supply voltage of 5 volts. | ut low and output high voltages for the |
| Parameters | | | |
| Inputs Outputs | Initial Conditions | | |
| Output initial state: | | Low | |
| | | ок с | ancel Help Apply |

Output initial state

Specify whether the initial output state of the block is High or Low. This parameter is used for both linear and quadratic output states, provided that the **Propagation delay** parameter is greater than zero and the Solver Configuration block does not have the **Start simulation from steady state** option selected. The default value is Low.

Ports

This block has the following ports:

S

Electrical input port corresponding to the set pin.

R

Electrical input port corresponding to the reset pin.

Q

Electrical output port corresponding to the output pin.

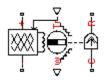
Servomotor

Purpose Brushless motor model with closed-loop torque control

Library

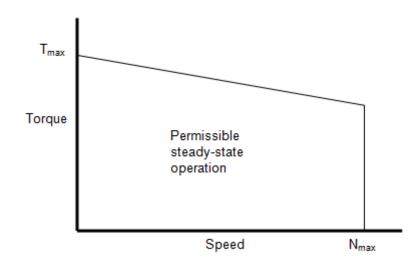
Rotational Actuators

Description



The Servomotor block represents a brushless motor model with closed-loop torque control. This block abstracts the torque-speed behavior of the combined motor and motor driver in order to support system-level simulation where simulation speed is important.

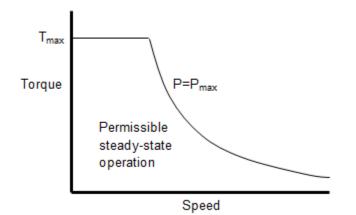
The block permits only the range of torques and speeds that the torque-speed envelope defines. In the default block configuration, you specify this data in the block dialog box as a set of speed data points and corresponding maximum torque values. The following figure shows a typical torque-speed envelope for a servomotor.



Specify the torque-speed envelope for the positive torque region only, that is, quadrants 1 and 4. If you specify only for positive speeds (quadrant 1 or, equivalently, the motoring region), then the quadrant 4 torque envelope is defined by the block as the mirror image of quadrant

1. The servomotor torque-speed envelope has the same profile when the motor is operating in a reverse direction (quadrants 2 and 3).

Instead of providing tabulated torque-speed data, you can specify a maximum torque and a maximum power. This results in the torque-speed envelope profile shown below. The other three operating quadrants are constrained by this same profile.



The block models the electrical losses as the sum of four terms:

- A series resistance between the DC power supply and the motor drive.
- Fixed losses independent of torque and speed, P_0 . Use this to account for fixed converter losses.
- A torque-dependent electrical loss $k\tau^2$, where τ is the torque and k is a constant. This represents ohmic losses in the copper windings.
- A speed-dependent electrical loss $k_{\rm w}\omega^2$, where ω is the speed and $k_{\rm w}$ is a constant. This represents iron losses due to eddy currents.

The block produces a positive torque acting from the mechanical C to R ports.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

This model is based on the following assumptions:

Basic Assumptions and Limitations

- The motor driver tracks a torque demand with a time constant Tc.
- Motor speed fluctuations due to mechanical load do not affect the motor torque tracking.

Servomotor

Dialog Box and Parameters

Electrical Torque Tab

| lock Parameters: Servomotor | | |
|--|--|-----------------------------|
| | | |
| ntrol mode. The motor's permissi | and drive electronics operating in torque-contro ible range of torques and speeds is defined by a ck the torque reference demand Tr with time co | torque-speed envelope, and |
| onstant term plus two additional te peed respectively. In addition, a re etween power supply and servome | nnected to a DC supply. Electrical losses are ass rms that are proportional to the square of the t sistor in series with the supply can be included tor driver. e acting from the mechanical C to R ports. | orque and the square of the |
| arameters | e acting from the mechanical C to K ports. | |
| Electrical Torque Electrical Los | ses Mechanical | |
| • | | |
| Parameterize by: | Tabulated torque-speed envelope | • |
| Vector of rotational speeds: | [0 3.75e+3 7.5e+3 8e+3] | rpm |
| Vector of maximum torque values: | [0.09 0.08 0.070000000000000 0] | N*m • |
| Torque control time constant, Tc: | 0.02 | 5 |
| | | |
| | | |

Parameterize by

Select one of the following methods for block parameterization:

- Tabulated torque-speed envelope Provide the vectors of rotational speeds and corresponding maximum torque values. This is the default option.
- Maximum torque and power Define the torque-speed envelope by providing values for maximum permissible torque and motor power.

Vector of rotational speeds

Rotational speeds for permissible steady-state operation. This parameter is visible only if you select Tabulated torque-speed envelope for the **Parameterize by** parameter. The default value is [0 3.75e+03 7.5e+03 8e+03] rpm. To avoid poor performance due to an infinite slope in the torque-speed curve, specify a vector of rotational speeds that does not contain duplicate consecutive values.

Vector of maximum torque values

Maximum torque values for permissible steady-state operation. This parameter is visible only if you select Tabulated torque-speed envelope for the **Parameterize by** parameter. These values correspond to the speeds in the **Vector of rotational speeds** parameter and define the torque-speed envelope for the motor. The default value is [0.09 0.08 0.07 0] Nm.

Maximum torque

The maximum permissible motor torque. This parameter is visible only if you select Maximum torque and power for the **Parameterize by** parameter. The default value is 0.1 Nm.

Maximum power

The maximum permissible motor power. This parameter is visible only if you select Maximum torque and power for the **Parameterize by** parameter. The default value is 30 W.

Torque Control time constant, Tc

Time constant with which the motor driver tracks a torque demand. The default value is 0.02 s.

Electrical Losses Tab

| Servomotor | | |
|--|--|--|
| ontrol mode. The motor's permis | r and drive electronics operating in torque sible range of torques and speeds is define ack the torque reference demand Tr with t | ed by a torque-speed envelope, and |
| onstant term plus two additional peed respectively. In addition, a r etween power supply and servon | onnected to a DC supply. Electrical losses a terms that are proportional to the square c esistor in series with the supply can be inc notor driver. ue acting from the mechanical C to R ports | of the torque and the square of the cluded to model transmission losses |
| arameters | | |
| and the second s | | |
| Electrical Torque Electrical Lo | osses Mechanical | |
| Electrical Torque Electrical Lo Motor and driver overall efficiency (percent): | 100 | |
| Motor and driver overall | | rpm 🔹 |
| Motor and driver overall efficiency (percent): Speed at which efficiency is | 100 | rpm ▾ N*m ▾ |
| Motor and driver overall efficiency (percent): Speed at which efficiency is measured: Torque at which efficiency is | 100 3.75e+3 | |
| Motor and driver overall efficiency (percent): Speed at which efficiency is measured: Torque at which efficiency is measured: | 100 3.75e+3 0.08 | N*m - |

Motor and driver overall efficiency (percent)

The block defines overall efficiency as

$$\eta = 100 \frac{\tau_0 \omega_0}{\tau_0 \omega_0 + P_0 + k \tau_0^2 + k_w \omega^2}$$

where:

- τ_0 represents the Torque at which efficiency is measured.
- ω_0 represents the **Speed at which efficiency is measured**.

- P₀ represents the Fixed losses independent of torque or speed.
- $k\tau_0^2$ represents the torque-dependent electrical losses.
- $k_{\rm w}\omega^2$ represents the speed-dependent iron losses.

At initialization, the block solves the efficiency equation for k. The block neglects losses associated with the rotor damping.

Speed at which efficiency is measured

Speed that the block uses to calculate torque-dependent electrical losses. The default value is 3.75e+03 rpm.

Torque at which efficiency is measured

Torque that the block uses to calculate torque-dependent electrical losses. The default value is 0.08 Nm.

Iron losses

Iron losses at the speed and torque at which efficiency is defined. The default value is 0 W.

Fixed losses independent of torque and speed

Fixed electrical loss associated with the driver when the motor current and torque are zero. The default value is 0 W.

Supply series resistance

The equivalent resistance used in series with the DC supply to model electrical losses that are proportional to the driver supply current. The block assumes that the DC supply current is approximately constant under constant load conditions. The default value is 0Ω .

Mechanical Tab

| Block Parameters: Servomotor | | * |
|--|--|------------------------|
| Servomotor | | |
| control mode. The motor's permissible | nd drive electronics operating in torque-control mo e range of torques and speeds is defined by a torq the torque reference demand Tr with time constar | ue-speed envelope, and |
| constant term plus two additional term speed respectively. In addition, a resis between power supply and servomoto | ected to a DC supply. Electrical losses are assumed as that are proportional to the square of the torque tor in series with the supply can be included to mo ir driver. acting from the mechanical C to R ports. | and the square of the |
| Parameters | | |
| Electrical Torque Electrical Losse | s Mechanical |] |
| Rotor inertia: | 5e-6 | kg*m^2 	▼ |
| Rotor damping: | 1e-5 | N*m/(rad/s) - |
| Initial rotor speed: | 0 | rpm 👻 |
| | OK Cancel | Help Apply |

Rotor inertia

Rotor resistance to change in motor motion. The default value is $5e-06 \text{ kg}^*\text{m}^2$. The value can be zero.

Rotor damping

Rotor damping. The default value is $1e\,{-}\,05$ N*m/(rad/s). The value can be zero.

Initial rotor speed

Rotor speed at the start of the simulation. The default value is $0\ \mbox{rpm}.$

Ports This block has the following ports:

| | + |
|----------|---|
| | Positive electrical DC supply |
| | - Negative electrical DC supply |
| | Tr Reference torque demand |
| | w Mechanical speed output |
| | C Mechanical rotational conserving port |
| | R Mechanical rotational conserving port |
| See Also | Generic Rotary Actuator, DC Motor, Induction Motor, Shunt Motor and Universal Motor. |

SFFM Current Source

| | Purpose | Model single-frequency | FM current source |
|--|---------|------------------------|-------------------|
|--|---------|------------------------|-------------------|

Library SPICE-Compatible Components/Sources

Description

The SFFM Current Source block represents a single-frequency current source whose frequency-modulated output current value is independent of the voltage across its terminals. The following equation describes the current through the source as a function of time:

$$I_{out} = IO + IA * \sin\left(\left(2\pi * FC * Time\right) + MI * \sin\left(2\pi * FS * Time\right)\right)$$

where:

- *I0* is the **Current offset**, **IO** parameter value.
- *IA* is the **Current amplitude**, **IA** parameter value.
- *FC* is the **Carrier frequency**, **FC** parameter value.
- *MI* is the **Modulation index**, **MI** parameter value.
- FS is the Signal frequency, FS parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the + and - ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

| Dialog |
|-------------------|
| Box and |
| Parameters |

| modulated current throu | M Current (SFFM) Source block mai Jgh its terminals, independent of th equation describes the current thr | ne voltage across its |
|--|---|--------------------------|
| Iout = IO+IA*sin((2*pi* | *FC*Time)+MI*sin(2*pi*FS*Time)) | |
| carrier frequency. MI is | value. IA is the magnitude of the s the signal modulation index. FS is t r (FC) and signal (FS) frequencies | he signal frequency. The |
| Parameters | | |
| Current offset, IO: | 0 | A |
| | 0 | A |
| Current amplitude, IA: | | |
| Current amplitude, IA: Carrier frequency, FC: | 0 | Hz |
| | 0 | Hz |
| Carrier frequency, FC: | - | Hz V |

Current offset, IO

The magnitude of the time-independent part of the output current. The default value is 0 A.

Current amplitude, IA

The magnitude of the sinusoidal part of the output current. The default value is 0 A. $\,$

Carrier frequency, FC

Frequency of the carrier wave. The default value is 0 Hz. The value must be greater than or equal to 0.

| | Modulation index, MI The amount by which the modulated signal varies around its unmodulated level. The default value is 0. The value must be greater than or equal to 0. |
|----------|--|
| | Signal frequency, FS Frequency of the modulated signal. The default value is 0 Hz. The value must be greater than or equal to 0. |
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | SFFM Voltage Source |

Purpose Model single-frequency FM voltage source

Library SPICE-Compatible Components/Sources

DescriptionThe SFFM Voltage Source block represents a single-frequency voltage
source whose frequency-modulated output voltage value is independent
of the current through the source. The following equation describes the
output voltage as a function of time:

$$V_{out} = VO + VA * \sin\left(\left(2\pi * FC * Time\right) + MI * \sin\left(2\pi * FS * Time\right)\right)$$

where:

- *V0* is the **Voltage offset**, **VO** parameter value.
- *VA* is the **Voltage amplitude**, **VA** parameter value.
- *FC* is the **Carrier frequency**, **FC** parameter value.
- *MI* is the **Modulation index**, **MI** parameter value.
- *FS* is the **Signal frequency**, **FS** parameter value.

SFFM Voltage Source

Dialog Box and Parameters

| 🙀 Block Parameters: S | FFM Voltage Source | x | |
|--------------------------|--|---|--|
| -SFFM Voltage Source- | | | |
| modulated voltage acros | 4 Voltage (SFFM) Source block maintains a frequency- is its terminals, independent of the current through its equation describes the voltage across the SFFM source as a | | |
| Vout = VO+VA*sin((2*pi | Vout = VO+VA*sin((2*pi*FC*Time)+MI*sin(2*pi*FS*Time)) | | |
| carrier frequency. MI is | value. VA is the magnitude of the signal voltage. FC is the the signal modulation index. FS is the signal frequency. The r (FC) and signal (FS) frequencies differ from SPICE, and are | | |
| Parameters | | | |
| Voltage offset, VO: | 0 | | |
| Voltage amplitude, VA: | 0 | | |
| Carrier frequency, FC: | 0 Hz 💌 | | |
| Modulation index, MI: | 0 | 1 | |
| Signal frequency, FS: | 0 Hz 💌 | [| |
| | | | |
| | | | |
| | OK Cancel Help Apply | | |

Voltage offset, VO

The magnitude of the time-independent part of the output voltage. The default value is 0 V.

Voltage amplitude, VA

The magnitude of the sinusoidal part of the output voltage. The default value is 0 V.

Carrier frequency, FC

Frequency of the carrier wave. The default value is 0 Hz. The value must be greater than or equal to 0.

| | Modulation index, MI The amount by which the modulated signal varies around its unmodulated level. The default value is 0. The value must be greater than or equal to 0. |
|----------|--|
| | Signal frequency, FS Frequency of the modulated signal. The default value is 0 Hz. The value must be greater than or equal to 0. |
| Ports | The block has the following ports: + Positive electrical voltage. - Negative electrical voltage. |
| See Also | SFFM Current Source |

Shunt Motor

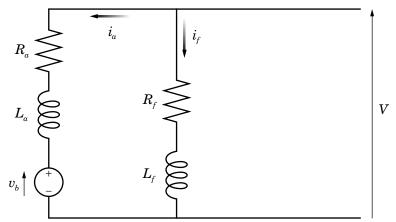
Purpose Model electrical and torque characteristics of shunt motor

Library

Rotational Actuators

Description

The Shunt Motor block represents the electrical and torque characteristics of a shunt motor using the following equivalent circuit model.



When you set the **Model parameterization** parameter to By equivalent circuit parameters, you specify the equivalent circuit parameters for this model:

- R_a Armature resistance
- L_a Armature inductance
- R_f Field winding resistance
- L_f Field winding inductance

The Shunt Motor block computes the motor torque as follows:

1 The magnetic field in the motor induces the following back $\operatorname{emf} v_b$ in the armature:

$$v_b = L_{af} i_f \omega$$

where $L_{\rm af}$ is a constant of proportionality and ω is the angular velocity.

2 The mechanical power is equal to the power reacted by the back emf:

$$P = v_b i_a = L_{af} i_f i_a \omega$$

3 The motor torque is:

$$T = P / \omega = L_{af} i_f i_a$$

The torque-speed characteristic for the Shunt Motor block model is related to the parameters in the preceding figure. When you set the **Model parameterization** parameter to By rated power, rated speed & no-load speed, the block solves for the equivalent circuit parameters as follows:

- **1** For the steady-state torque-speed relationship, *L* has no effect.
- **2** Sum the voltages around the loop:

$$V = i_a R_a + L_{af} i_f \omega$$
$$V = i_f R_f$$

3 Solve the preceding equations for i_a and i_f .

$$\begin{split} i_f &= \frac{V}{R_f} \\ i_a &= \frac{V}{R_a} \left(1 - \frac{L_{af} w}{R_f} \right) \end{split}$$

4 Substitute these values of i_a and i_f into the equation for torque:

$$T = \frac{L_{af}}{R_a R_f} \left(1 - \frac{L_{af} \omega}{R_f} \right) V^2$$

The block uses the rated speed and power to calculate the rated torque. The block uses the rated torque and no-load speed values to get one equation that relates R_a and L_{af}/R_f . It uses the no-load speed at zero torque to get a second equation that relates these two quantities. Then, it solves for R_a and L_{af}/R_f .

The block models motor inertia J and damping B for all values of the **Model parameterization** parameter. The output torque is:

$$T_{load} = \frac{L_{af}}{R_a R_f} \left(1 - \frac{L_{af} \omega}{R_f} \right) V^2 - J \dot{\omega} - B \omega$$

The block produces a positive torque acting from the mechanical C to R ports.

Thermal Ports

The block has two optional thermal ports, one per winding, hidden by default. To expose the thermal ports, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal ports on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box. These tabs are described further on this reference page.

Use the thermal ports to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports in actuator blocks, see "Simulating Thermal Effects in Rotational and Translational Actuators".

Dialog Box and Parameters

- "Electrical Torque Tab" on page 1-593
- "Mechanical Tab" on page 1-596
- "Temperature Dependence Tab" on page 1-597
- "Thermal Port Tab" on page 1-598

Electrical Torque Tab

| Shunt Motor | | |
|--|--|---|
| his block represents the electric | cal and torque characteristics of a shunt moto | or. |
| armature inductance), Rf (field back emf induced in the armatur nechanical angular speed. Alter bower & speed, nominal voltage vinding inductance, these paran | ned in terms of equivalent circuit parameters winding resistance), Lf (field winding inducta e is given by Vb = Laf * If * W where If is th atively, the motor characteristics can be defin , starting current, La and Lf. If no information teters can be set to a small non-zero value. rque acting from the mechanical C to R ports | nce) and Laf (back-emf constant). The e field current and W is the ed in terms of no-load speed, rated i is available on armature or field |
| Parameters | | |
| Electrical Torque Mechanica | al | |
| Model parameterization: | By equivalent circuit parameters | • |
| Armature resistance: | 110 | Ohm 👻 |
| Field winding resistance: | 2.5e+3 | Ohm 👻 |
| Back-emf constant: | 5.11 | s*V/rad/A ▼ |
| Armature inductance: 0.1 | | H – |
| | Field winding inductance: 0.1 H | |
| Field winding inductance: | 0.1 | H 🔻 |

Model parameterization

Select one of the following methods for block parameterization:

- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor. This is the default method.
- By rated power, rated speed & no-load speed Provide power and speed parameters that the block converts to an equivalent circuit model of the motor.

Armature resistance

Resistance of the armature. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is 110Ω .

Field winding resistance

Resistance of the field winding. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is $2.5e+03 \Omega$.

Back-emf constant

The ratio of the voltage generated by the motor to the motor speed. The default value is 5.11 s*V/rad/A.

Armature inductance

Inductance of the armature. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. The default value is 0.1 H. The value can be zero.

Field winding inductance

Inductance of the field winding. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. The default value is 0.1 H. The value can be zero.

No-load speed

Speed of the motor when no load is applied. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 4.6e+03 rpm.

Rated speed (at rated load)

Motor speed at the rated load. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 4e+03 rpm.

Rated load (mechanical power)

The mechanical load for which the motor is rated to operate. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 50 W.

Rated DC supply voltage

The voltage at which the motor is rated to operate. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 220 V.

Starting current at rated DC supply voltage

The initial current when starting the motor with the rated DC supply voltage. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 2.09 A.

Mechanical Tab

| 🙀 Block Parameters: Shunt Motor | | × | |
|---|---|---------------|--|
| Shunt Motor | | | |
| This block represents the electrical a | This block represents the electrical and torque characteristics of a shunt motor. | | |
| Motor characteristics can be defined in terms of equivalent circuit parameters Ra (armature resitance), La (armature inductance), Rf (field winding resistance), Lf (field winding inductance) and Laf (back-emf constant). The back emf induced in the armature is given by Vb = Laf * If * W where If is the field current and W is the mechanical angular speed. Alteratively, the motor characteristics can be defined in terms of no-load speed, rated power & speed, nominal voltage, starting current, La and Lf. If no information is available on armature or field winding inductance, these parameters can be set to a small non-zero value. | | | |
| Parameters | 5 | | |
| | | | |
| Electrical Torque Mechanical | | | |
| Rotor inertia: | 2e-4 | kg*m^2 | |
| Rotor damping: | 1e-6 | N*m/(rad/s) 🔻 | |
| Initial rotor speed: | 0 | rpm 👻 | |
| | | | |
| | OK Cancel | Help Apply | |

Rotor inertia

Rotor inertia. The default value is $2e \cdot 04~\mathrm{kg}^*\mathrm{m}^2.$ The value can be zero.

Rotor damping

Rotor damping. The default value is 1e-06 N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is $0\ \mathrm{rpm}.$

Temperature Dependence Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| 🙀 Block Parameters: Shunt Motor | | | — ——————————————————————————————————— |
|--|---------------------------------|--------------|--|
| Shunt Motor | | | |
| This block represents the electrical | and torque characteristics of a | shunt motor. | |
| Motor characteristics can be defined in terms of equivalent circuit parameters Ra (armature resitance), La (armature inductance), Rf (field winding resistance), Lf (field winding inductance) and Laf (back-emf constant). The back emf induced in the armature is given by Vb = Laf * If * W where If is the field current and W is the mechanical angular speed. Alteratively, the motor characteristics can be defined in terms of no-load speed, rated power & speed, nominal voltage, starting current, La and Lf. If no information is available on armature or field winding inductance, these parameters can be set to a small non-zero value. The block produces a positive torque acting from the mechanical C to R ports. | | | |
| Parameters | | | |
| Electrical Torque Mechanical | Temperature Dependence | Thermal Port | |
| Resistance temperature coefficients, [alpha_f alpha_a]: | [0.00393 0.00393] | | 1/K • |
| Measurement temperature: | 25 | | C • |
| | | | |
| | | OK Cancel | Help Apply |

Resistance temperature coefficients, [alpha_f alpha_a]

A 1 by 2 row vector defining the coefficient α in the equation relating resistance to temperature, as described in "Thermal Model for Actuator Blocks". The first element corresponds to the field winding, and the second to the armature. The default value is for copper, and is [0.00393 0.00393] 1/K.

Measurement temperature

The temperature for which motor parameters are defined. The default value is 25 C.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| 🛃 Block Parameters: Shunt Motor | | × |
|--|---|--|
| Shunt Motor | | |
| This block represents the electrical a | nd torque characteristics of a shunt motor. | |
| (armature inductance), Rf (field wind back emf induced in the armature is mechanical angular speed. Alterative power & speed, nominal voltage, sta winding inductance, these parameter | in terms of equivalent circuit parameters Ra (arma ling resistance), Lf (field winding inductance) and L given by Vb = Laf * If * W where If is the field cur ly, the motor characteristics can be defined in term rting current, La and Lf. If no information is availab rs can be set to a small non-zero value. acting from the mechanical C to R ports. | af (back-emf constant). The rent and W is the is of no-load speed, rated |
| Parameters | , , , , , , , , , , , , , , , , , , , | |
| Electrical Torque Mechanical | Temperature Dependence Thermal Port | |
| Thermal masses, [Mf Ma]: | [100 100] |]/К ╺ |
| Initial temperatures, [Tf Ta]: | [25 25] | C - |
| | | |
| | OK Cancel | Help Apply |

Thermal masses, [Mf Ma]

A 1 by 2 row vector defining the thermal mass for the field and armature windings. The thermal mass is the energy required to raise the temperature by one degree. The default value is [100 100] J/K.

Initial temperatures, [Tf Ta]

A 1 by 2 row vector defining the temperature of the field and armature thermal ports at the start of simulation. The default value is [$25 \ 25$] C.

Ports The block has the following ports:

| | + | Positive electrical input. |
|------------|---|--|
| | - | Negative electrical input. |
| | С | Mechanical rotational conserving port. |
| | R | Mechanical rotational conserving port. |
| | Ηf | Field winding thermal port. For more information, see "Thermal Ports" on page 1-897. |
| | На | Armature winding thermal port. For more information, see "Thermal Ports" on page 1-897. |
| References | | olton, W. Mechatronics: Electronic Control Systems in Mechanical Electrical Engineering, 3rd edition Pearson Education, 2004. |
| See Also | DC Motor, Induction Motor, Servomotor, and Universal Motor. | |

Purpose Model damped sinusoidal current source

SPICE-Compatible Components/Sources

Description

Library

The Sinusoidal Current Source block represents a damped sinusoidal current source whose output current is independent of the voltage across the terminals of the source. The following equations describe the current through the source as a function of time:

$$\begin{split} I_{out} \left(Time < TD \right) &= IO \\ I_{out} \left(Time \geq TD \right) &= IO + IA * e^{-(Time - TD)*DF} * \sin\left(2\pi * FREQ * (Time - TD) \right) \end{split}$$

where:

- *I0* is the **Current offset**, **IO** parameter value.
- *IA* is the **Sinusoidal amplitude**, **IA** parameter value.
- FREQ is the Sinusoidal frequency, FREQ parameter value.
- *TD* is the **Time delay**, **TD** parameter value.
- *DF* is the **Damping factor**, **DF** parameter value.

The block uses a small conductance internally to prevent numerical simulation issues. The conductance connects the + and - ports of the device and has a conductance *GMIN*:

- By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e–12.
- To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Dialog Box and Parameters

| 🖥 Block Parameters: Si | nusoidal Current Source | x | | |
|---|----------------------------------|------------|--|--|
| Sinusoidal Current Source | | | | |
| The Sinusoidal Current Source block maintains a damped sinusoidal current flow through its terminals, independent of the voltage across its terminals. The following equation describes the current through the sinusoidal source as a function of time: | | | | |
| Iout = IO+IA*exp(-(Time | e-TD)*DF)*sin(2*pi*FREQ*(Time-TD |)) | | |
| IO is the current offset value. IA is the magnitude of the signal current. FREQ is the frequency of the signal. TD is the signal time delay. DF is the signal damping factor. The default value for frequency (FREQ) differs from SPICE, and is equal to 1 MHz. | | | | |
| Parameters | | | | |
| Current offset, IO: | 0 | A | | |
| Sinusoidal amplitude, IA: | 0 | A | | |
| Sinusoidal frequency, FREQ: | 1e+06 | Hz | | |
| Time delay, TD: | 0 | s 💌 | | |
| Damping factor, DF: | 0 | 1/s 💌 | | |
| | | | | |
| | OK Cancel | Help Apply | | |

Current offset, I0

The magnitude of the time-independent part of the output current. The default value is 0 A.

Sinusoidal amplitude, IA

The magnitude of the sinusoidal part of the output current. The default value is **0** A.

Sinusoidal frequency, FREQ

The frequency of the output sine wave. The default value is 1e+06 Hz. The value can be less than 0.

Time delay, TD

The time at which the sine wave first starts. The default value is 0 s. The value can be less than 0.

| | Damping factor, DFThe amount by which to amplify or reduce the exponential damping term that multiples the sine wave to produce the output current. The default value is 0 1/s. The value must be greater than or equal to 0. |
|----------|--|
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | Negative electrical voltage. |
| See Also | Sinusoidal Voltage Source |

Sinusoidal Voltage Source

| Purpose | Model | damped | sinusoidal | voltage source |
|---------|-------|--------|------------|----------------|
|---------|-------|--------|------------|----------------|

Library SPICE-Compatible Components/Sources

Description

The Sinusoidal Voltage Source block represents a damped sinusoidal voltage source whose output voltage is independent of the current through the source. The following equations describe the output as a function of time:

 $V_{out} (Time < TD) = VO$ $V_{out} (Time \ge TD) = VO + VA * e^{-(Time - TD)*DF} * \sin(2\pi * FREQ * (Time - TD))$

where:

- *V0* is the **Voltage offset**, **VO** parameter value.
- *VA* is the **Sinusoidal amplitude**, **VA** parameter value.
- *FREQ* is the **Sinusoidal frequency**, **FREQ** parameter value.
- *TD* is the **Time delay**, **TD** parameter value.
- *DF* is the **Damping factor**, **DF** parameter value.

| Dialc | og |
|-------|--------|
| Box | and |
| Para | meters |

| 🙀 Block Parameters: 9 | 5inusoidal Volta | ige Source | | × |
|---|------------------|------------------|------|-------|
| - Sinusoidal Voltage Source | | | | |
| The Sinusoidal Voltage Source block maintains a damped sinusoidal voltage across its terminals, independent of the current through its terminals. The following equation describes the voltage across the sinusoidal source as a function of time: | | | | |
| Vout = VO+VA*exp(-(T | ime-TD)*DF)*sin(| 2*pi*FREQ*(Time- | TD)) | |
| VO is the voltage offset value. VA is the magnitude of the signal voltage. FREQ is the frequency of the signal. TD is the signal time delay. DF is the signal damping factor. The default value for frequency (FREQ) differs from SPICE, and is equal to 1 MHz. | | | | |
| -Parameters | | | | |
| Voltage offset, VO: | 0 | | V | • |
| Sinusoidal amplitude, VA: | 0 | | ٧ | • |
| Sinusoidal frequency, FREQ: | 1e+06 | | Hz | - |
| Time delay, TD: | 0 | | s | • |
| Damping factor, DF: | 0 | | 1/s | • |
| | | | | |
| | ОК | Cancel | Help | Apply |

Voltage offset, V0

The magnitude of the time-independent part of the output voltage. The default value is 0 V.

Sinusoidal amplitude, VA

The magnitude of the sinusoidal part of the output voltage. The default value is ${\bf 0}$ V.

Sinusoidal frequency, FREQ

The frequency of the output sine wave. The default value is 1e+06 Hz. The value can be less than 0.

Time delay, TD

The time at which the sine wave first starts. The default value is 0 s. The value can be less than 0.

| | Damping factor, DF The amount by which to amplify or reduce the exponential damping term that multiples the sine wave to produce the output voltage. The default value is 0 1/s. The value must be greater than or equal to 0. |
|----------|--|
| Ports | The block has the following ports: |
| | + Positive electrical voltage. |
| | - Negative electrical voltage. |
| See Also | Sinusoidal Current Source |

Solar Cell

| Purpose | Solar | cell | model |
|---------|-------|------|-------|
|---------|-------|------|-------|

Library

Sources

Description

The Solar Cell block represents a solar cell current source. The solar cell model includes the following components:

- "Solar-Induced Current" on page 1-607
- "Temperature Dependence" on page 1-610
- "Thermal Port" on page 1-611

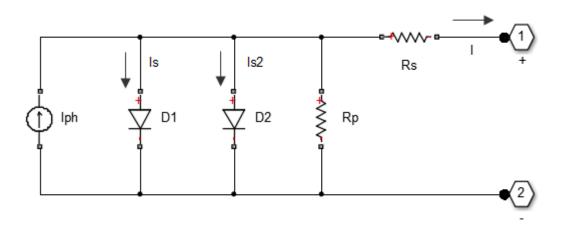
Solar-Induced Current

The block represents a single solar cell as a resistance R_s that is connected in series with a parallel combination of the following elements:

- Current source
- Two exponential diodes
- Parallel resistor R_p

The following illustration shows the equivalent circuit diagram:

Solar Cell



The output current I is:

$$I = I_{ph} - I_s * \left(e^{(V+I*R_s)/(N*V_t)} - 1 \right) - I_{s2} * \left(e^{(V+I*R_s)/(N_2*V_t)} - 1 \right) - \left(V + I*R_s \right) / R_p$$

where:

• I_{ph} is the solar-induced current:

$$I_{ph} = I_{ph0} \times \frac{I_r}{I_{r0}}$$

where:

- I_r is the irradiance (light intensity) in W/m² falling on the cell.
- I_{ph0} is the measured solar-generated current for the irradiance I_{r0} .
- I_s is the saturation current of the first diode.
- $I_{\rm s2}$ is the saturation current of the second diode.
- V_t is the thermal voltage, kT/q, where:
 - *k* is the Boltzmann constant.

- *T* is the **Device simulation temperature** parameter value.
- *q* is the elementary charge on an electron.
- *N* is the quality factor (diode emission coefficient) of the first diode.
- N_2 is the quality factor (diode emission coefficient) of the second diode.
- *V* is the voltage across the solar cell electrical ports.

The quality factor varies for amorphous cells, and is typically 2 for polycrystalline cells.

The block lets you choose between two models:

- An 8-parameter model where the preceding equation describes the output current
- A 5-parameter model that applies the following simplifying assumptions to the preceding equation:
 - The saturation current of the second diode is zero.
 - The impedance of the parallel resistor is infinite.

If you choose the 5-parameter model, you can parameterize this block in terms of the preceding equivalent circuit model parameters or in terms of the short-circuit current and open-circuit voltage the block uses to derive these parameters.

All models adjust the block resistance and current parameters as a function of temperature.

You can model any number of solar cells connected in series using a single Solar Cell block by setting the parameter **Number of series cells** to a value larger than 1. Internally the block still simulates only the equations for a single solar cell, but scales up the output voltage according to the number of cells. This results in a more efficient simulation than if equations for each cell were simulated individually.

If you want to model N cells in parallel, you can do so for single cells by scaling the parameter values accordingly. That is, multiply short-circuit current, diode saturation current, and solar-generated currents by N, and divide series resistance by N. To connect solar cell blocks in parallel, where each block contains multiple cells in series, make multiple copies of the block and connect accordingly.

Temperature Dependence

Several solar cell parameters depend on temperature. The solar cell temperature is specified by the **Device simulation temperature** parameter value.

The block provides the following relationship between the solar-induced current I_{ph} and the solar cell temperature *T*:

$$I_{ph}(t) = I_{ph} * (1 + TIPH1 * (T - T_{meas}))$$

where:

- *TIPH1* is the **First order temperature coefficient for Iph**, **TIPH1** parameter value.
- T_{meas} is the **Measurement temperature** parameter value.

The block provides the following relationship between the saturation current of the first diode I_s and the solar cell temperature T:

$$I_{s1}(T) = I_{s1} * \left(\frac{T}{T_{meas}}\right)^{TXIS1/N} * e^{\left(EG * \left(\frac{T}{T_{meas}} - 1\right)/(N*V_t)\right)}$$

where *TXIS1* is the **Temperature exponent for Is, TXIS1** parameter value.

The block provides the following relationship between the saturation current of the second diode I_{s2} and the solar cell temperature T:

$$I_{s2}(T) = I_{s2} * \left(\frac{T}{T_{meas}}\right)^{(TXIS2/N_2)} * e^{\left(EG^*\left(\frac{T}{T_{meas}} - 1\right)/(N_2^*V_t)\right)}$$

where *TXIS2* is the **Temperature exponent for Is2**, **TXIS2** parameter value.

The block provides the following relationship between the series resistance R_s and the solar cell temperature T:

$$R_s(T) = R_s * \left(\frac{T}{T_{meas}}\right)^{TRS1}$$

where *TRS1* is the **Temperature exponent for Rs, TRS1** parameter value.

The block provides the following relationship between the parallel resistance R_p and the solar cell temperature T:

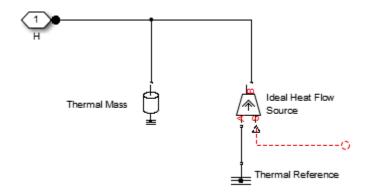
$$R_p(T) = R_p * \left(\frac{T}{T_{meas}}\right)^{TRP1}$$

where *TRP1* is the **Temperature exponent for Rp, TRP1** parameter value.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

The thermal port model, shown in the following illustration, represents just the thermal mass of the device. The thermal mass is directly connected to the component thermal port H. An internal Ideal Heat Flow Source supplies a heat flow to the port and thermal mass. This heat flow represents the internally generated heat.



The internally generated heat in the solar cell is calculated according to the equivalent circuit diagram, shown at the beginning of the reference page, in the "Solar-Induced Current" on page 1-607 section. It is the sum of the $i^2 \cdot R$ losses for each of the resistors plus the losses in each of the diodes.

The internally generated heat due to electrical losses is a separate heating effect to that of the solar irradation. To model thermal heating due to solar irradiation, you must account for it separately in your model and add the heat flow to the physical node connected to the solar cell thermal port.

- "Cell Characteristics Tab" on page 1-613
- "Configuration Tab" on page 1-616
- "Temperature Dependence Tab" on page 1-617
- "Thermal Port Tab" on page 1-618

Dialog Box and Parameters

Cell Characteristics Tab

| Block Parameters: Solar Cell | | | | |
|---|---|-------------------------|--|--|
| Solar Cell | | | | |
| | varallel combination of a current source, two expone eries with a resistance Rs. The output current I is giv | | | |
| I = Iph - Is*(e^((V+I*Rs)/(N*Vt))-1 | l) - Is2*(e^((V+I*Rs)/(N2*Vt))-1) - (V+I*Rs)/Rp | | | |
| where Is and Is2 are the diode satur (diode emission coefficients) and Iph | ration currents, Vt is the thermal voltage, N and N2 a h is the solar-generated current. | are the quality factors | | |
| typically has a value in the range of | Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. The physical signal input Ir is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current Iph is given by Ir*(Iph0/Ir0) where Iph0 is the measured solar-generated current for irradiance Ir0. | | | |
| Parameters | | | | |
| Cell Characteristics Configuration Temperature Dependence | | | | |
| Parameterize by: | By s/c current and o/c voltage, 5 parameter | • | | |
| Short-circuit current, Isc: | 7.34 | A • | | |
| Open-circuit voltage, Voc: | 0.6 | V • | | |
| Irradiance used for measurements, Ir0: | 1000 | W/m^2 - | | |
| Quality factor, N: | 1.5 | | | |
| Series resistance, Rs: | 0 | Ohm 👻 | | |
| <u></u> | OK Cancel | Help Apply | | |

Parameterize by

Select one of the following methods for block parameterization:

- By s/c current and o/c voltage, 5 parameter Provide short-circuit current and open-circuit voltage that the block converts to an equivalent circuit model of the solar cell. This is the default option.
- By equivalent circuit parameters, 5 parameter Provide electrical parameters for an equivalent circuit model

of the solar cell using the 5-parameter solar cell model that makes the following assumptions:

- The saturation current of the second diode is zero.
- The parallel resistor has infinite impedance.
- By equivalent circuit parameters, 8 parameter Provide electrical parameters for an equivalent circuit model of the solar cell using the 8-parameter solar cell model.

Short-circuit current, Isc

The current that flows when you short-circuit the solar cell. This parameter is only visible when you select By s/c current and o/c voltage, 5 parameter for the **Parameterize by** parameter. The default value is 7.34 A.

Open-circuit voltage, Voc

The voltage across the solar cell when it is not connected. This parameter is only visible when you select By s/c current and o/c voltage, 5 parameter for the **Parameterize by** parameter. The default value is 0.6 V.

Diode saturation current, Is

The asymptotic reverse current of the first diode for increasing reverse bias in the absence of any incident light. This parameter is only visible when you select one of the following settings:

- By equivalent circuit parameters, 5 parameter for the **Parameterize by** parameter
- By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter

The default value is 1e-06 A.

Diode saturation current, Is2

The asymptotic reverse current of the second diode for increasing reverse bias in the absence of any incident light. This parameter is only visible when you select By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter. The default value is 0 A.

Solar-generated current, Iph0

The solar-induced current when the irradiance is I_{r0} . This parameter is only visible when you select one of the following settings:

- By equivalent circuit parameters, 5 parameter for the **Parameterize by** parameter
- By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter

The default value is 7.34 A.

Irradiance used for measurements, Ir0

The irradiance that produces a current of I_{ph0} in the solar cell. The default value is 1000 W/m².

Quality factor, N

The emission coefficient of the first diode. The default value is 1.5.

Quality factor, N2

The emission coefficient of the second diode. This parameter is only visible when you select By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter. The default value is 2.

Series resistance, Rs

The internal series resistance. The default value is 0 Ω .

Parallel resistance, Rp

The internal parallel resistance. This parameter is only visible when you select By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter. The default value is inf Ω .

Configuration Tab

| 🖹 Block Parameters: Solar Cell |
|---|
| Solar Cell |
| This block models a solar cell as a parallel combination of a current source, two exponential diodes and a parallel resistor, Rp, that are connected in series with a resistance Rs. The output current I is given by |
| $I = Iph - Is^{*}(e^{(V+I^{*}Rs)/(N^{*}Vt))-1}) - Is2^{*}(e^{(V+I^{*}Rs)/(N2^{*}Vt))-1}) - (V+I^{*}Rs)/Rp$ |
| where Is and Is2 are the diode saturation currents, Vt is the thermal voltage, N and N2 are the quality factors (diode emission coefficients) and Iph is the solar-generated current. |
| Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. The physical signal input Ir is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current Iph is given by Ir*(Iph0/Ir0) where Iph0 is the measured solar-generated current for irradiance Ir0. |
| Parameters |
| Cell Characteristics Configuration Temperature Dependence |
| Number of series cells: 1 |
| |
| |
| |
| |
| OK Cancel Help Apply |

Number of series cells

The number of series-connected solar cells modeled by the block. The default value is 1. The value must be greater than 0.

