SimElectronics[™] 1 Reference

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 $SimElectronics^{\text{TM}} Reference$

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Functions — Alphabetical List

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Block Reference

| Actuators & Drivers (p. 1-2) | Mechanical control and motor devices |
|---|--|
| Integrated Circuits (p. 1-2) | Electronic circuits |
| Passive Devices (p. 1-3) | Passive electrical devices |
| Semiconductor Devices (p. 1-3) | Circuit components made from semiconductor material |
| Sensors (p. 1-4) | Electromechanical sensors |
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| SPICE-Compatible Semiconductors (p. 1-6) | SPICE-compatible circuit components made from semiconductor material |
| Utilities (p. 1-6) | System-level parameter specification |

Actuators & Drivers

| Controlled PWM Voltage | Model pulse-width modulated voltage source |
|------------------------|--|
| DC Motor | Model electrical and torque characteristics of DC motor |
| H-Bridge | Model H-bridge motor driver |
| Induction Motor | Model induction motor powered by ideal AC supply |
| Servomotor | Model brushless motor with closed-loop torque control |
| Shunt Motor | Model electrical and torque characteristics of shunt motor |
| Solenoid | Model electrical characteristics and generated force of solenoid |
| Stepper Motor | Model stepper motor |
| Stepper Motor Driver | Model stepper motor driver |
| Universal Motor | Model electrical and torque characteristics of a universal (or series) motor |

Integrated Circuits

| Band-Limited Op-Amp | Model band-limited operational amplifier |
|---------------------|--|
| Finite-Gain Op-Amp | Model gain-limited operational amplifier |

Passive Devices

Thermal Resistor Three-Winding Mutual Inductor Variable Capacitor Variable Inductor Model resistor with thermal port Model three coupled inductors Model linear time-varying capacitor Model linear time-varying inductor

Semiconductor Devices

| Diode | Model piecewise linear, piecewise linear zener, or exponential diode |
|------------------------|---|
| N-Channel IGBT | Model N-Channel IGBT |
| N-Channel JFET | Model N-Channel JFET |
| N-Channel MOSFET | Model N-Channel MOSFET using Shichman-Hodges equation |
| NPN Bipolar Transistor | Model NPN bipolar transistor using enhanced Ebers-Moll equations |
| Optocoupler | Model optocoupler as LED, current sensor, and controlled current source |
| P-Channel JFET | Model P-Channel JFET |
| P-Channel MOSFET | Model P-Channel MOSFET using Shichman-Hodges equation |
| PNP Bipolar Transistor | Model PNP bipolar transistor using enhanced Ebers-Moll equations |

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Sensors

| Incremental Shaft Encoder | Model device that converts information about angular shaft position into electrical pulses |
|---------------------------|--|
| Light-Emitting Diode | Model light-emitting diode as exponential diode and current sensor in series |
| Photodiode | Model photodiode as parallel controlled current source and exponential diode |
| Proximity Sensor | Model simple distance sensor |
| PS Sensor | Model generic linear sensor |
| Strain Gauge | Model deformation sensor |
| Thermistor | Model NTC thermistor using B-parameter equation |
| Thermocouple | Model sensor that converts thermal potential difference into electrical potential difference |
| | |

Sources

Generic Battery Negative Supply Rail Positive Supply Rail Solar Cell Model simple battery Model ideal negative supply rail Model ideal positive supply rail Model single solar cell

SPICE-Compatible Sources

| DC Current Source | Model constant current source |
|----------------------------|--|
| DC Voltage Source | Model constant voltage source |
| Exponential Current Source | Model exponential pulse current source |
| Exponential Voltage Source | Model exponential pulse voltage source |
| PCCCS | Model polynomial current-controlled current source |
| PCCVS | Model polynomial current-controlled voltage source |
| Pulse Current Source | Model periodic square pulse current source |
| Pulse Voltage Source | Model periodic square pulse voltage source |
| PVCCS | Model polynomial voltage-controlled current source |
| PVCVS | Model polynomial voltage-controlled voltage source |
| PWL Current Source | Model lookup table current source |
| PWL Voltage Source | Model lookup table voltage source |
| SFFM Current Source | Model single-frequency FM current source |
| SFFM Voltage Source | Model single-frequency FM voltage source |
| Sinusoidal Current Source | Model damped sinusoidal current source |
| Sinusoidal Voltage Source | Model damped sinusoidal voltage source |

SPICE-Compatible Semiconductors

| Diode (SPICE) | Model SPICE-compatible diode |
|---------------|---------------------------------------|
| NJFET | Model SPICE-compatible N-Channel JFET |
| NPN | Model Gummel-Poon NPN Transistor |
| PJFET | Model SPICE-compatible P-Channel JFET |
| PNP | Model Gummel-Poon PNP Transistor |

Utilities

| SPICE Environment Parameters | Set parameters that apply to all |
|------------------------------|-----------------------------------|
| | connected SPICE-compatible blocks |

Blocks — Alphabetical List

Band-Limited Op-Amp

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:

Band-Limited Op-Amp

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

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**

| | | , |
|--|--|--|
| Vout = A*(Vp-Vm)*1/(s/(2*p | pi*f)+1)-lout*Rout | |
| where A is the gain, Rout is Laplace operator, and f is t where Rin is the input resis Vmax, and the slew rate is | s the output resistance, lout is the ou he 3dB bandwidth. The input current tance. The no-load output voltage is limited to +-Vdot. | tput current, s is t t is given by (Vp-V limited the range |
| The Initial output voltage, V not take account of any vo select the Start simulation f | /0, sets the initial op-amp output volt ltage drop across Rout. The initial co rom steady state option in the Solver | age. Note that this ondition is not use Configuration blo |
| - 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 |
| 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 Ω

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 100 Ω

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

Controlled PWM Voltage

Purpose Model pulse-width modulated voltage source

Actuators & Drivers

Description

Library

•+refPWM• •-ref REF• Controlled PWM Voltage 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 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 duty cycle is set to zero.

The model is based on the following assumptions:

- The REF output of this block is floating, i.e. 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.
- Set the **Simulation mode** parameter to Averaged to speed up simulations when driving a motor via the H-Bridge block. You must also set the **Simulation mode** parameter of the H-Bridge block to Averaged mode. This applies the average of the demanded

Basic Assumptions and Limitations 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.

Dialog Box and Parameters

| ports. The duty cycle ir and Vmax are the minin amplitude is set by the At time zero, the pulse | n percent is given by 100*(Vref-Vm num and maximum values for Vref. Output voltage amplitude. is initialized as high (unless the dut | in)/(Vmax-Vmin) where Vmin The output voltage w cycle is set to zero) |
|--|---|---|
| The Simulation mode ca PWM signal. In Averag averaged PWM signal. Parameters | in histories of high (chilos the data in be set to PWM or Averaged. In I ed mode, the output is constant wi | PWM mode, the output is a th value equal to the |
| PWM frequency: | 1000 | Hz |
| Input value Vmin for | 0 | V |
| Input value Vmax for 100% duty cycle: | 5 | V |
| Output voltage | 5 | V |
| amplicade, | - | - |

PWM frequency

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

| | 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. |
| 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) demos. |
| See Also | Stepper Motor Driver |

Library SPICE-Compatible Sources

Description

DC Current Source

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

Dialog Box and Parameters

Ports

| 🙀 Block Parameters | : DC Current S | ource | | × |
|--|--|---------------------------------------|---|-----------------------|
| DC Current Source— | | | | |
| The DC Current Source its terminals, indepen parameters are not si | e block maintain dent of the volta upported. | is a time-invaria age across its t | ant (constant) cur erminals. The SPI | rent through CE AC |
| Parameters | | | | |
| Constant value, DC: | 0 | | A | • |
| | | | | |
| | | | 1 | |
| | ОК | Cancel | Help | Apply |

Constant value, DC

+

_

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

The block has the following ports:

Positive electrical voltage.