Temperature Dependence Tab

| 🚡 Block Parameters: Solar Cell | | | |
|---|---|----------------------------|--|
| Solar Cell | | | |
| | parallel combination of a current source, two exp eries with a resistance Rs. The output current I i | | |
| $I = Iph - Is^{*}(e^{(V+I^{*}Rs)/(N^{*}Vt))}$ | 1) - Is2*(e^((V+I*Rs)/(N2*Vt))-1) - (V+I*Rs)/R | p | |
| where Is and Is2 are the diode satu (diode emission coefficients) and Ip | ration currents, Vt is the thermal voltage, N and h is the solar-generated current. | N2 are the quality factors | |
| Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. The physical signal input Ir is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current Iph is given by Ir*(Iph0/Ir0) where Iph0 is the measured solar-generated current for irradiance Ir0. | | | |
| Parameters | | | |
| Cell Characteristics Configuration Temperature Dependence | | | |
| First order temperature coefficient for Iph, TIPH1: | 0 | 1/K 👻 | |
| Energy gap, EG: | 1.11 | eV 🗸 | |
| Temperature exponent for Is, TXIS1: | 3 | | |
| Temperature exponent for Rs, TRS1: | 0 | | |
| Measurement temperature: | 25 | C • | |
| Device simulation temperature: | 25 | C • | |
| L | | | |
| | OK Canc | | |
| | OK Canc | el Help Apply | |

First order temperature coefficient for Iph, TIPH1

The order of the linear increase in the solar-generated current as temperature increases. The default value is $0 \ 1/K$. The value must be greater than or equal to 0.

Energy gap, EG

The solar cell activation energy. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Temperature exponent for Is, TXIS1

The order of the exponential increase in the current from the first diode as temperature increases. The default value is **3**. The value must be greater than or equal to **0**.

Temperature exponent for Is2, TXIS2

The order of the exponential increase in the current from the second diode as temperature increases. This parameter is only visible when you select By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter. The default value is 3. The value must be greater than or equal to 0.

Temperature exponent for Rs, TRS1

The order of the exponential increase in the series resistance as temperature increases. The default value is 0. The value must be greater than or equal to 0.

Temperature exponent for Rp, TRP1

The order of the exponential increase in the parallel resistance as temperature increases. This parameter is only visible when you select By equivalent circuit parameters, 8 parameter for the **Parameterize by** parameter. The default value is 0. The value must be greater than or equal to 0.

Measurement temperature

The temperature at which the solar cell parameters were measured. The default value is 25 C. The value must be greater than 0.

Device simulation temperature

The temperature at which the solar cell is simulated. The default value is 25 C. The value must be greater than 0.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Port" on page 1-611.

| Block Parameters: Solar Cell | | | | | |
|--|---|---------------------------------|---------------------|---------------------------|--|
| Solar Cell | | | | | |
| | This block models a solar cell as a parallel combination of a current source, two exponential diodes and a parallel resistor, Rp, that are connected in series with a resistance Rs. The output current I is given by | | | | |
| $I = Iph - Is^{(e^{(V+I^*Rs)/(N^*Vt))}$ | -1) - Is | s2*(e^((V+I*Rs)/(N2*Vt))-1) | - (V+I*Rs)/Rp | | |
| where Is and Is2 are the diode sa (diode emission coefficients) and 3 | | | oltage, N and N2 a | are the quality factors | |
| Models of reduced complexity can typically has a value in the range of falling on the cell. The solar-gener generated current for irradiance In | of 1 to 2 ated c | 2. The physical signal input Ir | is the irradiance (| light intensity) in W/m^2 | |
| Parameters | | | | | |
| Cell Characteristics Configur | ation | Temperature Dependence | Thermal Port | | |
| Thermal mass: | 10 | 0 | | Ј/К ╺ | |
| Initial temperature: | Initial temperature: 25 C 🔹 | | | C 🗸 | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| OK Cancel Help Apply | | | | | |

Thermal mass

The heat energy required to raise the temperature of the solar cell by one degree. When modeling more than one cell in series, specify the thermal mass for a single cell. This value gets multiplied internally by the number of cells to determine the total thermal mass. The default value is 100 J/K.

Initial temperature

The temperature of the solar cell at the start of simulation. The default value is $\mathbf{25}\ \mathrm{C}.$

Ports The block has the following ports:

 Ir
 Incident irradiance

 +
 Positive electrical voltage

 Negative electrical voltage

 References
 [1] Gow, J.A. and C.D. Manning. "Development of a Photovoltaic Array Model for Use in Power-Electronics Simulation Studies." *IEEE Proceedings of Electric Power Applications*, Vol. 146, No. 2, 1999, pp.

193-200.

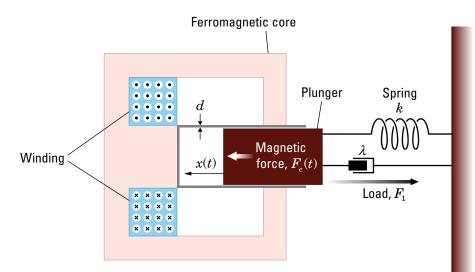
Purpose Model electrical characteristics and generated force of solenoid

Translational Actuators

Description

Library

The Solenoid block represents the electrical characteristics and generated force for the solenoid in the following figure:



The return spring is optional. To remove the effects of this spring from the model, set the **Spring constant** parameter to **0**.

The equation of motion for the plunger as a function of position, x, is:

 $F_1 + m\ddot{x} + \lambda\dot{x} + kx = F_e$

where F_e is the electromagnetic force, F_l is the load force, λ is the viscous damping term and m is the plunger mass. The electromagnetic force is related to the solenoid current and inductance by:

$$F_e = \frac{1}{2}i^2 \frac{\partial L(x)}{\partial x}$$

The inductance, which is derived in [1], can be written as:

$$\frac{\partial L(x)}{\partial x} = \frac{-\beta}{\left(\alpha + \beta x\right)^2}$$

where *a* and β are constants. Plugging the preceding equation into the equation for electromagnetic force gives the force-stroke relationship of the solenoid for a current i_0 :

$$F = \frac{1}{2}i_0^2 \frac{-\beta}{\left(\alpha + \beta x\right)^2}$$

The Solenoid block solves for a and β by taking the two specified force and stroke measurements and substituting them into the preceding equation. It solves the resulting equations for a and β .

A positive current from the electrical + to - ports creates a negative force (i.e., a pulling force) from the mechanical C to R ports.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box.

Use the thermal port to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using thermal ports and on the **Temperature Dependence** and **Thermal port** tab parameters, see "Simulating Thermal Effects in Rotational and Translational Actuators".

Dialog Box and Parameters

| Magnetic Force Tab |
|--------------------|
|--------------------|

| 🙀 Block Parameters: S | olenoid | | | × |
|--|--|--|---|---|
| Solenoid | | | | |
| This block implements th Parameterization is in te curve for a 100 percent X2>X1>0 are stoke valu in (i.e. air gap closed) co quadratically with the m- condition should hold: X2 The plunger Maximum st set by the Contact stiffr are used to model the co constant parameter is us can be set to zero. A positive current from t pulling force) acting from | rms of two points duty cycle at Ra les and F1>F2>C yrresponds to X= agnitude of X. To 2/X1>sqrt(F1/F2) roke is implement less and Contact ontact dynamics i sed to implement the electrical + to | s [X1,F1] and [X: ted voltage Vdc) are correspond 0, and pull-in for ensure the forc). ted as a hard sto damping param when the plunge a spring force the o - ports results is | 2,F2] on its force and Rated curre ing forces. The rce is assumed to e remains finite, op, the dynamics eters. The same r pulls fully in. Th nat pulls the plur | e-stroke int Idc where plunger fully o decrease the following ; of which are parameters he Spring nger out, and |
| Parameters | | | | |
| Magnetic Force M | echanical | | | 1 |
| Forces [F1 F2]: | [7.5 0.75] | | N | • |
| Stroke [X1 X2]: | [15] | | mm | • |
| Rated voltage Vdc: | 50 | | ۷ | • |
| Rated current Idc: | 0.05 | | A | • |
| | | | | |
| | ОК | Cancel | Help | Apply |

Forces [F1 F2]

A vector of the force values at the two points on the force-stroke curve. The second measurement point must be at a stroke that is greater than that of the first measurement point. When the manufacturer doesn't provide a force-stroke curve, set F1 to the holding torque (when X1 = 0) and F2 to the pull-in torque when running the solenoid at the **Rated voltage Vdc** and **Rated current Idc** values. The default value is [7.5 0.75] N.

Stroke [X1 X2]

A vector of the stroke (plunger distance from the fully closed position) values at the two points on the force-stroke curve. The second measurement point must be at a stroke that is greater than that of the first measurement point. To ensure a finite force value, the points must meet the condition

$$\frac{X2}{X1} > \sqrt{\frac{F1}{F2}}$$

The default value is [1 5] mm.

Rated voltage Vdc

The voltage at which the solenoid is rated to operate. This voltage value is used to measure the **Forces [F1 F2]** and **Stroke [X1 X2]** values. The default value is 50 V.

Rated current Idc

The current that flows when the solenoid is supplied with the **Rated voltage Vdc** voltage. The default value is 0.05 A.

Mechanical Tab

| Block Parameters: So | lenoid | | | × |
|--|-------------------|--------------------|---------|----------|
| Solenoid | | | | |
| This block implements the electrical and mechanical characteristics of a solenoid. Parameterization is in terms of two points [X1,F1] and [X2,F2] on its force-stroke curve for a 100 percent duty cycle at Rated voltage Vdc and Rated current Idc where X2>X1>O are stoke values and F1>F2>O are corresponding forces. The plunger fully in (i.e. air gap closed) corresponds to X=O, and pull-in force is assumed to decrease quadratically with the magnitude of X. To ensure the force remains finite, the following condition should hold: X2/X1>sqrt(F1/F2). The plunger Maximum stroke is implemented as a hard stop, the dynamics of which are set by the Contact stiffness and Contact damping parameters. The same parameters are used to model the contact dynamics when the plunger pulls fully in. The Spring constant parameter is used to implement a spring force that pulls the plunger out, and | | | | |
| can be set to zero. A positive current from th pulling force) acting from Parameters | e electrical + to | - ports results in | | |
| Magneder orce | | | | |
| Spring constant: | 200 | | N/m | |
| Stroke for zero spring force: | 5 | | mm | - |
| Damping: | 1 | | N/(m/s) | - I |
| Plunger mass: | 0.05 | | kg | - |
| Maximum stroke: | Inf | | mm | • |
| Initial plunger position: | 5 | | mm | • |
| Contact stiffness: | 1e+06 | | N/m | - |
| Contact damping: | 500 | | N/(m/s) | • |
| | | | | |
| | ОК | Cancel | Help | Apply |

Spring constant

Constant representing the stiffness of the spring that acts to retract the plunger when the solenoid is powered off. The force is zero when the plunger is displaced to the **Stroke for zero spring force** parameter value. The default value is 200 N/m. Set the spring constant to zero if there is no spring.

Stroke for zero spring force

The stroke at which the spring provides no force. The default value is 5 mm.

Damping

The term λ in the equation of motion for the plunger as a function of position that linearly damps the plunger motion. The default value is 1 N/(m/s). The value can be zero.

Plunger mass

The weight of the solenoid plunger. The default value is 0.05 kg. The value can be zero.

Maximum stroke

The maximum amount by which the plunger can be displaced. You can use this parameter to model a hard endstop that limits the stroke. The default value is Inf mm, which means no stroke limit.

Initial plunger position

The amount by which the plunger is displaced at the start of the simulation. The default value is 0 m.

Contact stiffness

Stiffness of the plunger contact that models the hard stop at the minimum (x = 0) and maximum (x = Maximum stroke) plunger positions. The default value is 1e+06 N/m.

Contact damping

Damping of the plunger contact that models the hard stop at the minimum (x = 0) and maximum (x = Maximum stroke) plunger positions. The default value is 500 N/(m/s).

The block has the following ports:

Ports

| | + | Positive electrical input. |
|------------|---|--|
| | - | Negative electrical input. |
| | С | Mechanical translational conserving port. |
| | R | Mechanical translational conserving port. |
| References | | .E. Lyshevski. Electromechanical Systems, Electric Machines, and ied MechatronicsCRC, 1999. |

SPDT Switch

| Purpose Model single-pole | e double-throw switch |
|---------------------------|-----------------------|
|---------------------------|-----------------------|

Library

Passive Devices/Switches

Description



The SPDT Switch block models a single-pole double-throw switch:

- When the switch is closed, port c is connected to port s2.
- When the switch is open, port c is connected to port s1.

Closed connections are modeled by a resistor with value equal to the **Closed resistance** parameter value. Open connections are modeled by a resistor with value equal to the reciprocal of the **Open conductance** parameter value.

The switch is closed if the voltage presented at the vT control port exceeds the value of the **Threshold** parameter.

Optionally, you can add a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing. To enable the delay, on the **Dynamics** tab, set the **Model dynamics** parameter to Model turn-on and turn-off times.

Dialog Box and Parameters

- "Main Tab" on page 1-629
- "Dynamics Tab" on page 1-630

Main Tab

| 🚂 Block Parameters: SPDT Switch | | |
|---------------------------------|--|---|
| SPDT Switch | | |
| | Pole Double-Throw (SPDT) switch then the switch is closed, otherwise | controlled by an external control signal vT. e the switch is open. |
| Parameters | | |
| Main Dynamics | | |
| Closed resistance: | 0.01 | Ohm |
| Open conductance: | 1e-6 | S |
| Threshold: | 0 | v |
| | | |
| | | OK Cancel Help A |

Closed resistance

Resistance between the c and s electrical ports when the switch is closed. The value must be greater than zero. The default value is 0.01Ω .

Open conductance

Conductance between the c and s electrical ports when the switch is open. The value must be greater than zero. The default value is $1e-6\ {\rm S}.$

Threshold

The threshold voltage for the control physical signal input vT above which the switch will turn on. The default value is 0 V.

Dynamics Tab

| 1 | 🙀 Block Parameters: SPDT Sw | tch |
|---|-----------------------------|--|
| | SPDT Switch | |
| | | gle-Pole Double-Throw (SPDT) switch controlled by an external control signal vT. If vT ld, then the switch is closed, otherwise the switch is open. |
| | Parameters | |
| | Main Dynamics | |
| | Model dynamics: | No dynamics 🔹 |
| | | |
| | | |
| | | |
| | | OK Cancel Help Apply |

Model dynamics

Select whether the block models a switching delay:

- No dynamics Do not model the delay. This is the default option.
- Model turn-on and turn-off times Use additional parameters to model a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing.

| Turn-on | delay |
|---------|-------|
|---------|-------|

Time between the input voltage exceeding the threshold voltage and the switch closing. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Turn-off delay

Time between the input voltage falling below the threshold voltage and the switch opening. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Initial input value, vT

The value of the physical signal input vT at time zero. This value is used to initialize the delayed control voltage parameter internally. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The default value is 0 V.

Ports This block has the following ports:

vТ

Physical signal that opens and closes the switch.

c, s1, s2

Electrical conserving ports.

See Also DPDT Switch

DPST Switch

SPST Switch

Simscape Switch

SPICE Diode

| Purpose | Model SPICE-compatible diode |
|-------------|--|
| Library | SPICE-Compatible Components/Semiconductor Devices |
| Description | The SPICE Diode block represents a SPICE-compatible diode. |
| •+ | The SPICE Diode block model includes the following components: |
| | "Current-Voltage Model" on page 1-632 |

- "Junction Charge Model" on page 1-634
- "Temperature Dependence" on page 1-635

Current-Voltage Model

The block provides the following relationship between the diode current I_d and the diode voltage V_d after adjusting the applicable model parameters for temperature.

| Applicable Range of V _d Values | Corresponding I _d Equation |
|--|---|
| $V_d > 80 * V_t$ | $I_d = IS\left(\left(\frac{V_d}{V_t} - 79\right)e^{80} - 1\right) + V_d * G \min$ |
| $80 * V_t \ge V_d \ge -3 * V_t$ | $I_d = IS * (e^{V_d/V_t} - 1) + V_d * G \min$ |

| Applicable Range of V _d Values | Corresponding I _d Equation |
|--|--|
| $-3*V_t > V_d \ge -BV$ | $I_d = -IS\left(1 + \frac{27}{\left(V_d / V_t\right)^3 e^3}\right) + V_d * G \min$ |
| $V_d < -BV$ | $I_d = -IBV * (e^{(-(BV+V_d)/V_t)} - 1) -$ |
| | $IS * \left(1 - \left(\frac{3}{e * BV_{V_t}} \right)^3 \right) + V_d * G \min$ |

Where:

- *IS* is the **Saturation current**, **IS** parameter value.
- $V_t = N * k * T/q$
- *N* is the **Emission coefficient**, **ND** parameter value.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.

- If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.
- BV is the Reverse breakdown voltage, BV parameter value.

Junction Charge Model

The block provides the following relationship between the diode charge Q_d and the diode voltage V_d after adjusting the applicable model parameters for temperature.

| Applicable Range of V _d Values | Corresponding Q _d Equation |
|---|--|
| $V_d < FC * VJ$ | $Q_{d} = TT * I_{d} + CJO * VJ * \frac{1 - \left(1 - \frac{V_{d}}{VJ}\right)^{1 - MG}}{1 - MG}$ |
| $V_d \ge FC * VJ$ | $Q_{d} = TT * I_{d} + CJO * \left(F1 + \frac{F3 * (V_{d} - FC * VJ) + (\frac{MG}{2 * VJ}) * (V_{d}^{2} - (FC * VJ)^{2})}{F2}\right)$ |

Where:

• *FC* is the **Capacitance coefficient FC** parameter value.

- *VJ* is the **Junction potential VJ** parameter value.
- *TT* is the **Transit time**, **TT** parameter value.
- CJ0 is the Zero-bias junction capacitance CJ0 parameter value.
- *MG* is the **Grading coefficient MG** parameter value.
- $F1 = VJ * (1 (1 FC)^{(1-MG)})/(1 MG)$
- $F2 = (1 FC)^{(1+MG)}$
- F3 = 1 FC * (1 + MG)

Temperature Dependence

Several diode parameters depend on temperature. There are two ways to specify the diode temperature:

• When you select Device temperature for the Model temperature dependence using parameter, the diode temperature is

$$T = T_C + T_O$$

where:

- T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the diode temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the saturation current IS and the diode temperature T:

$$IS(T) = IS * (T/T_{meas})^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}} - 1\right) * \frac{EG}{V_{t}}}$$

where:

- *IS* is the **Transport saturation current**, **IS** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent**, **XTI** parameter value.
- *ND* is the **Emission coefficient**, **ND** parameter value.
- *EG* is the **Activation energy**, **EG** parameter value.
- $V_t = kT/q$.

The block provides the following relationship between the junction potential VJ and the diode temperature T:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T_{meas}}$$

where:

- VJ is the Junction potential, VJ parameter value.
- $EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4 * T_{meas}^{2}) / (T_{meas} + 1108)$
- $EG_T = 1.16eV (7.02e 4 * T^2) / (T + 1108)$

The block provides the following relationship between the junction capacitance CJO and the diode temperature T:

$$CJO(T) = CJO*\left[1 + MG*\left(400e - 6*(T - T_{meas}) - \frac{VJ(T) - VJ}{VJ}\right)\right]$$

where $C\!J\!O$ is the Zero-bias junction capacitance CJ0 parameter value.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The SPICE Diode block does not support noise analysis.
- The SPICE Diode block applies initial conditions across junction capacitors and not across the block ports.

Dialog Box and Parameters

Main Tab

| Block Parameters: SPICE Diode | <u>×</u> |
|--|--|
| SPICE Diode | |
| | ou specify both model card and instance parameters as instance parameters on this mask. model parameters KF and AF are not supported. Additional instance parameters are SCALE |
| | nces for this device. SCALE multiplies the output current and device charge directly. This ultiples the device parameters IS, CJO and IBV, and divides RS. |
| You can set the diode temperature to a fixe plus TOFFSET. | ed temperature or to the circuit temperature (from the SPICE Environment Parameters block) |
| modeling uses the published equations, whi | itance modeling, initial conditions and reverse breakdown modeling. The capacitance ich may yield a slightly different value than SPICE for capacitance. The initial condition VO is ion, so it is only effective when junction capacitance is present. The breakdown voltage BV is vn current IBV. |
| Parameters | |
| | |
| Main Junction Capacitance Rev | verse Breakdown Temperature |
| Device area, AREA: | 1 m^2 |
| Number of parallel devices, SCALE: | 1 |
| Saturation current, IS: | 1e-14 A/m^2 |
| Ohmic resistance, RS: | 0.01 m^2*0hm 💌 |
| Emission coefficient, ND: | 1 |
| | |
| | |
| | OK Cancel Help Apply |

Device area, AREA

The diode area. This value multiplies the **Saturation current**, **IS**, **Zero-bias junction capacitance CJ0**, and **Reverse breakdown current**, **IBV** parameter values. It divides the **Ohmic resistance**, **RS** parameter value. The default value is 1 m^2 . The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel diodes the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Ohmic resistance, RS

The series diode connection resistance. The default value is 0.01 $m^{2*}\Omega$. The value must be greater than or equal to 0.

Emission coefficient, ND

The diode emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

Junction Capacitance Tab

| Block Parameters: SPICE Diode | | × |
|---|--|----------|
| SPICE Diode | | |
| | e. You specify both model card and instance parameters as instance parameters on this ma oise model parameters KF and AF are not supported. Additional instance parameters are S | |
| | nstances for this device. SCALE multiplies the output current and device charge directly. Th h multiples the device parameters IS, CJO and IBV, and divides RS. | nis |
| You can set the diode temperature to plus TOFFSET. | a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters | block) |
| modeling uses the published equations | apacitance modeling, initial conditions and reverse breakdown modeling. The capacitance , which may yield a slightly different value than SPICE for capacitance. The initial condition , unction, so it is only effective when junction capacitance is present. The breakdown voltag vdown current IBV. | |
| Parameters | | |
| Main Junction Capacitance | Reverse Breakdown Temperature | |
| Model junction capacitance?: | No | . |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel Help A | ipply |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient MG

The grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than 0.95.

Transit time, TT

The transit time of the minority carriers that cause diffusion capacitance. This parameter is only visible when you select Yes for the Model junction capacitance parameter. The default value is $0 \, s$. The value must be greater than or equal to 0.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

Note The SPICE Diode block applies the initial diode voltage across the junction capacitors and not across the ports.

Initial voltage V0

Diode voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Note The block applies the initial condition across the diode junction, so the initial condition is only effective when charge storage is included, i.e. when one or both of the **Zero-bias junction capacitance CJ0** and **Transit time, TT** parameters are greater than zero.

Reverse Breakdown Tab

| | 2 | | | | |
|---|--|----------------------|--------------------|---------------------|-------------------|
| PICE Diode | | | | | |
| 'his model approximates a SPICE dic 'he instance parameter OFF and the and TOFFSET. | | | | | |
| CALE is the number of parallel diode differs from the AREA parameter, wh | | | | | e directly. This |
| 'ou can set the diode temperature to olus TOFFSET. | o a fixed temperature or I | to the circuit tempe | rature (from the S | PICE Environment | : Parameters blo |
| he block lets you include or exclude nodeling uses the published equation he voltage across the internal diode not adjusted as a function of the bre | ns, which may yield a slig junction, so it is only effi | ntly different value | than SPICE for ca | pacitance. The init | tial condition VC |
| 'arameters | | | | | |
| Main Junction Capacitance | Reverse Breakdown | Temperature | | | |
| | | remperature | | | |
| Model reverse breakdown?: | No | Temperature | | | - |
| · · · | No | | | | • |
| · · · | No | | | | . |
| · · · | No | | | | <u>.</u> |
| · · · | No | | | | <u> </u> |
| · · · | No | | | | <u> </u> |
| · · · | No | | | | × |
| · · · | No | | | | ¥ |

Model reverse breakdown

Select one of the following options for modeling the diode reverse breakdown:

- No Don't model reverse breakdown. This is the default option.
- Yes Introduce a second exponential term to the diode I-V relationship, thereby modeling a rapid increase in conductance as the breakdown voltage is exceeded.

Reverse breakdown current, IBV

The diode current that corresponds to the **Reverse breakdown** voltage, BV value. This parameter is only visible when you select Yes for the **Model reverse breakdown** parameter. The default value is 0.001 A/m_2 . The value must be greater than 0.

Note The Diode model does not use this parameter at this time.

Reverse breakdown voltage, BV

The voltage below which to model the rapid increase in conductance that occurs at diode breakdown. This parameter is only visible when you select Yes for the **Model reverse breakdown** parameter. The default value is Inf V. The value must be greater than or equal to 0.

Temperature Tab

| Block Parameters: SPICE Diode | |
|--|--|
| 5PICE Diode | |
| | u specify both model card and instance parameters as instance parameters on this mask. model parameters KF and AF are not supported. Additional instance parameters are SCALE |
| | nces for this device. SCALE multiplies the output current and device charge directly. This ltiples the device parameters IS, CJO and IBV, and divides RS. |
| 'ou can set the diode temperature to a fixe plus TOFFSET. | ed temperature or to the circuit temperature (from the SPICE Environment Parameters bloc |
| nodeling uses the published equations, whi | tance modeling, initial conditions and reverse breakdown modeling. The capacitance ch may yield a slightly different value than SPICE for capacitance. The initial condition VO on, so it is only effective when junction capacitance is present. The breakdown voltage BV in current TBV |
| | I Current IDV. |
| Parameters | |
| Main Junction Capacitance Rev | erse Breakdown Temperature |
| Model temperature dependence using: | Device temperature |
| Saturation current temperature exponent, XTI: | 3 |
| Activation energy, EG: | 1.11 eV 💌 |
| Offset local circuit temperature, TOFFSET: | о К т |
| Parameter extraction temperature, TMEAS: | 300.15 K |
| | |
| | |
| | OK Cancel Help Apply |

Model temperature dependence using

Select one of the following options for modeling the diode temperature dependence:

- Device temperature Use the device temperature, which is the **Circuit temperature** parameter value (from the SPICE Environment Parameters block, if one exists in the circuit, or the default value for this block otherwise) plus the **Offset local circuit temperature**, **TOFFSET** parameter value.
- Fixed temperature Use a temperature that is independent of the circuit temperature to model temperature dependence.

| Saturation c | urrent temperature | exponent, XTI |
|--------------|--------------------|---------------|
|--------------|--------------------|---------------|

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than 0.

Activation energy, EG

The diode activation energy. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Offset local circuit temperature, TOFFSET

The amount by which the diode temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Parameter extraction temperature, TMEAS

The temperature at which the diode parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the diode. This parameter is only visible when you select Fixed temperature for the **Model** temperature dependence using parameter. The default value is 300.15 K. The value must be greater than 0.

+

Diode

Positive electrical voltage.

Negative electrical voltage.

| See Al | SO |
|--------|----|
|--------|----|

SPICE Environment Parameters

| Purpose | Set parameters that apply to all connected SPICE-compatible blocks |
|-------------|--|
| Library | SPICE-Compatible Components/Utilities |
| Description | The SPICE Environment Parameters block lets you set parameters that apply to all SPICE-compatible blocks in an electrical network: |
| L W | Circuit temperatureMinimum conductance |

If your Simulink model does not contain a SPICE Environment Parameters block, all blocks use the default values of these parameters. You must connect every network in the system to a SPICE Environment Parameters block to override the default values.

Note The simple semiconductor models in the Semiconductors sublibrary are not temperature dependent, so the SPICE Environment Parameters block only changes the minimum conductance parameter used by the exponential diode and bipolar transistor models.

Dialog Box and Parameters

Ports

| Block Parameters: S SPICE Environment Para This block controls the SI in the electrical network parameters have a direc Solver parameters and/o | meters PICE environment p to which it is conne t equivalent in Simb | parameters of a ected. Not all Si Electronics, and | all SPICE-compatit PICE environment d many relate to S | : |
|--|--|--|--|-------|
| -Parameters | | | | |
| SPICE | | | | |
| Circuit temperature: | 300.15 | | К | |
| Minimum conductance, GMIN: | 1e-12 | | 1/Ohm | • |
| | | | ······ | |
| | ОК | Cancel | Help | Apply |

Circuit temperature

The temperature of the connected SPICE-compatible blocks. The default value is $300.15\ {\rm K}.$

Minimum conductance GMIN

The minimum conductance used by some blocks. The default value is $1e\mathchar`e\mathch$

The block has the following ports:

0UT

Electrical output.

SPICE NJFET

| Purpose | Model SPICE-compatible N-Channel JFET |
|---------------------|--|
| Library | SPICE-Compatible Components/Semiconductor Devices |
| Description ▫+¦¦ | The NJFET block represents a SPICE-compatible N-channel JFET. The NJFET block model includes the following components: • "Gate-Source Current-Voltage Model" on page 1-648 |

- "Gate-Drain Current-Voltage Model" on page 1-649
- "Drain-Source Current-Voltage Model" on page 1-650
- "Junction Charge Model" on page 1-651
- "Temperature Dependence" on page 1-653

Gate-Source Current-Voltage Model

The block provides the following relationship between the gate-source current I_{gs} and the gate-source voltage V_{gs} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gs} Values | Corresponding I _{gs} Equation |
|---|--|
| $V_{gs} > 80 * V_t$ | $I_{gs} = IS * \left(\left(\frac{V_{gs}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{gs} * G \min$ |
| $80 * V_t \geq V_{gs}$ | $I_{gs} = IS * (e^{V_{gs}/V_{t}} - 1) + V_{gs} * G \min$ |

Where:

- *IS* is the **Saturation current**, **IS** parameter value.
- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient**, **ND** parameter value.

- *q* is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Gate-Drain Current-Voltage Model

The block provides the following relationship between the gate-drain current I_{gd} and the gate-drain voltage V_{gd} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gd} Values | Corresponding I _{gd} Equation |
|---|--|
| $V_{gd} > 80 * V_t$ | $I_{gd} = IS * \left(\left(\frac{V_{gd}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{gd} * G \min$ |
| $80 * V_t \ge V_{gd}$ | $I_{gd} = IS * (e^{V_{gd}/V_t} - 1) + V_{gd} * G \min$ |

Drain-Source Current-Voltage Model

The block provides the following relationship between the drain-source

current I_{ds} and the drain-source voltage V_{ds} in normal mode ($V_{ds} \ge 0$) after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gs} and V _{gd} Values | Corresponding I _{ds} Equation |
|--|--|
| V_{gs} - $V_{to} \leq 0$ | $I_{ds} = 0$ |
| $0 < V_{gs} - V_{to} \leq V_{ds}$ | $I_{ds} = \beta \left(V_{gs} - V_{to} \right)^2 \left(1 + \lambda V_{ds} \right)$ |
| $0 < V_{ds} < V_{gs} - V_{to}$ | $I_{ds} = \beta V_{ds} \left(2 \left(V_{gs} - V_{to} \right) - V_{ds} \right) \left(1 + \lambda V_{ds} \right)$ |

Where:

- V_{to} is the **Threshold voltage**, **VTO** parameter value.
- β is the **Transconductance**, **BETA** parameter value.
- λ is the **Channel modulation**, **LAMBDA** parameter value.

The block provides the following relationship between the drain-source

current I_{ds} and the drain-source voltage V_{ds} in inverse mode ($V_{ds} < 0$) after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gs} and V _{gd} Values | Corresponding I _{ds} Equation | |
|--|--|--|
| V_{gd} - $V_{to} \leq 0$ | $I_{ds} = 0$ | |
| $0 < V_{gd} - V_{to} \leq -V_{ds}$ | $I_{ds} = -\beta \left(V_{gd} - V_{to} \right)^2 \left(1 - \lambda V_{ds} \right)$ | |
| $0 < -V_{ds} < V_{gs} - V_{to}$ | $I_{ds} = \beta V_{ds} \left(2 \left(V_{gd} - V_{to} \right) + V_{ds} \right) \left(1 - \lambda V_{ds} \right)$ | |

Junction Charge Model

The block provides the following relationship between the gate-source charge $Q_{\rm gs}$ and the gate-source voltage $V_{\rm gs}$ after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gs} Values | Corresponding Q _{gs} Equation |
|--|--|
| $V_{gs} < FC * VJ$ | $Q_{gs} = \frac{CGS * VJ * \left(1 \cdot \left(1 \cdot \frac{V_{gs}}{VJ}\right)^{1-MG}\right)}{1 - MG}$ |
| $V_{gs} \ge FC * VJ$ | $Q_{gs} = CGS * \left(F1 + \frac{F3 * (V_{gs} - FC * VJ) + \frac{MG * (V_{gs}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$ |

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is the **Junction potential VJ** parameter value.
- CGS is the Zero-bias GS capacitance, CGS parameter value.
- *MG* is the **Grading coefficient**, **MG** parameter value.

•
$$F1 = \frac{VJ * (1 - (1 - FC)^{1-MG})}{1 - MG}$$

•
$$F2 = (1 - FC)^{1+MG}$$

• F3 = 1 - FC * (1 + MG)

The block provides the following relationship between the gate-drain charge Q_{gd} and the gate-drain voltage V_{gd} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{gd} Values | Corresponding Q _{gd} Equation |
|--|--|
| $V_{gd} < FC * VJ$ | $Q_{gd} = \frac{CGD * VJ * \left(1 \cdot \left(1 \cdot \frac{V_{gd}}{VJ}\right)^{1-MG}\right)}{1 - MG}$ |
| $V_{gd} \ge FC * VJ$ | $Q_{gd} = CGD * \left(F1 + \frac{F3 * (V_{gd} - FC * VJ) + \frac{MG * (V_{gd}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$ |

Where:

• CGD is the Zero-bias GD capacitance, CGD parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

• When you select Device temperature for the **Model temperature** dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

- *T_C* is the Circuit temperature parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, *T_C* is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the saturation current IS and the transistor temperature T:

$$IS(T) = IS * \left(T/T_{meas}\right)^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}} - 1\right)^{*}\frac{EG}{V_{t}}}$$

where:

- *IS* is the **Saturation current**, **IS** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent, XTI** parameter value.
- *EG* is the **Energy gap, EG** parameter value.

- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient**, **ND** parameter value.

The block provides the following relationship between the junction potential VJ and the transistor temperature T:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T}$$

where:

- *VJ* is the **Junction potential VJ** parameter value.
- $EG_{T_{meas}} = 1.16eV (7.02e 4 * T_{meas}^{2}) / (T_{meas} + 1108)$
- $EG_T = 1.16eV (7.02e 4*T^2)/(T + 1108)$

The block provides the following relationship between the gate-source junction capacitance CGS and the transistor temperature T:

$$CGS(T) = CGS * \left[1 + MG * \left(400e - 6 * (T - T_{meas}) - \frac{VJ(T) - VJ}{VJ} \right) \right]$$

where:

• CGS is the Zero-bias GS capacitance, CGS parameter value.

The block uses the CGS(T) equation to calculate the gate-drain junction capacitance by substituting CGD (the **Zero-bias GD capacitance**, **CGD** parameter value) for CGS.

The block provides the following relationship between the forward and reverse beta and the transistor temperature T:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}}\right)$$

where β is the **Transconductance**, **BETA** parameter value.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The NJFET block does not support noise analysis.
- The NJFET block applies initial conditions across junction capacitors and not across the block ports.

SPICE NJFET

Dialog Box and Parameters

Main Tab

| ICE NJFET | | |
|--|--|-------------------------------|
| | nel JFET. You specify both model card and instance paramete oise model parameters KF and AF are not supported. Addition | |
| | ances for this device. SCALE multiplies the output current and ultiples the device parameters BETA, IS, CGS, CGD, and divi | |
| | ed temperature or to the circuit temperature (from the SPIC TI and EG adjust temperature sensitive parameters. | E Environment Parameters blo |
| nperature equations, which may yield a | acitance modeling and initial conditions. The capacitance mode a slightly different value than SPICE for capacitance. The initi ions, and are only effective when the corresponding junction | al conditions ICVDS and ICVGS |
| | ons, and are only or ecove when the corresponding junction | requercances are present. |
| rameters | | |
| Main Junction Capacitance Te | mperature | |
| Device area, AREA: | 1 | m^2 • |
| Number of parallel devices, SCALE: | 1 | |
| Threshold voltage, VTO: | -2 | V |
| Transconductance, BETA: | le-4 | A/m^2/V^2 |
| Channel modulation, LAMBDA: | 0 | 1/∀ ▼ |
| | | A/m^2 💌 |
| Saturation current, IS: | 1e-14 | A/m^2 💌 |
| Saturation current, IS: Emission coefficient, ND: | 1e-14 1 | Appr 2 |
| ŕ | | m^2*Ohm |
| Emission coefficient, ND: | 1 | |

Device area, AREA

The transistor area. This value multiplies the **Transconductance, BETA**, **Zero-bias GS capacitance, CGS**, **Zero-bias GD capacitance, CGD**, and **Saturation current, IS** parameter values. It divides the **Source resistance, RS** and **Drain resistance, RD** parameter values. The default value is 1 m². The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel transistors the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is -2 V.

Transconductance, **BETA**

The derivative of drain current with respect to gate voltage. The default value is $1e - 04 \text{ A/m}^2/\text{V}^2$. The value must be greater than or equal to 0.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Emission coefficient, ND

The transistor emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

Source resistance, RS

The transistor source resistance. The default value is $1e - 4 m^{2*}\Omega$. The value must be greater than or equal to 0.

Drain resistance, RD

The transistor drain resistance. The default value is $0.01 \text{ m}^{2*}\Omega$. The value must be greater than or equal to 0.

Junction Capacitance Tab

| | arameters: SPICE NJFE1 | | | | |
|-----------|---|-------------------------------|--------------------------|---|----------------|
| PICE NJF | ET | | | | |
| iask. The | | nd noise model parameters | | nce parameters as instance pa orted. Additional instance para | |
| | | | | ut current and device charge o CGD, and divides RS and RD. | directly. This |
| | et the JFET temperature to SET. The parameters ND, N | | | from the SPICE Environment P eters. | arameters blo |
| emperatu | ire equations, which may y | eld a slightly different valu | e than SPICE for capacit | pacitance modeling uses the pu ance. The initial conditions ICV Inding junction capacitances ar | 'DS and ICVGS |
| arameter | 'S | | | | |
| Main | Junction Capacitance | Temperature | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

• No — Do not include junction capacitance in the model. This is the default option.

• Yes — Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias GS capacitance, CGS

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Zero-bias GD capacitance, CGD

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient, MG

The transistor grading coefficient. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than or equal to 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

Note The NJFET block applies the initial diode voltage across the junction capacitors and not across the ports.

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Temperature Tab

| Block Parameters: SPICE NJFET | | |
|---|--|---------------|
| PICE NJFET | | |
| | el JFET. You specify both model card and instance parameters as instance par ise model parameters KF and AF are not supported. Additional instance para | |
| | nces for this device. SCALE multiplies the output current and device charge d ultiples the device parameters BETA, IS, CGS, CGD, and divides RS and RD. | irectly. This |
| | ed temperature or to the circuit temperature (from the SPICE Environment Pa I and EG adjust temperature sensitive parameters. | rameters bloc |
| emperature equations, which may yield a | itance modeling and initial conditions. The capacitance modeling uses the put slightly different value than SPICE for capacitance. The initial conditions ICVI ons, and are only effective when the corresponding junction capacitances ar | DS and ICVGS |
| arameters | | |
| | nperature | |
| Model temperature dependence using: | Device temperature | - |
| Saturation current temperature exponent, XTI: | 0 | |
| Activation energy, EG: | 1.11 eV | - |
| Offset local circuit temperature, TOFFSET: | 0 К | • |
| Parameter extraction temperature, TMEAS: | 300.15 K | • |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel Help | Appl |

Model temperature dependence using

Select one of the following options for modeling the diode temperature dependence:

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.

• Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Saturation current temperature exponent, XTI

The order of the exponential increase in the saturation current as temperature increases. The default value is 0. The value must be greater than or equal to 0.

Activation energy, EG

The energy gap that affects the increase in the saturation current as temperature increases. The default value is 1.11 eV. The value must be greater than 0.1 eV.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Ports The block has the following ports:

G

Electrical conserving port associated with the transistor gate terminal.

| | D Electrical conserving port associated with the transistor drain terminal. |
|------------|--|
| | S Electrical conserving port associated with the transistor source terminal. |
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 3. |
| See Also | N-Channel JFET, SPICE PJFET |

SPICE NMOS

| Purpose | Model SPICE-compatible N-Channel MOSFET |
|-------------------|---|
| Library | SPICE-Compatible Components/Semiconductor Devices |
| Description ⊣⊑ | The NMOS block represents a SPICE-compatible N-channel MOSFET. The NMOS block model includes the following components: "Resistance Calculations" on page 1-664 "Bulk-Source Diode Model" on page 1-665 |

- "Bulk-Drain Diode Model" on page 1-666
- "Level 1 Drain Current Model" on page 1-667
- "Level 3 Drain Current Model" on page 1-670
- "Junction Charge Model" on page 1-676
- "Temperature Dependence" on page 1-681

Resistance Calculations

The following table shows how the NMOS block calculates the transistor drain resistance. The abbreviations in the table represent the values of the following block parameters:

- Drain resistance, RD
- Sheet resistance, RSH
- Number of drain squares, NRD

| Drain resistance, RD Parameter | Sheet resistance, RSH Parameter | Drain Resistance |
|-----------------------------------|------------------------------------|------------------|
| NaN | NaN | 0 |
| RD | NaN or RSH | RD |
| NaN | RSH | RSH*NRD |

The following table shows how the NMOS block calculates the transistor source resistance. The abbreviations in the table represent the values of the following block parameters:

- Source resistance, RS
- Sheet resistance, RSH
- Number of source squares, NRS

| Source resistance, RS Parameter | Sheet resistance, RSH Parameter | Source Resistance |
|------------------------------------|------------------------------------|-------------------|
| NaN | NaN | 0 |
| RS | NaN or RSH | RS |
| NaN | RSH | RSH*NRS |

Bulk-Source Diode Model

The block provides the following relationship between the bulk-source current I_{bs} and the bulk-source voltage V_{bs} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{bs} Values | Corresponding I _{gs} Equation |
|---|--|
| $V_{bs} > 80 * V_{tn}$ | $I_{bs} = IS_{bs} * \left(\left(\frac{V_{bs}}{V_{tn}} - 79 \right) e^{80} - 1 \right) + V_{bs} * G \min$ |
| $80V_{tn} \ge V_{bs}$ | $I_{bs} = IS_{bs} * (e^{V_{bs}/V_{tm}} - 1) + V_{bs} * G \min$ |

Where:

- IS_{bs} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of source**, **AS** parameter value if both these

parameter values and the **Area of drain**, **AD** parameter value are nonzero.

- The Bulk saturation current, IS parameter value, otherwise.
- $V_{tn} = NkT/q$
- q is the elementary charge on an electron, 1.6021918e-19 C.
- *N* is the **Emission coefficient**, **ND** parameter value.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Bulk-Drain Diode Model

The block provides the following relationship between the bulk-drain current I_{bd} and the bulk-drain voltage V_{bd} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{bs} Values | Corresponding I _{gs} Equation |
|---|---|
| $V_{bd} > 80 * V_{tn}$ | $I_{bd} = IS_{bd} * \left(\left(\frac{V_{bd}}{V_{m}} - 79 \right) e^{80} - 1 \right) + V_{bd} * G \min$ |
| $80V_{tn} \ge V_{bd}$ | $I_{bd} = IS_{bd} * (e^{V_{bd}/V_{tn}} - 1) + V_{bd} * G \min$ |

Where:

- *IS*_{bd} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of drain**, **AD** parameter value if both these parameter values and the **Area of source**, **AS** parameter value are nonzero.
 - The Bulk saturation current, IS parameter value, otherwise.

Level 1 Drain Current Model

The block provides the following relationship between the drain current

 I_d and the drain-source voltage V_{ds} in normal mode ($V_{ds} \geq 0$) after adjusting the applicable model parameters for temperature.

Normal Mode

| Applicable Range of V _{gs} and V _{ds} Values | Corresponding I _d Equation |
|--|---|
| V_{gs} - $V_{on} \leq 0$ | $I_d = 0$ |
| $0 < V_{gs} - V_{on} \le V_{ds}$ | $I_{d} = BETA * \left(V_{gs} - V_{on}\right)^{2} \frac{\left(1 + LAMBDA * V_{ds}\right)}{2}$ |
| $0 < V_{ds} < V_{gs} - V_{on}$ | $I_{d} = BETA *$ $V_{ds} \left(\left(V_{gs} - V_{on} \right) - \frac{V_{ds}}{2} \right) \left(1 + LAMBDA * V_{ds} \right)$ |

Where:

• *V*_{on} is:

•
$$MTYPE * VBI + GAMMA \sqrt{PHI - V_{bs}}$$
 if $V_{bs} \le 0$.

- $\begin{array}{ll} \bullet & MTYPE*VBI + GAMMA\left(\sqrt{PHI} \frac{V_{bs}}{2\sqrt{PHI}}\right) \text{ if } 0 < V_{bs} \leq 2*PHI \ . \\ \bullet & MTYPE*VBI \text{ if } V_{bs} > 2*PHI. \end{array}$
- *MTYPE* is 1.
- BETA is KP*WIDTH/(LENGTH-2*LD)
- *KP* is:
 - The **Transconductance**, **KP** parameter value, if this parameter has a numerical value.

- $U0*3.9*\varepsilon_0/TOX$, if Transconductance, KP is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- WIDTH is the Width of channel, WIDTH parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.
- *VBI* is an built-in voltage value the block uses in calculations. The value is a function of temperature. For a detailed definition, see "Temperature Dependence" on page 1-681.
- PHI is:
 - The **Surface potential**, **PHI** parameter value, if this parameter has a numerical value.
 - $2 * kT_{meas} / q * \log(NSUB / n_i)$, if Surface potential, PHI is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- *LAMBDA* is the **Channel modulation**, **LAMBDA** parameter value.
- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- ε_0 is the permittivity of free space, 8.854214871e-12 F/m.
- n_i is the carrier concentration of intrinsic silicon, 1.45e10 cm⁻³.

The block provides the following relationship between the drain current

 I_d and the drain-source voltage V_{ds} in inverse mode ($V_{ds} < 0$) after adjusting the applicable model parameters for temperature.

Inverse Mode

| Applicable Range of V _{gd} and V _{ds} Values | Corresponding I _d Equation |
|--|---|
| V_{gd} - $V_{on} \leq 0$ | $I_d = 0$ |
| $0 < V_{gd} - V_{on} \leq -V_{ds}$ | $I_{d} = -BETA \left(V_{gd} - V_{on} \right)^{2} \left(1 - LAMBDA * V_{ds} \right) / 2$ |
| $0 < V_{ds} < V_{gd} - V_{on}$ | $I_{d} = BETA *$ $V_{ds} \left(\left(V_{gd} - V_{on} \right) + V_{ds} / 2 \right) \left(1 - LAMBDA * V_{ds} \right)$ |

Where:

- V_{on} is:
 - $MTYPE * VBI + GAMMA \sqrt{PHI V_{bd}}$ if $V_{bd} \le 0$.

MTYPE * *VBI* + *GAMMA*
$$\left(\sqrt{PHI} - \frac{V_{bd}}{2\sqrt{PHI}}\right)$$
 if $0 < V_{bd} \le 2 * PHI$.
 *MTYPE***VBI* if $V_{bd} > 2*PHI$.

•
$$MTYPE*VBI$$
 if $V_{bd} > 2*PE$

Level 3 Drain Current Model

The block provides the following model for drain current $I_{\rm ds}$ in normal

mode ($V_{\rm ds} \geq 0$) after adjusting the applicable model parameters for temperature.

$$I_{DS} = I_{DS0} * Scale_{VMAX} * Scale_{LChan} * Scale_{INV}$$

Where:

• I_{DS0} is the Basic Drain Current Model.

- *Scale_{VMAX}* is the Velocity Saturation Scaling.
- $Scale_{LChan}$ is the Channel Length Modulation Scaling.
- *Scale*_{INV} is the Weak Inversion Scaling.

The blocks uses the same model for drain current in inverse mode $(V_{ds} < 0)$, with the following substitutions:

- $V_{bs} V_{ds}$ for V_{bs}
- $V_{gs} V_{ds}$ for V_{ds}
- $-V_{ds}$ for V_{ds}

Basic Drain Current Model

The block provides the following relationship between the drain current I_{ds} and the drain-source voltage V_{ds} :

$$I_{DS0} = BETA * F_{gate} * \left(V_{GSX} - V_{TH} - \frac{1 + F_B}{2} * V_{DSX} \right) * V_{DSX}$$

- The block calculates BETA as described in "Level 1 Drain Current Model" on page 1-667.
- The block calculates F_{GATE} using the following equation:

$$F_{gate} = \frac{1}{1 + THETA * (V_{gsx} - V_{TH})}$$

- *THETA* is the **Vgs dependence on mobility**, **THETA** parameter value.
- $V_{gsx} = \max(V_{GS}, V_{on})$
- If you specify a nonzero value for the Fast surface state density, NFS parameter, the block calculates V_{on} using the following equation:

$$V_{on} = V_{TH} + x_n V_T$$

Otherwise, $V_{on} = V_{TH}$.

• The block calculates x_n using the following equation:

$$x_{n} = 1 + \frac{q * NFS}{COX} + \frac{\left(GAMMA * F_{s} * \sqrt{V_{bulk}} + \frac{F_{n} * V_{bulk}}{WIDTH}\right)}{2 * V_{bulk}}$$

- The block calculates $V_{\it bulk}$ as follows:

• If
$$V_{BS} \leq 0$$
, $V_{bulk} = PHI - V_{BS}$.

- Otherwise, the block calculates V_{bulk} using the following equation:

$$V_{bulk} = \frac{PHI}{\left(1 + \frac{V_{BS}}{2*PHI}\right)^2}$$

- $V_T = kT/q$
- The block calculates V_{TH} using the equation following equation:

$$V_{TH} = V_{BI} - \frac{8.15e^{-22} * ETA}{COX * (LENGTH - 2 * LD)^3} * V_{DS} + GAMMA * F_s * \sqrt{V_{bulk}} + F_n * V_{bulk}$$

- For information about how the block calculates V_{BI} , see "Temperature Dependence" on page 1-681.
- ETA is the Vds dependence threshold volt, ETA parameter value.
- $COX = \varepsilon_{ox}/TOX$, where ε_{ox} is the permittivity of the oxide and TOX is the **Oxide thickness**, **TOX** parameter value.

• If you specify a nonzero value for the **Junction depth**, **XJ** parameter and a value for the **Substrate doping**, **NSUB** parameter, the block calculates F_s using the following equations:

$$\alpha = \frac{2\varepsilon_{si}}{qNSUB}$$

$$XD = \sqrt{\alpha}$$

$$wc = .0631353 + .8013292 * \frac{XD * \sqrt{V_{bulk}}}{XJ}$$

$$-.01110777 * \left(\frac{XD * \sqrt{V_{bulk}}}{XJ}\right)^2 + \frac{LD}{XJ}$$

$$F_s = 1 - \left(wc * \sqrt{1 - \left(\frac{XD * \sqrt{V_{bulk}}}{XJ + XD * \sqrt{V_{bulk}}}\right)^2} - \frac{LD}{XJ}\right)$$

where ε_{si} is the permittivity of silicon.

Otherwise, $F_s = 1$.

• The block calculates F_B using the following equation:

$$F_{B} = \frac{GAMMA * F_{s}}{4 * \sqrt{V_{bulk}}} + F_{n}$$

• The block calculates F_n using the following equation:

$$F_n = \frac{DELTA * \pi * \varepsilon_{si}}{2 * COX * WIDTH}$$

• *DELTA* is the **Width effect on threshold**, **DELTA** parameter value.

- V_{DSX} is the lesser of V_{DS} and the saturation voltage, V_{dsat}
 - If you specify a positive value for the Max carrier drift velocity, VMAX parameter, the block calculates V_{dsat} using the following equation:

$$V_{dsat} = \frac{V_{gsx} - V_{TH}}{1 + F_B} + \frac{(LENGTH - 2*LD)*VMAX}{UO*F_{gate}} - \sqrt{\left(\frac{V_{gsx} - V_{TH}}{1 + F_B}\right)^2 + \left(\frac{(LENGTH - 2*LD)*VMAX}{UO*F_{gate}}\right)^2}$$

Otherwise, the block calculates V_{dsat} using the following equation:

$$V_{dsat} = \frac{V_{gsx} - V_{TH}}{1 + F_B}$$

Velocity Saturation Scaling

If you specify a positive value for the **Max carrier drift velocity**, **VMAX** parameter, the block calculates $Scale_{VMAX}$ using the following equation:

$$Scale_{VMAX} = \frac{1}{1 + \frac{UO * F_{gate}}{(LENGTH - 2 * LD) * VMAX} * V_{DSX}}$$

Otherwise, $Scale_{VMAX} = 1$.

Channel Length Modulation Scaling

The block scales the drain current to account for channel length modulation if the block meets all of the following criteria:

• $V_{DS} > V_{sat}$

• The **Max carrier drift velocity**, **VMAX** parameter value is zero or *a* is nonzero.

The block scales the drain current using the following equation:

$$Scale_{LChan} = \frac{1}{1 - \frac{\Delta l}{(LENGTH - 2*LD)}}$$

The block uses the following procedure to calculate Δl :

- **1** The block first calculates the intermediate value Δl_{0} .
 - If you specify a positive value for the **Max carrier drift velocity**, **VMAX** parameter, the block computes the intermediate value g_{dsat} as the greater of 1e-12 and the result of the following equation:

$$I_{DS0} * \left(1 - \frac{1}{1 + Scale_{g_{dsat}} * V_{DSX}} \right) * Scale_{g_{dsat}}$$

where:

$$Scale_{g_{dsat}} = \frac{UO * F_{gate}}{(LENGTH - 2 * LD) * VMAX}$$

Then, the block uses the following equation to calculate the intermediate value Δl_{o} :

$$\Delta I_{0} = \sqrt{\left(\frac{KA * I_{DS}}{2 * (LENGTH - 2 * LD) * g_{dsat}}\right)^{2} + KA * (V_{DS} - V_{dsat})} - \frac{KA * I_{DS}}{2 * (LENGTH - 2 * LD) * g_{dsat}}$$

where *KA* is the product of the **Mobility modulation**, **KAPPA** parameter value and *a*.

• Otherwise, the block uses the following equation to calculate the intermediate value Δl_{o} :

$$\Delta l = \sqrt{KA * \left(V_{DS} - V_{dsat}\right)}$$

- **2** The block checks for punch through and calculates Δl .
 - If Δl_0 is greater than (*LENGTH*-2**LD*)/2, the block calculates Δl using the following equation:

$$\Delta l = \left(1 - \frac{(LENGTH - 2*LD)}{4*\Delta l_0}\right) * (LENGTH - 2*LD)$$

• Otherwise, $\Delta l = \Delta l_0$.

Weak Inversion Scaling

If $V_{\rm GS}$ is less than $V_{\rm on}$, the block calculates $Scale_{\rm INV}$ using the following equation:

$$Scale_{INV} = e^{\frac{V_{gs} - V_{on}}{x_n * V_T}}$$

Otherwise, $Scale_{INV} = 1$.

Junction Charge Model

The block models the following junction charges:

- Junction Overlap Charges
- Bulk Junction Charges

Junction Overlap Charges

The block calculates the following junction overlap charges:

• Q_{GS}=CGSO*WIDTH*V_{gs}

Where:

- Q_{GS} is the gate-source overlap charge.
- CGSO is the G-S overlap capacitance, CGSO parameter value.
- *WIDTH* is the **Width of channel, WIDTH** parameter value.
- $Q_{GD} = CGDO^*WIDTH^*V_{gd}$

Where:

- Q_{GD} is the gate-drain overlap charge.
- *CGDO* is the **G-D overlap capacitance**, **CGDO** parameter value.
- $Q_{GB} = CGBO^*(LENGTH-2^*LD)^*V_{gb}$

Where:

- Q_{GB} is the gate-bulk overlap charge.
- CGBO is the G-B overlap capacitance, CGBO parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.

Bulk Junction Charges

The block provides the following relationship between the bulk-drain bottom junction charge Q_{bottom} and the junction voltage V_{bd} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{bd} Values | Corresponding Q _{bottom} Equation |
|--|--|
| $V_{bd} < FC * PB$ | $Q_{bottom} = \frac{CBD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1-MJ}\right)}{1 - MJ} \text{ if } CBD > 0.$ $Q_{bottom} = \frac{CJ * AD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1-MJ}\right)}{1 - MJ} \text{ otherwise.}$ |
| $V_{bd} \ge FC * PB$ | $Q_{bottom} = CBD *$ $\left(F1 + \frac{F3*(V_{bd} - FC*PB) + \frac{MJ*(V_{bd}^2 - (FC*PB)^2)}{2*PB}}{F2} \right)$ if $CBD > 0$. $Q_{bottom} = CJ*AD *$ $\left(F1 + \frac{F3*(V_{bd} - FC*PB) + \frac{MJ*(V_{bd}^2 - (FC*PB)^2)}{2*PB}}{F2} \right)$ etherwise |
| | otherwise. |

Where:

- *PB* is the **Bulk junction potential**, **PB** parameter value.
- *FC* is the **Capacitance coefficient FC** parameter value.
- CBD is the Zero-bias BD capacitance, CBD parameter value.
- CJ is the Bottom junction cap per area, CJ parameter value.
- *AD* is the **Area of drain**, **AD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1-MJ})}{1 - MJ}$$

- $F2 = (1 FC)^{1+MJ}$
- F3 = 1 FC * (1 + MJ)

The block uses the equations in the preceding table to calculate the bulk-source bottom junction charge, with the following substitutions:

- V_{bs} replaces V_{bd}.
- AS (the Area of source, AS parameter value) replaces AD.
- *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) replaces *CBD*.

The block provides the following relationship between the bulk-drain sidewall junction charge $Q_{sidewall}$ and the junction voltage V_{bd} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{bd} Values | Corresponding Q _{sidewall} Equation |
|--|---|
| $V_{bd} < FC * PB$ | $Q_{sidewall} = \frac{CJSW * PD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1-MGSW}\right)}{1 - MGSW}$ |
| $V_{bd} \ge FC * PB$ | $Q_{sidewall} = CJSW * PD * \left(F1 + \frac{F3 * (V_{bd} - FC * PB) + \frac{MGSW * (V_{bd}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right)$ |

Where:

- *CJSW* is the **Side jct cap/area of jct perimeter**, **CJSW** parameter value.
- *PD* is the **Perimeter of drain, AD** parameter value.
- *MGSW* is the **Side grading coefficient**, **MJSW** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1 - MJSW})}{1 - MJSW}$$

•
$$F2 = (1 - FC)^{1+M}$$
.

• F3 = 1 - FC * (1 + MJSW)

The block uses the equations in the preceding table to calculate the bulk-source sidewall junction charge and the sidewall junction voltage, with the following substitutions:

- V_{bs} replaces V_{bd}.
- *PS* (the **Perimeter of source, PS** parameter value) replaces *PD*.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

• When you select Device temperature for the **Model temperature** dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

- T_C is the Circuit temperature parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the transconductance KP and the transistor temperature T:

$$KP(T) = \frac{KP}{\left(\frac{T}{T_{meas}}\right)^{3/2}}$$

where:

- *KP* is the **Transconductance**, **KP** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.

The block provides the following relationship between the surface potential *PHI* and the transistor temperature *T*:

$$\begin{split} PHI(T) &= \frac{T}{T_{meas}} \Bigg(PHI + \frac{kT_{meas}}{q} \Bigg(\log \Bigg(\frac{T_{meas}}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T_{meas}} \Bigg) \Bigg) \Bigg) \\ &- \frac{kT}{q} \Bigg(\log \Bigg(\frac{T}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_T}{T} \Bigg) \Bigg) \end{split}$$

where:

•
$$EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4*T_{meas}^{2}) / (T_{meas} + 1108)$$

•
$$EG_T = 1.16eV - (7.02e - 4 * T^2) / (T + 1108)$$

The block provides the following relationship between the built-in voltage VBI and the transistor temperature T:

$$VBI(T) = VTO + MTYPE * \left(\frac{PHI(T) - PHI}{2} - GAMMA\sqrt{PHI}\right) + \frac{EG_{T_{meas}} - EG_T}{2}$$

where:

- *VTO* is:
 - The **Threshold voltage**, **VTO** parameter value, if this parameter has a numerical value.

• $\Phi - 3.25 + EG_{T_{means}}/2 + MTYPE * PHI/2 - NSS * q * TOX / (3.9 * \varepsilon_0)$

+ $MTYPE * (GAMMA * \sqrt{PHI} + PHI)$, if Threshold voltage, VTO is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

- Φ is:
 - **3.2**, if *TPG* (the **Gate type?**, **TPG** parameter value) is **0**.

-
$$3.25 + EG_{T_{max}}/2 - MTYPE * TPG * EG_{T_{max}}/2$$
, otherwise.

- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

The block provides the following relationship between the bulk saturation current IS and the transistor temperature T:

$$IS(T) = IS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

- *ND* is the **Emission coefficient**, **ND** parameter value.
- IS is the **Bulk saturation current**, **IS** parameter value.

The block provides the following relationship between the bulk junction saturation current density JS and the transistor temperature T:

$$JS(T) = JS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

• JS is the Bulk jct sat current density, JS parameter value.

The block provides the following relationship between the bulk junction potential PB and the transistor temperature T:

$$PB(T) = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas}/T} - \frac{kT}{q} \left(\log \left(\frac{T}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_T}{T} \right) \right)$$

where:

• *PB* is the **Bulk junction potential**, **PB** parameter value.

The block provides the following relationship between the bulk-drain junction capacitance CBD and the transistor temperature T:

$$CBD(T) = CBD \frac{pbo + MJ * (4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo))}{pbo + MJ * (4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo))}$$

where:

- *CBD* is the **Zero-bias BD capacitance**, **CBD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$pbo = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas}}$$

The block uses the CBD(T) equation to calculate:

- The bulk-source junction capacitance by substituting *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) for *CBD*.
- The bottom junction capacitance by substituting *CJ* (the **Bottom junction cap per area**, *CJ* parameter value) for *CBD*.

The block provides the following relationship between the sidewall junction capacitance CJSW and the transistor temperature T:

$$CJSW(T) = CJSW \frac{pbo + MJSW * \left(4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo)\right)}{pbo + MJSW * \left(4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo)\right)}$$

where:

• *MJSW* is the **Side grading coefficient**, **MJSW** parameter value.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The NMOS block does not support noise analysis.
- The NMOS block applies initial conditions across junction capacitors and not across the block ports.

SPICE NMOS

Dialog Box and Parameters

Model Selection Tab

| Block Parameter | s: SPICE NMUS | | | | | | | |
|--|---|---|--|--|--|--|------------------------------------|-------------------------|
| SPICE NMOS | | | | | | | | |
| This model approxim on this mask. The ins MOS instances for th which multiples the c and RSH. | tance parameter : is device, SCALE r | OFF and noise multiplies the c | model paramel | ers KF and AF Ind device cha | [:] are not su irge directly | pported, SC/ . This differs | ALE is the numb from the AREA | per of par A paramet |
| You can set the MOS plus TOFFSET. The b ICVBS are the voltag If physical paramete TOX and NSUB. Para | ock lets you includ es across the inte 's VTO, KP, PHI, o | de or exclude (ernal junctions, or GAMMA are | capacitance mo , and are only e assigned a NaN | deling and initi ffective when value, they w | al condition the corresp vill be calcula | s. The initial conding jund ated from sp | conditions ICVI tion capacitanc | DS, ICVGS es are pre |
| Parameters | | | | | | | | |
| Model Selection | Dimensions | Resistors | DC currents | C-V F | Process | Temperatur | - I | |
| Model Belection | Dimensions | Resistors | DC currents | 10-11 | 100033 | Tomporada | ° | |
| MOS model: | Dimensions | | I1 MOS | | | | | |
| | Dimensions | | | | | | | |

MOS model

Select one of the following MOSFET model options:

- Level 1 MOS Use the "Level 1 Drain Current Model" on page 1-667. This is the default option.
- Level 3 MOS Use the "Level 3 Drain Current Model" on page 1-670.

Dimensions Tab

| SPICE NMOS | | |
|---|--|--|
| on this mask. The instance parameter (MOS instances for this device, SCALE n | 1 or 3 nMOSFET. You specify both model card and instance DFF and noise model parameters KF and AF are not support nultiplies the output current and device charge directly. This KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW a | ed. SCALE is the number of par differs from the AREA paramet |
| plus TOFFSET. The block lets you includ ICVBS are the voltages across the inter If physical parameters VTO, KP, PHI, or | Fixed temperature or to the circuit temperature (from the S le or exclude capacitance modeling and initial conditions. Th rnal junctions, and are only effective when the correspondi c GAMMA are assigned a NaV value, they will be calculated RSH are not used in block calculations when their value is N | e initial conditions ICVDS, ICVGS ng junction capacitances are pre from specified process paramete |
| Parameters | | |
| Model Selection Dimensions | | |
| Model Selection Differisions | Resistors DC currents C-V Process Tem | perature |
| Device area factor, AREA: | 1 | |
| Number parallel devices, SCALE: | 1 | |
| Length of channel, LENGTH: | 1e-4 | m |
| | | |
| Width of channel, WIDTH: | 1e-4 | m |
| ŕ | | |
| Area of drain, AD: | 0 | m^2 |
| Area of drain, AD: Area of source, AS: | 0 | m^2 |
| Area of drain, AD: | 0 | m^2 |
| Area of drain, AD: Area of source, AS: | 0 | m^2 |
| Area of drain, AD: Area of source, AS: Perimeter of drain, PD: | | m^2 m^2 |

Device area factor, AREA

The transistor area. This value multiplies the following parameter values:

- Transconductance, KP
- Bulk saturation current, IS
- Bulk jct sat current density, JS
- Zero-bias BD capacitance, CBD

- Zero-bias BS capacitance, CBS
- G-S overlap capacitance, CGSO
- G-D overlap capacitance, CGDO
- G-B overlap capacitance, CGBO
- Bottom junction cap per area CJ
- Side jct cap/area of jct perimeter CJSW

It divides the following parameter values:

- Drain resistance, RD
- Source resistance, RS
- Sheet resistance, RSH

The default value is 1. The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel MOS instances for this device. This parameter multiplies the output current and device charge. The default value is 1. The value must be greater than 0.

Length of channel, LENGTH

Length of the channel between the source and drain. The default value is 1e-04 m.

Width of channel, WIDTH

Width of the channel between the source and drain. The default value is 1e-04 m.

Area of drain, AD

Area of the transistor drain diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Area of source, AS

Area of the transistor source diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Perimeter of drain, PD

Perimeter of the transistor drain diffusion. The default value is 0 m. $\,$

Perimeter of source, PS

Perimeter of the transistor source diffusion. The default value is 0 m.

Resistors Tab

| this mask. The insta 05 instances for this | ince parameter | OFF and noise | ET. You specify b model paramete | rs KF and | AF are not s | supported. SC/ | ALE is the number | r of pa |
|---|-------------------|----------------|-------------------------------------|--------------|-----------------|------------------|-------------------|---------|
| hich multiples the dev d RSH. | | | | | | | | |
| u can set the MOS to | emperature to a | a fixed temper | ature or to the ci | rcuit tempe | rature (from | n the SPICE Fr | vironment Paran | neters |
| us TOFFSET. The blo VBS are the voltage: | :k lets you inclu | ide or exclude | capacitance mod | eling and ir | nitial conditio | ons. The initial | conditions ICVDS | , ICVG |
| physical parameters X and NSUB. Param | VTO, KP, PHI, (| or GAMMA are | assigned a NaN v | alue, they | will be calcu | ulated from sp | | |
| | | | | | | | | |
| rameters | | | | | | | | |
| Model Selection | Dimensions | Resistors | DC currents | C-V | Process | Temperatur | | |
| Model Delection 1 | Dimensions | | De carrents | < | FIOCOSS | | | |
| Drain resistance, RI |): | 0.01 | | | | | Ohm | |
| Source resistance, I | RS: | 1e-4 | | | | | Ohm | |
| Sheet resistance, R | SH: | NaN | | | | | Ohm | |
| Number of drain squ | uares, NRD: | 1 | | | | | | |
| Number of source s | quares, NRS: | 1 | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

Drain resistance, RD

The transistor drain ohmic resistance. The default value is 0.01Ω . If you set this parameter to NaN Ω , this value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 1-664. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Source resistance, RS

The transistor source ohmic resistance. The default value is $1e-4 \Omega$. If you set this parameter to NaN Ω , this value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 1-664. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Sheet resistance, RSH

Resistance per square of the transistor source and drain. The default value is NaN Ω . This value means the parameter is unspecified. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-664. The value must be greater than or equal to 0.

Number of drain squares, NRD

Number of squares of resistance that make up the transistor drain diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-664.

Number of source squares, NRS

Number of squares of resistance that make up the transistor source diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-664.

DC Currents Tab

| 😽 Block Parameters: SPICE NMOS | | × | | | | |
|---|---|--------------------|--|--|--|--|
| SPICE NMOS | | | | | | |
| This model approximates a SPICE level 1 or 3 nMOSFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, 15, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. | | | | | | |
| You can set the MOS 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 and initial conditions. The initial conditions ICVDS, ICVGS and ICVBS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NaN. | | | | | | |
| - Parameters - | | | | | | |
| Model Selection Dimensions Res | stors DC currents C-V Process Temperatu | re 1 | | | | |
| Threshold voltage, VTO: | 0 | V | | | | |
| Transconductance, KP: | 2e-5 | A/V^2 | | | | |
| Bulk threshold, GAMMA: | 0 | V^0.50000 • | | | | |
| Surface potential, PHI: | 0.6 | V | | | | |
| Channel modulation, LAMBDA: | 0 | 1/∀ ▼ | | | | |
| Bulk saturation current, IS: | 1e-14 | A | | | | |
| Bulk jct sat current density, JS: 0 | | A/m^2 | | | | |
| Emission coefficient, ND: | 1 | | | | | |
| | | | | | | |
| | | | | | | |
| | OK Cancel | Help Apply | | | | |

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is 0 V. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate**

doping, NSUB parameters. For more information about this calculation, see "Temperature Dependence" on page 1-681.

Transconductance, KP

The derivative of drain current with respect to gate voltage. The default value is 2e-05 A/V². The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-670 as appropriate for the selected value of the **MOS model** parameter.

Bulk threshold, GAMMA

Body effect parameter, which relates the threshold voltage, VTH, to the body bias, VBS, as described in "Level 1 Drain Current Model" on page 1-667 and "Level 3 Drain Current Model" on page

1-670. The default value is 0 \sqrt{V} . The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-670 as appropriate for the selected value of the **MOS model** parameter.

Surface potential, PHI

Twice the voltage at which the surface electron concentration becomes equal to the intrinsic concentration and the device transitions between depletion and inversion conditions. The default value is 0.6 V. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-670 as appropriate for the selected value of the **MOS model** parameter.

Channel modulation, LAMBDA

The channel-length modulation. This parameter is only visible when you select Level 1 MOS for the MOS model parameter. The default value is 0 1/V.

Bulk saturation current, IS

The magnitude of the current that the junction approaches asymptotically for very large reverse bias levels. The default value is 1e-14 A. The value must be greater than or equal to 0.

Bulk jct sat current density, JS

The magnitude of the current per unit area that the junction approaches asymptotically for very large reverse bias levels. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

Emission coefficient, ND

The transistor emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

Width effect on threshold, DELTA

The factor that controls the effect of transistor width on threshold voltage. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.

Max carrier drift velocity, VMAX

The maximum drift velocity of the carriers. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0 m/s.

Fast surface state density, NFS

The fast surface state density adjusts the drain current for the mobility reduction caused by the gate voltage. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is $0 \ 1/cm^2$.

Vds dependence threshold volt, ETA

The coefficient that controls how the threshold voltage depends on the drain-source voltage in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.

Vgs dependence on mobility, THETA

The coefficient that controls how the mobility affects the gate voltage in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0 1/V.

Mobility modulation, KAPPA

The coefficient that controls how the mobility affects the channel length in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.2.

C-V Tab

| Block Parameters: SPICE NMOS | × |
|--|---|
| -SPICE NMOS | |
| This model approximates a SPICE level 1 or 3 nMOSFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. | |
| You can set the MOS 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 and initial conditions. The initial conditions ICVDS, ICVDS and ICVBS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are preser If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NaN. | á |
| Parameters | |
| | |
| Model Selection Dimensions Resistors DC currents C-V Process Temperature | |
| | |
| | |
| OK Cancel Help Apply | |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion and capacitance coefficient.

G-S overlap capacitance, CGSO

Gate-source capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-D overlap capacitance, CGDO

Gate-drain capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-B overlap capacitance, CGBO

Gate-base capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BD capacitance, CBD

The value of the capacitance placed between the base and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BS capacitance, CBS

The value of the capacitance placed between the base and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom junction cap per area CJ

Zero-bias bulk junction bottom capacitance per junction area. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom grading coefficient, MJ

The transistor bottom grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Side jct cap/area of jct perimeter CJSW

Zero-bias bulk junction sidewall capacitance per junction perimeter. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Side grading coefficient, MJSW

The transistor sidewall grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Bulk junction potential, PB

The potential across the bulk junction. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.8 V. The value must be equal to 0 or greater than or equal to VJmin. VJmin is a built-in model constant whose value is 0.01.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than or equal to FCmax. FCmax is a built-in model constant whose value is 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

Note The NMOS block applies the initial diode voltage across the junction capacitors and not across the ports.

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Initial condition voltage ICVBS

Bulk-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Process Tab

| n this mask. The instance parameter OS instances for this device. SCALE r | I 1 or 3 nMOSFET. You specify both model card and insta OFF and noise model parameters KF and AF are not sup multiplies the output current and device charge directly. KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJ3 | pported. SCALE is the number of pai . This differs from the AREA parame |
|---|--|--|
| us TOFFSET. The block lets you includ IVBS are the voltages across the inte physical parameters VTO, KP, PHI, o | a fixed temperature or to the circuit temperature (from t de or exclude capacitance modeling and initial conditions ernal junctions, and are only effective when the corresp ir GAMMA are assigned a NaN value, they will be calcula RSH are not used in block calculations when their value | s. The initial conditions ICVDS, ICVG oonding junction capacitances are pr ated from specified process paramet |
| arameters | | |
| Model Selection Dimensions | Resistors DC currents C-V Process | Temperature |
| · · · · | | · · · |
| Oxide thickness, TOX: | NaN | m |
| Lateral diffusion, LD: | 0 | m |
| | | |
| Substrate doping, NSUB: | NaN | 1/cm^3 |
| Substrate doping, NSUB: Surface state density, NSS: | NaN 0 | 1/cm^3 |
| | | |
| Surface state density, NSS: Surface mobility, UO: | 0 | 1/cm^2 |
| Surface state density, NSS: | 0 600 | 1/cm^2 |
| Surface state density, NSS: Surface mobility, UO: | 0 600 | 1/cm^2 |
| Surface state density, NSS: Surface mobility, UO: | 0 600 | 1/cm^2 |
| Surface state density, NSS: Surface mobility, UO: | 0 600 | 1/cm^2 |

Oxide thickness, TOX

Thickness of the gate oxide. The default value is NaN m. The value must be greater than or equal to 0.

Note When you select Level 3 MOS for the **MOS model** parameter, the block uses a value of 1e-7 rather than NaN by default.

Lateral diffusion, LD

Length of lateral diffusion. The default value is 0 m.

Substrate doping, NSUB

Substrate doping. The default value is NaN 1/cm³. The value must be greater than or equal to 1.45e10 (the carrier concentration of intrinsic silicon).

Surface state density, NSS

Substrate doping. The default value is $0 \ 1/cm^2$.

Surface mobility, U0

Zero-bias surface mobility coefficient. The default value is $600 \text{ cm}^2/\text{V/s}$.

Junction depth, XJ

Junction depth. This parameter is only visible when you select Level 3 MOS for the MOS model parameter. The default value is 0 m.

Gate type?,TPG

Select one of the following MOSFET gate materials (as compared to the substrate):

- Opposite of substrate The gate material is the opposite of the substrate. This means that TPG = 1 in the device equations. This is the default option.
- Same as substrate The gate material is the same as the substrate. This means that TPG = -1 in the device equations.
- Aluminum The gate material is aluminum. This means that TPG = 0 in the device equations.

Temperature Tab

| block Parameter | s: SPICE NMOS | | | | | | |
|--|--|---|--|---|---|--|------------------------------|
| PICE NMOS | | | | | | | |
| n this mask. The insl IOS instances for thi | ance parameter : s device, SCALE r | OFF and nois multiplies the | e model paramet output current a | both model card and ers KF and AF are n nd device charge dii CGDO, CGBO, CJ ar | ot supported. S rectly. This differ | CALE is the numb rs from the AREA | er of paralle parameter, |
| lus TOFFSET. The bl IVBS are the voltag physical parameter | ock lets you includ es across the inte s VTO, KP, PHI, o | de or exclude rnal junction r GAMMA are | e capacitance mod s, and are only e e assigned a NaN | ircuit temperature (Jeling and initial con- ffective when the co- value, they will be o sulations when their | ditions. The initia prresponding jun alculated from s | al conditions ICVE action capacitance |)S, ICVGS ar es are prese |
| arameters | | | | | | | |
| Model Selection | Dimensions | Resistors | DC currents | C-V Proces | s Temperati | ure | |
| Model temperature Offset local circuit | | ng: Devic | e temperature | | | K | • |
| TOFFSET: | | Jo | | | | J.K. | |
| | | | | | | | |
| Parameter extract TMEAS: | ion temperature, | 300.1 | 15 | | | K | • |
| Parameter extract | ion temperature, | 300.1 | 15 | | | К | • |
| Parameter extract | ion temperature, | 300.1 | 15 | | | K | • |
| Parameter extract | ion temperature, | 300.1 | 15 | | | К | T |
| Parameter extract | ion temperature, | 300.1 | .5 | | | K | T |
| Parameter extract | ion temperature, | 300.1 | 5 | | | κ | T |
| Parameter extract | ion temperature, | 300.1 | .5 | | | K | T |
| Parameter extract | ion temperature, | 300.1 | 5 | | | κ | |
| Parameter extract | ion temperature, | 300.1 | .5 | | | K | × |

Model temperature dependence using

Select one of the following options for modeling the diode temperature dependence:

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.

• Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Ports The block has the following ports:

G

Electrical conserving port associated with the transistor gate terminal.

D

Electrical conserving port associated with the transistor drain terminal.

S

Electrical conserving port associated with the transistor source terminal.

В

Electrical conserving port associated with the transistor bulk terminal.

References [1] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling* with SPICE. 2nd Edition, McGraw-Hill, 1993. Chapter 3.

See Also SPICE PMOS

SPICE NPN

| Purpose | Model Gummel-Poon NPN Transistor |
|-------------|--|
| Library | SPICE-Compatible Components/Semiconductor Devices |
| Description | The NPN block represents a SPICE-compatible four-terminal Gummel-Poon NPN transistor. The substrate port is connected to the transistor body using a capacitor, so these devices are equivalent to a three-terminal transistor when you connect the substrate port to any other port and use the default value of zero for the C-S junction capacitance , CJS parameter. |

The NPN block model includes the following components:

- "Current-Voltage and Base Charge Model" on page 1-704
- "Base Resistance Model" on page 1-708
- "Transit Charge Modulation Model" on page 1-708
- "Junction Charge Model" on page 1-709
- "Temperature Dependence" on page 1-711

Current-Voltage and Base Charge Model

The current-voltage relationships and base charge relationships for the transistor are calculated adjusting the applicable model parameters for temperature as described in the following sections:

- Base-Emitter and Base-Collector Junction Currents on page 704
- Terminal Currents on page 707
- Base Charge Model on page 707

Base-Emitter and Base-Collector Junction Currents

The base-emitter junction current is calculated using the following equations:

• When $V_{BE} > 80 * V_{TF}$:

$$I_{bef} = IS * \left(\left(\frac{V_{BE}}{V_{TF}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{BE}$$
$$I_{bee} = ISE * \left((V_{BE} - 80 * V_{TF} + V_{TE}) * \frac{e^{(80*V_{TF}/V_{TE})}}{V_{TE}} - 1 \right)$$

• When $V_{BE} \leq 80 * V_{TF}$

$$I_{bef} = IS * (e^{(V_{BE}/V_{TF})} - 1) + G_{\min} * V_{BE}$$
$$I_{bee} = ISE * (e^{(V_{BE}/V_{TE})} - 1)$$

The base-collector junction current is calculated using the following equations:

• When $V_{BC} > 80 * V_{TR}$:

$$I_{bcr} = IS * \left(\left(\frac{V_{BC}}{V_{TR}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{BC}$$
$$I_{bcc} = ISC * \left(\left(V_{BC} - 80 * V_{TR} + V_{TC} \right) * \frac{e^{(80*V_{TR}/V_{TC})}}{V_{TC}} - 1 \right)$$

• When $V_{BC} \leq 80 * V_{TR}$

$$I_{bcr} = IS * (e^{(V_{BC}/V_{TR})} - 1) + G_{\min} * V_{BC}$$
$$I_{bcc} = ISC * (e^{(V_{BC}/V_{TC})} - 1)$$

In the preceding equations:

- V_{BE} is the base-emitter voltage and V_{BC} is the base-collector voltage.
- $V_{TE} = NE * k * T / q$, $V_{TC} = NC * k * T / q$, $V_{TF} = NF * k * T / q$, and • $V_{TE} = NR * k * T / q$
- V_{IB} = NR * k * T / q.
 ISC and ISE are the B-C leakage current, ISC and B-E leakage current, ISE parameter values, respectively.
- *NE*, *NC*, *NF*, and *NR* are the **B-E emission coefficient**, **NE**, **B-C emission coefficient**, **NC**, **Forward emission coefficient**, **NF** and **Reverse emission coefficient**, **NR** parameter values, respectively.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the transistor temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- G_{min} is the minimum conductance. By default, G_{min} matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change G_{min} , add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Terminal Currents

The terminal currents, I_B and I_C are the base and collector currents, defined as positive into the device. They are calculated as:

$$\begin{split} I_B &= -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)\\ I_C &= -\left(\frac{I_{ebf} - I_{cbr}}{q_b} - \frac{I_{cbr}}{BR} - I_{cbc}\right) \end{split}$$

where *BF* and *BR* are the **Forward beta**, **BF** and **Reverse beta**, **BR** parameter values, respectively.

Base Charge Model

The base charge, q_b , is calculated using the following equations:

$$\begin{split} q_{b} &= \frac{q_{1}}{2} \Biggl(1 + \sqrt{0.5 * \Bigl(\sqrt{(1 + 4 * q_{2} - eps)^{2}} + eps^{2}} + 1 + 4 * q_{2} - eps \Bigr) + eps \Biggr) \\ q_{1} &= \Biggl(1 - \frac{V_{BC}}{VAF} - \frac{V_{BE}}{VAR} \Biggr)^{-1} \\ q_{2} &= \frac{I_{bef}}{IKF} + \frac{I_{bcr}}{IKR} \end{split}$$

where

- *VAF* and *VAR* are the Forward Early voltage, VAF and Reverse Early voltage, VAR parameters, respectively.
- *IKF* and *IKR* are the **Forward knee current**, **IKF** and **Reverse knee current**, **IKR** parameter values, respectively.
- *eps* is 1e-4.

Base Resistance Model

The block models base resistance in one of two ways:

 If you use the default value of infinity for the Half base resistance cur, IRB parameter, the NPN block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + \frac{RB - RBM}{q_b}$$

where:

- *RBM* is the **Minimum base resistance**, **RBM** parameter value.
- *RB* is the **Zero-bias base resistance**, **RB** parameter value.
- If you specify a finite value for the **Half base resistance cur, IRB** parameter, the NPN block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + 3*(RB - RBM)*\left(\frac{\tan z - z}{z*\tan^2 z}\right)$$

where

$$z = \frac{\sqrt{1 + 144I_{B} / (\pi^{2}IRB)} - 1}{(24 / \pi^{2})\sqrt{(I_{B} / IRB)}}$$

Transit Charge Modulation Model

If you specify nonzero values for the **Coefficient of TF, XTF** parameter, the block models transit charge modulation by scaling the **Forward transit time, TF** parameter value as follows:

$$TF_{\rm mod} = \frac{TF * \left[1 + XTF * e^{V_{BC} / (1.44V_{TF})} \left(\frac{I_{BE}}{I_{BE} + ITF} \right)^2 \right]}{q_{\rm b}}$$

where *ITF* is the **Coefficient of TF**, **ITF** parameter value.