Negative electrical voltage.

DC Current Source

L

See Also DC Voltage Source

Purpose Model electrical and torque characteristics of DC motor

Library Actuators & Drivers

Description

DC Motor

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_b in the armature:

$$v_{b} = k_{v}\omega$$

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*: $T = k_t i$

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:

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

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:

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

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 B for all values of the **Model parameterization** parameter. The output torque is:

$$T_{load} = \frac{k_t}{R} (V - k_v \omega) - J \dot{\omega} - B \omega$$

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

DC Motor

Dialog Box and Parameters

| Electrical | Torque | Tab |
|------------|--------|-----|
| LIECHICUI | IUIYUE | IUD |

| The block assumes that r torque constants have tl either be specified direct is available on armature | to electromagnetic energy is lost, an the same numerical value when in SI to ly, or derived from no-load speed an inductance, this parameter can be se | d hence the back-emf and inits. Motor parameters can d stall torque. If no information at to some small non-zero value. |
|--|---|--|
| When a positive current mechanical C to R ports. back-emf or torque cons | flows from the electrical + to - ports, Motor torque direction can be chang tants. | , a positive torque acts from the ed by altering the sign of the |
| Parameters | 1 | |
| | lechanical | |
| Model parameterization: | By equivalent circuit parameters | _ |
| Armature resistance: | 3.9 | Ohm 💌 |
| Armature inductance: | 1.2e-05 | н |
| Define back-emf or torque constant: | Specify back-emf constant | • |
| Back-emf constant: | 7.2e-05 | V/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. 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 $3.9~\Omega$

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.

Mechanical Tab

| 🙀 Block Parameters: DC N | 1otor | × |
|---|---|---|
| DC Motor | | |
| This block represents the ele The block assumes that no of torque constants have the seither be specified directly, is available on armature inde When a positive current flow mechanical C to R ports. More | ectrical and torque characteristics of electromagnetic energy is lost, and he same numerical value when in SI units or derived from no-load speed and st uctance, this parameter can be set to ws from the electrical + to - ports, a p tor torque direction can be changed | a DC motor. ence the back-emf and s. Motor parameters can tall torque. If no information o some small non-zero value. positive torque acts from the by altering the sign of the |
| Parameters Electrical Torque Mec | hanical | |
| Rotor inertia: | 0.01 | g*cm^2 ▼ |
| Rotor damping: | 1e-08 | 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. 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. |
|------------|---|
| 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 demos: |
| | • 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 Sources

Description

DC Voltage Source

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

| 🙀 Block Parameters | s: DC Voltage Source |
|--|---|
| C Voltage Source | |
| The DC Voltage Source its output terminals, i parameters are not s | e block maintains a time-invariant (constant) voltage across ndependent of the current through the source. The SPICE AC upported. |
| Parameters | |
| Constant value, DC: | 0 |
| | |
| | OK Cancel 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.

DC Voltage Source

See Also DC Current Source

| Purpose | Model piecewise linear, piecewise linear zener, or exponential diode |
|-------------|---|
| Library | Semiconductor Devices |
| Description | The Diode block represents one of the following types of diodes: |
| ∎+ Diode | "Piecewise Linear" on page 2-21 "Piecewise Linear Zener" on page 2-21 |
| | |

• "Exponential" on page 2-22

Piecewise Linear

The piecewise linear diode model is the same model found in the SimscapeTM 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:

$$I = IS \times \left(e^{\frac{qV}{NkT}} - 1 \right) \qquad V > -Vz$$
$$I = -IS \times \left(e^{\frac{-q(V+Vz)}{kT}} - e^{\frac{qV}{NkT}} \right) \qquad V \le -Vz$$

where:

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

When $\frac{qV}{NkT} > 40$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} - 39\right)e^{40}$, which matches the gradient of the diode current at qV/(NkT) = 40 and extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, 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:

- $V_t = kT/q$.
- 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 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 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 $V < FC \times VJ$:

$$Q_i = CJ0 \times (VJ/(M-1)) \times ((1-V/VJ)^{1-M}-1)$$

• For $V \ge FC \times VJ$:

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

where:

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

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 Exponential diode model has the following limitations:

Basic 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 problems and poor estimates for *IS* and *N*.
- 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.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Diode

Dialog Box and Parameters

Main Tab

| Block Parameters: | Diode | × |
|--|--|---|
| -Diode | | |
| This block represents a following model types: | diode. Use the Diode model para | meter to select one of the |
| [1] Piecewise Linear Die Foundation Library. | ode. This option invokes the diode | model from the Simscape |
| [2] Piecewise Linear Ze characteristics). This m voltages above the Re breaks down with a low | ner Diode (i.e., piecewise linear dii odel is identical to the Piecewise L verse Breakdown Voltage Vz. For v corresponding Zener Resistance | ode with reverse breakdown .inear Diode for reverse voltages below Vz the diode .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 Br | eakdown 📔 Ohmic Resistance | Junction Capacitance |
| Diode model: | Piecewise Linear (Foundation L | ibrary) |
| Forward voltage: | 0.6 | V |
| On resistance: | 0.3 | Ohm 💌 |
| 055 | 1e-08 | |
| Orr conductance: | | |
| | | |

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 2-21. 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 2-21.
- Exponential Use a standard exponential model for the diode, as described in "Exponential" on page 2-22.

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 0.3 Ω

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 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 Exponential for the **Diode model** parameter and Use I-V curve data points for the

Parameterization parameter. The default value is [0.07 1.5] 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 I-V curve data points for the **Parameterization** parameter. The default value is [0.7 0.8] 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 Use parameters IS and N for the **Parameterization** parameter. The default value is 1e-14 A.

Measurement temperature

The temperature 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 $^{\circ}$ 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 Use parameters IS 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 Diode model parameter to select one of the following model types: |
| $\left[1\right]$ Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library. |
| [2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz. |
| [3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron. |
| Parameters |
| Main Reverse Breakdown Ohmic Resistance Junction Capacitance |
| Zener resistance Rz: 0.3 Ohm |
| Reverse breakdown voltage Vz: |
| |
| |
| OK 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 0.3 Ω

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 |
|---|
| Diode |
| This block represents a diode. Use the Diode model parameter to select one of the following model types: |
| Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library. |
| [2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz. |
| [3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = k*T/e where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron. |
| Parameters |
| Main Reverse Breakdown Ohmic Resistance Junction Capacitance |
| Ohmic resistance RS: 0.1 Ohm 💌 |
| |
| |
| |
| OK 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 0.1 Ω

Junction Capacitance Tab

| 🙀 Block Parameters: Diode 🛛 🗙 |
|--|
| Diode |
| This block represents a diode. Use the Diode model parameter to select one of the following model types: |
| $\left[1\right]$ 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 $I = Is^{*}(exp(V/(N^{*}t))-1)$ 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. |
| Main Reverse Breakdown Ohmic Resistance Junction Capacitance |
| Junction capacitance: 5 pF |
| |
| |
| 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 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.

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. |
| | <pre>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.</pre> |
| 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. <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. |
| See Also | Simscape Diode, Diode (SPICE) |

| Purpose | Model SPICE-compatible diode |
|---------|------------------------------|
|---------|------------------------------|

Library SPICE-Compatible Semiconductors

Description

▫┿ᢕ┾╍

Diode

The Diode block represents a SPICE-compatible diode.