Junction Charge Model

The block lets you model junction charge. The base-collector charge Q_{bc} and the base-emitter charge Q_{be} depend on an intermediate value, Q_{dep} as follows, after adjusting the applicable model parameters for temperature:

• For the internal base-emitter junctions:

$$Q_{be} = TF_{\text{mod}} * I_{be} + Q_{dep}$$

• For the internal base-collector junctions:

$$Q_{bc} = TR * I_{bc} + XCJC * Q_{dep}$$

• For the external base-collector junctions:

$$Q_{b_{ext}c} = (1 - XCJC) * Q_{dep}$$

 $Q_{\rm dep}$ depends on the junction voltage, $V_{\rm jct}$ (V_{BE} for the base-emitter junction and $V_{\rm BC}$ for the base-collector junction) as follows.

| Applicable Range of V _{jct} Values | Corresponding Q _{dep} Equation |
|---|---|
| $V_{jct} < FC * VJ$ | $Q_{dep} = C_{jct} * VJ * \frac{1 - (1 - V_{jct} / VJ)^{(1 - MJ)}}{1 - MJ}$ |
| $V_{jct} \ge FC * VJ$ | $Q_{dep} = C_{jct} * \left[F1 + \frac{F3 * (V_{jct} - FC * VJ) + \frac{MJ * [V_{jct}^{2} - (FC * VJ)^{2}]}{2 * VJ}}{F2} \right]$ |

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is:
 - The **B-E built-in potential**, **VJE** parameter value for the base-emitter junction.
 - The **B-C built-in potential**, **VJC** parameter value for the base-collector junction.
- *MJ* is:
 - The **B-E exponential factor**, **MJE** parameter value for the base-emitter junction.
 - The **B-C exponential factor**, **MJC** parameter value for the base-collector junction.
- C_{jct} is:
 - The **B-E depletion capacitance, CJE** parameter value for the base-emitter junction.

- The **B-C depletion capacitance, CJC** parameter value for the base-collector junction.
- $F1 = VJ * (1 (1 FC)^{(1-MJ)}) / (1 MJ)$
- $F2 = (1 FC)^{(1+MJ)}$
- F3 = 1 FC * (1 + MJ)

The collector-substrate charge Q_{cs} depends on the collector-substrate voltage V_{cs} as follows, after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{cs} Values | Corresponding Q _{cs} Equation |
|--|---|
| $V_{cs} < 0$ | $Q_{cs} = CJS * VJS * \left(\frac{1 - \left(1 - V_{cs} / VJS\right)^{(1-MJS)}}{1 - MJS}\right)$ |
| $V_{cs} \ge 0$ | $Q_{cs} = CJS * (1 + MJS * V_{cs} / (2 * VJS)) * V_{cs}$ |

where:

- CJS is the C-S junction capacitance, CJS parameter value.
- *VJS* is the **Substrate built-in potential**, **VJS** parameter value.
- *MJS* is the **Substrate exponential factor**, **MJS** parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature: • When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

 $T = T_C + T_O$

where:

- T_C is the Circuit temperature parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the saturation current IS and the transistor temperature T:

$$IS(T) = IS * \left(T/T_{meas}\right)^{XTI} * e^{\left(\frac{T}{T_{meas}} - 1\right) * \frac{EG}{V_t}}$$

where:

- IS is the Transport saturation current, IS parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Temperature exponent for IS, XTI** parameter value.
- *EG* is the **Energy gap**, **EG** parameter value.
- $V_t = kT/q$.

The block provides the following relationship between the base-emitter junction potential VJE and the transistor temperature T:

$$VJE(T) = VJE * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T_{meas}}$$

where:

- *VJE* is the **B-E built-in potential**, **VJE** parameter value.
- $EG_{T_{meas}} = 1.16eV (7.02e 4 * T_{meas}^{2}) / (T_{meas} + 1108)$
- $EG_T = 1.16eV \cdot (7.02e \cdot 4 * T^2) / (T + 1108)$

The block uses the VJE(T) equation to calculate the base-collector junction potential by substituting VJC (the **B-C built-in potential**, **VJC** parameter value) for VJE.

The block provides the following relationship between the base-emitter junction capacitance CJE and the transistor temperature T:

$$CJE(T) = CJE * \left[1 + MJE * \left(400e - 6 * \left(T - T_{meas} \right) - \frac{VJE(T) - VJE}{VJE} \right) \right]$$

where:

- CJE is the **B-E depletion capacitance**, CJE parameter value.
- *MJE* is the **B-E exponential factor**, **MJE** parameter value.

The block uses the CJE(T) equation to calculate the base-collector junction capacitance by substituting CJC (the **B-C depletion** capacitance, CJC parameter value) for CJE and MJC (the **B-C** exponential factor, MJC parameter value) for MJE.

The block provides the following relationship between the forward and reverse beta and the transistor temperature T:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}}\right)^{XTB}$$

where:

- β is the Forward beta, BF or Reverse beta, BR parameter value.
- *XTB* is the **Beta temperature exponent**, **XTB** parameter value.

The block provides the following relationship between the base-emitter leakage current *ISE* and the transistor temperature *T*:

$$ISE(T) = ISE * \left(\frac{T}{T_{meas}}\right)^{\text{XTB}} * \left(\frac{\text{IS}(T)}{\text{IS}}\right)^{1/NE}$$

where:

- *ISE* is the **B-E leakage current**, **ISE** parameter value.
- *NE* is the **B-E emission coefficient**, **NE** parameter value.

The block uses this equation to calculate the base-collector leakage current by substituting *ISC* (the **B-C leakage current, ISC** parameter value) for *ISE* and *NC* (the **B-C emission coefficient, NC** parameter value) for *NE*.

The model is based on the following assumptions:

• The NPN block does not support noise analysis.

Basic Assumptions and Limitations

• The NPN block applies initial conditions across junction capacitors and not across the block ports.

Dialog Box and Parameters

| м | ain | Tab |
|---|-----|-----|
| M | ain | Iap |

| Block Parameters: SPICE NPN | | > |
|--|--|-------------|
| | ransistor. You specify both model card and instance parameters as instance paramet I OFF and noise model parameters KF and AF are not supported. | ers on this |
| | ances for this device. SCALE multiplies the output current and device charge directly multiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, | |
| You can set the BJT temperature to a fix | ked temperature or to the circuit temperature (from the SPICE Environment Paramet and EG adjust temperature sensitive parameters. | ers block) |
| temperature equations, which may yield | pacitance modeling and initial conditions. The capacitance modeling uses the publishe I a slightly different value than SPICE for capacitance. The initial conditions ICVBE ar ctions, and are only effective when the corresponding junction capacitances are pre | nd ICVCE |
| -Parameters | | |
| Main Forward Gain Reverse | Gain Resistors Capacitance Temperature | 1 |
| Device area, AREA: | 1 m^2 | • |
| Number of parallel devices, SCALE: | 1 | |
| | | |
| | | |
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| | | |

Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transport saturation current, IS
- Forward knee current, IKF
- B-E leakage current, ISE
- Reverse knee current, IKR
- B-C leakage current, ISC

- Half base resistance cur, IRB
- B-E depletion capacitance, CJE
- Coefficient of TF, ITF
- B-C depletion capacitance, CJC
- C-S junction capacitance, CJS

It divides the following parameter values:

- Zero-bias base resistance, RB
- Minimum base resistance, RBM
- Emitter resistance, RE
- Collector resistance, RC

The default value is 1 m^2 . The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel transistors the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

Forward Gain Tab

| liffers from th | | eter, which m | ces for this device. ultiples the device p | | | | | |
|-----------------|-------------------|-----------------|---|--------------------|----------------|---------------|------------------|-------------|
| | | | d temperature or to nd EG adjust tempe | | | ie SPICE En | vironment Param | eters block |
| | · | ŕ | · · | | | | | |
| emperature e | equations, whic | h may yield a | citance modeling an slightly different va | alue than SPICE fo | r capacitance. | The initial o | onditions ICVBE | and ICVCE |
| are the voltag | jes across the i | nternal junctio | ons, and are only e | ffective when the | corresponding | junction ca | pacitances are p | resent. |
| Parameters — | | | | | | | | |
| Main F | orward Gain | Reverse G | ain Resistors | Capacitance | Temperatu | re | | |
| Transport s | aturation curre | nt, IS: | 1e-16 | | | | A/m^2 | - |
| Forward be | eta, BF: | | 100 | | | | | |
| Forward er | nission coefficie | nt, NF: | 1 | | | | | |
| B-E leakage | e current, ISE: | | 0 | | | | A/m^2 | • |
| - | n coefficient, N | IC. | 1.5 | | | | 1. dow = | |
| | | | | | | | | |
| Forward kr | iee current, IKF | - | Inf | | | | A/m^2 | - |
| | arly voltage, VA | F: | Inf | | | | V | • |

Transport saturation current, IS

The magnitude of the current at which the transistor saturates. The default value is $1e - 16 \text{ A/m}^2$. The value must be greater than or equal to 0.

Forward beta, BF

The ideal maximum reverse beta. The default value is 100. The value must be greater than 0.

Forward emission coefficient, NF

The reverse emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

B-E leakage current, ISE

The base-emitter leakage current. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

B-E emission coefficient, NE

The base-collector emission coefficient or ideality factor. The default value is 1.5. The value must be greater than 0.

Forward knee current, IKF

The current value at which forward-beta high-current roll-off occurs. The default value is $Inf A/m^2$. The value must be greater than or equal to 0.

Forward Early voltage, VAF

The forward Early voltage. The default value is Inf V. The value must be greater than or equal to 0.

Reverse Gain Tab

| | ces for this device. SCALE multiplies the | | | |
|---|---|-------------------------|----------------------|-----------|
| ffers from the AREA parameter, which r he parameters RB, RBM, RE and RC. | ultiples the device parameters IS, IKF, 3 | ISE, IKR, ISC, IRB, CJE | :, ITF, CJC and CJS, | and divi |
| ou can set the BJT temperature to a fixe | | | nvironment Paramet | ers block |
| us TOFFSET. The parameters XTB, XTI (| | | | |
| he block lets you include or exclude cap emperature equations, which may yield | | | | |
| re the voltages across the internal junct | | | | |
| arameters | | | | |
| Main Forward Gain Reverse | iain Resistors Capacitance | Temperature | | |
| Reverse beta, BR: | 1 | | | |
| Reverse emission coefficient, NR: | 1 | | | |
| B-C leakage current, ISC: | 0 | | A/m^2 | - |
| 2 , | | | I name | |
| B-C emission coefficient, NC: | 2 | | | |
| Reverse knee current, IKR: | Inf | | A/m^2 | _ |
| Reverse Early voltage, VAR: | Inf | | V | - |
| | | | | |

Reverse beta, BR

The ideal maximum reverse beta. The default value is 1. The value must be greater than 0.

Reverse emission coefficient, NR

The reverse emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

B-C leakage current, ISC

The base-collector leakage current. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

B-C emission coefficient, NC

The base-collector emission coefficient or ideality factor. The default value is 2. The value must be greater than 0.

Reverse knee current, IKR

The current value at which reverse-beta high-current roll-off occurs. The default value is $Inf A/m^2$. The value must be greater than or equal to 0.

Reverse Early voltage, VAR

The reverse Early voltage. The default value is Inf V. The value must be greater than or equal to 0.

Resistors Tab

| 😽 Block Parameters: SPICE NPN | | | × | | |
|---|----------------------------------|-----------------------------|------------------------------|--|--|
| SPICE NPN | | | | | |
| This model approximates a SPICE NPN transistor. You specify both model card and instance parameters as instance parameters on this mask. The instance parameters PTF and OFF and noise model parameters KF and AF are not supported. | | | | | |
| SCALE is the number of parallel BJT 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, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides the parameters RB, RBM, RE and RC. | | | | | |
| You can set the BJT temperature to a fixed t plus TOFFSET. The parameters XTB, XTI and | | | nvironment Parameters block) | | |
| The block lets you include or exclude capacit. temperature equations, which may yield a sli are the voltages across the internal junction: | ghtly different value than SPICE | or capacitance. The initial | conditions ICVBE and ICVCE | | |
| Parameters | | |] | | |
| Main Forward Gain Reverse Gain | Resistors Capacitance | Temperature | 1 | | |
| Emitter resistance, RE: | 1e-4 | | m^2*Ohm | | |
| Collector resistance, RC: | 0.01 | | m^2*Ohm 💌 | | |
| Zero-bias base resistance, RB: | 1 | | m^2*Ohm | | |
| Minimum base resistance, RBM: | 0 | | m^2*Ohm 💌 | | |
| Half base resistance cur, IRB: | Inf | | A/m^2 | | |
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| | | OK Cancel | Help Apply | | |

Emitter resistance, RE

The resistance of the emitter. The default value is $1e-4 m^{2*}\Omega$. The value must be greater than or equal to 0.

Collector resistance, RC

The resistance of the collector. The default value is $0.01 \text{ m}^{2*}\Omega$. The value must be greater than or equal to 0.

Zero-bias base resistance, RB

The resistance of the base. The default value is 1 $m^{2*}\Omega$. The value must be greater than or equal to 0.

Minimum base resistance, RBM

The minimum resistance of the base. The default value is $0 \text{ m}^{2*}\Omega$. The value must be less than or equal to the **Zero-bias base** resistance, **RB** parameter value.

Half base resistance cur, IRB

The base current at which the base resistance has dropped to half of its zero-bias value. The default value is $Inf A/m^2$. The value must be greater than or equal to 0. Use the default value of Inf if you do not want to model the change in base resistance as a function of base current.

Capacitance Tab

| Block P | arameters: SPIC | E NPN | | | | | | |
|-------------|--|---------------------|-------------------|-------------------|----------------|------------------|-----------------|----------------|
| SPICE NPM | N | | | | | | | |
| | el approximates a S e instance parameti | | | | | | instance paran | neters on this |
| differs fro | the number of para om the AREA param neters RB, RBM, RE | ieter, which multip | | | | | | |
| | et the BJT tempera FSET, The paramete | | | | | he SPICE Env | ironment Parar | meters block) |
| temperatu | lets you include or ure equations, whic oltages across the i | h may yield a slig | htly different va | lue than SPICE fo | or capacitance | . The initial co | onditions ICVBE | and ICVCE |
| Parameter | rs | | | | | | | |
| Main | Forward Gain | Reverse Gain | Resistors | Capacitance | Temperati | ure | | |
| Model j | junction capacitanc | e?: | No | | | | | - |
| | | | | | | | | |
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Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- No Do not include junction capacitance in the model. This is the default option.
- B-E Capacitance Model the junction capacitance across the base-emitter junction.

- B-C Capacitance Model the junction capacitance across the base-collector junction.
- C-S Capacitance Model the junction capacitance across the collector-substrate junction.

Note To include junction capacitance in the model:

- **1** Select B-E Capacitance and specify the base-emitter junction capacitance parameters.
- **2** Select B-C Capacitance and specify the base-collector junction capacitance parameters.
- **3** Select C-S Capacitance and specify the collector-substrate junction capacitance parameters.

You can specify or change any of the common parameters when you select any of the preceding options for the **Model junction capacitance** parameter.

B-E depletion capacitance, CJE

The depletion capacitance across the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m². The value must be greater than or equal to 0.

B-E built-in potential, VJE

The base-emitter junction potential. This parameter is only visible when you select B-E Capacitance for the Model junction capacitance parameter. The default value is 0.75 V. The value must be greater than or equal to 0.01 V.

B-E exponential factor, MJE

The grading coefficient for the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value

is 0.33. The value must be greater than or equal to 0 and less than or equal to 0.9.

Forward transit time, TF

The transit time of the minority carriers that cause diffusion capacitance when the base-emitter junction is forward-biased. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0.

Coefficient of TF, XTF

The coefficient for the base-emitter and base-collector bias dependence of the transit time, which produces a charge across the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0. Use the default value of 0 if you do not want to model the effect of base-emitter bias on transit time.

VBC dependence of TF, VTF

The coefficient for the base-emitter bias dependence of the transit time. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is Inf V. The value must be greater than or equal to 0.

Coefficient of TF, ITF

The coefficient for the dependence of the transit time on collector current. This parameter is only visible when you select B-E Capacitance for the Model junction capacitance parameter. The default value is 0 A/m^2 . The value must be greater than or equal to 0. Use the default value of 0 if you do not want to model the effect of collector current on transit time.

B-C depletion capacitance, CJC

The depletion capacitance across the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than 0.

B-C built-in potential, VJC

The base-collector junction potential. This parameter is only visible when you select B-C Capacitance for the Model junction capacitance parameter. The default value is 0.75 V. The value must be greater than or equal to 0.01 V.

B-C exponential factor, MJC

The grading coefficient for the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.33. The value must be greater than or equal to 0 and less than or equal to 0.9.

B-C capacitance fraction, XCJC

The fraction of the base-collector depletion capacitance that is connected between the internal base and the internal collector. The rest of the base-collector depletion capacitance is connected between the external base and the internal collector. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0 and less than or equal to 1.

Reverse transit time, TR

The transit time of the minority carriers that cause diffusion capacitance when the base-collector junction is reverse-biased. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0 s. The value must be greater than or equal to 0.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than or equal to 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial transistor conditions.

Note The NPN block applies the initial transistor voltages across the junction capacitors and not across the ports.

This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter.

Initial condition voltage ICVBE

Base-emitter voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the Model junction capacitance and Yes for the Specify initial condition parameter. The default value is 0 V.

Initial condition voltage ICVCE

Base-collector voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the Model junction capacitance and Yes for the Specify initial condition parameter. The default value is 0 V.

C-S junction capacitance, CJS

The collector-substrate junction capacitance. This parameter is only visible when you select C-S Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Substrate built-in potential, VJS

The potential of the substrate. This parameter is only visible when you select C-S Capacitance for the **Model junction capacitance** parameter. The default value is 0.75 V.

Substrate exponential factor, MJS

The grading coefficient for the collector-substrate junction. This parameter is only visible when you select C-S Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0 and less than or equal to 0.9.

Temperature Tab

| Block Parameters: SPICE NPN | | |
|--|--|-----|
| PICE NPN | | |
| | istor. You specify both model card and instance parameters as instance parameters on th F and noise model parameters KF and AF are not supported. | s |
| | es for this device. SCALE multiplies the output current and device charge directly. This Itiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divic | les |
| | temperature or to the circuit temperature (from the SPICE Environment Parameters block d EG adjust temperature sensitive parameters. |) |
| emperature equations, which may yield a s | tance modeling and initial conditions. The capacitance modeling uses the published lightly different value than SPICE for capacitance. The initial conditions ICVBE and ICVCE ns, and are only effective when the corresponding junction capacitances are present. | |
| | b) and all only officiarly whom the consistentiang junction capacitances are present. | |
| arameters | | |
| Main Forward Gain Reverse Ga | in Resistors Capacitance Temperature | |
| Model temperature dependence using: | Device temperature | |
| Beta temperature exponent, XTB: | 0 | |
| Energy gap, EG: | 1.11 eV 💌 | |
| Temperature exponent for IS, XTI: | 3 | |
| Offset local circuit temperature TOFFSET: | 0 K ¥ | |
| Parameter extraction temperature, TMEAS: | 300.15 K | |
| | | |
| | | |
| | | |
| | OK Cancel Help Apply | 1 |

Model temperature dependence using

Select one of the following options for modeling the transistor temperature dependence:

- Device temperature Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
- Fixed temperature Use a temperature that is independent of the circuit temperature to model temperature dependence.

Beta temperature exponent, XTB

The forward and reverse beta temperature exponent that models base current temperature dependence. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0. The value must be greater than or equal to 0.

Energy gap, EG

The energy gap that affects the increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Temperature exponent for IS, XTI

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than or equal to 0.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

| | Parameter extraction temperature, TMEAS The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0. | | |
|---|---|--|--|
| Fixed circuit temperature, TFIXED The temperature at which to simulate the transistor. T parameter is only visible when you select Fixed temperature the Model temperature dependence using parameter default value is 300.15 K. The value must be greater that | | | |
| Ports | The block has the following ports: | | |
| | B Electrical conserving port associated with the transistor base terminal. | | |
| | C Electrical conserving port associated with the transistor collector terminal. | | |
| | E Electrical conserving port associated with the transistor emitter terminal. | | |
| | S Electrical conserving port associated with the transistor substrate terminal. | | |
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2. | | |
| See Also | NPN Bipolar Transistor | | |

SPICE PJFET

| Purpose | Model SPICE-compatible P-Channel JFET |
|--------------------|--|
| Library | SPICE-Compatible Components/Semiconductor Devices |
| Description ⊶¦° | The PJFET block represents a SPICE-compatible P-channel JFET. The PJFET block model includes the following components: • "Source-Gate Current-Voltage Model" on page 1-730 |

- "Drain-Gate Current-Voltage Model" on page 1-731
- "Source-Drain Current-Voltage Model" on page 1-732
- "Junction Charge Model" on page 1-733
- "Temperature Dependence" on page 1-735

Source-Gate Current-Voltage Model

The block provides the following relationship between the source-gate current I_{sg} and the source-gate voltage V_{sg} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sg} Values | Corresponding I _{sg} Equation |
|---|--|
| $V_{sg} > 80 * V_t$ | $I_{sg} = IS * \left(\left(\frac{V_{sg}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{sg} * G \min$ |
| $80 * V_t \geq V_{sg}$ | $I_{sg} = IS * (e^{V_{sg}/V_t} - 1) + V_{sg} * G \min$ |

Where:

- *IS* is the **Saturation current**, **IS** parameter value.
- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient**, **ND** parameter value.

- *q* is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Drain-Gate Current-Voltage Model

The block provides the following relationship between the drain-gate current I_{dg} and the drain-gate voltage V_{dg} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{dg} Values | Corresponding I _{dg} Equation |
|---|--|
| $V_{dg} > 80 * V_t$ | $I_{dg} = IS * \left(\left(\frac{V_{dg}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{dg} * G \min$ |
| $80 * V_t \ge V_{dg}$ | $I_{dg} = IS * (e^{V_{dg}/V_t} - 1) + V_{dg} * G \min$ |

Source-Drain Current-Voltage Model

The block provides the following relationship between the source-drain current I_{sd} and the source-drain voltage V_{sd} in normal mode ($V_{sd} \ge 0$) after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sg} and V _{dg} Values | Corresponding I _{sd} Equation |
|--|--|
| V_{sg} - $V_{to} \leq 0$ | $I_{sd} = 0$ |
| $0 < V_{sg} - V_{to} \leq V_{sd}$ | $I_{sd} = -\beta * \left(V_{sg} - V_{to} \right)^2 * \left(1 + \lambda * V_{sd} \right)$ |
| $0 < V_{sd} < V_{sg} - V_{to}$ | $I_{sd} = \beta * V_{sd} * (2 * (V_{sg} - V_{to}) - V_{sd}) * (1 + \lambda * V_{sd})$ |

Where:

- V_{to} is the **Threshold voltage**, **VTO** parameter value.
- β is the **Transconductance**, **BETA** parameter value.
- λ is the **Channel modulation**, **LAMBDA** parameter value.

The block provides the following relationship between the source-drain current I_{sd} and the source-drain voltage V_{sd} in inverse mode ($V_{sd} < 0$) after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sg} and V _{dg} Values | Corresponding I _{sd} Equation | |
|--|---|--|
| V_{dg} - $V_{to} \leq 0$ | $I_{sd} = 0$ | |
| $0 < V_{dg} - V_{to} \leq -V_{sd}$ | $I_{sd} = \beta * (V_{dg} - V_{to})^{2} * (1 - \lambda * V_{sd})$ | |
| $0 < -V_{sd} < V_{dg} - V_{to}$ | $I_{sd} = \beta * V_{sd} * (2 * (V_{dg} - V_{to}) + V_{sd}) * (1 - \lambda * V_{sd})$ | |

Junction Charge Model

The block provides the following relationship between the source-gate charge $Q_{\rm sg}$ and the source-gate voltage $V_{\rm sg}$ after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sg} Values | Corresponding Q _{sg} Equation |
|--|--|
| $V_{sg} < FC * VJ$ | $Q_{sg} = \frac{CGS * VJ * \left(1 \cdot \left(1 \cdot \frac{V_{sg}}{VJ}\right)^{1-MG}\right)}{1 - MG}$ |
| $V_{sg} \geq FC * VJ$ | $Q_{sg} = CGS * \left(F1 + \frac{F3 * (V_{sg} - FC * VJ) + \frac{MG * (V_{sg}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$ |

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is the **Junction potential VJ** parameter value.
- CGS is the Zero-bias GS capacitance, CGS parameter value.
- *MG* is the **Grading coefficient**, **MG** parameter value.

•
$$F1 = \frac{VJ * (1 - (1 - FC)^{1-MG})}{1 - MG}$$

•
$$F2 = (1 - FC)^{1+MG}$$

• F3 = 1 - FC * (1 + MG)

The block provides the following relationship between the drain-gate charge Q_{dg} and the drain-gate voltage V_{dg} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{dg} Values | Corresponding Q _{dg} Equation |
|--|--|
| $V_{dg} < FC * VJ$ | $Q_{dg} = \frac{CGD * VJ * \left(1 - \left(1 - \frac{V_{dg}}{VJ}\right)^{1-MG}\right)}{1 - MG}$ |
| $V_{dg} \ge FC * VJ$ | $Q_{dg} = CGD * \left(F1 + \frac{F3 * (V_{dg} - FC * VJ) + \frac{MG * (V_{dg}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$ |

Where:

• CGD is the Zero-bias GD capacitance, CGD parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

• When you select Device temperature for the **Model temperature** dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

- T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the saturation current IS and the transistor temperature T:

$$IS(T) = IS * (T/T_{meas})^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}} - 1\right) * \frac{EG}{V_t}}$$

where:

- *IS* is the **Saturation current**, **IS** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent, XTI** parameter value.
- *EG* is the **Energy gap, EG** parameter value.

- $V_t = ND * k * T/q$
- ND is the Emission coefficient, ND parameter value.

The block provides the following relationship between the junction potential VJ and the transistor temperature T:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T}$$

where:

- *VJ* is the **Junction potential VJ** parameter value.
- $EG_{T_{meas}} = 1.16eV (7.02e 4 * T_{meas}^{2}) / (T_{meas} + 1108)$
- $EG_T = 1.16eV (7.02e 4*T^2)/(T + 1108)$

The block provides the following relationship between the gate-source junction capacitance CGS and the transistor temperature T:

$$CGS(T) = CGS * \left[1 + MG * \left(400e - 6 * (T - T_{meas}) - \frac{VJ(T) - VJ}{VJ} \right) \right]$$

where:

• CGS is the Zero-bias GS capacitance, CGS parameter value.

The block uses the CGS(T) equation to calculate the gate-drain junction capacitance by substituting CGD (the **Zero-bias GD capacitance**, **CGD** parameter value) for CGS.

The block provides the following relationship between the forward and reverse beta and the transistor temperature T:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}}\right)$$

where β is the **Transconductance**, **BETA** parameter value.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The PJFET block does not support noise analysis.
- The PJFET block applies initial conditions across junction capacitors and not across the block ports.

SPICE PJFET

Dialog Box and Parameters

Main Tab

| ICE PJFET | | | | |
|---|---|-------------------------|-----------------------|---------|
| | el JFET. You specify both model card and in bise model parameters KF and AF are not s | | | |
| | nces for this device. SCALE multiplies the o ultiples the device parameters BETA, IS, C | | | This |
| | ed temperature or to the circuit temperatu TI and EG adjust temperature sensitive par | | invironment Paramet | ers blo |
| mperature equations, which may yield | citance modeling and initial conditions. The slightly different value than SPICE for cap ons, and are only effective when the corre | acitance. The initial (| conditions ICVDS and | ICVG |
| | ons, and are only enective when the corre | sponding junction co | apacicances are prese | 310. |
| rameters | | | | |
| Main Junction Capacitance Te | mperature | | | |
| Device area, AREA: | 1 | | m^2 | - |
| Number of parallel devices, SCALE: | 1 | | | |
| Threshold voltage, VTO: | -2 | | ٧ | v |
| Transconductance, BETA: | 1e-4 | | A/m^2/V^2 | • |
| Channel modulation, LAMBDA: | 0 | | 1/V | • |
| Saturation current, IS: | 1e-14 | | A/m^2 | - |
| Emission coefficient, ND: | 1 | | | |
| | 1e-4 | | m^2*Ohm | - |
| Source resistance, RS: | | | L adval | • |
| Source resistance, RS: Drain resistance, RD: | 0.01 | | m^2*Ohm | - |

Device area, AREA

The transistor area. This value multiplies the **Transconductance, BETA**, **Zero-bias GS capacitance, CGS**, **Zero-bias GD capacitance, CGD**, and **Saturation current, IS** parameter values. It divides the **Source resistance, RS** and **Drain resistance, RD** parameter values. The default value is 1 m². The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel transistors the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is -2 V.

Transconductance, **BETA**

The derivative of drain current with respect to gate voltage. The default value is $1e - 04 \text{ A/m}^2/\text{V}^2$. The value must be greater than or equal to 0.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Emission coefficient, ND

The transistor emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

Source resistance, RS

The transistor source resistance. The default value is $1e - 4 m^{2*}\Omega$. The value must be greater than or equal to 0.

Drain resistance, RD

The transistor drain resistance. The default value is $0.01 \text{ m}^{2*}\Omega$. The value must be greater than or equal to 0.

Junction Capacitance Tab

| Block Pa | rameters: SPICE PJFET |
|-----------|---|
| PICE PJF | л.— |
| nask. The | approximates a SPICE P-channel JFET. You specify both model card and instance parameters as instance parameters on instance parameter OFF and noise model parameters KF and AF are not supported. Additional instance parameters are FFSET, ND, MG, XTI and EG. |
| | e number of parallel JFET instances for this device. SCALE multiplies the output current and device charge directly. This n the AREA parameter, which multiples the device parameters BETA, IS, CGS, CGD, and divides RS and RD. |
| | : the JFET temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters bl ET. The parameters ND, MG, XTI and EG adjust temperature sensitive parameters. |
| emperatu | ets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published e equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVD5 and ICVG tages across the internal junctions, and are only effective when the corresponding junction capacitances are present. |
| arameter | |
| Main | Junction Capacitance Temperature |
| | |
| | |
| | |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

• No — Do not include junction capacitance in the model. This is the default option.

• Yes — Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias GS capacitance, CGS

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Zero-bias GD capacitance, CGD

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient, MG

The transistor grading coefficient. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than or equal to 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

Note The PJFET block applies the initial diode voltage across the junction capacitors and not across the ports.

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Temperature Tab

| Block Parameters: SPICE PJFET | | |
|---|---|----------------------------------|
| PICE PJFET | | |
| | el JFET. You specify both model card and instance paramet bise model parameters KF and AF are not supported. Addit | |
| | nces for this device. SCALE multiplies the output current a ultiples the device parameters BETA, IS, CGS, CGD, and di | |
| | ed temperature or to the circuit temperature (from the SPI TI and EG adjust temperature sensitive parameters. | ICE Environment Parameters bloc |
| emperature equations, which may yield a | citance modeling and initial conditions. The capacitance mo slightly different value than SPICE for capacitance. The in ons, and are only effective when the corresponding juncti | itial conditions ICVDS and ICVGS |
| arameters | | |
| Main Junction Capacitance Te | mperature | |
| Model temperature dependence using: | Device temperature | • |
| Saturation current temperature exponent, XTI: | 0 | |
| Activation energy, EG: | 1.11 | eV 💌 |
| Offset local circuit temperature, TOFFSET: | 0 | К |
| Parameter extraction temperature, TMEAS: | 300.15 | K |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel | Help Appl |

Model temperature dependence using

Select one of the following options for modeling the diode temperature dependence:

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.

• Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Saturation current temperature exponent, XTI

The order of the exponential increase in the saturation current as temperature increases. The default value is 0. The value must be greater than or equal to 0.

Activation energy, EG

The energy gap that affects the increase in the saturation current as temperature increases. The default value is 1.11 eV. The value must be greater than 0.1 eV.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Ports The block has the following ports:

G

Electrical conserving port associated with the transistor gate terminal.

| | D Electrical conserving port associated with the transistor drain terminal. |
|------------|--|
| | S Electrical conserving port associated with the transistor source terminal. |
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 3. |
| See Also | P-Channel JFET, SPICE NJFET |

SPICE PMOS

| Purpose | Model SPICE-compatible P-Channel MOSFET | |
|----------------------|--|--|
| Library | SPICE-Compatible Components/Semiconductor Devices | |
| Description | The PMOS block represents a SPICE-compatible P-channel MOSFET. | |
| ▫┥ <mark>╞</mark> ╌╹ | The PMOS block model includes the following components: | |
| - ⁻¹⁻ | • "Resistance Calculations" on page 1-746 | |
| | • "Bulk-Source Diode Model" on page 1-747 | |
| | • "Bulk-Drain Diode Model" on page 1-748 | |

- "Level 1 Drain Current Model" on page 1-749
- "Level 3 Drain Current Model" on page 1-752
- "Junction Charge Model" on page 1-758
- "Temperature Dependence" on page 1-763

Resistance Calculations

The following table shows how the PMOS block calculates the transistor drain resistance. The abbreviations in the table represent the values of the following block parameters:

- Drain resistance, RD
- Sheet resistance, RSH
- Number of drain squares, NRD

| Drain resistance, RD Parameter | Sheet resistance, RSH Parameter | Drain Resistance |
|-----------------------------------|------------------------------------|------------------|
| NaN | NaN | 0 |
| RD | NaN or RSH | RD |
| NaN | RSH | RSH*NRD |

The following table shows how the PMOS block calculates the transistor source resistance. The abbreviations in the table represent the values of the following block parameters:

- Source resistance, RS
- Sheet resistance, RSH
- Number of source squares, NRS

| Source resistance, RS Parameter | Sheet resistance, RSH Parameter | Source Resistance |
|------------------------------------|------------------------------------|-------------------|
| NaN | NaN | 0 |
| RS | NaN or RSH | RS |
| NaN | RSH | RSH*NRS |

Bulk-Source Diode Model

The block provides the following relationship between the bulk-source current I_{sb} and the bulk-source voltage V_{sb} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sb} Values | Corresponding I _{gs} Equation | |
|---|--|--|
| $V_{sb} > 80 * V_{tn}$ | $I_{sb} = IS_{sb} * \left(\left(\frac{V_{sb}}{V_{tn}} - 79 \right) e^{80} - 1 \right) + V_{sb} * G \min$ | |
| $80V_{tn} \ge V_{sb}$ | $I_{sb} = IS_{sb} * (e^{V_{sb}/V_{tn}} - 1) + V_{sb} * G \min$ | |

Where:

- IS_{sb} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of source**, **AS** parameter value if both these

parameter values and the Area of drain, AD parameter value are nonzero.

- The Bulk saturation current, IS parameter value, otherwise.
- $V_{tn} = NkT/q$
- q is the elementary charge on an electron, 1.6021918e-19 C.
- *N* is the **Emission coefficient**, **ND** parameter value.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Bulk-Drain Diode Model

The block provides the following relationship between the bulk-drain current I_{db} and the bulk-drain voltage V_{db} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{db} Values | Corresponding I _{gs} Equation | |
|---|---|--|
| $V_{db} > 80 * V_{tn}$ | $I_{db} = IS_{db} * \left(\left(\frac{V_{db}}{V_{m}} - 79 \right) e^{80} - 1 \right) + V_{db} * G \min$ | |
| $80V_{tn} \ge V_{db}$ | $I_{db} = IS_{db} * (e^{V_{db}/V_{m}} - 1) + V_{db} * G \min$ | |

Where:

- IS_{db} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of drain**, **AD** parameter value if both these parameter values and the **Area of source**, **AS** parameter value are nonzero.
 - The Bulk saturation current, IS parameter value, otherwise.

Level 1 Drain Current Model

The block provides the following relationship between the drain current

 I_{sd} and the drain-source voltage V_{sd} in normal mode ($V_{sd} \geq 0$) after adjusting the applicable model parameters for temperature.

Normal Mode

| Applicable Range of V _{sg} and V _{sd} Values | Corresponding I _{sd} Equation |
|--|--|
| V_{sg} - $V_{on} \leq 0$ | $I_{sd} = 0$ |
| $0 < V_{sg} - V_{on} \leq V_{sd}$ | $I_{sd} = BETA * \left(V_{sg} - V_{on}\right)^2 \frac{\left(1 + LAMBDA * V_{sd}\right)}{2}$ |
| $0 < V_{sd} < V_{sg} - V_{on}$ | $I_{sd} = BETA *$ $V_{sd} \left(\left(V_{sg} - V_{on} \right) - \frac{V_{sd}}{2} \right) \left(1 + LAMBDA * V_{sd} \right)$ |

Where:

• *V*_{on} is:

•
$$MTYPE * VBI + GAMMA \sqrt{PHI - V_{sb}}$$
 if $V_{sb} \le 0$.

- $\begin{array}{ll} \bullet & MTYPE*VBI+GAMMA\left(\sqrt{PHI}-\frac{V_{sb}}{2\sqrt{PHI}}\right) \text{ if } 0 < V_{sb} \leq 2*PHI \ . \\ \bullet & MTYPE*VBI \text{ if } V_{sb} > 2*PHI. \end{array}$
- MTYPE is -1.
- BETA is KP*WIDTH/(LENGTH-2*LD)
- *KP* is:
 - The **Transconductance**, **KP** parameter value, if this parameter has a numerical value.

- $U0*3.9*\varepsilon_0/TOX$, if Transconductance, KP is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- WIDTH is the Width of channel, WIDTH parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.
- *VBI* is an built-in voltage value the block uses in calculations. The value is a function of temperature. For a detailed definition, see "Temperature Dependence" on page 1-681.
- *PHI* is:
 - The **Surface potential**, **PHI** parameter value, if this parameter has a numerical value.
 - $2 * kT_{meas} / q * \log(NSUB / n_i)$, if Surface potential, PHI is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- LAMBDA is the Channel modulation, LAMBDA parameter value.
- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- ε_0 is the permittivity of free space, 8.854214871e-12 F/m.
- n_i is the carrier concentration of intrinsic silicon, 1.45e10 cm⁻³.

The block provides the following relationship between the drain current

 I_{sd} and the drain-source voltage V_{sd} in inverse mode ($V_{sd} < 0$) after adjusting the applicable model parameters for temperature.

Inverse Mode

| Applicable Range of V _{dg} and V _{sd} Values | Corresponding I _{sd} Equation |
|--|--|
| V_{dg} - $V_{on} \leq 0$ | $I_{sd} = 0$ |
| $0 < V_{dg} - V_{on} \leq -V_{sd}$ | $I_{sd} = -BETA (V_{dg} - V_{on})^2 (1 - LAMBDA * V_{sd})/2$ |
| $0 < V_{sd} < V_{dg} - V_{on}$ | $I_{sd} = BETA *$ $V_{sd} \left(\left(V_{dg} - V_{on} \right) + V_{sd} / 2 \right) \left(1 - LAMBDA * V_{sd} \right)$ |

Where:

• *V*_{on} is:

•

- $MTYPE * VBI + GAMMA \sqrt{PHI - V_{db}}$ if

$$V_{db} \leq 0$$

- $MTYPE * VBI + GAMMA \left(\sqrt{PHI} \frac{V_{db}}{2\sqrt{PHI}} \right)$ if $0 < V_{db} \le 2 * PHI$
- MTYPE*VBI if $V_{db} > 2*PHI$.

Level 3 Drain Current Model

The block provides the following model for drain current I_{sd} in normal

mode ($V_{\rm sd} \geq 0$) after adjusting the applicable model parameters for temperature.

$$I_{SD} = I_{SD0} * Scale_{VMAX} * Scale_{LChan} * Scale_{INV}$$

Where:

- I_{SD0} is the Basic Drain Current Model.
- *Scale_{VMAX}* is the Velocity Saturation Scaling.
- $Scale_{LChan}$ is the Channel Length Modulation Scaling.
- *Scale*_{INV} is the Weak Inversion Scaling.

The blocks uses the same model for drain current in inverse mode ($V_{sd} < 0$), with the following substitutions:

- $V_{sb} V_{sd}$ for V_{sb}
- $V_{sg} V_{sd}$ for V_{sd}
- $-V_{sd}$ for V_{sd}

Basic Drain Current Model

The block provides the following relationship between the drain current I_{sd} and the drain-source voltage V_{ds} :

$$I_{SD0} = BETA * F_{gate} * \left(V_{SGX} - V_{TH} - \frac{1 + F_B}{2} * V_{SDX} \right) * V_{SDX}$$

- The block calculates BETA as described in "Level 1 Drain Current Model" on page 1-749.
- The block calculates F_{GATE} using the following equation:

$$F_{gate} = \frac{1}{1 + THETA * (V_{sgx} - V_{TH})}$$

• *THETA* is the **Vgs dependence on mobility, THETA** parameter value.

- $V_{sgx} = \max(V_{SG}, V_{on})$
- If you specify a nonzero value for the **Fast surface state density**, **NFS** parameter, the block calculates V_{on} using the following equation:

$$V_{on} = V_{TH} + x_n V_T$$

Otherwise, $V_{on} = V_{TH}$.

• The block calculates x_n using the following equation:

$$x_{n} = 1 + \frac{q * NFS}{COX} + \frac{\left(GAMMA * F_{s} * \sqrt{V_{bulk}} + \frac{F_{n} * V_{bulk}}{WIDTH}\right)}{2 * V_{bulk}}$$

- The block calculates V_{bulk} as follows:
 - If $V_{SB} \leq 0$, $V_{bulk} = PHI V_{BS}$.
 - Otherwise, the block calculates V_{bulk} using the following equation:

$$V_{bulk} = \frac{PHI}{\left(1 + \frac{V_{SB}}{2*PHI}\right)^2}$$

- $V_T = kT/q$
- The block calculates V_{TH} using the equation following equation:

$$V_{TH} = V_{BI} - \frac{8.15e^{-22} * ETA}{COX * (LENGTH - 2 * LD)^3} * V_{SD}$$
$$+ GAMMA * F_s * \sqrt{V_{bulk}} + F_n * V_{bulk}$$

• For information about how the block calculates V_{BI} , see "Temperature Dependence" on page 1-763.

- ETA is the Vds dependence threshold volt, ETA parameter value.
- $COX = \varepsilon_{ox}/TOX$, where ε_{ox} is the permittivity of the oxide and TOX is the **Oxide thickness**, **TOX** parameter value.
- If you specify a nonzero value for the **Junction depth**, **XJ** parameter and a value for the **Substrate doping**, **NSUB** parameter, the block calculates F_s using the following equations:

$$\alpha = \frac{2\varepsilon_{si}}{qNSUB}$$

$$XD = \sqrt{\alpha}$$

$$wc = .0631353 + .8013292 * \frac{XD * \sqrt{V_{bulk}}}{XJ}$$

$$-.01110777 * \left(\frac{XD * \sqrt{V_{bulk}}}{XJ}\right)^2 + \frac{LD}{XJ}$$

$$F_s = 1 - \left(wc * \sqrt{1 - \left(\frac{XD * \sqrt{V_{bulk}}}{XJ + XD * \sqrt{V_{bulk}}}\right)^2} - \frac{LD}{XJ}\right)$$

where ε_{si} is the permittivity of silicon.

Otherwise, $F_s = 1$.

• The block calculates F_B using the following equation:

$$F_B = \frac{GAMMA * F_s}{4 * \sqrt{V_{bulk}}} + F_n$$

• The block calculates F_n using the following equation:

SPICE PMOS

$$F_n = \frac{DELTA * \pi * \varepsilon_{si}}{2 * COX * WIDTH}$$

- *DELTA* is the **Width effect on threshold**, **DELTA** parameter value.
- V_{SDX} is the lesser of V_{SD} and the saturation voltage, V_{dsat} .
 - If you specify a positive value for the Max carrier drift velocity, VMAX parameter, the block calculates V_{dsat} using the following equation:

$$V_{dsat} = \frac{V_{sgx} - V_{TH}}{1 + F_B} + \frac{(LENGTH - 2*LD)*VMAX}{UO*F_{gate}}$$
$$-\sqrt{\left(\frac{V_{sgx} - V_{TH}}{1 + F_B}\right)^2 + \left(\frac{(LENGTH - 2*LD)*VMAX}{UO*F_{gate}}\right)^2}$$

Otherwise, the block calculates V_{dsat} using the following equation:

$$V_{dsat} = \frac{V_{sgx} - V_{TH}}{1 + F_{B}}$$

Velocity Saturation Scaling

If you specify a positive value for the **Max carrier drift velocity**, **VMAX** parameter, the block calculates $Scale_{VMAX}$ using the following equation:

$$Scale_{VMAX} = \frac{1}{1 + \frac{UO * F_{gate}}{(LENGTH - 2 * LD) * VMAX} * V_{SDX}}$$

Otherwise, $Scale_{VMAX} = 1$.

Channel Length Modulation Scaling

The block scales the drain current to account for channel length modulation if the block meets all of the following criteria:

- $V_{SD} > V_{sat}$
- The **Max carrier drift velocity**, **VMAX** parameter value is zero or *a* is nonzero.

The block scales the drain current using the following equation:

$$Scale_{LChan} = \frac{1}{1 - \frac{\Delta l}{(LENGTH - 2*LD)}}$$

The block uses the following procedure to calculate Δl :

- **1** The block first calculates the intermediate value Δl_{0} .
 - If you specify a positive value for the **Max carrier drift velocity**, **VMAX** parameter, the block computes the intermediate value g_{dsat} as the greater of 1e-12 and the result of the following equation:

$$I_{SD0} * \left(1 - \frac{1}{1 + Scale_{g_{dsat}} * V_{SDX}} \right) * Scale_{g_{dsat}}$$

where:

$$Scale_{g_{dsat}} = \frac{UO * F_{gate}}{(LENGTH - 2 * LD) * VMAX}$$

Then, the block uses the following equation to calculate the intermediate value Δl_{o} :

$$\Delta l_{0} = \sqrt{\left(\frac{KA * I_{SD}}{2 * (LENGTH - 2 * LD) * g_{dsat}}\right)^{2} + KA * (V_{SD} - V_{dsat})} - \frac{KA * I_{SD}}{2 * (LENGTH - 2 * LD) * g_{dsat}}$$

where *KA* is the product of the **Mobility modulation**, **KAPPA** parameter value and *a*.

• Otherwise, the block uses the following equation to calculate the intermediate value Δl_{a} :

$$\Delta l = \sqrt{KA * \left(V_{SD} - V_{dsat}\right)}$$

- **2** The block checks for punch through and calculates Δl .
 - If Δl_0 is greater than (*LENGTH*-2**LD*)/2, the block calculates Δl using the following equation:

$$\Delta l = \left(1 - \frac{\left(LENGTH - 2*LD\right)}{4*\Delta l_0}\right) * \left(LENGTH - 2*LD\right)$$

• Otherwise, $\Delta l = \Delta l_0$.

Weak Inversion Scaling

If V_{SG} is less than V_{on} , the block calculates $Scale_{INV}$ using the following equation:

$$Scale_{INV} = e^{\frac{V_{sg} - V_{on}}{x_n * V_T}}$$

Otherwise, $Scale_{INV} = 1$.

Junction Charge Model

The block models the following junction charges:

- Junction Overlap Charges
- Bulk Junction Charges

Junction Overlap Charges

The block calculates the following junction overlap charges:

• Q_{SG}=CGSO*WIDTH*V_{so}

Where:

- Q_{SG} is the gate-source overlap charge.
- CGSO is the G-S overlap capacitance, CGSO parameter value.
- *WIDTH* is the **Width of channel**, **WIDTH** parameter value.
- $Q_{DG} = CGDO^*WIDTH^*V_{dg}$

Where:

- Q_{DG} is the gate-drain overlap charge.
- *CGDO* is the **G-D overlap capacitance**, **CGDO** parameter value.
- Q_{BG} =CGBO*(LENGTH-2*LD)* V_{bg}

Where:

- Q_{BG} is the gate-bulk overlap charge.
- *CGBO* is the **G-B overlap capacitance**, **CGBO** parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.

Bulk Junction Charges

The block provides the following relationship between the bulk-drain bottom junction charge Q_{bottom} and the junction voltage V_{db} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{db} Values | Corresponding Q _{bottom} Equation |
|--|--|
| $V_{db} < FC * PB$ | $Q_{bottom} = \frac{CBD * PB * \left(1 - \left(1 - \frac{V_{db}}{PB}\right)^{1-MJ}\right)}{1 - MJ} \text{ if } CBD > 0.$ $Q_{bottom} = \frac{CJ * AD * PB * \left(1 - \left(1 - \frac{V_{db}}{PB}\right)^{1-MJ}\right)}{1 - MJ} \text{ otherwise.}$ |
| $V_{db} \ge FC * PB$ | $\begin{split} \mathcal{Q}_{bottom} &= CBD * \\ & \left(F1 + \frac{F3^* (V_{db} - FC * PB) + \frac{MJ^* (V_{db}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right) \\ & \text{if } CBD > 0. \\ \mathcal{Q}_{bottom} &= CJ * AD * \\ & \left(F1 + \frac{F3^* (V_{db} - FC * PB) + \frac{MJ^* (V_{db}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right) \\ & \text{otherwise.} \end{split}$ |

Where:

- *PB* is the **Bulk junction potential**, **PB** parameter value.
- FC is the Capacitance coefficient FC parameter value.
- CBD is the Zero-bias BD capacitance, CBD parameter value.
- CJ is the Bottom junction cap per area, CJ parameter value.
- *AD* is the **Area of drain**, **AD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1-MJ})}{1 - MJ}$$

- $F2 = (1 FC)^{1+MJ}$
- F3 = 1 FC * (1 + MJ)

The block uses the equations in the preceding table to calculate the bulk-source bottom junction charge, with the following substitutions:

- V_{sb} replaces V_{db}.
- *AS* (the **Area of source, AS** parameter value) replaces *AD*.
- *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) replaces *CBD*.

The block provides the following relationship between the bulk-drain sidewall junction charge $Q_{sidewall}$ and the junction voltage V_{db} after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{db} Values | Corresponding Q _{sidewall} Equation |
|--|--|
| $V_{db} < FC * PB$ | $Q_{sidewall} = \frac{CJSW * PD * PB * \left(1 - \left(1 - \frac{V_{db}}{PB}\right)^{1 - MJSW}\right)}{1 - MJSW}$ |
| $V_{db} \ge FC * PB$ | $Q_{sidewall} = CJSW * PD * \left(F1 + \frac{F3 * (V_{db} - FC * PB) + \frac{MJSW * (V_{db}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right)$ |

Where:

- *CJSW* is the **Side jct cap/area of jct perimeter**, **CJSW** parameter value.
- *PD* is the **Perimeter of drain**, **AD** parameter value.
- *MJSW* is the **Side grading coefficient**, **MJSW** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1 - MJSW})}{1 - MJSW}$$

•
$$F2 = (1 - FC)^{1 + MJ}$$

• F3 = 1 - FC * (1 + MJSW)

The block uses the equations in the preceding table to calculate the bulk-source sidewall junction charge and the sidewall junction voltage, with the following substitutions:

- V_{sb} replaces V_{db}.
- *PS* (the **Perimeter of source, PS** parameter value) replaces *PD*.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

• When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

- T_C is the Circuit temperature parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the transconductance KP and the transistor temperature T:

$$KP(T) = \frac{KP}{\left(\frac{T}{T_{meas}}\right)^{3/2}}$$

where:

- *KP* is the **Transconductance**, **KP** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.

The block provides the following relationship between the surface potential *PHI* and the transistor temperature *T*:

$$\begin{split} PHI(T) &= \frac{T}{T_{meas}} \Bigg(PHI + \frac{kT_{meas}}{q} \Bigg(\log \Bigg(\frac{T_{meas}}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T_{meas}} \Bigg) \Bigg) \Bigg) \\ &- \frac{kT}{q} \Bigg(\log \Bigg(\frac{T}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_T}{T} \Bigg) \Bigg) \end{split}$$

where:

•
$$EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4 * T_{meas}^{2}) / (T_{meas} + 1108)$$

•
$$EG_T = 1.16eV \cdot (7.02e \cdot 4 * T^2) / (T + 1108)$$

The block provides the following relationship between the built-in voltage *VBI* and the transistor temperature *T*:

$$VBI(T) = VTO + MTYPE * \left(\frac{PHI(T) - PHI}{2} - GAMMA\sqrt{PHI}\right) + \frac{EG_{T_{meas}} - EG_T}{2}$$

where:

- *VTO* is:
 - The **Threshold voltage**, **VTO** parameter value, if this parameter has a numerical value.

• $\Phi - 3.25 + EG_{T_{more}}/2 + MTYPE * PHI/2 - NSS * q * TOX / (3.9 * \varepsilon_0)$

+ $MTYPE * (GAMMA * \sqrt{PHI} + PHI)$, if Threshold voltage, VTO is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

- Φ is:
 - **3.2**, if *TPG* (the **Gate type?**, **TPG** parameter value) is **0**.

-
$$3.25 + EG_{T_{max}}/2 - MTYPE * TPG * EG_{T_{max}}/2$$
, otherwise.

- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

The block provides the following relationship between the bulk saturation current IS and the transistor temperature T:

$$IS(T) = IS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

- *ND* is the **Emission coefficient**, **ND** parameter value.
- *IS* is the **Bulk saturation current**, **IS** parameter value.

The block provides the following relationship between the bulk junction saturation current density JS and the transistor temperature T:

$$JS(T) = JS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

• JS is the **Bulk jct sat current density**, JS parameter value.

The block provides the following relationship between the bulk junction potential PB and the transistor temperature T:

$$PB(T) = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas} / T} - \frac{kT}{q} \left(\log \left(\frac{T}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_T}{T} \right) \right)$$

where:

• *PB* is the **Bulk junction potential**, **PB** parameter value.

The block provides the following relationship between the bulk-drain junction capacitance CBD and the transistor temperature T:

$$CBD(T) = CBD \frac{pbo + MJ * (4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo))}{pbo + MJ * (4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo))}$$

where:

- CBD is the Zero-bias BD capacitance, CBD parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$pbo = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas}/300.15}$$

The block uses the CBD(T) equation to calculate:

- The bulk-source junction capacitance by substituting *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) for *CBD*.
- The bottom junction capacitance by substituting *CJ* (the **Bottom junction cap per area**, *CJ* parameter value) for *CBD*.

The block provides the following relationship between the sidewall junction capacitance CJSW and the transistor temperature T:

$$CJSW(T) = CJSW \frac{pbo + MJSW * \left(4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo)\right)}{pbo + MJSW * \left(4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo)\right)}$$

where:

• *MJSW* is the **Side grading coefficient**, **MJSW** parameter value.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The PMOS block does not support noise analysis.
- The PMOS block applies initial conditions across junction capacitors and not across the block ports.

Dialog Box and Parameters

Model Selection Tab

| Block Parameter | SPICE PMOS | | | | | | | | |
|--|---|---|---|---|--|--|------------------------------|--------------------------|-------------------|
| SPICE PMOS | | | | | | | | | |
| This model approxima on this mask. The ins MOS instances for th which multiples the d and RSH. | ance parameter OFI s device, SCALE mul | F and noise n tiplies the ou | nodel paramet tput current a | ers KF and A nd device ch | F are not arge direc | supported. tly. This dif | SCALE is t fers from t | he number he AREA pa | of par- aramet |
| You can set the MOS plus TOFFSET. The bl ICVBS are the voltag If physical parameter TOX and NSUB. Para | ock lets you include o es across the interna s VTO, KP, PHI, or G | or exclude ca al junctions, a AMMA are as | pacitance mod and are only el isigned a NaN | deling and ini ffective whe value, they | tial conditi n the corr will be cale | ons. The in esponding ; :ulated fror | itial conditi junction ca | ons ICVDS, pacitances | ICVGS are pre |
| Parameters | | | | | | | | | |
| Model Selection | Dimensions R | esistors | DC currents | c-v | Process | Temper | ature | | |
| MOS model: | | Level 1 | MOS | | | | | | 1 |
| 1105 110001 | | perior. | | | | | | | |
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MOS model

Select one of the following MOSFET model options:

- Level 1 MOS Use the "Level 1 Drain Current Model" on page 1-749. This is the default option.
- Level 3 MOS Use the "Level 3 Drain Current Model" on page 1-752.

Dimensions Tab

| Block Parameters: SPICE PMOS | | | | |
|--|--|--|---|---------------------------------------|
| PICE PMOS | | | | |
| his model approximates a SPICE level 1 h this mask. The instance parameter O OS instances for this device. SCALE m hich multiples the device parameters K hd RSH. | FF and noise model paramete ultiplies the output current ar | ers KF and AF are not s nd device charge direct | upported. SCALE is y. This differs from I | the number of pa the AREA parame |
| ou can set the MOS temperature to a f us TOFFSET. The block lets you include IVBS are the voltages across the inter physical parameters VTO, KP, PHI, or OX and NSUB. Parameters RD, RS or R | or exclude capacitance mod nal junctions, and are only ef GAMMA are assigned a NaN | eling and initial condition fective when the corre value, they will be calcu | ns. The initial condit sponding junction ca llated from specified | ions ICVDS, ICVG apacitances are p |
| rameters | | | | |
| Model Selection Dimensions | Resistors DC currents | C-V Process | Temperature | |
| Device area factor, AREA: | 1 | | | |
| Number parallel devices, SCALE: | 1 | | | |
| Length of channel, LENGTH: | 1e-4 | | m | |
| Width of channel, WIDTH: | 1e-4 | | m | |
| Area of drain, AD: | 0 | | m^ | `2 |
| Area of source, AS: | 0 | | m^ | 2 |
| Perimeter of drain, PD: | 0 | | m | |
| Perimeter of source, PS: | 0 | | m | |
| | | | | |
| | | | | |
| | | | | |

Device area factor, AREA

The transistor area. This value multiplies the following parameter values:

- Transconductance, KP
- Bulk saturation current, IS
- Bulk jct sat current density, JS
- Zero-bias BD capacitance, CBD
- Zero-bias BS capacitance, CBS

- G-S overlap capacitance, CGSO
- G-D overlap capacitance, CGDO
- G-B overlap capacitance, CGBO
- Bottom junction cap per area CJ
- Side jct cap/area of jct perimeter CJSW

It divides the following parameter values:

- Drain resistance, RD
- Source resistance, RS
- Sheet resistance, RSH

The default value is 1. The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel MOS instances for this device. This parameter multiplies the output current and device charge. The default value is 1. The value must be greater than 0.

Length of channel, LENGTH

Length of the channel between the source and drain. The default value is 1e-04 m.

Width of channel, WIDTH

Width of the channel between the source and drain. The default value is 1e-04 m.

Area of drain, AD

Area of the transistor drain diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Area of source, AS

Area of the transistor source diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Perimeter of drain, PD

Perimeter of the transistor drain diffusion. The default value is 0 m. $\,$

Perimeter of source, PS

Perimeter of the transistor source diffusion. The default value is 0 m.

Resistors Tab

| Block Parameters: SPICE PMOS | | |
|---|---|---------------|
| PICE PMOS | | |
| n this mask. The instance parameter OFF OS instances for this device. SCALE mull | or 3 pMOSFET. You specify both model card and instance parameters as instance parame = and noise model parameters KF and AF are not supported. SCALE is the number of par tiplies the output current and device charge directly. This differs from the AREA paramet 15, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, F | ralle ter, |
| us TOFFSET. The block lets you include o VBS are the voltages across the interna physical parameters VTO, KP, PHI, or G | ed temperature or to the circuit temperature (from the SPICE Environment Parameters b or exclude capacitance modeling and initial conditions. The initial conditions ICVDS, ICVG3 I) junctions, and are only effective when the corresponding junction capacitances are pro AMMA are assigned a NaN value, they will be calculated from specified process parameter H are not used in block calculations when their value is NaN. | S ar 'ese |
| · | esistors DC currents C-V Process Temperature | |
| Drain resistance, RD: | 0.01 Ohm | - |
| Source resistance, RS: | le-4 Ohm | <u> </u> |
| Sheet resistance, RSH: | NaN | • |
| Number of drain squares, NRD: | 1 | _ |
| Number of source squares, NRS: | 1 | _ |
| | | |
| | | |
| | | |
| | | _ |
| | | |

Drain resistance, RD

The transistor drain ohmic resistance. The default value is $0.01~\Omega.$ If you set this parameter to NaN $\Omega,$ this value means

the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 1-746. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Source resistance, RS

The transistor source ohmic resistance. The default value is $1e-4 \Omega$. If you set this parameter to NaN Ω , this value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 1-746. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Sheet resistance, RSH

Resistance per square of the transistor source and drain. The default value is Nan Ω . This value means the parameter is unspecified. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-746. The value must be greater than or equal to 0.

Number of drain squares, NRD

Number of squares of resistance that make up the transistor drain diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-746.

Number of source squares, NRS

Number of squares of resistance that make up the transistor source diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 1-746.

DC Currents Tab

| SPICE PMOS | | | |
|---|---|---|--|
| This model approximates a SPICE level on this mask. The instance parameter C MOS instances for this device, SCALE m which multiples the device parameters k and RSH. | FF and noise model parameters KF and ultiplies the output current and device o | AF are not supported. SCALE is t harge directly. This differs from t | he number of par he AREA paramet |
| You can set the MOS temperature to a I plus TOFFSET. The block lets you includ ICVBS are the voltages across the inter If physical parameters VTO, KP, PHI, or TOX and NSUB. Parameters RD, RS or F | or exclude capacitance modeling and in nal junctions, and are only effective wh GAMMA are assigned a NaN value, the | nitial conditions. The initial conditi en the corresponding junction ca y will be calculated from specified | ons ICVDS, ICVGS pacitances are pre |
| Parameters | | | |
| Model Selection Dimensions | Resistors DC currents C-V | Process Temperature | |
| Threshold voltage, VTO: | 0 | V | |
| Transconductance, KP: | 2e-5 | A/V | ^2 |
| Bulk threshold, GAMMA: | 0 | V^C |).50000 |
| Surface potential, PHI: | 0.6 | V | |
| Channel modulation, LAMBDA: | 0 | 1/V | |
| Bulk saturation current, IS: | 1e-14 | A | |
| Bulk jct sat current density, JS: | 0 | A/m | ^2 |
| Emission coefficient, ND: | 1 | | |
| | | | |
| | | | |
| | | | |

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is 0 V. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Temperature Dependence" on page 1-681.

Transconductance, KP

The derivative of drain current with respect to gate voltage. The default value is 2e-05 A/V². The value must be greater than

or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-752 as appropriate for the selected value of the **MOS model** parameter.

Bulk threshold, GAMMA

Body effect parameter, which relates the threshold voltage, VTH, to the body bias, VBS, as described in "Level 1 Drain Current

Model" on page 1-667. The default value is 0 \sqrt{V} . The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-752 as appropriate for the selected value of the **MOS model** parameter.

Surface potential, PHI

Twice the voltage at which the surface electron concentration becomes equal to the intrinsic concentration and the device transitions between depletion and inversion conditions. The default value is 0.6 V. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters. For more information about this calculation, see "Level 1 Drain Current Model" on page 1-667 or "Level 3 Drain Current Model" on page 1-752 as appropriate for the selected value of the **MOS model** parameter.

Channel modulation, LAMBDA

The channel-length modulation. This parameter is only visible when you select Level 1 MOS for the MOS model parameter. The default value is 0 1/V.

Bulk saturation current, IS

The magnitude of the current that the junction approaches asymptotically for very large reverse bias levels. The default value is 1e-14 A. The value must be greater than or equal to 0.

Bulk jct sat current density, JS

The magnitude of the current per unit area that the junction approaches asymptotically for very large reverse bias levels. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

Emission coefficient, ND

The transistor emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

Width effect on threshold, DELTA

The factor that controls the effect of transistor width on threshold voltage. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.

Max carrier drift velocity, VMAX

The maximum drift velocity of the carriers. This parameter is only visible when you select Level $3 \mod 1000$ for the **MOS model** parameter. The default value is $0 \mod 1000$ m/s.

Fast surface state density, NFS

The fast surface state density adjusts the drain current for the mobility reduction caused by the gate voltage. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0 $1/cm^2$.

Vds dependence threshold volt, ETA

The coefficient that controls how the threshold voltage depends on the drain-source voltage in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.

Vgs dependence on mobility, THETA

The coefficient that controls how the mobility affects the gate voltage in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the ${\bf MOS}$ model parameter. The default value is 0 1/V.

Mobility modulation, KAPPA

The coefficient that controls how the mobility affects the channel length in the drain current calculation. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0.2.

C-V Tab

| Block Parameters: SPICE PMOS |
|---|
| |
| This model approximates a SPICE level 1 or 3 pMOSFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. |
| You can set the MOS 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 and initial conditions. The initial conditions ICVDS, ICVGS and ICVBS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NaN. |
| Parameters |
| Model Selection Dimensions Resistors DC currents C-V Process Temperature |
| Model junction capacitance?: No |
| OK Cancel Help Apply |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion and capacitance coefficient.

G-S overlap capacitance, CGSO

Gate-source capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-D overlap capacitance, CGDO

Gate-drain capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-B overlap capacitance, CGBO

Gate-base capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BD capacitance, CBD

The value of the capacitance placed between the base and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0

F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BS capacitance, CBS

The value of the capacitance placed between the base and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom junction cap per area CJ

Zero-bias bulk junction bottom capacitance per junction area. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m². The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom grading coefficient, MJ

The transistor bottom grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Side jct cap/area of jct perimeter CJSW

Zero-bias bulk junction sidewall capacitance per junction perimeter. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Side grading coefficient, MJSW

The transistor sidewall grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Bulk junction potential, PB

The potential across the bulk junction. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.8 V. The value must be equal to 0 or greater than or equal to VJmin. VJmin is a built-in model constant whose value is 0.01.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than or equal to FCmax. FCmax is a built-in model constant whose value is 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

Note The PMOS block applies the initial diode voltage across the junction capacitors and not across the ports.

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction** capacitance and Yes for the Specify initial condition parameter. The default value is 0 V.

Initial condition voltage ICVBS

Bulk-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Process Tab

| 😽 Block Parameters: SPICE PMOS | | × |
|---|--|--|
| SPICE PMOS | | |
| on this mask. The instance parameter OFF a MOS instances for this device. SCALE multipli | pMOSFET. You specify both model card and instance parame nd noise model parameters KF and AF are not supported. SC es the output current and device charge directly. This differ 35, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divice | ALE is the number of parallel from the AREA parameter, |
| plus TOFFSET. The block lets you include or e ICVBS are the voltages across the internal ju If physical parameters VTO, KP, PHI, or GAM | temperature or to the circuit temperature (from the SPICE E exclude capacitance modeling and initial conditions. The initial nctions, and are only effective when the corresponding junc MA are assigned a NaN value, they will be calculated from sp re not used in block calculations when their value is NaN. | conditions ICVDS, ICVGS and tion capacitances are present. |
| Parameters | | |
| Model Selection Dimensions Resi | stors DC currents C-V Process Temperatu | re |
| Oxide thickness, TOX: | NaN | m |
| Lateral diffusion, LD: | 0 | m |
| Substrate doping, NSUB: | NaN | 1/cm^3 |
| Surface state density, NSS: | 0 | 1/cm^2 |
| Surface mobility, U0: | 600 | cm^2/s/V ▼ |
| Gate type?, TPG: | Opposite of substrate (1) | _ |
| | | |
| | OK Cancel | Help Apply |

Oxide thickness, TOX

Thickness of the gate oxide. The default value is NaN m. The value must be greater than or equal to 0.

Note When you select Level 3 MOS for the **MOS model** parameter, the block uses a value of 1e-7 rather than NaN by default.

Lateral diffusion, LD

Length of lateral diffusion. The default value is 0 m.

Substrate doping, NSUB

Substrate doping. The default value is NaN 1/cm³. The value must be greater than or equal to 1.45e10 (the carrier concentration of intrinsic silicon).

Surface state density, NSS

Substrate doping. The default value is $0 \ 1/cm^2$.

Surface mobility, U0

Zero-bias surface mobility coefficient. The default value is $600 \text{ cm}^2/\text{V/s}$.

Junction depth, XJ

Junction depth. This parameter is only visible when you select Level 3 MOS for the **MOS model** parameter. The default value is 0 m.

Gate type?,TPG

Select one of the following MOSFET gate materials (as compared to the substrate):

- Opposite of substrate The gate material is the opposite of the substrate. This means that TPG = 1 in the device equations. This is the default option.
- Same as substrate The gate material is the same as the substrate. This means that TPG = -1 in the device equations.

• Aluminum — The gate material is aluminum. This means that TPG = 0 in the device equations.

Temperature Tab

| 😽 Block Parameters: SPICE PMOS | | × |
|---|---|--|
| -SPICE PMOS | | |
| on this mask. The instance parameter OFF MOS instances for this device. SCALE multi which multiples the device parameters KP, i and RSH. You can set the MOS temperature to a fixe plus TOFFSET. The block lets you include or | 3 pMOSFET. You specify both model card and and noise model parameters KP and AF are no plies the output current and device charge dire S, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and d temperature or to the circuit temperature (fr exclude capacitance modeling and initial condi- | it supported. SCALE is the number of parallel ctly. This differs from the AREA parameter, d CJSW and divides the parameters RD, RS rom the SPICE Environment Parameters block) itions. The initial conditions ICVDS, ICVGS and |
| If physical parameters VTO, KP, PHI, or GA | junctions, and are only effective when the cor MMA are assigned a NaN value, they will be ca are not used in block calculations when their v | |
| Parameters | | |
| Model Selection Dimensions Re | sistors DC currents C-V Process | Temperature |
| Model temperature dependence using: | Device temperature | |
| Offset local circuit temperature, TOFFSET: | 0 | K |
| Parameter extraction temperature, TMEAS: | 300.15 | K |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | ОК | Cancel Help Apply |

Model temperature dependence using

Select one of the following options for modeling the diode temperature dependence:

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if

| one exists in the circuit | Otherwise, | it comes | from | the default |
|---------------------------|------------|----------|------|-------------|
| value for this block. | | | | |

• Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Ports The block has the following ports:

G

Electrical conserving port associated with the transistor gate terminal.

D

Electrical conserving port associated with the transistor drain terminal.

s

Electrical conserving port associated with the transistor source terminal.

В

Electrical conserving port associated with the transistor bulk terminal.

References [1] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling* with SPICE. 2nd Edition, McGraw-Hill, 1993. Chapter 3.

See Also SPICE NMOS

Purpose Model Gummel-Poon PNP Transistor

Library SPICE-Compatible Components/Semiconductor Devices

Description

ť:

The PNP block represents a SPICE-compatible four-terminal Gummel-Poon PNP transistor. The substrate port is connected to the transistor body using a capacitor, so these devices are equivalent to a three-terminal transistor when you connect the substrate port to any other port and use the default value of zero for the **C-S junction capacitance**, **CJS** parameter.

The PNP block model includes the following components:

- "Current-Voltage and Base Charge Model" on page 1-785
- "Base Resistance Model" on page 1-789
- "Transit Charge Modulation Model" on page 1-789
- "Junction Charge Model" on page 1-790
- "Temperature Dependence" on page 1-792

Current-Voltage and Base Charge Model

The current-voltage relationships and base charge relationships for the transistor are calculated after adjusting the applicable model parameters for temperature as described in the following sections:

- Emitter-Base and Collector-Base Junction Currents on page 785
- Terminal Currents on page 788
- Base Charge Model on page 788

Emitter-Base and Collector-Base Junction Currents

The base-emitter junction current is calculated using the following equations:

• When $V_{EB} > 80 * V_{TF}$:

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$$I_{ebf} = IS * \left(\left(\frac{V_{EB}}{V_{TF}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{EB}$$
$$I_{ebe} = ISE * \left((V_{EB} - 80 * V_{TF} + V_{TE}) * \frac{e^{(80*V_{TF}/V_{TE})}}{V_{TE}} - 1 \right)$$

• When $V_{EB} \le 80 * V_{TF}$

$$I_{ebf} = IS * (e^{(V_{EB}/V_{TF})} - 1) + G_{\min} * V_{EB}$$
$$I_{ebe} = ISE * (e^{(V_{EB}/V_{TE})} - 1)$$

The base-collector junction current is calculated using the following equations:

• When $V_{CB} > 80 * V_{TR}$:

$$I_{cbr} = IS * \left(\left(\frac{V_{CB}}{V_{TR}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{CB}$$
$$I_{cbc} = ISC * \left(\left(V_{CB} - 80 * V_{TR} + V_{TC} \right) * \frac{e^{(80*V_{TR}/V_{TC})}}{V_{TC}} - 1 \right)$$

• When $V_{CB} \leq 80 * V_{TR}$

$$I_{cbr} = IS * (e^{(V_{CB}/V_{TR})} - 1) + G_{\min} * V_{CB}$$
$$I_{cbc} = ISC * (e^{(V_{CB}/V_{TC})} - 1)$$

In the preceding equations:

- V_{EB} is the emitter-base voltage and V_{CB} is the collector-base voltage.
- $V_{TE} = NE * k * T / q$, $V_{TC} = NC * k * T / q$, $V_{TF} = NF * k * T / q$, and • $V_{TE} = NR * k * T / q$
- V_{IB} = NR * k * T / q.
 ISC and ISE are the B-C leakage current, ISC and B-E leakage current, ISE parameter values, respectively.
- *NE*, *NC*, *NF*, and *NR* are the **B-E emission coefficient**, **NE**, **B-C emission coefficient**, **NC**, **Forward emission coefficient**, **NF** and **Reverse emission coefficient**, **NR** parameter values, respectively.
- *q* is the elementary charge on an electron.
- *k* is the Boltzmann constant.
- *T* is the transistor temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- G_{min} is the minimum conductance. By default, G_{min} matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change G_{min} , add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Terminal Currents

The terminal currents, I_B and I_C are the base and collector currents, defined as positive into the device. They are calculated as:

$$\begin{split} I_B &= -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)\\ I_C &= -\left(\frac{I_{ebf} - I_{cbr}}{q_b} - \frac{I_{cbr}}{BR} - I_{cbc}\right) \end{split}$$

where *BF* and *BR* are the **Forward beta**, **BF** and **Reverse beta**, **BR** parameter values, respectively.

Base Charge Model

The base charge, q_b , is calculated using the following equations:

$$\begin{split} q_{b} &= \frac{q_{1}}{2} \Biggl(1 + \sqrt{0.5 * \Bigl(\sqrt{(1 + 4 * q_{2} - eps)^{2}} + eps^{2}} + 1 + 4 * q_{2} - eps \Bigr) + eps \Biggr) \\ q_{1} &= \Biggl(1 - \frac{V_{CB}}{VAF} - \frac{V_{EB}}{VAR} \Biggr)^{-1} \\ q_{2} &= \frac{I_{ebf}}{IKF} + \frac{I_{cbr}}{IKR} \end{split}$$

where

- *VAF* and *VAR* are the Forward Early voltage, VAF and Reverse Early voltage, VAR parameters, respectively.
- *IKF* and *IKR* are the **Forward knee current**, **IKF** and **Reverse knee current**, **IKR** parameter values, respectively.
- *eps* is 1e-4.

Base Resistance Model

The block models base resistance in one of two ways:

 If you use the default value of infinity for the Half base resistance cur, IRB parameter, the PNP block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + \frac{RB - RBM}{q_b}$$

where:

- *RBM* is the **Minimum base resistance**, **RBM** parameter value.
- *RB* is the **Zero-bias base resistance**, **RB** parameter value.
- If you specify a finite value for the **Half base resistance cur, IRB** parameter, the PNP block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + 3*(RB - RBM)*\left(\frac{\tan z - z}{z*\tan^2 z}\right)$$

where:

$$z = \frac{\sqrt{1 + 144I_{B} / (\pi^{2}IRB)} - 1}{(24 / \pi^{2})\sqrt{(I_{B} / IRB)}}$$

Transit Charge Modulation Model

If you specify nonzero values for the **Coefficient of TF, XTF** parameter, the block models transit charge modulation by scaling the **Forward transit time, TF** parameter value as follows:

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$$TF_{\rm mod} = \frac{TF * \left[1 + XTF * e^{V_{CB}/(1.44V_{TF})} \left(\frac{I_{EB}}{I_{EB} + ITF} \right)^2 \right]}{q_b}$$



Junction Charge Model

The PNP block lets you model junction charge. The collector-base charge Q_{cb} and the emitter-base charge Q_{eb} depend on an intermediate value, Q_{dep} as follows, after adjusting the applicable model parameters for temperature:

• For the internal base-emitter junctions:

$$Q_{eb} = TF_{mod} * I_{eb} + Q_{dep}$$

• For the internal base-collector junctions:

$$Q_{cb} = TR * I_{cb} + XCJC * Q_{det}$$

• For the external base-collector junctions:

$$Q_{cb_{ext}} = (1 - XCJC) * Q_{dep}$$

 Q_{dep} depends on the junction voltage, V_{jct} (V_{EB} for the emitter-base junction and V_{CB} for the collector-base junction) as follows.

| Applicable Range of V _{jct} Values | Corresponding Q _{dep} Equation |
|---|---|
| $V_{jct} < FC * VJ$ | $Q_{dep} = C_{jct} * VJ * \frac{1 - (1 - V_{jct} / VJ)^{(1 - MJ)}}{1 - MJ}$ |
| $V_{jct} \ge FC * VJ$ | $Q_{dep} = C_{jct} * \left[F1 + \frac{F3 * (V_{jct} - FC * VJ) + \frac{MJ * [V_{jct}^{2} - (FC * VJ)^{2}]}{2 * VJ}}{F2} \right]$ |

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is:
 - The **B-E built-in potential**, **VJE** parameter value for the emitter-base junction.
 - The **B-C built-in potential**, **VJC** parameter value for the collector-base junction.
- *MJ* is:
 - The **B-E exponential factor**, **MJE** parameter value for the emitter-base junction.
 - The **B-C exponential factor**, **MJC** parameter value for the collector-base junction.
- C_{jct} is:
 - The **B-E depletion capacitance**, **CJE** parameter value for the emitter-base junction.

- The **B-C depletion capacitance**, **CJC** parameter value for the collector-base junction.
- $F1 = VJ * (1 (1 FC)^{(1-MJ)}) / (1 MJ)$
- $F2 = (1 FC)^{(1+MJ)}$
- F3 = 1 FC * (1 + MJ)

The collector-substrate charge Q_{sc} depends on the collector-substrate voltage V_{sc} as follows, after adjusting the applicable model parameters for temperature.

| Applicable Range of V _{sc} Values | Corresponding Q _{sc} Equation |
|--|--|
| <i>V</i> _{sc} < 0 | $Q_{sc} = CJS * VJS * \left(\frac{1 - (1 - V_{sc} / VJS)^{(1 - MJS)}}{1 - MJS}\right)$ |
| $V_{sc} \geq 0$ | $Q_{sc} = CJS * (1 + MJS * V_{sc} / (2 * VJS)) * V_{sc}$ |
| | where |

where:

- *CJS* is the **C-S junction capacitance**, **CJS** parameter value.
- *VJS* is the **Substrate built-in potential**, **VJS** parameter value.
- *MJS* is the **Substrate exponential factor**, **MJS** parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

• When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

- T_C is the Circuit temperature parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_O* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the transistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block provides the following relationship between the saturation current IS and the transistor temperature T:

$$IS(T) = IS * \left(T/T_{meas}\right)^{XTI} * e^{\left(\frac{T}{T_{meas}} - 1\right) * \frac{EG}{V_t}}$$

where:

- *IS* is the **Transport saturation current**, **IS** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Temperature exponent for IS, XTI** parameter value.
- EG is the Energy gap, EG parameter value.
- $V_t = kT/q$.

The block provides the following relationship between the base-emitter junction potential VJE and the transistor temperature T:

$$VJE(T) = VJE * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T}$$

where:

• *VJE* is the **B-E built-in potential**, **VJE** parameter value.

•
$$EG_{T_{meas}} = 1.16eV - (7.02e - 4 * T_{meas}^{2}) / (T_{meas} + 1108)$$

• $EG_T = 1.16eV - (7.02e - 4 * T^2) / (T + 1108)$

The block uses the VJE(T) equation to calculate the base-collector junction potential by substituting VJC (the **B-C built-in potential**, **VJC** parameter value) for VJE.

The block provides the following relationship between the base-emitter junction capacitance CJE and the transistor temperature T:

$$CJE(T) = CJE * \left[1 + MJE * \left(400e - 6 * \left(T - T_{meas} \right) - \frac{VJE(T) - VJE}{VJE} \right) \right]$$

where:

- CJE is the B-E depletion capacitance, CJE parameter value.
- *MJE* is the **B-E exponential factor**, **MJE** parameter value.

The block uses this equation to calculate the base-collector junction capacitance by substituting *CJC* (the **B-C depletion capacitance**, **CJC** parameter value) for *CJE* and *MJC* (the **B-C exponential factor**, **MJC** parameter value) for *MJE*.

The block provides the following relationship between the forward and reverse beta and the transistor temperature T:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}}\right)^{XTB}$$

where:

- β is the Forward beta, BF or Reverse beta, BR parameter value.
- *XTB* is the **Beta temperature exponent**, **XTB** parameter value.

The block provides the following relationship between the base-emitter leakage current ISE and the transistor temperature T:

$$ISE(T) = ISE * \left(\frac{T}{T_{meas}}\right)^{\text{XTB}} * \left(\frac{\text{IS}(T)}{\text{IS}}\right)^{1/NE}$$

where:

- *ISE* is the **B-E leakage current**, **ISE** parameter value.
- *NE* is the **B-E emission coefficient**, **NE** parameter value.

The block uses this equation to calculate the base-collector leakage current by substituting *ISC* (the **B-C leakage current, ISC** parameter value) for *ISE* and *NC* (the **B-C emission coefficient, NC** parameter value) for *NE*.

The model is based on the following assumptions:

• The PNP block does not support noise analysis.

Basic Assumptions and Limitations

• The PNP block applies initial conditions across junction capacitors and not across the block ports.

SPICE PNP

Dialog Box and Parameters

Main Tab

| 🙀 Block Parameters: SPICE PNP | | | | × |
|---|-----------------------------------|-----------------------------|------------------------------------|--------|
| SPICE PNP | | | | |
| This model approximates a SPICE PNP mask. The instance parameters PTF ar | | | | this |
| SCALE is the number of parallel BJT in: differs from the AREA parameter, whic the parameters RB, RBM, RE and RC. | | | | ivides |
| You can set the BJT temperature to a plus TOFFSET. The parameters XTB, X | | | PICE Environment Parameters blo | ock) |
| The block lets you include or exclude or temperature equations, which may yie are the voltages across the internal ju | d a slightly different value than | n SPICE for capacitance. Th | e initial conditions ICVBE and ICV | CE |
| Parameters | | | | |
| Main Forward Gain Revers | e Gain Resistors Capa | acitance Temperature | 1 | 1 |
| Device area, AREA: | 1 | | m^2 | J |
| Number of parallel devices, SCALE: | 1 | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | OK Can | cel Help Ac | oply |

Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transport saturation current, IS
- Forward knee current, IKF
- B-E leakage current, ISE
- Reverse knee current, IKR
- B-C leakage current, ISC

- Half base resistance cur, IRB
- B-E depletion capacitance, CJE
- Coefficient of TF, ITF
- B-C depletion capacitance, CJC
- C-S junction capacitance, CJS

It divides the following parameter values:

- Zero-bias base resistance, RB
- Minimum base resistance, RBM
- Emitter resistance, RE
- Collector resistance, RC

The default value is 1 m^2 . The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel transistors the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

Forward Gain Tab

| iask. The instance parameters PTF and (| OFF and noise model parameters KF and AF are not supported. | |
|---|--|-----------|
| | nces for this device. SCALE multiplies the output current and device charge directly. nultiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, | |
| | ed temperature or to the circuit temperature (from the SPICE Environment Paramete and EG adjust temperature sensitive parameters. | ers block |
| emperature equations, which may yield a | acitance modeling and initial conditions. The capacitance modeling uses the publishe a slightly different value than SPICE for capacitance. The initial conditions ICVBE an ions, and are only effective when the corresponding junction capacitances are pres | ICVCE |
| arameters | | |
| Main Forward Gain Reverse G | aain Resistors Capacitance Temperature | |
| Transport saturation current, IS: | 1e-16 A/m^2 | • |
| Forward beta, BF: | 100 | |
| Forward emission coefficient, NF: | 1 | |
| B-E leakage current, ISE: | 0 A/m^2 | • |
| B-E emission coefficient, NE: | 1.5 | |
| Forward knee current, IKF: | Inf A/m^2 | • |
| Forward Early voltage, VAF: | Inf | • |
| | | |

Transport saturation current, IS

The magnitude of the current at which the transistor saturates. The default value is $1e\cdot 16$ A/m^2 . The value must be greater than or equal to 0.