The Diode block model includes the following components:

- "Current-Voltage Model" on page 2-35
- "Junction Charge Model" on page 2-37
- "Temperature Dependence" on page 2-38

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 | |
|--|--|---|
| $-3*V_t > V_d \ge -BV$ | $I_{d} = -IS\left(1 + \frac{27}{(V_{d} / V_{t})^{3} e^{3}}\right) + V_{d} * G \min$ | |
| $V_d < -BV$ | | |
| | $I_{d} = -IBV * (e^{(-(BV+V_{d}))V_{t}} - 1) - IS * \left(1 - \left(\frac{3}{e * BV/V_{t}}\right) - 1\right) - IS + \left(1 - \left(\frac{3}{e * BV$ | - |
| 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.



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:

$$IS(T) = IS * \left(T/T_{meas}\right)^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}}-1\right)^{*}\frac{EG}{V_{t}}}$$

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:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T}$$

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:

$$CJO(T) = CJO * \left[1 + MJ * \left(400e - 6 * (T - T_{meas}) - \frac{VJ(T) - VJ}{VJ} \right) \right]$$

where *CJO* is the **Zero-bias junction capacitance CJ0** parameter value.

Diode (SPICE)

| Basic | The model is based on the following assumptions: |
|--------------------|---|
| Assumptions and | • The Diode block does not support noise analysis. |
| Limitations | • The Diode block applies initial conditions across junction capacitors and not across the block ports. |

Diode (SPICE)

Dialog Box and Parameters

| м | ain | Tah |
|---|-----|-----|
| | am | IGD |

| This as in para | model approximates a S nstance parameters on t ameters KF and AF are n FESET | 5PICE diode. You specify both model this mask. The instance parameter Of not supported. Additional instance pa | card and instance paramete =F and the noise model rameters are SCALE and |
|--|---|--|--|
| SCA curr devi | LE is the number of para rent and device charge d ice parameters IS, CJO | allel diode instances for this device. S directly. This differs from the AREA pa and IBV, and divides RS. | CALE multiplies the output arameter, which multiples th |
| You | can set the diode tempe | erature to a fixed temperature or to t | the circuit temperature (from |
| a slig acro | ightly different value that oss the internal diode jur breakdown voltage BV i | an SPICE for capacitance. The initial of nction, so it is only effective when jur is not adjusted as a function of the b | condition VO is the voltage action capacitance is present reakdown current IBV. |
| a sli acro The Para M | ightly different value that oss the internal diode jur breakdown voltage BV i ameters lain Junction Capacil | an SPICE for capacitance. The initial onction, so it is only effective when jur is not adjusted as a function of the burned of t | condition VO is the voltage nction capacitance is preseni reakdown current IBV. emperature |
| a sli acro The Para M | ightly different value that oss the internal diode jur breakdown voltage BV i ameters lain Junction Capacil Device area, AREA: | an SPICE for capacitance. The initial onction, so it is only effective when jur is not adjusted as a function of the but tance Reverse Breakdown Te | condition VO is the voltage nction capacitance is present reakdown current IBV. emperature |
| a sli acro The Para M D N d | ightly different value that so the internal diode jur breakdown voltage BV i ameters lain Junction Capacil Device area, AREA: Jumber of parallel levices, SCALE: | an SPICE for capacitance. The initial ontion, so it is only effective when juris not adjusted as a function of the bound o | condition VO is the voltage nction capacitance is preseni reakdown current IBV. emperature |
| a sli acro The Para M D N d | ightly different value that so the internal diode jur breakdown voltage BV i ameters lain Junction Capacil Device area, AREA: Jumber of parallel levices, SCALE: iaturation current, IS: | an SPICE for capacitance. The initial ontion, so it is only effective when juris not adjusted as a function of the bound o | condition VO is the voltage nction capacitance is present reakdown current IBV. emperature m^2 |
| a sli acro The Para M D N d S | ightly different value that bases the internal diode jur breakdown voltage BV i ameters lain Junction Capacil Device area, AREA: Jumber of parallel levices, SCALE: Saturation current, IS: Dhmic resistance, RS: | an SPICE for capacitance. The initial ontion, so it is only effective when juris not adjusted as a function of the but ance Reverse Breakdown Te | condition VO is the voltage nction capacitance is present reakdown current IBV. emperature m^2 A/m^2 m^2*Ohm |
| a slii acro The Para M D N d S C E | ightly different value tha bass the internal diode jur breakdown voltage BV i ameters lain Junction Capacil Device area, AREA: Jumber of parallel devices, SCALE: Saturation current, IS: Dhmic resistance, RS: imission coefficient, ND: | an SPICE for capacitance. The initial ontion, so it is only effective when juris not adjusted as a function of the buttance Reverse Breakdown Te | condition VO is the voltage nction capacitance is present reakdown current IBV. emperature m^2 A/m^2 m^2*Ohm |

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 $m^{2*}\Omega$ 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

| DIUCK Pa | arameters: Diode | |
|---|---|--------------------|
|)iode | | |
| This mode as instance arameter OFFSET. | el approximates a SPICE diode. You specify both model card and instance parame ce parameters on this mask. The instance parameter OFF and the noise model rs KF and AF are not supported. Additional instance parameters are SCALE and | eters |
| SCALE is t arrent ar levice pai | the number of parallel diode instances for this device. SCALE multiplies the outpund device charge directly. This differs from the AREA parameter, which multiples rameters IS, CJO and IBV, and divides RS. | it the |
| 'ou can se he Custo | et the diode temperature to a fixed temperature or to the circuit temperature (fi m Electrical Environment block) plus TOFFSET. | rom |
| The block preakdow a slightly o across the | lets you include or exclude capacitance modeling, initial conditions and reverse in modeling. The capacitance modeling uses the published equations, which may different value than SPICE for capacitance. The initial condition VO is the voltag e internal diode junction, so it is only effective when junction capacitance is pres | yield e ent. |
| 'he break | down voltage BV is not adjusted as a function of the breakdown current IBV. | |
| 'he break Parameter | xdown voltage BV is not adjusted as a function of the breakdown current IBV. rs | |
| 'he break Parameter Main | xdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature | |
| 'he break 'arametei Main Model j | xdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature junction capacitance?: No | · |
| 'he break 'arameter Main Model j | xdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature junction capacitance?: No | • |
| 'he break 'arameter Main Model j | kdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature junction capacitance?: No | • |

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 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