Forward beta, BF

The ideal maximum reverse beta. The default value is 100. The value must be greater than 0.

Forward emission coefficient, NF

The reverse emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

B-E leakage current, ISE

The base-emitter leakage current. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

B-E emission coefficient, NE

The base-collector emission coefficient or ideality factor. The default value is 1.5. The value must be greater than 0.

Forward knee current, IKF

The current value at which forward-beta high-current roll-off occurs. The default value is 0 A/m^2 . The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Forward Early voltage, VAF

The forward Early voltage. The default value is 0 V. The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Reverse Gain Tab

| the contract of the | | tiplies the output current and | device charge directly. This |
|--|-----------------------------------|--------------------------------|--------------------------------|
| infers from the AREA parameter, which he parameters RB, RBM, RE and RC. | multiples the device parameters | IS, IKF, ISE, IKR, ISC, IRB, C | DE, ITF, CJC and CJS, and divi |
| 'ou can set the BJT temperature to a fix olus TOFFSET. The parameters XTB, XTI | | | Environment Parameters bloc |
| he block lets you include or exclude cap emperature equations, which may yield are the voltages across the internal junc | a slightly different value than S | PICE for capacitance. The init | ial conditions ICVBE and ICVCE |
| arameters | cuons, and are only effective wi | ien ane corresponding jancaor | r capacitances are present. |
| | | (- · ·) | |
| Main Forward Gain Reverse | Gain Resistors Capaci | tance Temperature | |
| Reverse beta, BR: | 1 | | |
| Reverse emission coefficient, NR: | 1 | | |
| B-C leakage current, ISC: | 0 | | A/m^2 |
| B-C emission coefficient, NC: | 2 | | |
| | Inf | | A/m^2 |
| Reverse knee current, IKR: | | | |
| Reverse knee current, IKR: Reverse Early voltage, VAR: | Inf | | V 🔻 |

Reverse beta, BR

The ideal maximum reverse beta. The default value is 1. The value must be greater than 0.

Reverse emission coefficient, NR

The reverse emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

B-C leakage current, ISC

The base-collector leakage current. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

B-C emission coefficient, NC

The base-collector emission coefficient or ideality factor. The default value is **2**. The value must be greater than **0**.

Reverse knee current, IKR

The current value at which reverse-beta high-current roll-off occurs. The default value is 0 A/m^2 . The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Reverse Early voltage, VAR

The reverse Early voltage. The default value is 0 V. The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Resistors Tab

| | ances for this device. SCALE multiplies the output current a multiples the device parameters IS, IKF, ISE, IKR, ISC, IRE | |
|---|--|----------------------------------|
| ne parameters RB, RBM, RE and RC. | | , c.c., m, c.c. and c.c., and an |
| | xed temperature or to the circuit temperature (from the SP. I and EG adjust temperature sensitive parameters. | ICE Environment Parameters bloc |
| | pacitance modeling and initial conditions. The capacitance n d a slightly different value than SPICE for capacitance. The | |
| | ctions, and are only effective when the corresponding junc | |
| arameters | | |
| Main 🗍 Forward Gain 🗍 Reverse | e Gain Resistors Capacitance Temperature | |
| Emitter resistance, RE: | 1e-4 | m^2*Ohm • |
| Collector resistance, RC: | 0.01 | m^2*Ohm - |
| | 1 | m^2*Ohm 💌 |
| Zero-bias base resistance, RB: | | m^2*Ohm 💌 |
| Zero-bias base resistance, RB: Minimum base resistance, RBM: | 0 | |
| ŕ | 0 Inf | A/m^2 |
| Minimum base resistance, RBM: | | |

Emitter resistance, RE

The resistance of the emitter. The default value is $1e - 4 m^{2*}\Omega$. The value must be greater than or equal to 0.

Collector resistance, RC

The resistance of the collector. The default value is $0.01~m^{2*}\Omega.$ The value must be greater than or equal to 0.

Zero-bias base resistance, RB

The resistance of the base. The default value is $1\ m^{2*}\Omega.$ The value must be greater than or equal to 0.

Minimum base resistance, RBM

The minimum resistance of the base. The default value is $0 \text{ m}^{2*}\Omega$. The value must be less than or equal to the **Zero-bias base** resistance, **RB** parameter value.

Half base resistance cur, IRB

The base current at which the base resistance has dropped to half of its zero-bias value. The default value is $Inf A/m^2$. The value must be greater than or equal to 0. Use the default value of Inf if you do not want to model the change in base resistance as a function of base current.

Capacitance Tab

| 🙀 Block Parameters: SPICE PNP | × |
|---|-------|
| | |
| This model approximates a SPICE PNP transistor. You specify both model card and instance parameters as instance parameters on t mask. The instance parameters PTF and OFF and noise model parameters KF and AF are not supported. | his |
| SCALE is the number of parallel BJT 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, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and dive the parameters RB, RBM, RE and RC. | /ides |
| You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters bloc plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. | :k) |
| The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVBE and ICVC are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. | .E |
| Parameters | |
| Main Forward Gain Reverse Gain Resistors Capacitance Temperature | |
| Model junction capacitance?: No |] |
| | , |
| OK Cancel Help App | эlA |

Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- No Do not include junction capacitance in the model. This is the default option.
- B-E Capacitance Model the junction capacitance across the base-emitter junction.
- B-C Capacitance Model the junction capacitance across the base-collector junction.
- C-S Capacitance Model the junction capacitance across the collector-substrate junction.

Note To include junction capacitance in the model:

- **1** Select B-E Capacitance and specify the base-emitter junction capacitance parameters.
- **2** Select B-C Capacitance and specify the base-collector junction capacitance parameters.
- **3** Select C-S Capacitance and specify the collector-substrate junction capacitance parameters.

You can specify or change any of the common parameters when you select any of the preceding options for the **Model junction capacitance** parameter.

B-E depletion capacitance, CJE

The depletion capacitance across the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

B-E built-in potential, VJE

The base-emitter junction potential. This parameter is only visible when you select B-E Capacitance for the Model junction capacitance parameter. The default value is 0.75 V. The value must be greater than or equal to 0.01 V.

B-E exponential factor, MJE

The grading coefficient for the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0.33. The value must be greater than or equal to 0 and less than or equal to 0.9.

Forward transit time, TF

The transit time of the minority carriers that cause diffusion capacitance when the base-emitter junction is forward-biased. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0.

Coefficient of TF, XTF

The coefficient for the base-emitter and base-collector bias dependence of the transit time, which produces a charge across the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0. Use the default value of 0 if you do not want to model the effect of base-emitter bias on transit time.

VBC dependence of TF, VTF

The coefficient for the base-emitter bias dependence of the transit time. This parameter is only visible when you select B-E Capacitance for the Model junction capacitance parameter. The default value is 0 V. The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Coefficient of TF, ITF

The coefficient for the dependence of the transit time on collector current. This parameter is only visible when you select B-E Capacitance for the Model junction capacitance parameter. The default value is 0 A/m^2 . The value must be greater than or equal to 0. Use the default value of 0 if you do not want to model the effect of collector current on transit time.

B-C depletion capacitance, CJC

The depletion capacitance across the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than 0.

B-C built-in potential, VJC

The base-collector junction potential. This parameter is only visible when you select B-C Capacitance for the **Model junction** capacitance parameter. The default value is 0.75 V. The value must be greater than or equal to 0.01 V.

B-C exponential factor, MJC

The grading coefficient for the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.33. The value must be greater than or equal to 0 and less than or equal to 0.9.

B-C capacitance fraction, XCJC

The fraction of the base-collector depletion capacitance that is connected between the internal base and the internal collector. The rest of the base-collector depletion capacitance is connected between the external base and the internal collector. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0 and less than or equal to 1.

Reverse transit time, TR

The transit time of the minority carriers that cause diffusion capacitance when the base-collector junction is reverse-biased. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0 s. The value must be greater than or equal to 0.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than or equal to 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial transistor conditions.

Note The PNP block applies the initial transistor voltages across the junction capacitors and not across the ports.

This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter.

Initial condition voltage ICVBE

Base-emitter voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the Model junction capacitance and Yes for the Specify initial condition parameter. The default value is 0 V.

Initial condition voltage ICVCE

Base-collector voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the Model junction capacitance and Yes for the Specify initial condition parameter. The default value is 0 V.

C-S junction capacitance, CJS

The collector-substrate junction capacitance. This parameter is only visible when you select C-S Capacitance for the **Model** junction capacitance parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Substrate built-in potential, VJS

The potential of the substrate. This parameter is only visible when you select C-S Capacitance for the Model junction capacitance parameter. The default value is 0.75 V.

Substrate exponential factor, MJS

The grading coefficient for the collector-substrate junction. This parameter is only visible when you select C-S Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0 and less than or equal to 0.9.

Temperature Tab

| lodel temperature dependence using: Devi | noise model parar this device. SCALE the device parame erature or to the ci djust temperature modeling and initis different value th d are only effectiv | meters KF and A E multiplies the of eters 15, 1KF, 15 incuit temperatu e sensitive paran al conditions. Th nan SPICE for co when the cor | F are not suppo output current a E, IKR, ISC, IRB re (from the SP) neters. e capacitance m pacitance. The | rted. nd device charge c , CJE, ITF, CJC an ICE Environment P nodeling uses the p initial conditions IC | directly. This d CJS, and divide arameters block) iublished :VBE and ICVCE |
|---|---|---|---|--|--|
| rs from the AREA parameter, which multiples I parameters RB, RBM, RE and RC. can set the BJT temperature to a fixed tempe TOFFSET. The parameters XTB, XTI and EG an block lets you include or exclude capacitance perature equations, which may yield a slightly the voltages across the internal junctions, and meters ain Forward Gain Reverse Gain lodel temperature dependence using: | the device parame erature or to the ci djust temperature modeling and initia different value th d are only effectiv Resistors Ca | eters IS, IKF, IS ircuit temperatu e sensitive parai al conditions. Th an SPICE for ca re when the cor | E, İKR, ISC, IRB re (from the SPI neters. e capacitance m ipacitance. The responding juncl | :, CJE, ITF, CJC an ICE Environment P nodeling uses the p initial conditions IC | d CJS, and divide arameters block) wblished WBE and ICVCE |
| TOFFSET. The parameters XTB, XTI and EG and block lets you include or exclude capacitance berature equations, which may yield a slightly the voltages across the internal junctions, and meters ain Forward Gain Reverse Gain lodel temperature dependence using: | djust temperature modeling and initia different value th d are only effectiv Resistors Ca | e sensitive parai al conditions. Th han SPICE for ca ve when the cor | neters. le capacitance m lapacitance. The responding junct | nodeling uses the p initial conditions IC | ublished WBE and ICVCE |
| berature equations, which may yield a slightly the voltages across the internal junctions, and meters ain Forward Gain Reverse Gain lodel temperature dependence using: Devi | different value th d are only effectiv Resistors Ca | nan SPICE for ca ve when the cor | pacitance. The i responding junct | initial conditions IC | WBE and ICVCE |
| meters ain Forward Gain Reverse Gain lodel temperature dependence using: Devi | Resistors Ca | | | tion capacitances a | are present. |
| ain Forward Gain Reverse Gain | | apacitance | Temperature | | |
| lodel temperature dependence using: Devi | | apacitance | Temperature | | |
| | ice temperature | | | | |
| | | | | | • |
| eta temperature exponent, XTB: 0 | | | | | |
| nergy gap, EG: 1.11 | 1 | | | eV | • |
| emperature exponent for IS, XTI: 3 | | | | | |
| ffset local circuit temperature 0 OFFSET: | | | | К | • |
| arameter extraction temperature, 300 MEAS: | .15 | | | К | • |
| | | | | | |
| | | | | | |
| | | ок | Cance | el Help | Apply |

Model temperature dependence using

Select one of the following options for modeling the transistor temperature dependence:

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block. • Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Beta temperature exponent, XTB

The forward and reverse beta temperature exponent that models base current temperature dependence. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0. The value must be greater than or equal to 0.

Energy gap, EG

The energy gap that affects the increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Temperature exponent for IS, XTI

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than or equal to 0.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

| Ports | The block has the following ports: |
|------------|--|
| | B Electrical conserving port associated with the transistor base terminal. |
| | C Electrical conserving port associated with the transistor collector terminal. |
| | E Electrical conserving port associated with the transistor emitter terminal. |
| | S Electrical conserving port associated with the transistor substrate terminal. |
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2. |
| See Also | Generic Linear Actuator |

SPICE Resistor

| Purpose | Model SPICE-compatible resistor |
|-------------|---|
| Library | SPICE-Compatible Components/Passive Devices |
| Description | The SPICE Resistor block represents a SPICE-compatible resistor. You can specify the resistance in one of the following ways: |
| | • As a resistance value |
| | • As process information that the block uses to calculate a resistance |

• As process information that the block uses to calculate a resistance value

The block models temperature dependence. There are two ways to specify the resistor temperature:

• When you select Device temperature for the Model temperature dependence using parameter, the resistor temperature is

$$T = T_C + T_O$$

where:

- T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
- *T_o* is the Offset local circuit temperature, TOFFSET parameter value.
- When you select Fixed temperature for the Model temperature dependence using parameter, the resistor temperature is the Fixed circuit temperature, TFIXED parameter value.

The block adjusts the specified or calculated resistance value for temperature using the following equation:

$$R = R_0 (1 + TC1(T - T_{nom}) + TC2(T - T_{nom})^2)$$

Where

- R_0 is the specified or calculated resistance value.
- *TC1* is the **First order temperature coefficient**, **TC1** parameter value.
- *TC2* is the **Second order temperature coefficient**, **TC2** parameter value.
- T_{nom} is the **Parameter extraction temperature**, **TMEAS** parameter value.

Dialog Resis Box and

Parameters

Resistance Tab

| ising this block only to specify the re | sistance parameter R is eq | uivalent to using the r | esistor from the Si | mscape Foundation | library |
|---|----------------------------|-------------------------|---------------------|-------------------|---------|
| arameters Resistance Temperature | | | | | |
| Device scale factor, SCALE: | 1 Use specified resis | tance | | | |
| Resistance, R: | 0 | | | Ohm | - |
| | | | | | |

Device scale factor, SCALE

The number of parallel resistors that the block represents. This value multiplies the output current. The default value is 1.

Resistor parameterization

Select one of the following options for specifying the resistor value:

- Use specified resistance Provide the resistance value directly. This option is the default.
- Calculate from process information Provide process parameters that the block uses to calculate the resistance value.

When you select this option, the block calculates the resistance using the following equation:

$$R = RSH * \frac{(LENGTH - NARROW)}{(WIDTH - NARROW)}$$

where:

- *RSH* is the **Sheet resistance**, **RSH** parameter value.
- *LENGTH* is the **Resistor length**, **LENGTH** parameter value.
- *WIDTH* is the **Resistor width**, **WIDTH** parameter value.
- *NARROW* is the **Etch narrowing**, **NARROW** parameter value.

Resistance, R

Resistance value. This parameter is only visible when you select Use specified resistance for the **Resistor parameterization** parameter. The default value is 0 Ω .

Sheet resistance, RSH

Resistance per square of the resistor. This parameter is only visible when you select Calculate from process information for the **Resistor parameterization** parameter. The default value is 0 Ω .

Resistor length, LENGTH

Length dimension of the resistor. This parameter is only visible when you select Calculate from process information for the **Resistor parameterization** parameter. The default value is 1e-06 m.

Resistor width, WIDTH

Width dimension of the resistor. This parameter is only visible when you select Calculate from process information for the **Resistor parameterization** parameter. The default value is 1e-06 m.

Etch narrowing, NARROW

Amount by which the resistor length and width are reduced due to side etching. This parameter is only visible when you select Calculate from process information for the **Resistor parameterization** parameter. The default value is 0 m.

Temperature Tab

| Block Parameters: SPICE Resistor PICE Resistor | | | | | |
|--|---|---|---|------------------------------|------------|
| odel a temperature-dependent resistor us fter determining the resistance value, the FIXED, or to the circuit temperature (from sing this block only to specify the resistan | block adjusts for temp the SPICE Environme | perature. You set the nt Parameters block) | resistor temperat plus an offset, TC | ure to a fixed ter FFSET. | nperature, |
| arameters Resistance Temperature | | | | | |
| First order temperature coefficient, TC1: | 0 | | | 1/K | • |
| Second order temperature coefficient, TC2: | 0 | | | 1/K^2 | • |
| Model temperature dependence using: | Device temperature | • | | | • |
| Offset local circuit temperature, TOFFSET: | 0 | | | K | - |
| Parameter extraction temperature, TMEAS: | 300.15 | | | К | • |
| | | | | | |
| | | ОК | Cancel | Help | Apply |

First order temperature coefficient, TC1

Coefficient for the linear term in the equation that the block uses to adjust the specified or calculated resistance value for temperature. The default value is $0 \ 1/K$.

Second order temperature coefficient, TC2

Coefficient for the quadratic term in the equation the block uses to adjust the specified or calculated resistance value for temperature. The default value is $0 \ 1/K^2$.

Model temperature dependence using

Select one of the following options for modeling the resistor temperature dependence:

- Device temperature Use the device temperature, which is the **Circuit temperature** parameter value (from the SPICE Environment Parameters block, if one exists in the circuit, or the default value for this block otherwise) plus the **Offset local circuit temperature**, **TOFFSET** parameter value.
- Fixed temperature Use a temperature that is independent of the circuit temperature to model temperature dependence.

Offset local circuit temperature, TOFFSET

The amount by which the resistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0 K.

Parameter extraction temperature, TMEAS

The temperature at which the resistor parameters were measured. The default value is **300.15** K. The value must be greater than 0.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the resistor. This parameter is only visible when you select Fixed temperature for the **Model temperature dependence using** parameter. The default value is 300.15 K. The value must be greater than 0.

Ports The block has the following ports:

+

Positive electrical voltage.

Negative electrical voltage.

See Also Diode

-

SPST Switch

| Purpose | Model single-pole single-throw switch |
|---------|---------------------------------------|
|---------|---------------------------------------|

Passive Devices/Switches

Library

Description



The SPST Switch block models a single-pole single-throw switch:

- When the switch is closed, port c is connected to port s through a resistance with value equal to the **Closed resistance** parameter value.
- When the switch is open, port c is connected to port s through a resistance with value equal to the reciprocal of the **Open conductance** parameter value.

The switch is closed if the voltage presented at the vT control port exceeds the value of the **Threshold** parameter.

Optionally, you can add a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing. To enable the delay, on the **Dynamics** tab, set the **Model dynamics** parameter to Model turn-on and turn-off times.

Dialog Box and Parameters

- "Main Tab" on page 1-819
- "Dynamics Tab" on page 1-820

Main Tab

| 🙀 Block Parameters: SPST Switch | | |
|---------------------------------|--|---|
| SPST Switch | | |
| | Pole Single-Throw (SPST) switch o en the switch is closed, otherwise th | ontrolled by an external control signal vT. I le switch is open. |
| Parameters | | |
| Main Dynamics | | |
| Closed resistance: | 0.01 | Ohm |
| Open conductance: | 1e-6 | S |
| Threshold: | 0 | V |
| | | |
| | | OK Cancel Help A |

Closed resistance

Resistance between the c and s electrical ports when the switch is closed. The value must be greater than zero. The default value is 0.01Ω .

Open conductance

Conductance between the c and s electrical ports when the switch is open. The value must be greater than zero. The default value is $1e-6\ {\rm S}.$

Threshold

The threshold voltage for the control physical signal input vT above which the switch will turn on. The default value is 0 V.

Dynamics Tab

| 😺 Block Parameters: SPST Switch | | | |
|---|----------------------|--|--|
| SPST Switch | | | |
| The block represents a Single-Pole Single-Throw (SPST) switch controlled by an external control signal vT. If vT greater than the threshold, then the switch is closed, otherwise the switch is open. | | | |
| Parameters | | | |
| Main Dynamics | | | |
| Model dynamics: | No dynamics | | |
| | | | |
| | OK Cancel Help Apply | | |

Model dynamics

Select whether the block models a switching delay:

- No dynamics Do not model the delay. This is the default option.
- Model turn-on and turn-off times Use additional parameters to model a delay between the point at which the voltage at vT passes the threshold and the switch opening or closing.

| Turn-on | delay |
|---------|-------|
|---------|-------|

Time between the input voltage exceeding the threshold voltage and the switch closing. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Turn-off delay

Time between the input voltage falling below the threshold voltage and the switch opening. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The value must be greater than zero. The default value is 1e-3 seconds.

Initial input value, vT

The value of the physical signal input vT at time zero. This value is used to initialize the delayed control voltage parameter internally. This parameter is only visible when you select Model turn-on and turn-off times for the **Model dynamics** parameter. The default value is 0 V.

| rts: |
|------|
| r |

vТ

Physical signal that opens and closes the switch.

C, S

Electrical conserving ports.

See Also DPDT Switch

DPST Switch

SPDT Switch

Simscape Switch

Stepper Motor

| Purpose | Model stepper motor |
|---------|---------------------|
|---------|---------------------|

Library

Rotational Actuators

Description

The Stepper Motor block represents a stepper motor. It uses the input pulse trains, A and B, to control the mechanical output according to the following equations:

 $e_{A} = -K_{m}\omega\sin(N_{r}\theta)$ $e_{B} = K_{m}\omega\cos(N_{r}\theta)$ $\frac{di_{A}}{dt} = (v_{A} - Ri_{A} - e_{A})/L$ $\frac{di_{B}}{dt} = (v_{B} - Ri_{B} - e_{B})/L$ $\frac{d\omega}{dt} = (-K_{m}(i_{A} - e_{A}/R_{m})\sin(N_{r}\theta) + K_{m}(i_{B} - e_{B}/R_{m})\cos(N_{r}\theta) - B\omega)/J$ $\frac{d\theta}{dt} = \omega$ where:

- $e_{\rm A}$ and $e_{\rm B}$ are the back emfs induced in the A and B phase windings, respectively.
- $i_{\rm A}$ and $i_{\rm B}$ are the A and B phase winding currents.
- + $v_{\rm A}$ and $v_{\rm B}$ are the A and B phase winding voltages.
- $K_{\rm m}$ is the motor torque constant.

- N_r is the number of teeth on each of the two rotor poles. The Full step size parameter is (π/2)/N_r.
- *R* is the winding resistance.
- *L* is the winding inductance.
- $R_{\rm m}$ is the magnetizing resistance.
- *B* is the rotational damping.
- *J* is the inertia.
- ω is the rotor speed.
- Θ is the rotor angle.

If the initial rotor is zero or some multiple of $(\pi/2)/N_r$, the rotor is aligned with the phase winding of pulse A. This happens when there is a positive current flowing from the A+ to the A- ports and there is no current flowing from the B+ to the B- ports.

Use the Stepper Motor Driver block to create the pulse trains for the Stepper Motor block.

The Stepper Motor block produces a positive torque acting from the mechanical C to R ports when the phase of pulse A leads the phase of pulse B.

Thermal Ports

The block has three optional thermal ports, one for each of the two windings and one for the rotor. These ports are hidden by default. To expose the thermal ports, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal ports on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box. These tabs are described further on this reference page.

Use the thermal ports to simulate the effects of copper resistance and iron losses that convert electrical power to heat. For more information

Stepper Motor

| | on using thermal ports in actuator blocks, see "Simulating Thermal Effects in Rotational and Translational Actuators". |
|-----------------------|--|
| Basic Assumptions | The model is based on the following assumptions: |
| and Limitations | • This model neglects magnetic saturation effects, detent torque, and any magnetic coupling between phases. |
| | • When you select the Start simulation from steady state check box in the Simscape Solver Configuration block, this block will not initialize an Initial rotor angle value between –π and π. |
| Dialog | • "Electrical Torque Tab" on page 1-825 |
| Box and Parameters | • "Mechanical Tab" on page 1-827 |
| Furdineiers | "Temperature Dependence Tab" on page 1-828 |
| | "Thermal Port Tab" on page 1-830 |

Electrical Torque Tab

| r | | | | |
|--|--|-----------------------|--|--|
| 🙀 Block Parameters: Stepper Motor | | | | |
| Stepper Motor | | | | |
| This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The bl can be driven directly from the Stepper Motor Driver block, and produces a positive torque acting from the mechanical C to R ports when Phase A leads Phase B. | | | | |
| poles, then the rotor is aligned with | ome multiple of (pi/2)/Nr where Nr is the number of the A-phase winding. This condition is held if there and no current flows from the B+ to the B- terminal | is a positive current | | |
| Parameters | | | | |
| Electrical Torque Mechanical | | | | |
| Phase winding resistance: | 0.55 | Ohm | | |
| Phase winding inductance: | 0.0015 | Н | | |
| Motor torque constant: | 0.19 | N*m/A | | |
| Magnetizing resistance: | Inf | Ohm | | |
| Full step size: | 1.8 | deg | | |
| <u>L</u> | | | | |
| | OK Cancel | Help | | |

Phase winding resistance

Resistance of the A and B phase windings. The default value is $0.55\ \Omega.$

Phase winding inductance

Inductance of the A and B phase windings. The default value is 0.0015 H.

Motor torque constant

Motor torque constant K_m . The default value is 0.19 N*m/A.

Magnetizing resistance

The total magnetizing resistance seen from each of the phase windings. The value must be greater than zero. The default value is Inf, which implies that there are no iron losses.

Full step size

Step size when changing the polarity of either the A or B phase current. The default value is 1.8°.

Mechanical Tab

| 🙀 Block Parameters: Stepper Motor | | |
|---|---|-----------------------|
| Stepper Motor | | |
| | nd torque characteristics of a permanent magnet s per Motor Driver block, and produces a positive toro A leads Phase B. | |
| poles, then the rotor is aligned with t | me multiple of (pi/2)/Nr where Nr is the number of the A-phase winding. This condition is held if there and no current flows from the B+ to the B- terminal | is a positive current |
| Parameters | | |
| Electrical Torque Mechanical | | |
| Rotor inertia: | 4.5e-5 | kg*m^2 |
| Rotor damping: | 8e-4 | N*m/(rad/s) |
| Initial rotor speed: | 0 | rpm |
| Initial rotor angle: | 0 | deg |
| [<u></u> | | |
| | OK Cancel | Help A |

Rotor inertia

Resistance of the rotor to change in motor motion. The default value is $4.5e{-}05~{\rm kg}^{*}{\rm m}^{2}.$ The value can be zero.

Rotor damping

Energy dissipated by the rotor. The default value is $8e{-}04$ N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is $0\ \mathrm{rpm}.$

Initial rotor angle

Angle of the rotor at the start of the simulation. The default value is $0\ \mathrm{rad}.$

Temperature Dependence Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-823.

Stepper Motor

| 🙀 Block Parameters: Stepper Motor | | | | | |
|---|------------------------|--------------|----------|--|--|
| Stepper Motor | | | | | |
| This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The bl can be driven directly from the Stepper Motor Driver block, and produces a positive torque acting from the mechanical C to R ports when Phase A leads Phase B. | | | | | |
| If the initial angle is set to zero or some multiple of (pi/2)/Nr where Nr is the number of teeth on each of the poles, then the rotor is aligned with the A-phase winding. This condition is held if there is a positive current flowing from the A+ to A- terminals and no current flows from the B+ to the B- terminals. | | | | | |
| Parameters | | | | | |
| Electrical Torque Mechanical | Temperature Dependence | Thermal Port | | | |
| Resistance temperature coefficients, [alpha_A alpha_B]: | [0.00393 0.00393] | | 1/К | | |
| Measurement temperature: | 25 | | С | | |
| | | | | | |
| | | OK Cance | I Help A | | |

Resistance temperature coefficients, [alpha_A alpha_B]

A 1 by 2 row vector defining the coefficient α in the equation relating resistance to temperature, as described in "Thermal Model for Actuator Blocks". The first element corresponds to winding A, and the second to winding B. The default value is for copper, and is [0.00393 0.00393] 1/K.

Measurement temperature

The temperature for which motor parameters are defined. The default value is 25 C.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-823.

Block Parameters: Stepper Motor

Stepper Motor

This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The ble be driven directly from the Stepper Motor Driver block, and produces a positive torque acting from the mech C to R ports when Phase A leads Phase B.

If the initial angle is set to zero or some multiple of (pi/2)/Nr where Nr is the number of teeth on each of the poles, then the rotor is aligned with the A-phase winding. This condition is held if there is a positive current from the A+ to A- terminals and no current flows from the B+ to the B- terminals.

| Mechanical | Temperature Dependence | Thermal Port | |
|--------------------------|--|--|--|
| nasses, [M_A | [100 100] | | J/K |
| peratures, | [25 25] | | С |
| s: | 50 | | Ј/К |
| rature: | 25 | | С |
| netizing ted with the | 90 | | |
| | peratures, s: rature: jnetizing | [100 100] peratures, [25 25] ss: 50 rature: 25 gnetizing | peratures, [25 25] ss: 50 rature: 25 |

Winding thermal masses, [M_A M_B]

A 1 by 2 row vector defining the thermal mass for the A and B windings. The thermal mass is the energy required to raise the temperature by one degree. The default value is $[100\ 100\]$ J/K.

Winding initial temperatures, [T_A T_B]

A 1 by 2 row vector defining the temperature of the A and B thermal ports at the start of simulation. The default value is [$25\ 25\]$ C.

Rotor thermal mass

The thermal mass of the rotor, that is, the energy required to raise the temperature of the rotor by one degree. The default value is 50 J/K.

Rotor initial temperature

The temperature of the rotor at the start of simulation. The default value is 25 C.

Percentage of magnetizing resistance associated with the rotor The percentage of the magnetizing resistance associated with the magnetic path through the rotor. It determines how much of the iron loss heating is attributed to the rotor thermal port HR, and how much is attributed to the two winding thermal ports HA and HB. The default value is 90%.

The block has the following ports:

A+

Top A-phase electrical connection.

Α-

Lower A-phase electrical connection

B+

Top B-phase electrical connection.

В-

Lower B-phase electrical connection.

Ports

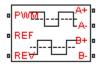
| | С |
|------------|---|
| | Mechanical rotational conserving port. |
| | R Mechanical rotational conserving port. |
| | HA Winding A thermal port. For more information, see "Thermal Ports" on page 1-823. |
| | HB Winding B thermal port. For more information, see "Thermal Ports" on page 1-823. |
| | HR Rotor thermal port. For more information, see "Thermal Ports" on page 1-823. |
| Examples | See the Controlled Stepper Motor example. |
| References | M. Bodson, J. N. Chiasson, R. T. Novotnak and R. B. Rekowski. "High-Performance Nonlinear Feedback Control of a Permanent Magnet Stepper Motor." IEEE Transactions on Control Systems Technology, Vol. 1, No. 1, March 1993. |
| | [2] P. P. Acarnley. Stepping Motors: A Guide to Modern Theory and Practice. New York: Peregrinus, 1982. |
| | [3] S.E. Lyshevski. <i>Electromechanical Systems, Electric Machines, and Applied Mechatronics</i> . CRC, 1999. |
| See Also | Stepper Motor Driver |
| | Unipolar Stepper Motor |

Stepper Motor Driver

| Purpose Model ste | pper motor driver |
|-------------------|-------------------|
|-------------------|-------------------|

Library Drivers

Description



The Stepper Motor Driver block represents a stepper motor driver. It creates the pulse trains, A and B, required to control the motor. This block initiates a step each time the voltage at the PWM port rises above the **Enable threshold voltage**.

If the voltage at the REV port is less than or equal to the **Reverse threshold voltage**, pulse A leads pulse B by 90 degrees. If the voltage at the REV port is greater than the **Reverse threshold voltage**, pulse B leads pulse A by 90 degrees and the motor direction is reversed.

At time zero, pulse A is positive and pulse B is negative.

Use the Controlled PWM Voltage block to create the voltage at the PWM port. This block creates a network engine event every time the PWM signal goes high. The network engine event triggers a simulation time point when the PWM signal goes high, which ensures good simulation accuracy. If you instead use the Controlled Voltage Source block from the Foundation library, you need to set a suitably small time step for the simulation. For information about specifying the Simulink step size, see "Choose a Solver" in the Simulink documentation.

| Dialog |
|-------------------|
| Box and |
| Parameters |

| Block Parameters: | Stepper Motor | Driver | | × |
|---|---|--------|------|-------|
| Stepper Motor Driver- | | | | |
| This block represents a stepper motor driver and creates the A and B pulse trains required to control the motor. The PWM input sets the step rate, and the driver initiates a step each time the PWM signal rises above the Enable threshold voltage. | | | | |
| If the REV port voltage is less than or equal to the Reverse threshold voltage, then pulse A leads pulse B by 90 degrees. If REV increases above the threshold, then pulse B leads pulse A by 90 degrees and the motor direction is reversed. At time zero, pulse A is initialized positive and pulse B negative. | | | | |
| Voltages at ports PWM | Voltages at ports PWM and REF are defined relative to the REF port. | | | |
| Parameters | | | | |
| Enable threshold voltage: | 2.5 | | V | • |
| Reverse threshold voltage: | 2.5 | | V | • |
| Output voltage amplitude: | 10 | | V | • |
| | ОК | Cancel | Help | Apply |

Enable threshold voltage

When the voltage at the PWM port rises above this threshold, the Stepper Motor Driver block initiates a step. The default value is 2.5 V.

Reverse threshold voltage

When the voltage at the REV port rises above this threshold, pulse B leads pulse A by 90 degrees and the motor direction is reversed. The default value is 2.5 V.

Output voltage amplitude

Amplitude of the output pulse trains. The default value is 10 V.

The block has the following ports:

A+

Ports

Positive electrical output of pulse A.

| | A - | |
|----------|------------|--|
| | D . | Negative electrical output of pulse A |
| | B+ | Positive electrical output of pulse B. |
| | В- | |
| | | Negative electrical output of pulse B. |
| | PWM | Triggering input step voltage. |
| | REF | Input floating reference voltage. |
| | REV | Input voltage that controls motor direction. |
| Examples | See t | he Controlled Stepper Motor example. |
| See Also | Cont | rolled PWM Voltage and Stepper Motor. |

 Purpose
 Model deformation sensor

Library Sensors

Description

The Strain Gauge block represents a sensor that generates a change in resistance as a function of strain using the following equation:

 $\frac{\Delta R}{R} = K\varepsilon$

where:

- $\Delta R/R$ is the fractional change in resistance.
- ϵ is the strain at port B.
- *K* is the **Gauge factor** parameter value.

Dialog Box and Parameters

| This block models a strain gauge. The relationship between strain E presented at the physical signal input port and change in resistance dR is dR/R = K*E where R is the unstressed gauge resistance and K is the gauge factor. | | | | |
|---|-----|--|-----|---|
| Parameters | | | | |
| Gauge resistance: | 100 | | Ohm | • |
| Gauge factor: | 2 | | | |
| | | | | |
| | | | | |

Gauge resistance

The unstressed gauge resistance. The default value is 100 $\Omega.$

Gauge factor

The ratio K of the fractional change in resistance to the fractional change in length. The default value is 2.

Ports The block has the following ports:

В

+

-

Strain input.

Positive electrical port.

Negative electrical port.

- **Purpose** Model resistor with thermal port
- **Library** Passive Devices

Description

▫≁ਿ⊤ ⋼₊г⁴ѴѴѴѵ₋Г⁻╹ The Thermal Resistor block represents a temperature-dependent resistor. The resistance when the temperature at the thermal port is T is

$$R = R_0(1 + a(T - T_0))$$

where:

- R_0 is the nominal resistance at the reference temperature T_0 .
- *a* is the temperature coefficient.

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt} - i^2 R$$

where:

- *Q* is the net heat flow into port A.
- K_d is the **Dissipation factor** parameter value.
- t_c is the **Thermal time constant** parameter value.
- dT/dt is the rate of change of the temperature.
- *i* is the current through the resistor.

Thermal Resistor

Dialog Box and Parameters

Electrical Tab

| 皆 Block Parameters: Thermal Resisto | r | | | |
|---|--------|------------------|--|--|
| Thermal Resistor | | | | |
| This block represents a resistor with a thermal port. The resistance at temperature T is given by $R(T) = R0^*(1+alpha(T-T0))$ where R0 is the Nominal resistance at the Reference temperature T0, and alpha is the Temperature coefficient. The temperature T of the resistor is governed by the equation $m^*c^*dT/dt = Q + i^2R(T)$ where Q is the net heat flow into port A, m is the mass, c is the lumped specific heat capacity and i is the current. The thermal mass m^*c is calculated from the Thermal time constant t_c and the Dissipation factor K_d using the equation $m^*c = K_d^*t_c$. | | | | |
| Parameters Electrical Thermal | | | | |
| Nominal resistance: | 1 | Ohm 👻 | | |
| Reference temperature: | 298.15 | К | | |
| Temperature coefficient: 50e-6 1/K - | | | | |
| <u> </u> | | 1 | | |
| | ОК | ancel Help Apply | | |

Nominal resistance

The nominal resistance of the thermistor at the reference temperature. Many datasheets quote the nominal resistance at 25°C (298.15 K) and list it as R25. The default value is 1 Ω .

Reference temperature

The temperature at which the nominal resistance was measured. The default value is 298.15 K.

Temperature coefficient

The coefficient a in the equation that describes resistance as a function of temperature. The default value is 5e-05 1/K.

Thermal Tab

| 皆 Block Parameters: Thermal Resisto | r | — |
|--|---|--|
| Thermal Resistor | | |
| R0*(1+alpha(T-T0)) where R0 is Temperature coefficient. The tem i^2*R(T) where Q is the net heat | vith a thermal port. The resistance at temperature T the Nominal resistance at the Reference temperature perature T of the resistor is governed by the equati flow into port A, m is the mass, c is the lumped sp *c is calculated from the Thermal time constant t_c d*t_c. | re T0, and alpha is the on m*c*dT/dt = Q + ecific heat capacity and i is |
| Parameters | | |
| Electrical Thermal | | |
| Thermal time constant: | 10 | S T |
| Dissipation factor: | 1e-3 | W/K - |
| Initial temperature: | 298.15 | K |
| | | |
| | OK | Help Apply |

Thermal time constant

The time it takes the resistor temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 10 s.

Dissipation factor

The thermal power required to raise the thermal resistor temperature by one K. The default value is 0.001 W/K.

Initial temperature

The temperature of the thermal resistor at the start of the simulation. The default value is 298.15 K.

Ports The block has the following ports:

А

Resistor thermal port

Thermal Resistor

Positive electrical port

Negative electrical port

See Also Thermistor, Thermocouple.

+

-

Purpose Model NTC thermistor using B-parameter equation

Library Sensors

Description

•-#О т

The Thermistor block represents an NTC thermistor using the B-parameter equation. The resistance at temperature T is

$$R = R_0 (e^{B(1/T - 1/T_0)} - 1)$$

where:

- R_0 is the nominal resistance at the reference temperature T_0 .
- B is the characteristic temperature constant.

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt}$$

where:

- *Q* is the net heat flow into port A.
- K_d is the **Dissipation factor** parameter value.
- *t_c* is the **Thermal time constant** parameter value.
- dT/dt is the rate of change of the temperature.

To model the thermistor in free space:

- **1** Connect the thermistor to the B port of a Simscape Convective Heat Transfer block.
- **2** Connect the A port of the Convective Heat Transfer block to a Simscape Ideal Temperature Source block whose temperature is set to the ambient temperature.

- **3** Set the Area parameter of the Convective Heat Transfer block to an approximate area A_{nom} .
- **4** Set the **Heat transfer coefficient** parameter of the Convective Heat Transfer block to K_d/A_{nom} .

Dialog Electrical Tab Box and Parameters

🚹 Block Parameters: Thermistor

Thermistor

This block represents an NTC thermistor using the B-parameter equation. The resistance at temperature T is given by $R(T) = R0^* \exp(B^*(1/T-1/T0))$ where R0 is the Nominal resistance at the reference temperature T0 B is the Characteristic temperature constant. The temperature T of the thermistor is governed by the equation $m^*c^*dT/dt = Q$ where Q is the net heat flow into port A, m is the mass and c is the lumped specific heat can The thermal mass m^*c is calculated from the Thermal time constant t_c and the Dissipation factor K_d using equation $m^*c = K_d^*t_c$.

| Nominal resistance R0 at reference temperature T0: | 1000 | Ohm |
|---|--------|-----|
| Characteristic temperature constant B: | 3500 | К |
| Reference temperature T0: | 298.15 | К |

Nominal resistance R0 at reference temperature T0

The nominal resistance of the thermistor at the reference temperature. Many datasheets quote the nominal resistance at 25° C and list it as R25. The default value is 1000 Ω .

Characteristic temperature constant B

The coefficient B in the equation that describes resistance as a function of temperature. The default value is **3500** K.