| 🙀 Block Parameters: Diode | x |
|--|------------|
| - Diode | |
| This model approximates a SPICE diode. You specify both model card and instance parameter as instance parameters on this mask. The instance parameter OFF and the noise model parameters KF and AF are not supported. Additional instance parameters are SCALE and TOFFSET. | ers |
| SCALE is the number of parallel diode instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, CJO and IBV, and divides RS. | ne |
| You can set the diode temperature to a fixed temperature or to the circuit temperature (fro the Custom Electrical Environment block) plus TOFFSET. | m |
| The block lets you include or exclude capacitance modeling, initial conditions and reverse breakdown modeling. The capacitance modeling uses the published equations, which may yi a slightly different value than SPICE for capacitance. The initial condition VO is the voltage across the internal diode junction, so it is only effective when junction capacitance is preser The breakdown voltage BV is not adjusted as a function of the breakdown current IBV. | eld nt. |
| -Parameters | |
| Main Junction Capacitance Reverse Breakdown Temperature | |
| Model reverse breakdown?: 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: Diode | | | × | |
|---|--|--|---------------------|--|
| -Diode | | | | |
| This model approximates a SPICE diode as instance parameters on this mask. T parameters KF and AF are not support TOFFSET. | e. You specify both mo 'he instance paramete ed. Additional instance | del card and instance para r OFF and the noise mode e parameters are SCALE a | ameters :I nd | |
| SCALE is the number of parallel diode in current and device charge directly. Thi device parameters IS, CJO and IBV, ar | nstances for this devic s differs from the ARE nd divides RS. | e. SCALE multiplies the ou A parameter, which multip | itput bles the | |
| You can set the diode temperature to a the Custom Electrical Environment bloc | a fixed temperature or k) plus TOFFSET. | r to the circuit temperature | e (from | |
| The block lets you include or exclude capacitance modeling, initial conditions and reverse breakdown modeling. The capacitance modeling uses the published equations, which may yield a slightly different value than SPICE for capacitance. The initial condition VO is the voltage across the internal diode junction, so it is only effective when junction capacitance is present. The breakdown voltage BV is not adjusted as a function of the breakdown current IBV. | | | | |
| Parameters | | | | |
| Main Junction Capacitance | Reverse Breakdown | Temperature | | |
| Model temperature dependence using: | Device temperature | | • | |
| Saturation current temperature exponent, XTI: | 3 | | | |
| Activation energy, EG: | 1.11 | eV | - | |
| Offset local circuit temperature, TOFFSET: | 0 | K | • | |
| Parameter extraction temperature, TMEAS: | 300.15 | K | | |
| | | | | |
| | ~ - | | | |
| | | Help | Арріу | |

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 current 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.

Ports The block has the following ports:

Positive electrical voltage.

Negative electrical voltage.



+

Purpose Model exponential pulse current source

Library SPICE-Compatible Sources

Description

Exponential Current Source

> 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:

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

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.

Dialog Box and Parameters

| 🙀 Block Parameters: E | xponential Cur | rent Source | | × | |
|---|-------------------|-------------------|------------------|-------|--|
| -Exponential Current Source | | | | | |
| The Exponential Current Source block maintains an exponential current through its terminals, independent of the voltage across its terminals. The following equations describe the current through the exponential source as a function of time: | | | | | |
| Iout(0<=Time<=TDR) | = I1 | | | | |
| Iout(TDR <time<=tdf)< td=""><td>= I1+(I2-I1)*(1</td><td>-exp(-(Time-TDR))</td><td>'TR))</td><td></td></time<=tdf)<> | = I1+(I2-I1)*(1 | -exp(-(Time-TDR)) | 'TR)) | | |
| Iout(TDF <time) =="" i1+<br="">TDF)/TF))</time)> | (I2-I1)*(1-exp(-(| Time-TDR)/TR))+(| I1-I2)*(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, I1: | 0 | | A | - | |
| Pulse value, I2: | 0 | | A | - | |
| 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, I1

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

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 |

Exponential Voltage Source

Purpose Model exponential pulse voltage source

Library SPICE-Compatible Sources

Description

Exponential Voltage Source

> 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:

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

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

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

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 | 🙀 Block Parameters: I | Exponential Voltage Source | × | |
|------------|---|------------------------------------|------------|--|
| Box and | Exponential Voltage Sou | urce | | |
| Parameters | 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)< th=""><th>) = V1+(V2-V1)*(1-exp(-(Time-TDR))</th><th>'TR))</th></time<=tdf)<> |) = V1+(V2-V1)*(1-exp(-(Time-TDR)) | 'TR)) | |
| | $\label{eq:Vout} \begin{array}{llllllllllllllllllllllllllllllllllll$ | | | |
| | 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 | V | |
| | Pulse value, V2: | 0 | V | |
| | Rise delay time, TDR: | 0 | s • | |
| | Rise time, TR: | 1e-09 | s 💌 | |
| | Fall delay time, TDF: | 0 | 5 | |
| | Fall time, TF: | 1e-09 | 5 💌 | |
| | | | | |
| | | 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 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 |

Purpose Model gain-limited operational amplifier

Library

Integrated Circuits

Description



Finite Gain Op-Amp

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: Finit Finite Gain Op-Amp This block models a gain-lim are denoted Vp and Vm, the where A is the gain, Rout is t input current is given by (Vp- voltage is limited by the minir | e Gain Op-Amp ted op-amp. If the voltages at the positive an n the output voltage is given by Vout = A*{V the output resistance and lout is the output of Vm}/Rin where Rin is the input resistance. T num and maximum values Vmin and Vmax. | nd negative pins p-Vm)-lout*Rout current. The he 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 | |

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 Ω

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 100 Ω

| | 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 | | |

Generic Battery

| Purpose Model simple batte |
|-----------------------------------|
|-----------------------------------|

Library Sources

Description

Generic Battery

The Generic Battery block represents a simple battery. 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.
- V₀ is the voltage when the battery is fully charged, as defined by the **Nominal voltage, V_nominal** parameter.
- The block calculates the constants α 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.

Dialog Box and Parameters

| 🙀 Block Parameters: Gene | ric Batte | ary 👘 | | | × |
|---|--|---|---|--|---------------|
| Generic Battery | | | | | |
| This block models a generic I parameter, the block models source. If you select Finite for the battery as a series resisto | battery. If y the battery r the Batte r plus a ch | you select Infinit v as a series res ry charge capar arge-dependen | te for the Battery istor and a cons city parameter, t t voltage source | v charge capa tant voltage he block mod e defined by: | acity Iels |
| V = V_nominal*(1 - alpha*(1-x | :)/(1-beta*(| (1-x))) | | | |
| where x = (Ampere-Hours ren are calculated to satisfy a use charge. | naining)/(R er-defined | ated Ampere-H data point [AH1 | ours). Coefficier ,V1] and zero v | nts alpha and oltage for zero | beta D |
| Parameters | | | | | |
| Nominal voltage, V_nominal: | 12 | | | V | • |
| Internal resistance, R1: | 2 | | | Ohm | • |
| Battery charge capacity: | Infinite | | | | • |
| | | | | | |
| | | | | | |
| | | | | | |
| | ОК | Cancel | Help | App | yly |

Nominal voltage, V_nominal

The voltage at the output port when the battery is fully charged. The default value is $12\ \text{V}.$

Internal resistance, R1

Internal connection resistance. The default value is 2 $\boldsymbol{\Omega}$

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.

$\mathbf{R2}$

The resistance across the battery output terminals that represents battery self-discharge. This parameter is only visible when you select Include for the **Self-discharge resistance**, **R2** parameter. The default value is 2e+03 Ω

Ports The block has the following ports:
| | + Positive electrical voltage. |
|----------|---|
| | - Negative electrical voltage. |
| See Also | Simscape [™] DC Voltage Source, Simscape Controlled Voltage Source |

H-Bridge

| | Purpose | Model H-bridge motor | driver |
|--|---------|----------------------|--------|
|--|---------|----------------------|--------|

Library

Actuators & Drivers

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 load is connected to the supply via two freewheeling diodes that maintain current flow through the load. 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 The H-Bridge output is

 $V_O V_{PWM}$ $\overline{A_{PWM}}$

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.

The model is based on the following assumptions:

Basic Assumptions and Limitations

• 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 Averaged mode assumes that the effect 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.

• You can only linearize the H-Bridge block when you set the **Simulation mode** parameter to Averaged.

Dialog Box and Parameters

| H-Bridge | H-Bridge | | | | | |
|--|--|--|---|--|--|--|
| This block represents an H-bridge motor driver. | | | | | | |
| The block can be driver PWM mode, the motor i threshold voltage. In A to the PWM port voltag PWM signal amplitude. | by the PWM Di is powered if th veraged mode, ie V, reaching a | river block in PWM e PWM port voltag the output voltag maximum when V | or Averaged mo e V is above the e magnitude is p is equal to the p | ode. In e Enable proportional parameter | | |
| If the REV port voltage output voltage polarity Braking threshold volta | is greater than is reversed. If I ge, then the ou | the Reverse thre: the BRK port volta tput terminals are | shold voltage, th ge is greater th short circuited. | hen the an the | | |
| Voltages at ports PWM, | REV and BRK a | re defined relative | to the REF por | t. | | |
| Parameters | | | | | | |
| Enable threshold voltage: | 2.5 | | V | • | | |
| PWM signal amplitude: | 5 | | ٧ | • | | |
| Reverse threshold voltage: | 2.5 | | V | • | | |
| Braking threshold voltage: | 2.5 | | V | • | | |
| Output voltage amplitude: | 12 | | V | • | | |
| Simulation mode: | PWM | | | • | | |
| Bridge on resistance: | 0.1 | | Ohm | • | | |
| Freewheeling diode on resistance: | 0.1 | | Ohm | • | | |
| | | | | | | |
| | ок | 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 only used when the **Simulation mode** parameter 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 only uses this parameter when the **Simulation mode** parameter 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. The default value is 2.5 V.

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.

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.

Bridge on resistance

The total effective resistance of the semiconductor switches that connect the motor to the two power rails when the voltage at the PWM port is greater than the **Enable threshold voltage**. The default value is 0.1Ω

Freewheeling 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 Enable threshold voltage . The default value is $0.1~\Omega$ |
|----------|---------------|--|
| Ports | The k | 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 t Mode | he Controlled DC Motor, Linear Electrical Actuator (System-Level el) and Linear Electrical Actuator (Implementation Model) demos. |

Incremental Shaft Encoder

Purpose Model device that converts information about angular shaft position into electrical pulses

Library

Sensors

Description



Encoder

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 SimscapeTM 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

| 🙀 Block Parameters: Incremental Sha | aft Encoder | | × |
|---|--|--|---|
| _ Incremental Shaft Encoder | | | |
| This block represents an incremental shaft per shaft revolution, where N is the value Pulses A and B are 90 degrees out of pha leads B. The block produces a single index positive transition always coincides with a and Z are defined relative to the REF refe | : encoder. N pulses a you specify for the se. If the shaft rotal pulse on output Z o n A pulse positive tra rence terminal. | are produced on ports Pulses per revolution p ces in a positive direction nce per revolution. Th ansition. Output termin | A and B varameter. on, then A ve Z pulse als A, B |
| Parameters | | | |
| Pulses per revolution: | 2 | | |
| Output voltage amplitude: | 5 | V | • |
| Index pulse offset relative to shaft initial angle: | 0 | deg | • |
| | | | |
| | K 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°.

The block has the following ports:

R

Ports

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 | Encoded electrical output. |
| | 2 REF | Index, or synchronization, electrical output. |
| | | Floating zero volt reference. |
| See Also | Sims | cape Ideal Rotational Motion Sensor |

Purpose Model induction motor powered by ideal AC supply

Library Actuators & Drivers

Description



Induction Motor

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.

$$\bar{V} = \int \left(\begin{array}{ccc} & & & & & \\ \bar{I} & & & \\ R_1 & & & \\ jX_1 = j\omega L_1 & & \\ jX_2 = j\omega L_2 & & \\ I_2 & & R_2 \\ jX_m = j\omega L_m & & \\ \frac{1-s}{s}R_2 \\ \end{array} \right)$$

In the figure:

- R₁ is the stator resistance.
- R_2 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_{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.

| 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 magnetizing inductance L_m is very large compared to L_1 and L_2 .

Induction Motor

Dialog Box and Parameters

Electrical Torque Tab

| duction Motor | | | |
|---|--|--|--|
| his block represents the electrical and hideal AC supply. The block may be arameters expressed with respect to al power (W), imaginary power (VAF hase induction motor, then the effec- odeled. he block produces a positive torque a | d torque characteristics of an im parameterized via motor ratings) the stator. Physical signal outp () and mechanical speed (wm). 1 t of the starting mechanism (e.g acting from the mechanical C to | duction motor powered or equivalent circuit uts are provided for slij f used to model a singl J, shaded-pole) is not R ports. | |
| rameters | | | |
| Electrical Torque Power Supply | Mechanical | | |
| Model parameterization: | By motor ratings | | |
| Magnetizing inductance Lm: | 0.5 | н | |
| Rated mechanical power: | 825 | W | |
| Rated speed: | 3.5e+03 | rpm | |
| Rated RMS line-to-line voltage: | 200 | V | |
| Rated supply frequency: | 60 | Hz | |
| Rated RMS line current: | 2.7 | A | |
| L1+L2 parameterization: | From starting current | - | |
| RMS starting (or locked rotor) line current: | 7.5 | A | |
| R1 parameterization: | From motor efficiency | | |
| Motor efficiency (percent): | 95 | | |
| Number of pole pairs: | 1 | | |
| Number of phases: | 3 | | |
| | Star configuration | | |

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 magnetizing inductance is very large compared to L_1 and L_2 . 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. 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.

L1+L2 parameterization

Select one of the following parameterizations for the equivalent circuit inductance, L_1+L_2 , of the motor:

- From starting current Estimate the total equivalent circuit inductance from the motor starting current. This is the default method.
- From maximum torque Estimate the total equivalent circuit inductance from the motor maximum torque.

This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

RMS starting (or locked rotor) line current

The current that flows when the motor starts, or when the rotor is locked so that it cannot turn. The default value is 7.5 A. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter and From starting current for the **L1+L2 parameterization** parameter.

Maximum torque

The maximum value of torque on the torque-slip curve. The default value is 3.3 N*m. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter and From maximum torque for the **L1+L2 parameterization** parameter.

R1 parameterization

Select one of the following parameterizations for the equivalent circuit resistance, R_1 , of the motor:

- From motor efficiency Calculate ${\rm R}_1$ from the motor efficiency. This is the default method.
- From power factor Calculate $R_{1} \mbox{ from the motor power factor.}$

• 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 Mo | tor | | | |
|---|---|---|--|--|---|
| Induction Motor | | | | | |
| This block represents ti an ideal AC supply. The parameters expressed real power (W), imagin phase induction motor, modeled. The block produces a p | ne electrical and a block may be with respect to ary power (VAF then the effect ositive torque a | d torque charac parameterized \ the stator. Phy and mechanic t of the starting acting from the r | teristics of an i via motor ratini vsical signal ou al speed (wm) mechanism (e mechanical C t | nduction motor gs or equivaleni tputs are provid . If used to moo .g. shaded-pol o R ports. | powered by t circuit ded for slip (s) del a single- e) is not |
| Parameters | | | | | |
| Electrical Torque | Power Supply | Mechanical | 1 | | |
| Supply RMS line-to-li voltage: | ine 200 | | | V | • |
| Supply frequency: | 60 | | | Hz | • |
| | | | | | |
| | | | | | |
| | | ОК | Cancel | Help | Apply |

Supply RMS line-to-line voltage

The line-to-line voltage that supplies the motor. The default value is 200 V.

Supply frequency

Frequency of the AC supply voltage. The default value is 60 hertz.