Reference temperature T0

The temperature at which the nominal resistance was measured. The default value is **298.15** K.

Thermal Tab

| ▶ | Block | Param | eters: 1 | [hermist | tor |
|---|-------|-------|----------|----------|-----|
|---|-------|-------|----------|----------|-----|

Thermistor

This block represents an NTC thermistor using the B-parameter equation. The resistance at temperature T is given by $R(T) = R0^* \exp(B^*(1/T-1/T0))$ where R0 is the Nominal resistance at the reference temperature T0, an B is the Characteristic temperature constant. The temperature T of the thermistor is governed by the equation $m^*c^*dT/dt = Q$ where Q is the net heat flow into port A, m is the mass and c is the lumped specific heat capacit The thermal mass m^*c is calculated from the Thermal time constant t_c and the Dissipation factor K_d using the equation $m^*c = K_d^*t_c$.

| Parameters | | | | |
|------------------------|---------|-----------|------|-------|
| Electrical Thermal | | | | |
| Thermal time constant: | 5.0 | | S | • |
| Dissipation factor: | 0.75e-3 | | W/K | • |
| Initial temperature: | 298.15 | | К | • |
| | | | | |
| | | | | Amel |
| | | OK Cancel | Help | Apply |

| | Thermal time constant The time it takes the sensor temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 5 s. |
|----------|---|
| | Dissipation factor The thermal power required to raise the thermistor temperature by one K. The default value is 0.75e-4 W/K. |
| | Initial temperature The temperature of the thermistor at the start of the simulation. The default value is 298.15 K. |
| Ports | The block has the following ports: |
| | A Thermal port. |
| | + Positive electrical port. |
| | - Negative electrical port. |
| See Also | PTC Thermistor |
| | Thermal Resistor |

Thermocouple

Purpose Model sensor that converts thermal potential difference into electrical potential difference

Library

Description

The Thermocouple block represents a thermocouple using the standard polynomial parameterization defined in the NIST ITS-90 Thermocouple Database [1]. The voltage E across the device in mV is

 $E(mV) = c0 + c1^{*}t + \dots + cn^{*}t^{n}$

where:

Sensors

- *ci* is the *i*th element of the **Coefficients** [**c0 c1 ... cn**] parameter value.
- *t* is the temperature difference in degrees Celsius between the temperature at the thermal port A and the **Reference temperature** parameter value.

Note The equation for voltage across the device as a function of temperature difference is defined in mV. The units of the voltage across the actual device is V.

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt}$$

where:

- *T* is the temperature at port A.
- *Q* is the net heat flow into port A.
- K_d is the **Dissipation factor** parameter value.

- *t_c* is the **Thermal time constant** parameter value.
- dT/dt is the rate of change of the temperature.

To model the thermocouple in free space:

- **1** Connect the thermocouple to the B port of a Simscape Convective Heat Transfer block.
- **2** Connect the A port of the Convective Heat Transfer block to a Simscape Ideal Temperature Source block whose temperature is set to the ambient temperature.
- **3** Set the Area parameter of the Convective Heat Transfer block to an approximate area A_{nom} .
- **4** Set the **Heat transfer coefficient** parameter of the Convective Heat Transfer block to K_d/A_{nom} .

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The high-order polynomials this block uses are very sensitive to the number of significant figures used for computation. Use all available significant figures when specifying the **Coefficients [c0 c1 ... cn]** parameter.
- **Coefficients [c0 c1 ... cn]** are defined for use over a specified temperature range.
- This block does not include the additional exponential term that Type K thermocouples use when parameterized for t > 0.

Thermocouple

Dialog Box and Parameters

Electrical Tab

| Block Parameters: Thermocouple | × |
|--|---|
| This block implements a thermocouple mod temperature difference in degrees Celsius The voltage presented across the output The absolute temperature T of the thermo | el. The thermocouple voltage is given by E(mV) = c0 + c1 [*] t +, cn [*] t^n where t is the between the temperature presented at thermal port A and the Reference temperature, terminals is in units of volts. The default parameters are for a Type S thermocouple. couple is governed by the equation m [*] c [*] dT/dt = Q where Q is the net heat flow into port fic heat capacity. The thermal mass m [*] c is calculated from the Thermal time constant t_c public m [*] c = K_d [*] t_c. |
| Parameters Electrical Thermal Coefficients [c0 c1 cn]: | 3e-05 -2.3248e-08 3.2203e-11 -3.315e-14 2.5574e-17 -1.2507e-20 2.7144e-24] |
| | OK Cancel Help Apply |

Coefficients [c0 c1 ... cn]

The vector of coefficients c in the equation that describes voltage as a function of temperature. The default value is [0 0.0054031 1.2593e-05 -2.3248e-08 3.2203e-11 -3.315e-14 2.5574e-17 -1.2507e-20 2.7144e-24]. This value specifies a Type S thermocouple, which is valid in the range -50 to 1064 degrees C.

Note You can download parameters for other standard thermocouple types from the NIST database [1]. For information on how to do this, see the Simulink Approximating Nonlinear Relationships: Type S Thermocouple example.

Thermal Tab

| 🙀 Block Parameters: Thermocoupl | e | | | × |
|--|--|--|--|--------------------------------------|
| Thermocouple | | | | |
| This block implements a thermocouple r temperature difference in degrees Cel The voltage presented across the outp The absolute temperature T of the the A, m is the mass and c is the lumped sp and the Dissipation factor K_d using the Parameters | sius between the tempera out terminals is in units of v rmocouple is governed by pecific heat capacity. The | ture presented at thermal port <i>i</i> volts. The default parameters ar the equation m*c*dT/dt = Q wi thermal mass m*c is calculated f | A and the Reference ten re for a Type S thermoco here Q is the net heat fi | nperature. ouple. ow into port |
| Electrical Thermal | | | | |
| Reference temperature: | 0 | | С | • |
| Thermal time constant: | 1 | | s | • |
| Dissipation factor: | 0.001 | | W/K | • |
| Initial temperature: | 25 | | С | • |
| | | | | |
| | | OK Canc | el Help | Apply |

Reference temperature

The temperature the block subtracts from the temperature at the thermal port in calculating the voltage across the device. The default value is 0 °C.

Thermal time constant

The time it takes the thermocouple temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 1 s.

Dissipation factor

The thermal power required to raise the thermocouple temperature by one K. The default value is 0.001 W/K.

Initial temperature

The temperature of the thermocouple at the start of the simulation. The default value is 25 °C.

Thermocouple

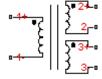
| Ports | The block has the following ports: | |
|------------|--|--|
| | A Thermocouple thermal port. | |
| | + Positive electrical port. | |
| | - Negative electrical port. | |
| References | [1] NIST ITS-90 Thermocouple Database http://srdata.nist.gov/its90/main | |
| See Also | Thermal Resistor. | |

Purpose Model three coupled inductors

Library Passive Devices

Description

The Three-Winding Mutual Inductor block represents a set of three coupled inductors or windings. The voltage across the three windings is



$$V_{1} = L_{1} \frac{dI_{1}}{dt} + M_{12} \frac{dI_{2}}{dt} + M_{13} \frac{dI_{3}}{dt}$$
$$V_{2} = M_{12} \frac{dI_{1}}{dt} + L_{2} \frac{dI_{2}}{dt} + M_{23} \frac{dI_{3}}{dt}$$
$$V_{3} = M_{13} \frac{dI_{1}}{dt} + M_{23} \frac{dI_{2}}{dt} + L_{3} \frac{dI_{3}}{dt}$$

where:

- V_i is voltage across the *i*th winding.
- I_i is current through the *i*th winding.
- L_i is self inductance of the *i*th winding.
- M_{ij} is mutual inductance of the *i*th and *j*th windings, $M_{ij} = K_{ij} \sqrt{L_i L_j}$.

In the preceding equations, currents are positive when flowing into the positive node of their respective inductor terminals.

When you run a simulation that includes this block, the software checks the specified parameter values to ensure that the resulting device is passive. If it is not, the software issues an error. Dialog Box and Parameters

| 당 Block Parameters: T | hree-Winding | Mutual Inducto |)r | X |
|---|--------------|----------------|------|-------|
| Three-Winding Mutual Inductor | | | | |
| This block models three coupled inductors. The following equations decsribe the voltage-current relationships, where currents are positive when flowing into the positive node of their respective inductor terminals. | | | | |
| V1 = L1*dI1/dt + M12*dI2/dt + M13*dI3/dt | | | | |
| V2 = M12*dI1/dt + L2*dI2/dt + M23*dI3/dt | | | | |
| V3 = M13*dI1/dt + M23*dI2/dt + L3*dI3/dt | | | | |
| where parameters L1, L2 and L3 are the winding self-inductances, and the Mi, js are the mutual inductances. Mi, j is defined in terms of the Coefficient of Coupling Ki, j using the equation Mi, j=Ki, j*sqrt(Li*Lj). The absolute value of K must be less than one and the eignevalues of above system of equations must be greater than zero. | | | | |
| The parameters IC1, IC2 and IC3 set the initial currents flowing through windings 1, 2 and 3. | | | | |
| Parameters | | | | |
| Inductance L1: | 0.001 | | Н | • |
| Inductance L2: | 0.001 | | Н | • |
| Inductance L3: | 0.001 | | н | • |
| Coefficient of coupling, K12: | 0.9 | | | |
| Coefficient of coupling, K13: | 0.9 | | | |
| Coefficient of coupling, K23: | 0.9 | | | |
| Specify initial condition?: | No | | | • |
| | | | | |
| | ОК | Cancel | Help | Apply |

Inductance L1

The self inductance of the first winding. The default value is $0.001\ \mathrm{H}.$

Inductance L2

The self inductance of the second winding. The default value is 0.001 H.

Inductance L3

The self inductance of the third winding. The default value is $0.001\ {\rm H}.$

Coefficient of coupling, K12

The coefficient that defines the mutual inductance between the first and second windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Coefficient of coupling, K13

The coefficient that defines the mutual inductance between the first and third windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Coefficient of coupling, K23

The coefficient that defines the mutual inductance between the second and third windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial inductor currents.

Initial current port 1, IC1

The current flowing through the first winding at the start of the simulation. This parameter is only visible when you select Yes for the **Specify initial condition** parameter. The default value is 0 A.

Initial current port 2, IC2

The current flowing through the second winding at the start of the simulation. This parameter is only visible when you select

| | Yes for the Specify initial condition parameter. The default value is 0 A. Initial current port 3, IC3 The current flowing through the third winding at the start of the simulation. This parameter is only visible when you select Yes for the Specify initial condition parameter. The default value is 0 A. |
|-------|--|
| Ports | The block has the following ports: 1+ Positive electrical voltage of the first mutual inductor. 1- Negative electrical voltage of the first mutual inductor. |
| | 2+ Positive electrical voltage of the second mutual inductor. 2- Negative electrical voltage of the second mutual inductor. 3+ Positive electrical voltage of the third mutual inductor. 3- Negative electrical voltage of the third mutual inductor. |

 Purpose
 Model thyristor using NPN and PNP transistors

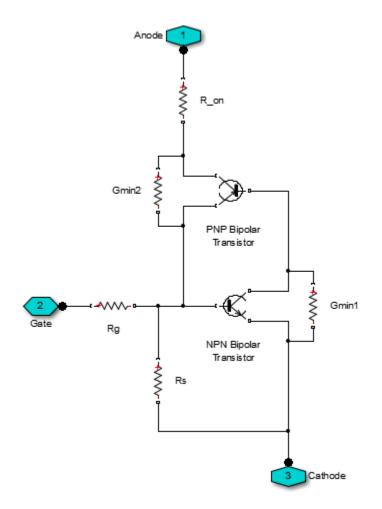
Library Semiconductor Devices

Thyristor

Description



The Thyristor block represents a system-level thyristor model that can be parameterized from a typical datasheet. The thyristor model is built from a pair of NPN and PNP bipolar transistors, as shown in the following illustration.



The P-N-P-N structure of a thyristor is matched by the P-N-P and N-P-N structures of the bipolar transistors, the base of each device being connected to the collector of the other device. Ensuring that this circuit behaves like a thyristor is primarily picking suitable parameter values of the NPN and PNP devices, plus external resistors. For example, for the circuit to latch into the on-state, once triggered by a suitable gate current, the total gain of the two transistors must be greater than one. This model structure replicates the behavior of a thyristor in typical application circuits, while at the same time presenting a minimum number of equations to the solver, to improve simulation speed.

The model captures the following thyristor behaviors:

- Off-state currents, I_{DRM} and I_{RRM} . These are typically quoted for the maximum off-state voltages V_{DRM} and V_{RRM} . It is assumed, as is the case for most thyristors, that $I_{DRM} = I_{RRM}$ and $V_{DRM} = V_{RRM}$.
- The gate trigger voltage is equal to the **Gate trigger voltage**, **v_GT** parameter value when the gate current is equal to the **Gate trigger current**, **i_GT** parameter value.
- The thyristor latches on when the gate current is equal to the **Gate trigger current**, **i**_**GT**. The thyristor does not latch on until the gate current reaches this value. To ensure this is the case, you must set the **Internal shunt resistor**, **Rs** parameter correctly. If the resistance is too high, then the gate triggers before the gate current reaches i_{GT} . If the resistance is too small, then the gate does not trigger.

You can determine the value of the internal shunt resistor Rs by running the simulation. To see how this can be done, refer to the Thyristor Static Behavior Validation example. Alternatively, if you are using the thyristor in a circuit where there is an external resistor R_{GK} connected from gate to cathode, then the effect of Rs is usually very small, and it can be set to inf.

• With the thyristor in the on-state, if the gate current is removed, the thyristor stays in the on-state, provided that the load current is higher than the latching current. You do not specify the latching

current directly because its value is primarily determined by other block parameters.

However, the latching current can be influenced by the **Product** of NPN and PNP forward current gains parameter on the Advanced tab. Reducing the gain increases the latching current.

- The on-state voltage is equal to the **On-state voltage**, **V_T** parameter value when the load current is equal to the **On-state current**, **I_T** parameter value. This is ensured by the R_on resistance value, which takes into account the voltage drop seen across the PNP and NPN devices.
- Triggering by rate of rise of off-state voltage. A rapid change in anode-cathode voltage induces a current in the base-collector capacitance terms. If this current is large enough, it triggers the thyristor into the on-state. The thyristor initialization routine calculates a suitable value for the base-collector capacitance, so that when the rate of change of voltage is equal to the **Critical rate of rise of off-state voltage**, **dV/dt** parameter value, the thyristor triggers on. This calculation is based on the approximation that the required current is v_{GT}/R_{GK} where R_{GK} is the gate-cathode resistance value used when quoting the critical dV/dt value.
- A nonzero gate-controlled turn-on time. This is primarily influenced by the **NPN transistor forward transit time, TF**. You either specify this parameter directly, or calculate an approximate value for TF from the turn-on time.
- A nonzero commuted turn-off time. This is primarily influenced by the **PNP transistor forward transit time, TF**. You can either specify this parameter directly, or set it to be equal to the forward transit time for the NPN transistor.

Resistors Gmin1 and Gmin2 improve numerical robustness at large forward and reverse voltages. Their values influence the off-state currents by no more than 1% at the maximum off-state forward and reverse voltages.

Thermal Port

The block has an optional thermal port, hidden by default. To expose the thermal port, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal port H on the block icon, and adds the **Thermal port** tab to the block dialog box.

Use the thermal port to simulate the effects of generated heat and device temperature. For more information on using thermal ports and on the **Thermal port** tab parameters, see "Simulating Thermal Effects in Semiconductors".

The Thyristor block has the following limitations:

- This block does not model temperature-dependent effects. SimElectronics simulates the block at the temperature at which the component behavior was measured, as specified by the **Measurement temperature** parameter value. All parameters must be quoted for this temperature.
- In sensitive gate circuits (that is, where there is no external gate-cathode resistor R_{GK}), you must set the value of the **Internal shunt resistor**, **Rs** parameter to ensure correct triggering. If the internal shunt resistance is too high, then the thyristor triggers for currents less than i_{GT} . If the internal shunt resistance is too low, the thyristor does not trigger for an input current of i_{GT} . For details on using simulation to determine the acceptable internal shunt resistance value, see the Thyristor Static Behavior Validation example.
- Triggering by exceeding the break-over voltage is not modeled.
- Numerically the thyristor can be demanding to simulate, given the very small gate currents in comparison to the load current, and also the very steep current gradients during switching. However, for most typical thyristor-based circuits, you can use the default simulation parameters. In some cases you may need to tighten the **Absolute Tolerance** and **Relative Tolerance** parameters on the **Solver** tab

Basic Assumptions and Limitations

of the Configuration Parameters dialog box, to ensure convergence. In such cases, changing the default value of **Absolute Tolerance** from auto to 1e-4 or 1e-5 is usually sufficient, because it prevents adaptive changing of this parameter during simulation.

Dialog Box and Parameters

Main Tab

| 🙀 Block Parameters: Thyristor | | | | | × | |
|---|------------|----------------|----------|------|------------|--|
| Thyristor | Thyristor | | | | | |
| This block represents a thyristor modeled using an NPN and a PNP transistor. The collector of each device is connected to the base of the other device so as to give the P-N-P-N junction structure of a thyristor. For more details of the model structure, consult the documentation. The device model can be turned on using both gate and dV/dt triggering. Triggering via exceeding of the break-over voltage is not modeled. | | | | | | |
| Parameters | | | | | | |
| Main Gate Triggering dV/dt | Triggering | Time Constants | Advanced | | | |
| On-state voltage, V_T: | 1.2 | | | V | • | |
| On-state current, I_T: | 1 | | | Α | - | |
| Off-state current, I_DRM: | 0.01 | | | m/ | ↓ | |
| Corresponding off-state voltage, V_DRM: | 400 | | | V | | |
| Measurement temperature: | 25 | | | С | | |
| L | | 0 | K Car | ncel | Help Apply | |

On-state voltage, V_T

The anode-cathode static voltage drop when in the on-state, and the current flowing is equal to the on-state current I_T . The default value is 1.2 V.

On-state current, I_T

Static load (or equivalently anode) current that flows when the anode-cathode voltage is equal to the on-state voltage V_T . The default value is 1 A.

Off-state current, I_DRM

The off-state anode current I_{DRM} that flows when the anode-cathode voltage is equal to the off-state voltage V_{DRM} . The default value is 0.01 mA.

Corresponding off-state voltage, V_DRM

Corresponding off-state voltage, V_{DRM} . The anode-cathode voltage V_{DRM} applied with the thyristor in the off-state when quoting the off-state current I_{DRM} . The default value is 400 V.

Measurement temperature

The device simulation temperature. You must specify all block parameter values for this temperature. The default value is 25 °C.

Gate Triggering Tab

| 🙀 Block Parameters: Thyristor | | | | | | |
|---|------------|----------------|----------|-----------------|--|--|
| Thyristor | | | | | | |
| This block represents a thyristor modeled using an NPN and a PNP transistor. The collector of each device is connected to the base of the other device so as to give the P-N-P-N junction structure of a thyristor. For more details of the model structure, consult the documentation. The device model can be turned on using both gate and dV/dt triggering. Triggering via exceeding of the break-over voltage is not modeled. | | | | | | |
| Parameters | | | | | | |
| Main Gate Triggering dV/dt | Triggering | Time Constants | Advanced | | | |
| Gate trigger current, I_GT: | 3 | | | uA 👻 | | |
| Corresponding gate voltage, V_GT: | 0.6 | | | V • | | |
| Test voltage, V_D: | 12 | | | V | | |
| Test load resistor: | 120 | | | Ohm 👻 | | |
| | | | | | | |
| | | | | | | |
| | | 0 | K Car | icel Help Apply | | |

Gate trigger current, I_GT

Critical gate current i_{GT} required to turn the transistor on, resulting in a gate voltage equal to the gate trigger voltage v_{GT} .

You must set the value of the **Internal shunt resistor**, **Rs** parameter on the **Advanced** tab to ensure that the gate triggers at i_{GT} , and not for currents less that i_{GT} . The default value is 3 µA.

Corresponding gate voltage, V_GT

Gate-cathode voltage v_{GT} when the gate current is equal to the gate trigger current i_{GT} . The default value is 0.6 V.

Test voltage, V_D

Supply voltage used when quoting values for $v_{\rm GT}$ and $i_{\rm GT}.$ The default value is 12 V.

Test load resistor

Load resistor used when quoting values for v_{GT} and i_{GT} . The default value is 120 Ω .

dV/dt Triggering Tab

| 😝 Block Parameters: Thyristor | | X |
|--|--|--|
| Thyristor | | |
| This block represents a thyristor more connected to the base of the other do details of the model structure, consu dV/dt triggering. Triggering via excee | evice so as to give the P-N-P-N junct It the documentation. The device mo | ion structure of a thyristor. For more del can be turned on using both gate and |
| Parameters | | |
| Main Gate Triggering dV/dt | Triggering Time Constants Ac | lvanced |
| Critical rate of rise of off-state voltage, dV/dt: | 150 | V/us 👻 |
| Test gate-cathode resistor, R_GK: | 1000 | Ohm 👻 |
| | | |
| | | |
| | | |
| | | |
| | ОК | Cancel Help Apply |

Critical rate of rise of off-state voltage, dV/dt

Rate at which the off-state anode-cathode voltage must be increased for the thyristor to turn on. The default value is $150\ V/\mu s.$

Test gate-cathode resistor, R_GK

Gate-cathode resistor used when quoting the critical rate of rise off off-state voltage. The default value is 1 K Ω .

Time Constants Tab

| 📓 Block Parameters: Thyristor | — |
|--|-----------------------|
| Thyristor | |
| This block represents a thyristor modeled using an NPN and a PNP transistor. The collector connected to the base of the other device so as to give the P-N-P-N junction structure of a details of the model structure, consult the documentation. The device model can be turner dV/dt triggering. Triggering via exceeding of the break-over voltage is not modeled. | a thyristor. For more |
| Parameters | |
| Main Gate Triggering dV/dt Triggering Time Constants Advanced | |
| NPN device forward transit time parameterization: Derive approximate value from gate-controlled turn | -on time |
| Gate-controlled turn-on time: 2 | us 🔻 |
| Corresponding gate current: 10 | mA 💌 |
| PNP device forward transit time parameterization: Set equal to NPN device forward transit time | |
| | |
| OK Cancel | Help Apply |

NPN device forward transit time parameterization Select one of the following options:

• Derive approximate value from gate-controlled turn-on time — The block calculates the NPN device forward transit time based on the values for the gate-controlled turn-on time and corresponding gate current that you specify. • Specify directly — Provide the value directly by using the NPN device forward transit time parameter.

Gate-controlled turn-on time

Time for the gate to turn from the off to the on state when a gate current is applied. This parameter is visible only when you select Derive approximate value from gate-controlled turn-on time for NPN device forward transit time parameterization. The default value is 2 µs.

Corresponding gate current

The gate current used when quoting the gate-controlled turn-on time. The gate current and turn-on time are used to calculate an approximate value for the NPN transistor forward transit time on the assumption that all of the input charge is used to raise the gate voltage to the gate trigger voltage v_{GT} . This parameter is visible only when you select Derive approximate value from gate-controlled turn-on time for NPN device forward transit time parameterization. The default value is 10 mA.

NPN device forward transit time

Represents the mean time for the minority carriers to cross the base region from the emitter to the collector of the NPN device [1]. This parameter is visible only when you select Specify directly for NPN device forward transit time parameterization. The default value is 0.3 µs.

PNP device forward transit time parameterization

Select one of the following options:

- Set equal to NPN device forward transit time The block uses the NPN device forward transit time value.
- Specify directly Provide the value directly by using the **PNP device forward transit time** parameter.

PNP device forward transit time

Represents the mean time for the minority carriers to cross the base region from the emitter to the collector of the PNP device [1]. This parameter is visible only when you select Specify directly for PNP device forward transit time parameterization. The default value is $0.3\ \mu s.$

Advanced Tab

| 🙀 Block Parameters: Thyristor | | | | | | | × |
|---|------------------------|----------------------------|---|------------------------------------|----------------------|---------------------|-------|
| Thyristor | | | | | | | |
| This block represents a thyris connected to the base of the details of the model structure dV/dt triggering. Triggering vi | other dev , consult | vice so as to the docum | o give the P-N-P-N entation. The devic | junction structu e model can be | ure of a e turned | thyristor. For more | |
| Parameters | | | | | | | |
| Main Gate Triggering | dV/dt T | riggering | Time Constants | Advanced | | | |
| Internal shunt resistor, Rs: | | 87 | | | | kOhm | • |
| Internal series gate resistor | r, Rg: | 10 | | | | Ohm | • |
| Product of NPN and PNP for current gains: | ward | 10 | | | | | |
| 5 | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | C | K Can | cel | Help | Apply |

Internal shunt resistor, Rs

Represents the gate-cathode shunt resistance. It is important to set this parameter value to ensure that the gate triggers at i_{GT} , and not for currents less that i_{GT} . For details, see the Thyristor Static Behavior Validation example. If you are using the thyristor in a circuit where there is an external gate-cathode resistor R_{GK} , then usually the effect of Rs is small, and it can be set to inf. The default value is 87 k Ω .

Internal series gate resistor, Rg

Represents the resistance associated with the gate connection. A typical value is of the order of a few ohms, and its impact on static and dynamic characteristics is small. Therefore, its precise value is not important, but its presence helps avoid numerical

| | simulation issues if the gate is driven directly by a voltage source. You can specify any positive value. The default value is 10 Ω . Product of NPN and PNP forward current gains This is the product of the NPN forward gain BF_{NPN} and the PNP forward gain BF_{PNP} . The value must be greater than one for latching to occur. The smaller the value, the larger the latching current becomes. However, latching current is primarily set by other block parameters, and the total gain has only a small effect. The default value is 10. |
|------------|--|
| Ports | The block has the following ports: |
| | G Electrical conserving port associated with the gate. |
| | Electrical conserving port associated with the anode. |
| | K Electrical conserving port associated with the cathode. |
| Examples | See the Thyristor Static Behavior Validation and Thyristor Dynamic Behavior Validation examples. |
| References | [1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. |
| See Also | NPN Bipolar Transistor, PNP Bipolar Transistor |

Purpose Model timer integrated circuit behaviorally

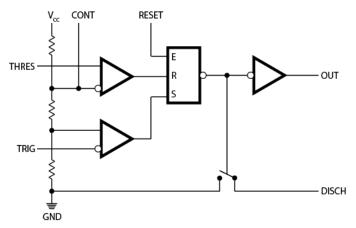
Library Integrated Circuits

Description

The Timer block is a behavioral model of a timer integrated circuit such as the NE555.

• TRIG UDISCH • • OUT THRES • • RESET CONT •

The following figure shows the implementation structure.



The **Potential divider component resistance** parameter sets the values of the three resistors creating the potential divider. The two comparator inputs have infinite input resistance and zero input capacitance. The S-R Latch block provides the functionality of the set-reset latch. It includes an output capacitor and a resistor with values set to match the **Propagation delay** parameter value. The block models the output stage inverter using a SimElectronics CMOS NOT block. You define the output resistance, low-level output voltage, and high-level output voltage for the CMOS gate in the Timer block dialog box. The discharge switch approximates the NPN bipolar transistor on a real timer as a switch with defined switch on-resistance and off-resistance values.

Timer

| Basic | This block has the following limitations: |
|-----------------------------------|---|
| Assumptions and Limitations | • The behavior is abstracted. Results are not as accurate as a transistor-level model. |
| | • Delay in response to changing inputs depends solely upon the RC time constant of the resistor-capacitor network at the output of the latch. In practice, the delay has a more complex dependency on the device structure. Set this value based on the output-pulse rise and |

- The drop in output voltage is a linear function of output current. In practice, the relationship is that of a bipolar transistor push-pull pair.
- The controlled switch arrangement used by the block is an approximation of an open-collector arrangement.
- The power supply connects internally within the component, and the block assumes that the GND pin is grounded.

Dialog Box and Parameters

Supply Tab

fall times.

| 🙀 Block Parameters: Timer | × |
|--|--------------------------------|
| Timer — This block implements a simple functional model of a timer integrated circuit. Default values are repr devices. Consult the documentation for assumptions and description of parameters. | esentative of the 555 class of |
| Parameters Supply Outputs Discharge Potential Divider | 1 |
| Power supply voltage: 15 | V |
| | |
| | |
| OK Cancel | Help Apply |

Power supply voltage

The voltage value V_{cc} that the block applies internally to the timer component. The default value is 15 V.

Outputs Tab

| 🙀 Block Parameters: Timer | | | |
|--|-------------------|-----------|-------------------------------|
| Timer This block implements a simple functional devices. Consult the documentation for a | | | sentative of the 555 class of |
| Parameters Supply Outputs Discharge | Potential Divider | | |
| Low level output voltage: | 0 | | V |
| High level output voltage: | 14.1 | | V |
| Output resistance: | 8 | | Ohm |
| Propagation delay: | 1e-07 | | s 💌 |
| <u></u> | | | |
| | | OK Cancel | Help Apply |

Low level output voltage

The output voltage when the timer output is low and no output current is drawn. The default value is 0 V.

High level output voltage

The output voltage V_{OH} when the timer output is high and no current is drawn. The default value is 14.1 V.

Output resistance

The ratio of output voltage drop to output current. Set this

parameter to $(V_{OH} - V_{OH1}) / I_{OH1}$, where V_{OH1} is the reduced

output high voltage when the output current is $I_{OH1}.$ The default value is 8 $\Omega.$

Propagation delay

Set this value to the input-pulse or output-pulse rise time. The default value is 1e-07 s.

Discharge Tab

| 🙀 Block Parameters: Timer | × |
|--|---|
| Timer This block implements a simple functional model of a timer integrated circuit. Default values are representative of the 555 class of devices. Consult the documentation for assumptions and description of parameters. | |
| Parameters Supply Outputs Discharge Potential Divider Discharge switch on-resistance: 12 Ohm V | 1 |
| Discharge switch off-resistance: 5e+08 Ohm | |
| OK Cancel Help Apply | |

Discharge switch on-resistance

A representative value is the discharge pin saturation voltage divided by the corresponding current. The default value is 12Ω .

Discharge switch off-resistance

A representative value is the discharge pin leakage current divided by the corresponding pin voltage. The default value is $5e+08 \Omega$.

Potential Divider Tab

| Block Parameters: Timer | × |
|--|---|
| Timer This block implements a simple functional model of a timer integrated circuit. Default values are representative of the 555 class of devices. Consult the documentation for assumptions and description of parameters. | |
| Parameters Supply Outputs Discharge Potential Divider | |
| Potential divider component resistance: 5 kOhm 💌 | |
| OK Cancel Help Apply | |

Potential divider component resistance

A typical value for a 555-type timer is 5 k Ω . You can measure it directly across the positive supply and control pins when the chip does not connect to a circuit. The default value is 5 k Ω .

Ports This block has the following ports:

THRES

Electrical port corresponding to the threshold pin.

TRIG

Electrical port corresponding to the trigger pin.

CONT

Electrical port corresponding to the control pin.

RESET

Electrical port corresponding to the reset pin.

OUT

Electrical port corresponding to the output pin.

Timer

DISCH Electrical port corresponding to the discharge pin.

See Also S-R Latch and Comparator.

| Purpose | Model delay-based | l or lumped | parameter f | transmission line |
|---------|-------------------|-------------|-------------|-------------------|
| | | | | |

Library

Passive Devices

Description

The Transmission Line block lets you choose between the following models of a transmission line:

- 1 Delay-based and lossless
- 2 Delay-based and lossy
- 3 Lumped parameter L-section
- 4 Lumped parameter pi-section

The first option provides the best simulation performance, with options 2, 3 and 4 requiring progressively more computing power.

Delay-Based and Lossless

This first option, Delay-based and lossless, models the transmission line as a fixed impedance, irrespective of frequency, plus a delay term. The defining equations are:

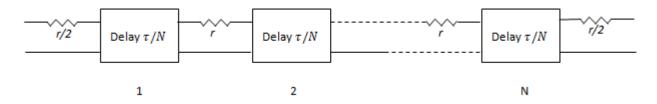
$$\begin{split} v_1(t) &- i_1(t) \; Z_0 = v_2(t-\tau) + i_2(t-\tau) \; Z_0 \\ v_2(t) &- i_2(t) \; Z_0 = v_1(t-\tau) + i_1(t-\tau) \; Z_0 \end{split}$$

where:

- v_1 is the voltage across the left-hand end of the transmission line.
- i_1 is the current into the left-hand end of the transmission line.
- v_2 is the voltage across the right-hand end of the transmission line.
- i_2 is the current into the right-hand end of the transmission line.
- τ is the transmission line delay.
- Z_0 is the line characteristic impedance.

Delay-Based and Lossy

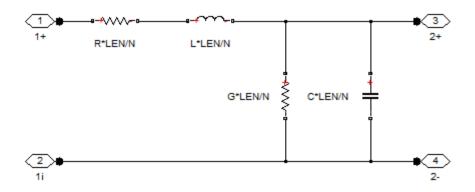
To introduce losses, the second option, Delay-based and lossy, connects N delay-based components, each defined by the above equations, in series via a set of resistors, as shown in the following illustration.



N is an integer greater than or equal to 1. $r = R \cdot LEN / N$, where *R* is the line resistance per unit length and *LEN* is the line length.

Lumped Parameter L-Section

The following block diagram shows the model of one L-line segment.



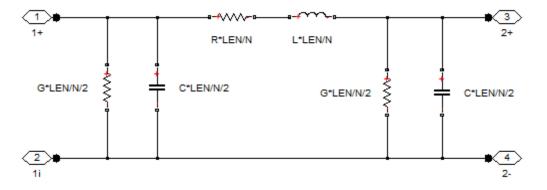
The lumped parameter parameterization uses N copies of the above segment model connected in series.

Parameters are as follows:

- *R* is line resistance per unit length.
- *L* is the line inductance per unit length.
- *C* is the line capacitance per unit length.
- *G* is the line conductance per unit length.
- *LEN* is the length of the line.
- *N* is the number of series segments.

Lumped Parameter Pi-Section

The following block diagram shows the model of one pi-line segment.



The lumped parameter parameterization uses N copies of the above segment model connected in series. The parameters are as defined for the L-section transmission line model. Unlike the L-section model, the pi-section model is symmetric.

Lumped Parameter Line Model Parameterization

The lumped-parameter models (L-section or pi-section) are the most challenging to simulate, typically needing many more segments (greater N) than for the delay-based and lossy model [1].

Cable manufacturers do not typically quote an inductance value per unit length, but instead give the characteristic impedance. The inductance, capacitance, and characteristic impedance are related by:

$$L = C \cdot Z_0^2$$

The block lets you specify either L or Z_0 when using the lumped parameter model.

The Transmission Line model has the following limitations:

• For the lumped parameter options, MathWorks recommends that you use a trapezoidal solver such as ode23t. This is because lumped parameter transmission models have very lightly damped internal dynamics, which are best suited to trapezoidal solvers for numerical accuracy.

• The lumped parameter pi-section model has a parallel capacitor at both ends. This means that you should not connect it directly to an ideal voltage source, that is, a source with no internal resistance. The lumped parameter L-section model, however, has a series input resistor, and therefore you can connect it directly to an ideal voltage source.

| Dialog | Block Parameters: Transmission | Line | | | × |
|------------|--|------------------------|-----------|---------|-----|
| Box and | Transmission Line | | | | |
| Parameters | This block represents a transmission line. The transmission line is modeled either using delays, or by a lumped parameter model. The delay-based models are recommended for better simulation performance. | | | | |
| | Parameters | | | | |
| | Model type: | Delay-based and lossle | ess | | - |
| | Transmission delay: | 5 | | ns | • |
| | Characteristic impedance: | 50 | | Ohm | • |
| | | | | | |
| | | [| OK Cancel | Help Ap | ply |

Basic Assumptions and Limitations

Model type

Select one of the following transmission line models:

- Delay-based and lossless Model the transmission line as a fixed impedance, irrespective of frequency, plus a delay term, as described in "Delay-Based and Lossless" on page 1-875. This is the default method. It provides the best simulation performance.
- Delay-based and lossy Model the transmission line as a number of delay-based components, connected in series via a set of resistors, as described in "Delay-Based and Lossy" on page 1-876.
- Lumped parameter L-section Model the transmission line as a number of L-line segments, connected in series, as described in "Lumped Parameter L-Section" on page 1-876.
- Lumped parameter pi-section Model the transmission line as a number of pi-line segments, connected in series, as described in "Lumped Parameter Pi-Section" on page 1-877.

Transmission delay

The total transmission line delay. This parameter appears for delay-based models only. The parameter value must be greater than zero. The default value is 5 ns, which is a typical value for a one-meter coaxial cable.

Characteristic impedance

The characteristic impedance of the transmission line. This parameter appears for delay-based models, and for lumped parameter models where **Parameterization** is By characteristic impedance and capacitance. The parameter value must be greater than zero. The default value is 50 Ω .

Parameterization

This parameter appears for lumped parameter models only. Select the model parameterization method, as described in "Lumped Parameter Line Model Parameterization" on page 1-877:

- By characteristic impedance and capacitance Specify values for the **Characteristic impedance** and **Capacitance per unit length** parameters. This is the default method.
- By inductance and capacitance Specify values for the Inductance per unit length and Capacitance per unit length parameters.

Inductance per unit length

The effective inductance of the transmission line per unit length. For lumped parameter models where **Parameterization** is By inductance and capacitance, this parameter appears instead of the **Characteristic impedance** parameter. The parameter value must be greater than zero. The default value is 220 μ H/m.

Capacitance per unit length

The transmission line capacitance per unit length. This parameter appears for lumped parameter models only. The parameter value must be greater than zero. The default value is 90 pF/m.

Resistance per unit length

The total transmission line resistance (that is, the sum of the resistance for the two conducting paths) per unit length. This parameter appears for Delay-based and lossy and for lumped parameter models. The parameter value must be greater than zero. The default value is $0.3 \Omega/m$.

Insulation conductance per unit length

The conductance between the two transmission line conductors per unit length. This parameter appears for lumped parameter models only. The parameter value must be greater than, or equal to, zero. The default value is 5e-6 S/m.

Line length

The total transmission line length. This parameter appears for Delay-based and lossy and for lumped parameter models. The parameter value must be greater than zero. The default value is 1 m.

| | Number of segments The number of model segments used to represent the transmission line. This parameter appears for Delay-based and lossy and for lumped parameter models. The parameter value must be an integer greater than, or equal to, 1. The default value is 1. |
|------------|---|
| Ports | The block has four conserving electrical ports. For a coaxial cable, the two top ports correspond to the inner conductor, and the two lower ports to the external shielding conductor. |
| References | [1] Sussman-Fort, S.E. and J.C. Hantgan. "SPICE Implementation of Lossy Transmission Line and Schottky Diode Models." <i>IEEE Transactions on Microwave Theory and Techniques</i> . Vol. 36, No. 1, January, 1988. |

Unipolar Stepper Motor

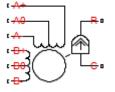
Purpose Model stepper motor with center taps on phase windings

Rotational Actuators

Description

Library

The Unipolar Stepper Motor block represents a stepper motor that has center taps on the two phase windings. The winding currents and mechanical output are defined by the following equations:



 $e_{A+} = -K_m \omega \sin(N_r \theta)$ $e_{A-} = K_m \omega \sin(N_r \theta)$ $e_{B+} = K_m \omega \sin(N_r \theta)$ $e_{B-} = -K_m \omega \sin(N_r \theta)$ $\frac{di_{A+}}{dt} = \left(v_{A+} - Ri_{A+} - e_{A+}\right)/L$ $\frac{di_{A-}}{dt} = \left(v_{A-} - Ri_{A-} + e_{A-}\right)/L$ $\frac{di_{B+}}{dt} = \left(v_{B+} - Ri_{B+} - e_{B+}\right)/L$ $\frac{di_{B-}}{dt} = \left(v_{B-} - Ri_{B-} + e_{B-}\right)/L$

$$\frac{d\omega}{dt} = \left(-K_m \left(i_{A+} - i_{A-} - \left(e_{A+} - e_{A-}\right) / R_m\right) \sin\left(N_r \theta\right) + K_m \left(i_{B+} - i_{B-} - \left(e_{B+} - e_{B-}\right) / R_m\right) \cos\left(N_r \theta\right) - B\omega\right) / J$$

$$\frac{d\theta}{dt} = \omega$$

where:

- e_{A+} is the back emf induced across the A+ to A0 half-winding.
- e_{A} is the back emf induced across the A- to A0 half-winding.
- e_{B+} is the back emf induced across the B+ to B0 half-winding.
- $e_{\rm B}$ is the back emf induced across the B- to B0 half-winding.
- i_{A+} is the current flowing from the A+ port to the A0 center tap port.
- i_{A} is the current flowing from the A- port to the A0 center tap port.
- i_{B+} is the current flowing from the B+ port to the B0 center tap port.
- $i_{\rm B}$ is the current flowing from the B- port to the B0 center tap port.
- v_{A+} is the voltage at the A+ port relative to the A0 center tap port.
- $v_{\rm A}$ is the voltage at the A- port relative to the A0 center tap port.
- $v_{\rm B+}$ is the voltage at the B+ port relative to the B0 center tap port.
- $v_{\rm B}$ is the voltage at the B- port relative to the B0 center tap port.
- $K_{\rm m}$ is the motor torque constant.
- N_r is the number of teeth on each of the two rotor poles. The Full step size parameter is (π/2)/N_r.
- *R* is the half-winding resistance. For example, it is the resistance between A+ and A0 ports.
- *L* is the half-winding inductance. For example, it is the inductance between A+ and A0 ports.
- $R_{\rm m}$ is the magnetizing resistance.
- *B* is the rotational damping.
- *J* is the inertia.

- ω is the rotor speed.
- Θ is the rotor angle.

If the initial rotor is zero or some multiple of $(\pi/2)/N_r$, the rotor is aligned with the A-phase winding. If a positive current flows from the A+ port to the A0 center tap port, then the stepper acts to stay aligned with the A-phase. Equivalently, a positive current flowing from the A0 center tap port to the A- port also acts on the rotor to stay aligned with the A-phase.