Mechanical Tab

| an ideal AC supply. The b | electrical and torque characti ock may be parameterized vi | a motor ratings or equivalent circuit | elie / |
|---------------------------|---|--|--------|
| real power (W), imaginary | power (VAR) and mechanica power (VAR) and mechanica | il speed (wm). If used to model a sin mechanism (e.g. shaded-pole) is pot | gle- |
| modeled. | en die en ett of die starting | mechanism (e.g. snaded-pole) is not | |
| The block produces a posi | tive torque acting from the m | echanical C to R ports. | |
| -Parameters | | | |
| Electrical Torque Po | wer Supply Mechanical | | |
| Rotor inertia: | 0.001 | kg*m^2 | • |
| Rotor damping: | 1e-04 | N*m/(rad/s) | • |
| Initial rotor speed: | 0 | rpm | • |
| | | | |
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| | Rotor inertia Botor inertia. The default value is $0, 1 \text{ kg}^*\text{m}^2$. 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 rpm. |
| 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. |
| References | [1] S.E. Lyshevski. Electromechanical Systems, Electric Machines, and Applied Mechatronics, CRC, 1999. |
| See Also | DC Motor, Servomotor, Shunt Motor, and Universal Motor. |

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.

Light-Emitting Diode

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

$$\begin{split} I &= IS \times \left(e^{\frac{qV}{NkT}} - 1 \right) & V > -Vz \\ I &= -IS \times \left(e^{\frac{-q(V+Vz)}{kT}} - e^{\frac{qV}{NkT}} \right) & V \leq -Vz \end{split}$$

where:

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

When $\frac{qV}{NkT} > 40$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} - 39\right)e^{40}$, which matches the gradient of the diode current at $\frac{qV}{NkT} = 40$ and

extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, 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:

- $V_t = kT/q$
- 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 capacitance is defined in terms of the capacitor charge storage $Q_{\rm j}$ as:

• For $V < FC \times VJ$:

$$Q_i = CJ0 \times (VJ/(M-1)) \times ((1-V/VJ)^{1-M}-1)$$

• For $V \ge FC \times VJ$:

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

where:

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

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 has the following limitations:

Basic 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 problems and poor estimates for *IS* and *N*.
- 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.

• You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Dialog Box and Parameters

| Light-Emitting Diode | Light-Emitting Diode | |
|---|---|--|
| This block represents a diode in series with a co W is equal to the produ power per unit current | light-emitting diode. Structurally irrent sensor. The optical power ct of the current flowing through parameter. | it consists of an exponential presented at the signal port n the diode and the Optical |
| Parameters | | |
| Main Ohmic Resi | stance 📔 Junction Capacitance | 1 |
| 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

Main Tab

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-05 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

| 당 Block P | 🙀 Block Parameters: Light-Emitting Diode 🛛 🛛 🔀 | | | | | | | |
|--|--|-------------|------------------|------|-------|--|--|--|
| Light-Emi | 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 Resis | stance June | tion Capacitance | 1 | | | | |
| Ohmic | resistance RS | : 0.1 | | Ohm | | | | |
| | | ОК | 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 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 | | | | | | | |
| Junction capacitance: | Fixed or zero junction capacitance | | | | | | | |
| capacitance CJ0: | 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 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 [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.

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. | |
| See Also | Diode, Optocoupler, Photodiode | |

Purpose Model N-Channel IGBT

Library Semiconductor Devices

Description

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N-Channel IGBT

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, $V_{\rm be}$, and the saturation current, I_S
 - **1** 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:

$$I_{b} = 0 = I_{s} \left[\frac{1}{\beta_{F}} \left(e^{-qV_{be}/(NkT)} - 1 \right) - \frac{1}{\beta_{R}} \right]$$
$$I_{c} = I_{s} \left[e^{-qV_{be}/(NkT)} + 1/\beta_{R} \right]$$

where N is the **Emission coefficient N** parameter value, I_c is the **Zero gate voltage collector current Ices** parameter value, and I_c and I_b are defined as positive flowing out of the collector and base respectively. See the PNP Bipolar Transistor reference page for definitions of the remaining variables.

2 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 doesn't require and exact value for β_F because it can adjust the MOSFET gain *K* to ensure the overall device gain is correct.

- The block uses the on characteristics to calculate the MOSFET gain, *K*.
 - **1** The block approximates the base saturation current as

$$I_{b(sat)} = \frac{I_{ce(sat)}}{\beta_F + 1}$$

where $I_{ce(sat)}$ is the **Collector-emitter saturation current Ice(sat)** parameter value.

2 When saturated, PNP transistor base current equation simplifies to:

$$I_{b} = I_{s} \left[\frac{1}{\beta_{F}} \left(e^{-qV_{be}/(NkT)} - 1 \right) - \frac{1}{\beta_{R}} \right]$$

The block substitutes $I_{b(sat)}$ for I_b and solves this equation for $V_{be(sat)}$:

$$V_{be(sat)} = \frac{-NkT}{q} \log \left(\beta_F \left(\frac{I_{b(sat)}}{I_s} + \frac{1}{\beta_R} \right) + 1 \right)$$

3 When saturated, the MOSFET equation is:

$$I_{ds} = I_{b} = K \left[(V_{GE(sat)} - V_{th}) V_{ds} - \frac{V_{ds}^{2}}{2} \right]$$

where V_{th} is the **Gate-emitter threshold voltage Vge(th)** parameter value and $V_{GE(sat)}$ is the **Gate-emitter voltage for** {**Vce(sat),Ice(sat)**} 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_{GE} values, then the N and V_{th} can be tuned by hand to improve the match.

The block models gate junction capacitance as a fixed gate-emitter capacitance C_{GE} and a fixed gate-collector capacitance C_{GC} . If you select Specify using equation parameters directly for the **Parameterization** parameter, you specify these values directly using the **Gate-emitter junction capacitance** and **Gate-collector junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Cies** and **Reverse transfer capacitance Cres** parameter values that IGBT datasheets usually provide. The two parameterizations are related as follows:

- $C_{GE} = Cres$
- $C_{GC} = Cies Cres$

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.
- 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.
- You may need to use nonzero junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Basic Assumptions and Limitations

N-Channel IGBT

Dialog Box and Parameters

Main 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 and the bipolar forward Early voltage are infinite. There is no integral reverse diode, and reverse breakdown is not modeled. | | | | | | | | |
| Parameters | | | | | | | | |
| Main Junction Capacitance | | 1 | | | | | | |
| Zero gate voltage collector current Ices: | 2 | mA 💌 | | | | | | |
| Gate-emitter threshold voltage Vge(th): | 6 | V | | | | | | |
| Collector-emitter saturation voltage Vce(sat): | 2.8 | V | | | | | | |
| Collector-emitter saturation current Ice(sat): | 400 | A | | | | | | |
| Gate-emitter voltage for {Vce(sat),Ice(sat)}: | 15 | V | | | | | | |
| Emission coefficient N: | 1 | | | | | | | |
| Measurement temperature: | 25 | C 🗨 | | | | | | |
| | | | | | | | | |
| ОК | Cancel | Help Apply | | | | | | |

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 i.e. the device is in the off-state. The default value is 2 mA.

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-emitter saturation current Ice(sat)

The collector-emitter current when the gate-emitter voltage is $V_{ge(sat)}$ and collector-emitter voltage is $V_{ce(sat)}$. The default value is 400 A.

Gate-emitter voltage for {Vce(sat),Ice(sat)}

The gate voltage used when measuring $V_{ce(sat)}$ and $I_{ce(sat)}$. The default value is 15 V.

Emission coefficient N

The emission coefficient or ideality factor of the bipolar transistor. The default value is 1.