The Unipolar Stepper Motor block produces a positive torque acting from the mechanical C to R ports for either of the following sequences. Both sequences assume the rotor initial angle is zero or some multiple of $(\pi/2)/N_{\rm r}$.

| Sequenc | eCenter taps connected to ground | Center taps connected to positive supply |
|---------|-----------------------------------|--|
| 1 | Positive current from A+ to A0 | Positive current from A0 to A- |
| 2 | Positive current from B+ to B0 | Positive current from B0 to B- |
| 3 | Positive current from A- to A0 | Positive current from A0 to A- |
| 4 | Positive current from B- to B0 | Positive current from B0 to B- |

Thermal Ports

The block has five optional thermal ports, one for each of the four half-windings and one for the rotor. These ports are hidden by default. To expose the thermal ports, right-click the block in your model, and then from the context menu select **Simscape block choices > Show thermal port**. This action displays the thermal ports on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box. These tabs are described further on this reference page.

| | Use the thermal ports to simulate the effects of copper resistance and iron losses that convert electrical power to heat. For more information on using thermal ports in actuator blocks, see "Simulating Thermal Effects in Rotational and Translational Actuators". |
|-----------------------------------|--|
| Basic | The model is based on the following assumptions: |
| Assumptions and Limitations | • This model neglects magnetic saturation effects, detent torque, and any magnetic coupling between phases. |
| | • When you select the Start simulation from steady state check box in the Simscape Solver Configuration block, this block will not initialize an Initial rotor angle value between –п and п. |
| | • All four half-windings are assumed to be identical, and therefore have the same resistance temperature coefficient, alpha, and the same thermal mass. |
| Dialog | • "Electrical Torque Tab" on page 1-886 |
| Box and | • "Mechanical Tab" on page 1-888 |
| Parameters | • "Temperature Dependence Tab" on page 1-889 |
| | "Thermal Port Tab" on page 1-891 |

Electrical Torque Tab

| 😽 Block Parameters: Unipolar Stepper M | otor | | | | |
|--|---|------------------------|--|--|--|
| Unipolar Stepper Motor | | | | | |
| This block represents the electrical a | This block represents the electrical and torque characteristics of a permanent magnet unipolar stepper motor. | | | | |
| poles, then the rotor is aligned with from the A+ to the A0 port. If this cu motor shaft takes one step in the pos | ome multiple of (pi/2)/Nr where Nr is the number of the A-phase winding, and will maintain position if a irrent is replaced by a positive current flowing from sitive direction. | positive current flows | | | |
| Parameters | | | | | |
| Electrical Torque Mechanical | | | | | |
| Half-winding resistance: | 0.55 | Ohm 👻 | | | |
| Half-winding inductance: | 0.0015 | Η - | | | |
| Motor torque constant: | 0.19 | N*m/A ← | | | |
| Magnetizing resistance: | Inf | Ohm 👻 | | | |
| Full step size: | 1.8 | deg 👻 | | | |
| | | | | | |
| | OK Cancel | Help Apply | | | |

Half-winding resistance

Half of the resistance of the A and B phase windings as measured between the A+ and A-, and the B+ and B- ports. The default value is 0.55Ω .

Half-winding inductance

Half of the inductance of the A and B phase windings as measured between the A+ and A-, and the B+ and B- ports. The default value is 0.0015 H.

Motor torque constant

Motor torque constant K_m . The default value is 0.19 N*m/A.

Magnetizing resistance

The total magnetizing resistance seen from each of the phase windings, for example across A+ and A0. The value must be greater than zero. The default value is Inf, which implies that there are no iron losses.

Full step size

Step size when changing the polarity of either the A or B phase current. The default value is 1.8°.

Mechanical Tab

| 😺 Block Parameters: Unipolar Ste | pper Motor | |
|----------------------------------|---|---|
| -Unipolar Stepper Motor | | |
| This block represents the elec | trical and torque characteristics of a | permanent magnet unipolar stepper motor. |
| poles, then the rotor is aligned | with the A-phase winding, and will this current is replaced by a positive | e Nr is the number of teeth on each of the roto maintain position if a positive current flows current flowing from the B+ to the B0 port, the |
| Parameters | | |
| Electrical Torque Mechan | lical | |
| Rotor inertia: | 4.5e-5 | kg*m^2 ▼ |
| Rotor damping: | 8e-4 | N*m/(rad/s) ▼ |
| Initial rotor speed: | 0 | rpm 👻 |
| Initial rotor angle: | 0 | deg 👻 |
| | | |
| | | Cancel Help Apply |

Rotor inertia

Resistance of the rotor to change in motor motion. The default value is $4.5e-05~{\rm kg}^{\star}{\rm m}^2.$ The value can be zero.

Rotor damping

Energy dissipated by the rotor. The default value is $8e{-}04$ N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is $0\ \mathrm{rpm}.$

Initial rotor angle

Angle of the rotor at the start of the simulation. The default value is $0\ \mathrm{rad}.$

Temperature Dependence Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-884.

| 🙀 Block Parameters: Un | nipolar Stepper N | lotor | | | (|
|--|---------------------------------------|--|-------------------|---------------------------|-----------|
| Unipolar Stepper Mot | tor | | | | |
| This block represents | s the electrical | and torque characteristics of a | permanent mag | net unipolar stepper n | notor. |
| poles, then the rotor the A+ to the A0 port shaft takes one step | is aligned with t. If this current | ome multiple of (pi/2)/Nr whe the A-phase winding, and will is replaced by a positive curr direction. | maintain positior | n if a positive current f | flows fro |
| Parameters | | | ~ | | |
| Electrical Torque | Mechanical | Temperature Dependence | Thermal Port | | |
| Resistance temper coefficient: | ature | 0.00393 | | 1/K | • |
| Measurement temp | perature: | 25 | | С | • |
| | | | | | |
| | | | OK Can | cel Help | Appl |

Resistance temperature coefficient

Parameter α in the equation defining resistance as a function of temperature, as described in "Thermal Model for Actuator Blocks". It is assumed that all windings are made of the same material, and therefore have the same resistance temperature coefficient. The default value is for copper, and is 0.00393 1/K.

Measurement temperature

The temperature for which motor parameters are defined. The default value is 25 C.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-884.

Block Parameters: Unipolar Stepper Motor

Unipolar Stepper Motor

This block represents the electrical and torque characteristics of a permanent magnet unipolar stepper motor.

If the initial angle is set to zero or some multiple of (pi/2)/Nr where Nr is the number of teeth on each of the rotor poles, then the rotor is aligned with the A-phase winding, and will maintain position if a positive current flows from the A+ to the A0 port. If this current is replaced by a positive current flowing from the B+ to the B0 port, the mot shaft takes one step in the positive direction.

| Electrical Torque | Mechanical | Temperature Dependence | Thermal Port | |
|---|------------|------------------------|--------------|-----|
| Half-winding thermal mass: | | 100 | | Ј/К |
| Half-winding initial [T_A+ T_A- T_B+ ` | | [25 25 25 25] | | С |
| Rotor thermal mass: | | 50 | | J/K |
| Rotor initial temperature: | | 25 | | С |
| Percentage of magnetizing resistance associated with the rotor: | | 90 | | |

Half-winding thermal mass

The thermal mass for half of either the A or B winding. The thermal mass is the energy required to raise the temperature by one degree. It is assumed that all four half-windings have the same thermal mass. The default value is 100 J/K.

| Ha | Half-winding initial temperatures, [T_A+ T_A- T_B+ T_B-] A 1 by 4 row vector defining the temperature of the four half-windings at the start of simulation. The default value is [25 25 25 25] C. | |
|----------|---|--|
| Ro | otor thermal mass The thermal mass of the rotor, that is, the energy required to raise the temperature of the rotor by one degree. The default value is 50 J/K. | |
| Ro | otor initial temperature The temperature of the rotor at the start of simulation. The default value is 25 C. | |
| Ре | Ercentage of magnetizing resistance associated with the rotor The percentage of the magnetizing resistance associated with the magnetic path through the rotor. It determines how much of the iron loss heating is attributed to the rotor thermal port HR, and how much is attributed to the four winding thermal ports. The default value is 90%. | |
| Ports Th | e block has the following ports: | |
| A+ | Top A-phase electrical connection. | |
| A0 | A-phase center tap connection | |
| A- | Lower A-phase electrical connection | |
| В+ | Top B-phase electrical connection. | |
| ВО | B-phase center tap connection | |
| В- | Lower B-phase electrical connection. | |

| | c |
|------------|---|
| | Mechanical rotational conserving port. |
| | R Mechanical rotational conserving port. |
| | HA+ |
| | Thermal port for winding between A+ and A0. For more information, see "Thermal Ports" on page 1-884. |
| | |
| | Thermal port for winding between A- and A0. For more information, see "Thermal Ports" on page 1-884. |
| | HB+ |
| | Thermal port for winding between B+ and B0. For more information, see "Thermal Ports" on page 1-884. |
| | HB- Thermal port for winding between B- and B0. For more information, see "Thermal Ports" on page 1-884. |
| | HR |
| | Thermal port for rotor. For more information, see "Thermal Ports" on page 1-884. |
| References | [1] M. Bodson, J. N. Chiasson, R. T. Novotnak and R. B. Rekowski. "High-Performance Nonlinear Feedback Control of a Permanent Magnet Stepper Motor." IEEE Transactions on Control Systems Technology, Vol. 1, No. 1, March 1993. |
| | [2] P. P. Acarnley. Stepping Motors: A Guide to Modern Theory and Practice. New York: Peregrinus, 1982. |
| | [3] S.E. Lyshevski. <i>Electromechanical Systems, Electric Machines, and</i> <i>Applied Mechatronics</i> . CRC, 1999. |
| See Also | Stepper Motor |
| | Stepper Motor Driver |

Purpose Model electrical and torque characteristics of a universal (or series) motor

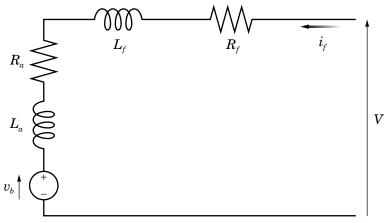
Library

Rotational Actuators

Description



The Universal Motor block represents the electrical and torque characteristics of a universal (or series) motor using the following equivalent circuit model.



Where:

- R_a is the armature resistance.
- L_a is the armature inductance.
- R_f is the field winding resistance.
- L_f is the field winding inductance.

When you set the **Model parameterization** parameter to By equivalent circuit parameters, you specify the equivalent circuit parameters for this model. The Universal Motor block computes the motor torque as follows: 1 The magnetic field in the motor induces the following back emf \boldsymbol{v}_b in the armature:

$$v_b = L_{af} i_f \omega$$

where L_{af} is a constant of proportionality and ω is the angular velocity.

2 The mechanical power is equal to the power reacted by the back emf:

$$P = v_b i_f = L_{af} i_f^2 \omega$$

3 The motor torque is:

$$T = P / \omega = L_{af} i_f^2$$

The torque-speed characteristic for the Shunt Motor block model is related to the parameters in the preceding figure. When you set the **Model parameterization** parameter to By DC rated power, rated speed & maximum torque or By DC rated power, rated speed & electrical power, the block solves for the equivalent circuit parameters as follows:

- 1 For the steady-state torque-speed relationship when using a DC supply, *L* has no effect.
- **2** Sum the voltages around the loop:

$$V = (R_f + R_a)i_f + v_b = (R_f + R_a + L_{af}\omega)i_f$$

3 Solve the preceding equation for i_f and substitute this value into the equation for torque:

$$T = L_{af} \left(\frac{V}{R_f + R_a + L_{af} \omega} \right)^2$$

The block uses the rated speed and power to calculate the rated torque. The block uses the rated torque and rated speed values in the preceding equation plus the corresponding electrical power to determine values for R_f+R_a and L_{af} .

When you set the **Model parameterization** parameter to By AC rated power, rated speed, current & electrical power, then the block must include the inductive terms L_a and L_f in the model. This requires information about the RMS rated current and voltage for the total inductance.

The block models motor inertia J and damping B for all values of the **Model parameterization** parameter. The output torque is:

$$T_{load} = L_{af} \left(\frac{V}{R_f + R_a + L_{af}\omega} \right)^2 - J\dot{\omega} - B\omega$$

The block produces a positive torque acting from the mechanical C to R ports.

Thermal Ports

The block has two optional thermal ports, one per winding, hidden by default. To expose the thermal ports, right-click the block in your model, and then from the context menu select **Simscape block choices** > **Show thermal port**. This action displays the thermal ports on the block icon, and adds the **Temperature Dependence** and **Thermal port** tabs to the block dialog box. These tabs are described further on this reference page.

Use the thermal ports to simulate the effects of copper resistance losses that convert electrical power to heat. For more information on using

thermal ports in actuator blocks, see "Simulating Thermal Effects in Rotational and Translational Actuators".

Dialog Box and Parameters

- "Electrical Torque Tab" on page 1-899
- "Mechanical Tab" on page 1-903
- "Temperature Dependence Tab" on page 1-904
- "Thermal Port Tab" on page 1-905

Electrical Torque Tab

| Universal Motor | | |
|--|---|---|
| This block represents the electrical a wound motor). | and torque characteristics of a universal motor (als | o sometimes called a series |
| resistance), L (total armature and fi the armature is given by Vb = Laf * Alternatively, the motor characterist electrical power, nominal DC voltage L can be set to a suitably small non- | d in terms of equivalent circuit parameters R (total a ield winding inductance) and Laf (back-emf constant I * W where I is the motor current and W is the m cics can be defined in terms of rated mechanical pow e, and L. If no information is available on armature -zero value when driving the motor with DC. e acting from the mechanical C to R ports. | t). The back emf induced in echanical angular speed. wer & speed, stall torque or |
| Parameters Electrical Torque Mechanical | | |
| Electrical forque Mechanical | | |
| Model parameterization: | By DC rated power, rated speed & electrical power | er 🔻 |
| | | 51 |
| Rated speed (at rated load): | 6.5e+3 | rpm 👻 |
| Rated speed (at rated load): Rated load (mechanical power): | 6.5e+3 75 | |
| | | rpm - |
| Rated load (mechanical power): | 75 200 | rpm • |

Model parameterization

Select one of the following methods for block parameterization:

• By equivalent circuit parameters — Provide electrical parameters for an equivalent circuit model of the motor.

- By DC rated power, rated speed & maximum torque Provide DC power and speed parameters that the block converts to an equivalent circuit model of the motor. This is the default method.
- By DC rated power, rated speed & electrical power — Provide AC power and speed parameters that the block converts to an equivalent circuit model of the motor.
- By AC rated power, rated speed, current & electrical power Provide AC power and speed parameters that the block converts to an equivalent circuit model of the motor.

Total armature and field winding resistance

Total resistance of the armature and field winding. This parameter is only visible when you select By equivalent circuit parameters for the Model parameterization parameter. The default value is 132.8 Ω .

Rated speed (at rated load)

Motor speed at the rated mechanical load. This parameter is only visible when you select By DC rated power, rated speed & maximum torque, By DC rated power, rated speed & electrical power, or By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is 6.5e+03 rpm.

Rated load (mechanical power)

The mechanical load for which the motor is rated to operate. This parameter is only visible when you select By DC rated power, rated speed & maximum torque, By DC rated power, rated speed & electrical power, or By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is 75 W.

Rated DC supply voltage

The DC voltage at which the motor is rated to operate. This parameter is only visible when you select By DC rated power, rated speed & maximum torque or By DC rated power, rated speed & electrical power for the **Model parameterization** parameter. The default value is 200 V.

Electrical power in at rated load

The amount of electrical power the motor uses at the rated mechanical power. This parameter is only visible when you select By DC rated power, rated speed & electrical power or By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is 160 W.

Maximum (starting) torque

Maximum torque the motor produces. This parameter is only visible when you select By DC rated power, rated speed & maximum torque for the **Model parameterization** parameter. The default value is 0.39 N*m.

Total armature and field winding inductance

Total inductance of the armature and field winding. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. This parameter is only visible when you select By equivalent circuit parameters, By DC rated power, rated speed & maximum torque, or By DC rated power, rated speed & electrical power for the **Model parameterization** parameter. The default value is 0.525 H.

Note You can set the **Total armature and field winding inductance** value to zero, but this only makes sense if you are driving the motor with a DC source.

RMS rated voltage

RMS supply voltage when the motor operates on AC power. This parameter is only visible when you select By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is 240 V.

RMS current at rated load

RMS current when the motor operates on AC power at the rated load. This parameter is only visible when you select By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is **0.8** A.

AC frequency

Frequency of the AC supply voltage. This parameter is only visible when you select By AC rated power, rated speed, current & electrical power for the **Model parameterization** parameter. The default value is 50 Hz.

Mechanical Tab

| 🙀 Block Parameters: Universal Motor | | × |
|--|---|--|
| - Universal Motor | | |
| This block represents the electrica wound motor). | I and torque characteristics of a universal motor (als | o sometimes called a series- |
| resistance), L (total armature and the armature is given by Vb = Laf Alternatively, the motor characteri electrical power, nominal DC voltar L can be set to a suitably small no | ed in terms of equivalent circuit parameters R (total a field winding inductance) and Laf (back-emf constant * I * W where I is the motor current and W is the m stics can be defined in terms of rated mechanical poo ge, and L. If no information is available on armature n-zero value when driving the motor with DC. ue acting from the mechanical C to R ports. | t). The back emf induced in lechanical angular speed. wer & speed, stall torque or |
| Parameters | _ | |
| Electrical Torque Mechanical | | |
| Rotor inertia: | 2e-4 | kg*m^2 ▼ |
| Rotor damping: | 1e-6 | N*m/(rad/s) - |
| Initial rotor speed: | 0 | rpm 👻 |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel | Help Apply |

Rotor inertia

Rotor inertia. The default value is $2e \cdot 04~\mathrm{kg}^*\mathrm{m}^2.$ The value can be zero.

Rotor damping

Rotor damping. The default value is $1e\,{-}\,06$ N*m/(rad/s). The value can be zero.

Initial rotor speed

Speed of the rotor at the start of the simulation. The default value is 0 rpm.

Temperature Dependence Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| 🙀 Block Parameters: Universal Motor | | | — × |
|--|---|--|---|
| Universal Motor | | | |
| This block represents the electrical a wound motor). | and torque characteristics of a | universal motor (also s | sometimes called a series- |
| Motor characteristics can be defined resistance), L (total armature and fie the armature is given by Vb = Laf * Alternatively, the motor characteristi electrical power, nominal DC voltage L can be set to a suitably small non- The block produces a positive torque | eld winding inductance) and Li I*W where I is the motor cu cs can be defined in terms of , and L. If no information is av zero value when driving the m | af (back-emf constant). Irrent and W is the med rated mechanical powe vailable on armature or notor with DC. | The back emf induced in chanical angular speed. er & speed, stall torque or |
| Parameters | | | |
| Electrical Torque Mechanical | Temperature Dependence | Thermal Port | |
| Field to armature resistance ratio, Rf/Ra: | 1 | | |
| Resistance temperature coefficients, [alpha_f alpha_a]: | [0.00393 0.00393] | | 1/K • |
| Measurement temperature: | 25 | | C • |
| | | | |
| | | OK Cancel | Help Apply |

Field to armature resistance ratio, Rf/Ra

The ratio of the field to the armature resistance. This parameter is required only when showing the field and armature thermal ports. It is used to determine individual resistance values for the field and armature windings so that the thermal heat generated by the two resistors can be apportioned correctly. The default value is 1.

Resistance temperature coefficients, [alpha_f alpha_a]

A 1 by 2 row vector defining the coefficient α in the equation relating resistance to temperature, as described in "Thermal Model for Actuator Blocks". The first element corresponds to the field winding, and the second to the armature. The default value is for copper, and is [0.00393 0.00393] 1/K.

Measurement temperature

The temperature for which motor parameters are defined. The default value is 25 C.

Thermal Port Tab

This tab appears only for blocks with exposed thermal ports. For more information, see "Thermal Ports" on page 1-897.

| Universal Motor | | | | |
|--|---|--|--|---|
| This block represent wound motor). | s the electrical a | and torque characteristics of a | i universal motor (| also sometimes called a se |
| resistance), L (total the armature is give Alternatively, the mo electrical power, nor L can be set to a sui | armature and fi n by Vb = Laf * tor characteristi ninal DC voltage tably small non- | I in terms of equivalent circuit eld winding inductance) and L I*W where I is the motor ci ics can be defined in terms of e, and L. If no information is ar zero value when driving the n e acting from the mechanical | af (back-emf cons urrent and W is the rated mechanical vailable on armatu notor with DC. | tant). The back emf induce e mechanical angular spee power & speed, stall torqu |
| Parameters | | | | |
| Electrical Torque | Mechanical | Temperature Dependence | Thermal Port | |
| Thermal masses, | [Mf Ma]: | [100 100] | | Ј/К |
| Initial temperature | s, [Tf Ta]: | [25 25] | | С |
| | | | | |
| | | | | |
| | | | | |

Thermal masses, [Mf Ma]

A 1 by 2 row vector defining the thermal mass for the field and armature windings. The thermal mass is the energy required to raise the temperature by one degree. The default value is [100 100] J/K.

Initial temperatures, [Tf Ta]

A 1 by 2 row vector defining the temperature of the field and armature thermal ports at the start of simulation. The default value is $[25\ 25\]$ C.

The block has the following ports:

Ports

| | + | Positive electrical port. |
|------------|------|--|
| | - | Negative electrical port. |
| | С | Mechanical rotational conserving port. |
| | R | Mechanical rotational conserving port. |
| | Hf | Field winding thermal port. For more information, see "Thermal Ports" on page 1-897. |
| | На | Armature winding thermal port. For more information, see "Thermal Ports" on page 1-897. |
| References | | olton, W. Mechatronics: <i>Electronic Control Systems in Mechanical</i> <i>Electrical Engineering</i> 3rd edition, Pearson Education, 2004. |
| See Also | DC N | lotor, Induction Motor, Servomotor, and Shunt Motor. |

Variable Capacitor

Purpose Model linear time-varying capacitor

Library

Passive Devices

Description

┉╜╫╌╸

The Variable Capacitor block represents a linear time-varying capacitor. The block provides two options for the relationship between the current i through the capacitor and the voltage v across the device when the capacitance at port C is C. The **Equation** parameter determines which of the following equations the block uses:

•
$$i = \frac{dC}{dt}v + C\frac{dv}{dt}$$

Use the preceding equation when the capacitance is defined as the ratio of the charge Q to the steady-state voltage:

$$C(v) = \frac{Q(v)}{v}$$

•
$$i = C \frac{dv}{dt}$$

Use the preceding equation when the capacitance is defined as the local gradient of the charge-voltage curve for a given voltage:

$$C(v) = \frac{dQ(v)}{dv}$$

The block includes a resistor in series with the variable capacitor. You can use this resistor to represent the total ohmic connection resistance of the capacitor. You may need to use this resistor to prevent numerical issues for some circuit topologies, such as where a Variable Capacitor block is connected in parallel with another capacitor block that does not have a series resistance.

Dialog Box and Parameters

| apacitance parameter prevents z omponent internal resistance, and parallel with another capacitor. | | | | |
|--|----------------------|--------|---------|---|
| arameters | | | | |
| quation: | $I = C^* dV/dt + dt$ | C/dt*V | | |
| linimum capacitance C>0: | 1e-09 | | F | ľ |
| eries resistance: | 1e-06 | | Ohm | ľ |
| nitial charge: | 0 | | c | |

Equation

Select one of the following options for block capacitance:

- I = C*dV/dt + dC/dt*V This equation assumes the capacitance is defined as the ratio of the charge to the steady-state voltage. This option is the default.
- I = C*dV/dt This equation assumes the capacitance is defined as the local gradient of the charge-voltage curve for a given voltage.

Minimum capacitance C>0

The lower limit on the value of the signal at port C. This limit prevents the signal from reaching a value that has no physical meaning. The default value is 1e-09 F.

Series resistance

The value of the resistance placed in series with the variable capacitor. The default value is $1e-06 \Omega$.

Initial charge

The charge at the start of the simulation. This parameter is only visible when you select I = C*dV/dt + dC/dt*V for the **Equation** parameter. The default value is 0 c.

Initial voltage

The output voltage at the start of the simulation. This parameter is only visible when you select I = C*dV/dt for the **Equation** parameter. The default value is 0 V.

Ports The block has the following ports:

С

+

Capacitance. C must be finite and greater than zero.

Positive electrical port.

Negative electrical port.

See Also Variable Inductor, Simscape Variable Resistor

Purpose Model linear time-varying inductor

Library

Passive Devices

Description

""

The Variable Inductor block represents a linear time-varying inductor. The block provides two options for the relationship between the voltage v across the device and the current through the inductor i when the inductance at port L is L. The **Equation** parameter determines which of the following equations the block uses:

•
$$v = \frac{dL}{dt}i + L\frac{di}{dt}$$

Use the preceding equation when the inductance is defined as the ratio of the magnetic flux Φ to the steady-state current:

$$L(i) = \frac{\Phi(i)}{i}$$

•
$$v = L \frac{di}{dt}$$

Use the preceding equation when the inductance is defined as the local gradient of the flux-current curve for a given current:

$$L(i) = \frac{d\Phi(i)}{di}$$

The block includes a conductance in parallel with the variable inductor. You can use the conductor to represent the total insulation conductance of the inductor. You may need to use the conductor to prevent numerical issues for some circuit topologies, such as where a Variable Inductor block is connected in series with another inductor block that does not have a parallel conductance.

Variable Inductor

Dialog Box and Parameters

| Variable Inductor This block models a linear time-var inductance parameter prevents ze insulation conductance, and may l with another inductor. | ero or negative inductan | nce values. The Par | allel conductan | ce parameter can b | e used to model |
|---|--------------------------|---------------------|-----------------|--------------------|-----------------|
| Parameters | | | | | |
| Equation: | V = L*dI/dt + d | dL/dt*I | | | - |
| Minimum inductance L>0: | 1e-06 | | | Н | • |
| Parallel conductance: | 1e-09 | | | 1/Oh | m 💌 |
| Initial magnetic flux: | 0 | | | Wb | • |
| | | | | | |
| | | ОК | Can | cel Help | Apply |

Equation

Select one of the following options for block inductance:

- V = L*dI/dt + dL/dt*I This equation assumes the inductance is defined as the ratio of the magnetic flux to the steady-state current. This option is the default.
- V = L*dI/dt This equation assumes the inductance is defined as the local gradient of the flux-current curve for a given current.

Minimum inductance L>0

The lower limit on the value of the signal at port L. This limit prevents the signal from reaching a value that has no physical meaning. The default value is 1e-06 H.

Parallel conductance

The value of the conductance placed in parallel with the variable inductor. The default value is $1e-09 \ 1/\Omega$.

Initial magnetic flux

The magnetic flux at the start of the simulation. This parameter is only visible when you select V = L*dI/dt + dL/dt*I for the **Equation** parameter. The default value is 0 Wb.

| Ports | <pre>Initial current The output current at the start of the simulation. This parameter is only visible when you select V = L*dI/dt for the Equation parameter. The default value is 0 A. The block has the following ports:</pre> |
|----------|---|
| | L Inductance. L must be finite and greater than zero. + Positive electrical port. |
| | - Negative electrical port. |
| See Also | Variable Capacitor, Simscape Variable Resistor |

Voltage-Controlled Oscillator

Purpose Behavioral model of voltage-controlled oscillator

Library

Integrated Circuits

Description

The Voltage-Controlled Oscillator block provides a behavioral model of a voltage-controlled oscillator (VCO). The output voltage is defined by the following equations:

$$v_{\text{lim}} = \begin{cases} v_{\text{min}} & \text{for } v_{\text{in}} < v_{m \text{in}} \\ v_{\text{in}} & \text{for } v_{m \text{in}} \le v_{\text{in}} \le v_{\text{max}} \\ v_{\text{max}} & \text{for } v_{\text{in}} > v_{\text{max}} \end{cases}$$

 $\dot{\Phi} = 2\pi F(v_{\rm lim})$

$$v_{out} = A\sin\left(2\pi f_{nom}t + \Phi\right) - i_{out}R_{out}$$

where:

- v_{in} is the voltage applied across the 1+ and 1- ports.
- $v_{\rm out}$ is the voltage across the 2+ and 2– ports.
- f_{nom} is the oscillator frequency when the input control voltage is v_{nom} .
- *F* is a linear function of $v_{\rm lim}$ or a lookup table function of $v_{\rm lim}$.
- A is the output voltage peak amplitude.
- *t* is simulation time.
- i_{out} is the output current.
- R_{out} is the output resistance.

If you choose Linear for the **Frequency dependence on input voltage** parameter, then the function *F* is given by:

```
F = f_{nom} + k \left( v_{lim} - v_{nom} \right)
```

where *k* is the rate of change of frequency with input voltage.

If you choose Tabulated for the **Frequency dependence on input voltage** parameter, then the function F is defined by the vectors of input voltages and corresponding output frequency deviations from nominal that you supply. The values for v_{\min} and v_{\max} are the first and the last values of the input voltage vector.

You can model the time delay between a change in the input control voltage and the oscillator frequency. Do this by modeling a first-order dynamic between v_{lim} and the value passed to the function F.

Voltage-Controlled Oscillator

Dialog Frequency Tab Box and Parameters

| oltage-Controlled Oscillator | | |
|--|---|--------|
| | rolled Oscillator (VCO). A sinusoidal voltage is pres e sinusoid is a function of the voltage presented ac | |
| arameters | | |
| Frequency Electrical Characteri | stics Dynamics | |
| Frequency dependence on input voltage: | Linear | • |
| Nominal frequency: | 1000 | Hz 🔹 |
| Input voltage corresponding to nominal frequency: | 0.5 | ۷ • |
| Rate of change of frequency with input voltage: | 0 | Hz/V 👻 |
| Minimum input voltage: | 0 | V • |
| Maximum input voltage: | 1 | V • |
| | | |
| | OK Cancel | |

Frequency dependence on input voltage

Select one of the following methods for block parameterization:

- Linear Define a linear function by specifying the rate of change of frequency with input voltage. This is the default option.
- Tabulated Provide the vectors of input voltages and corresponding output frequency deviations from nominal. The

block determines the frequency deviation by table lookup based on these values.

Nominal frequency

The oscillator frequency when the input control voltage is at the nominal value. The default value is 1000 Hz.

Input voltage corresponding to nominal frequency

The input voltage corresponding to the oscillator nominal frequency. This parameter is visible only if you select Linear for the **Frequency dependence on input voltage** parameter. The default value is 0.5 V.

Rate of change of frequency with input voltage

The linear coefficient defining the rate of change of frequency depending on input voltage. This parameter is visible only if you select Linear for the **Frequency dependence on input voltage** parameter. The default value is 0 Hz/V.

Minimum input voltage

The minimum input voltage that affects VCO frequency. This parameter is visible only if you select Linear for the **Frequency dependence on input voltage** parameter. The default value is 0 V.

Maximum input voltage

The maximum input voltage that affects VCO frequency. This parameter is visible only if you select Linear for the **Frequency dependence on input voltage** parameter. The default value is 1 V.

Input voltage vector

The vector of voltages for the tabulated VCO frequency. This parameter is visible only if you select Tabulated for the **Frequency dependence on input voltage** parameter. The default value is [0 0.2 0.4 0.6 0.8 1] V.

Frequency deviation from nominal

The corresponding vector of VCO frequencies relative to the nominal frequency. This parameter is visible only if you select Tabulated for the **Frequency dependence on input voltage** parameter. The default value is [-1000 -329 -51 162 342 500] Hz.

Electrical Characteristics Tab

| Block Parameters: Voltage-Controlled | Oscillator | — |
|--|---|------------|
| Voltage-Controlled Oscillator | | |
| | trolled Oscillator (VCO). A sinusoidal voltage is prese te sinusoid is a function of the voltage presented acr | |
| Parameters Frequency Electrical Character | istics Dynamics | |
| Output voltage peak amplitude: | 1 | V · |
| Input resistance: | Inf | Ohm 👻 |
| Output resistance: | 0 | Ohm 👻 |
| | | |
| | OK Cancel | Help Apply |

Output voltage peak amplitude

The peak amplitude of the voltage across the 2+ and 2- terminals. The default value is 1 V.

Input resistance

The resistance seen at the 1+ and 1– terminals. The default value is Inf Ohm.

Output resistance

The value of the series output resistance. The default value is 0 Ohm.

Dynamics Tab

| 😼 Block Parameters: V | oltage-Controlled Oscillator |
|-----------------------|---|
| -Voltage-Controlled | Dscillator |
| | ts a Voltage-Controlled Oscillator (VCO). A sinusoidal voltage is presented across the output e frequency of the sinusoid is a function of the voltage presented across the input ports 1+ and |
| Parameters | |
| Frequency Ele | ctrical Characteristics Dynamics |
| Dynamics: | No dynamics 🔹 |
| | |
| | |
| | |
| | |
| | |
| | OK Cancel Help Apply |

Dynamics

Select one of the following methods for specifying dynamics:

• No dynamics — Do not model the time delay between a change in the input control voltage and the oscillator frequency. This is the default option.

| ٠ | Model frequency tracking dynamics — $Model \ a \ first \ order$ |
|---|---|
| | dynamic between the input control voltage and the oscillator |
| | frequency. |

Frequency tracking time constant

Time constant for the first-order filter that delays the measured input control voltage, to model the lag between a change in VCO demanded frequency and the resulting VCO frequency. This parameter is visible only if you select Model frequency tracking dynamics for the **Dynamics** parameter. The default value is 0.001 s.

Initial frequency

The initial VCO output frequency. This parameter is visible only if you select Model frequency tracking dynamics for the **Dynamics** parameter. The default value is 1000 Hz.

Ports The block has the following ports:

1+

Positive input voltage

1 -

Negative input voltage

2+

Positive output voltage

2-

Negative output voltage

 Purpose
 Model voltage-controlled switch with hysteresis

Library SPICE-Compatible Components/Passive Devices

Description



The Voltage-Controlled Switch block represents the electrical characteristics of a switch whose state is controlled by the voltage across the input ports (the *controlling voltage*):

- When the controlling voltage is greater than the sum of the **Threshold voltage, VT** and **Hysteresis voltage, VH** parameter values, the switch is closed and has a resistance equal to the **On resistance, RON** parameter value.
- When the controlling voltage is less than the **Threshold voltage**, **VT** parameter value minus the **Hysteresis voltage**, **VH** parameter value, the switch is open and has a resistance equal to the **Off resistance**, **ROFF** parameter value.
- When the controlling voltage is greater than or less than the **Threshold voltage**, **VT** parameter value by an amount less than or equal to the **Hysteresis voltage**, **VH** parameter value, the voltage is in the *crossover region* and the state of the switch remains unchanged.

Basic Assumptions and Limitations

The block output resistance model is discontinuous during switching. The discontinuity might cause numerical issues. Try the following actions to resolve the issues:

- Set the **On resistance**, **RON** and **Off resistance**, **ROFF** parameter values to keep the ratio *RON/ROFF* as small as possible, and less than 1e+12.
- Increase the **Hysteresis voltage**, **VH** parameter value to reduce switch chatter.
- Decrease the **Max step size** parameter value (in the Configuration Parameters block dialog box).

Note This increases the simulation time.

| Dial | og |
|------|---------|
| Box | and |
| Para | imeters |

| the hysteresis voltage the switch | | nce value is RON. If the | e controlling voltag | e is less than the dif | ference o |
|---|-------|--------------------------|----------------------|------------------------|-----------|
| the threshold voltage minus the l voltage value is within the crosso | | | ts resistance value | is ROFF. If the con | trolling |
| | | | | | |
| Parameters | | | | | |
| Threshold voltage, VT: | 0 | | | V | • |
| Hysteresis voltage, VH: | 0 | | | V | • |
| On resistance, RON: | 1 | | | Ohm | • |
| Off resistance, ROFF: | 1e+12 | | | Ohm | • |
| Initial switch state: | On | | | | • |

Threshold voltage, VT

The voltage above which the block interprets the controlling voltage as HIGH. The default value is 0 V.

Note The controlling voltage must differ from the threshold voltage by at least the **Hysteresis voltage**, **VH** parameter value to change the state of the switch.

Hysteresis voltage, VH

The amount by which the controlling voltage must exceed or fall below the **Threshold voltage**, **VT** parameter value to change the state of the switch. The default value is 0 V.

| | On resistance, RON The resistance of the switch when it is closed. The default value is 1 Ω . |
|-------|---|
| | Off resistance, ROFF The resistance of the switch when it is open. The default value is $1e+12 \Omega$. |
| | Initial switch state Select one of the following options for the state of the switch at the start of the simulation: |
| | • On — The switch is initially closed and its resistance value is equal to the On resistance , RON parameter value. This is the default option. |
| | • Off — The switch is initially open and its resistance value is equal to the Off resistance , ROFF parameter value. |
| Ports | The block has the following ports: |
| | + Positive electrical input and output ports. |
| | - Negative electrical input and output ports. |

Voltage Source

| Purpose | Simulate voltage source with DC, AC, and noise components | |
|-------------|---|--|
| Library | Sources | |
| Description | The Voltage Source block implements a voltage source with DC, AC, and noise components. The voltage across the + and – terminals is given by: $v = v_{DC} + v_{AC} \sin(2\pi f t + \phi) + v_N$ | |
| Ţ | <i>v</i>_{DC} is the steady-state DC voltage component. | |

- $v_{\rm AC}$ is the amplitude of the AC voltage component.
- *f* is the frequency of the AC component.
- φ is the phase offset of the AC component.
- $v_{\rm N}$ is the noise voltage.

You can configure your source as DC-only, AC-only, or a combination of both. By default, both AC and DC components are set to 0. Define the AC/DC voltage by specifying nonzero parameter values after placing the block in your model.

The noise component is also optional. If you set the **Noise mode** parameter to **Enabled**, then the added noise voltage is given by:

$$v_N = \sqrt{P_v/2} \, \frac{N(0,1)}{\sqrt{h}}$$

where:

- $P_{\rm v}$ is the single-sided noise power spectral density for a 1 ohm load, in V^2/Hz.
- *N* is a Gaussian random number with zero mean and standard deviation of one.

• *h* is the sampling interval.

By default, the **Noise mode** parameter is set to **Disabled**, and the voltage source generates no thermal noise.

Noise Options

The block generates Gaussian noise by using the Random Number source in the Simscape Foundation library. You can control the random number seed by setting the **Repeatability** parameter:

• Not repeatable — Every time you simulate your model, the block resets the random seed using the MATLAB random number generator:

seed = $randi(2^{32-1});$

- Repeatable The block uses a hidden parameter, called auto_seed, to always start the simulation with the same random number. The value of auto_seed is set whenever you copy the Resistor block from the block library to the model, or when you make a new copy of the Resistor block from an existing one in a model. The block sets the value using the MATLAB random number generator command shown above.
- Specify seed If you select this option, the additional Seed parameter lets you directly specify the random number seed value.

Basic Assumptions and Limitations

Simulating with noise enabled slows down simulation. Choose the sample time (h) so that noise is generated only at frequencies of interest, and not higher.

Dialog DC & AC Components Tab Box and Parameters

| Block Parameters: Voltage Source Voltage Source | | X |
|--|---|--------------|
| | with DC, AC and noise components. The output v where v_dc is the DC amplitude, v_ac is the peak d v_n is the noise voltage. | |
| Parameters | | |
| DC & AC Components Noise | | |
| DC voltage: | 0 | V · |
| AC voltage peak amplitude: | 0 | V • |
| AC voltage phase shift: | 0 | deg 👻 |
| AC voltage frequency: | 60 | Hz 🗸 |
| | | |
| | OK Cancel | I Help Apply |

DC voltage

The DC component of the output voltage. The default value is 0 V. Enter a nonzero value to add a DC component to the voltage source.

AC voltage peak amplitude

Amplitude of the AC component of the output voltage. The default value is 0 V. Enter a nonzero value to add an AC component to the voltage source.

AC voltage phase shift

Phase offset of the AC component of the output voltage. The default value is **0** degrees.

AC voltage frequency

Frequency of the AC component of the output voltage. The default value is $60\ \mathrm{Hz}.$

Noise Tab

| 🚡 Block Parameters: Voltage Source | |
|------------------------------------|---|
| Voltage Source | |
| | with DC, AC and noise components. The output voltage is defined by v = v_dc where v_dc is the DC amplitude, v_ac is the peak AC amplitude, f is the v_n is the noise voltage. |
| Parameters | |
| DC & AC Components Noise | |
| Noise mode: | Disabled 🔹 |
| | |
| | |
| | |
| | OK Cancel Help Apply |
| | |

Noise mode

Select the noise option:

- **Disabled** No noise is produced by the voltage source. This is the default.
- Enabled The voltage source generates thermal noise, and the associated parameters become visible on the **Noise** tab.

Power spectral density

The single-sided spectrum noise power. Strictly-speaking, this is a density function for the square of the voltage, commonly

thought of as a power into a 1 ohm load, and therefore the units are V^2/Hz. To avoid this unit ambiguity, some datasheets quote noise voltage as a noise density with units of V/ \sqrt{Hz} . In this case, you should enter the square of the noise density quoted in the datasheet as the parameter value. The default value is 0 V^2/Hz.

Sample time

Defines the rate at which the noise source is sampled. Choose it to reflect the frequencies of interest in your model. Making the sample time too small will unnecessarily slow down your simulation. The default value is 1e-3 s.

Repeatability

Select the noise control option:

- Not repeatable The random sequence used for noise generation is not repeatable. This is the default.
- Repeatable The random sequence used for noise generation is repeatable, with a system-generated seed.
- Specify seed The random sequence used for noise generation is repeatable, and you control the seed by using the Seed parameter.

Seed

Random number seed used by the noise random number generator. This parameter is visible only if you select Specify seed for the **Repeatability** parameter. The default value is 0.

Ports The block has the following ports:

Positive electrical port.

Negative electrical port.

See Also Current Source, Resistor.

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