Measurement temperature

The temperature for which the parameters are quoted. It is also the temperature at which the device is simulated. The default value is 25 C.
Junction Capacitance Tab

| Block Parameters: I | N-Channel IGBT | | | |
|---|---|--|--|--|
| N-Channel IGBT | | | | |
| This block represents a bipolar transistor plus ar datasheet parameters. I bipolar forward Early vo breakdown is not mode | n N-channel IGBT. T N-channel MOSFET t is assumed that bot tage are infinite. The ed. | he underlying mo whose paramet h the MOSFET g re is no integral r | odel is based on a ers are derived fro jate resistance an everse diode, and | PNP om the IGB1 d the f reverse |
| Parameters | | | | |
| Main Junction Ca | pacitance | | | |
| | | | | |
| Parameterization: | Specify from a da | tasheet | | • |
| Input capacitance | 26.4 | | nF | • |
| Reverse transfer | 27 | | рЕ | - |
| capacitance Cres: | 1 | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| L | | | | |
| | OK | Connect | 11-16 | 6 h. |
| | UN | Lancer | нер | Abbili |

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.

The block has the following ports:

С

Electrical conserving port associated with the PNP emitter terminal.

G

Electrical conserving port associated with the MOSFET gate terminal.

Е

Electrical conserving port associated with the PNP collector terminal.

Ports

Purpose Model N-Channel JFET

Library

Semiconductor Devices

Description



The N-Channel JFET block uses the Shichman and Hodges equations to represent an N-Channel JFET using a model with the following structure:

N-Channel JFET



G is the transistor gate, D is the transistor drain and S is the transistor source. The drain-source current, I_{ds} , 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-source current I_{ds} and the drain-source voltage V_{ds} .

| Region | Applicable Range of V _{gs} and V _{ds} Values | Corresponding I _{ds} Equation |
|--------|--|--|
| Off | V_{gs} - $V_{to} \leq 0$ | $I_{ds} = 0$ |

| Region | Applicable Range of V _{gs} and V _{ds} Values | Corresponding I _{ds} Equation |
|-----------|--|--|
| Linear | $0 < V_{ds} < V_{gs} - V_{to}$ | $I_{ds} = \beta V_{ds} \left(2 \left(V_{gs} - V_{to} \right) - V_{ds} \right) \left(1 + \lambda V_{ds} \right)$ |
| Saturated | $0 < V_{gs} - V_{to} \leq V_{ds}$ | $I_{ds} = \beta \left(V_{gs} - V_{to} \right)^2 \left(1 + \lambda V_{ds} \right)$ |

• In inverse mode ($V_{ds} < 0$), the block provides the following relationship between the drain-source current I_{ds} and the drain-source voltage V_{ds} .

| Region | Applicable Range of V _{gs} and V _{ds} Values | Corresponding I _{ds} Equation |
|-----------|--|--|
| Off | V_{gd} - $V_{to} \leq 0$ | $I_{ds} = 0$ |
| Linear | $0 < -V_{ds} < V_{gs} - V_{to}$ | $I_{ds} = \beta V_{ds} \left(2 \left(V_{gd} - V_{to} \right) + V_{ds} \right) \left(1 - \lambda V_{ds} \right)$ |
| Saturated | $0 < V_{gd} - V_{to} \leq -V_{ds}$ | $I_{ds} = -\beta \left(V_{gd} - V_{to} \right)^2 \left(1 - \lambda V_{ds} \right)$ |

In the preceding equations:

- V_{gs} is the gate-source voltage.
- V_{gd} is the gate-drain voltage.

- V_{to} is the threshold voltage. If you select Specify using equation parameters directly for the **Parameterization** parameter, V_{to} is the **Threshold voltage** parameter value. Otherwise, the block calculates V_{to} 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

$$\begin{split} I_{gd} &= I_S \times \left(e^{\frac{qV_{gd}}{kT}} - 1 \right) \\ I_{gs} &= I_S \times \left(e^{\frac{qV_{gs}}{kT}} - 1 \right) \end{split}$$

Where:

- I_S is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, I_S is the **Saturation current** parameter value. Otherwise, the block calculates I_S from the datasheet parameters you specify.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode 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** C_iss and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = Ciss Crss$

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.
 - 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.
 - You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Basic Assumptions and Limitations

N-Channel JFET

Dialog Box and Parameters

| м | ain | Tab |
|---|-----|-----|
| | um | IUD |

| This block represents an N-Chappel | LIFET. The drain current ld for posi | tive Vds (normal operation) is div |
|--|--|------------------------------------|
| by: | | ave vas (normal operation) is gr |
| ld = 0 if Vgs-Vt0 < 0 (off) | | |
| lds = B*Vds*[2*(Vgs - Vt0) - Vds]*(1+ | -L*Vds) if 0 < Vds < Vgs - Vt0] (linea | r region) |
| lds = B*(Vgs - Vt0)^2*(1+L*Vds) if 0 | < Vgs - Vt0 < Vds (saturated region |) |
| where B is the Transconductance p | arameter. Vt0 is the Threshold volta | age L is the Channel-length |
| modulation, Vgs is the gate-source v | voltage and Vds is the drain-source | voltage. |
| Parameters | | |
| Main Ohmic Resistance | Junction Capacitance | |
| | | |
| 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 \ | /_ds]: [0 15] | V |
| Small-signal parameters [g_fs.g_c | os]: [3e+03 10] | uS |
| omainsignal parameters [g_1s g_t | | V |
| Small-signal measurement point [V_ds]: | ·==· [[015] | |
| Small-signal measurement point [V_ds]: Measurement temperature: | 25 | C |
| Small-signal measurement point [V_ds]: Measurement 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. This is the default method.

• Specify using equation parameters directly — Provide equation parameters V_{to} , β , λ , and I_S .

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_{gs} and V_{ds} at which I_{dss} is measured. Normally V_{gs} is zero. V_{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, i.e. the conductance for a fixed drain-source voltage. g_{os} is the output conductance, i.e. 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_{gs} and V_{ds} at which g_{fs} and g_{os} are measured. V_{ds} should be greater than zero. For depletion-mode devices, $V_{\rho s}$ is typically zero. This parameter is only visible when

you select Specify from a datasheet for the ${\bf Parameterization}$ 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.

Measurement temperature

The temperature for which the datasheet parameters are quoted. It is also the temperature at which the device is simulated. The default value is 25 C.

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.

Ohmic Resistance Tab

| Block Par | ameters: N-Chann | el JFET | | | | |
|---------------------------|--|----------------------------------|---------------------------------------|------------------------------------|---------------------------|------------------|
| N-Channel (| JFET | | | | | |
| his block re | epresents an N-Chan | nel JFET. The | drain current Io | d for positive V | ds (normal operatio | on) is given by: |
| d = 0 if Vg | s-VtO < O (off) | | | | | |
| ds = B*Vds | s*[2*(Vgs - VtO) - Vds | ;]*(1+L*Vds) | if 0 < Vds < Vg: | s - Vt0] (linear i | region) | |
| ds = B*(Vg | gs - VtO)^2*(1+L*Vds | s) if 0 < Vgs - | Vt0 < Vds (satu | rated region) | | |
| here B is t odulation, | the Transconductance , Vgs is the gate-sour | ; parameter, \ ce voltage an; | /t0 is the Thresl d Vds is the dra | hold voltage, L in-source volta | is the Channel-len ge. | gth |
| arameters | | | | | | |
| Main | Ohmic Resistance | Junction Ca | pacitance | | | |
| Source o | ohmic resistance: | 0.1 | | | Ohm | - |
| Drain oh | mic resistance: | 0.1 | | | Ohm | |
| | | | | | , | |
| | | | | | | |
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| | | | | | | |

Source ohmic resistance

The transistor source resistance. The default value is $0.1\ \Omega$ The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is $0.1\ \Omega$ The value must be greater than or equal to 0.

Junction Capacitance Tab

| 🙀 Block Parameters: N-Chann | el JFET | x |
|---|--|---|
| N-Channel JFET | | _ |
| This block represents an N-Chan by: | nel JFET. The drain current Id for positive Vds (normal operation) is given | |
| Id = 0 if Vgs-Vt0 < 0 (off) | | |
| Ids = B*Vds*[2*(Vgs · Vt0) · Vds]* | (1+L*Vds) if 0 < Vds < Vgs - Vt0] (linear region) | |
| Ids = B*(Vgs · Vt0)^2*(1+L*Vds) if | 0 < Vgs - Vt0 < Vds (saturated region) | |
| where B is the Transconductance modulation, Vgs is the gate-source | e parameter, Vt0 is the Threshold voltage, L is the Channel-length e voltage and Vds is the drain-source voltage. | |
| Parameters | | |
| Main Ohmic Resistance | Junction Capacitance | |
| Parameterization: | Specify from a datasheet | |
| Input capacitance C_iss: | 4.5 pF 💌 | |
| Reverse transfer capacitance Crss: | 1.5 PF 💌 | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel Help Apply | |

Parameterization

Select one of the following methods for block parameterization:

| • | Specify | from | а | datasheet — Provide paran | neters that the |
|---|-----------|--------|----|------------------------------|-----------------|
| | block con | verts | to | junction capacitance values. | This is the |
| | default n | nethod | l. | | |

• Specify using equation parameters directly — Provide junction capacitance parameters directly.

Input capacitance C_iss

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 C_rss

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.

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.

Ports

| | 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

Purpose Model N-Channel MOSFET using Shichman-Hodges equation

Library Semiconductor Devices

DescriptionThe 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:

N-Channel MOSFET

• In the off region ($V_{GS} < V_{th}$) the drain-source current is:

$$I_{DS} = 0$$

• In the linear region ($0 < V_{DS} < V_{GS} - V_{th}$) the drain-source current is:

$$I_{DS} = K \left((V_{GS} - V_{th}) V_{DS} - V_{DS}^{2} / 2 \right)$$

• In the saturated region ($0 < V_{GS} - V_{th} < V_{DS}$) the drain-source current is:

$$I_{DS} = (K/2)(V_{GS} - V_{th})^2$$

In the preceding equations:

- *K* is the transistor gain.
- V_{DS} is the positive drain-source voltage.
- V_{GS} is the gate-source voltage.
- V_{th} is the threshold voltage.

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 in the **Junction Capacitance** tab, 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 C_iss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = C_{iss} Crss$

N-Channel MOSFET

Dialog Box and Parameters

Main Tab

| 뒑 Block Parameters: N | -Channel MOSFET | | | × | | |
|---|--|---------------------|------------------|-----------|--|--|
| N-Channel MOSFET | | | | | | |
| This block represents an positive Vds is given by: | 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] if 0 < Vd | ls < Vgs - Vth] (li | inear region) | | | |
| $Ids = (K/2)^*(Vgs - Vth)^*$ | 2 if 0 < Vgs - Vth < \ | /ds (saturated re | egion) | | | |
| where K is a constant, V Vds is the drain-source v | th is the Threshold vo oltage. | oltage, Vgs is the | e gate-source vo | ltage and | | |
| Parameters | | | | | | |
| Main Ohmic Resist | ance Junction Ca | apacitance | | | | |
| Parameterization: | Specify from a data | asheet | | • | | |
| Drain-source on resistance, R. DS(op): | 0.025 | | Ohm | . | | |
| Drain current, Ids, for R_DS(on): | 6 | | A | • | | |
| Gate-source voltage, Vgs, for R_DS(on): | 10 | | ٧ | • | | |
| Gate-source threshold voltage Vth: | 1.7 | | V | • | | |
| | | | | | | |
| | | | | | | |
| | ОК | Cancel | Help | Apply | | |

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_{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_{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_{th} in the Shichman and Hodges equations. For an enhancement device, V_{th} should be positive. For a depletion mode device, V_{th} should be negative. The default value is 1.7 V.

Ohmic Resistance Tab

| 5 | Block Parameters: N-C | hannel MOSFET | | × | |
|---|--|--|-------------------------|---|--|
| Г | N-Channel MOSFET | | | | |
| | This block represents an N-channel MOSFET (or IGFET). The drain-source current Ids for positive Vds is given by: | | | | |
| | $Ids = 0 	ext{ if } Vgs < Vth (off)$ | | | | |
| | Ids = K*[(Vgs - Vth)*Vds - | Vds^2/2] if 0 < Vds < Vgs - Vth] (lir | near region) | | |
| | Ids = (K/2)*(Vgs - Vth)^2 i | f 0 < Vgs - Vth < Vds (saturated re | gion) | | |
| | where K is a constant, Vth Vds is the drain-source volt | is the Threshold voltage, Vgs is the age. | gate-source voltage and | | |
| Г | Parameters | | | | |
| | Main Ohmic Resistan | ce Junction Capacitance | | | |
| | Source ohmic resistance: 0.001 Ohm | | | | |
| | Drain ohmic resistance: | 0.001 | Ohm 💌 | | |
| | | | | | |
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| | | | | | |
| | | | | | |
| | | | | | |
| | | OK Cancel | Help Apply | | |

Source ohmic resistance

The transistor source resistance. The default value is $0.001\ \Omega$ 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 Param | eters: N-Cha | nnel MOSFET | | | × |
|---------------------------------------|------------------------------------|------------------------|---------------------|-------------------|------------|
| -N-Channel MOS | FET | | | | |
| This block repre positive Vds is g | sents an N-ch given by: | annel MOSFET (| or IGFET). The d | rain-source curre | nt Ids for |
| Ids = 0 if Vgs < | : Vth (off) | | | | |
| Ids = K*[(Vgs - | Vth)*Vds - Vd | s^2/2] if 0 < Vd | s < Vgs - Vth] (lir | near region) | |
| Ids = (K/2)*(Vg | js - Vth)^2 if 0 | < Vgs - Vth < V | 'ds (saturated re | gion) | |
| where K is a co Vds is the drain | nstant, Vth is I -source voltag | the Threshold vo e. | lltage, Vgs is the | gate-source volt | age and |
| - Parameters | | | | | |
| Main Ohr | mic Resistance | Junction Ca | apacitance | | |
| Parameteriza | ation: Spe | cify from a data | asheet | | • |
| Input capaci C_iss: | tance 35 |) | | pF | - |
| Reverse tran | nsfer 80 | | | pF | - |
| capacitance | C135. | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | 01 | Crew 1 | 11-1- | Analy I |
| | | UK | | неір | Арріу |

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 | capacit | ance paran | neters directly | у. |

Input capacitance C_iss

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.

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

Negative Supply Rail

 Purpose
 Model ideal negative supply rail

Library Sources

Description

↓ V− Negative Supply Rail

The Negative Supply Rail block represents an ideal negative supply rail. Use this block instead of the SimscapeTM 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 | 🙀 Block Parameters: Negative Supply Rail 🔀 |
|-----------------------|--|
| Box and Parameters | 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 which must be negative. Do not attach more than one Negative Supply Rail block to any connected line. |
| | Parameters Constant voltage: -1 V - |

| | Constant voltage The voltage at the output port relative to the Electrical Reference block ground port. The value must be less than zero. The default value is -1 V. |
|----------|--|
| Ports | The block has the following ports: |
| | - Negative electrical voltage. |
| See Also | Simscape DC Voltage Source, Positive Supply Rail |

NJFET

| Purpose | Model SPICE-compatible N-Channel JFET |
|------------------|--|
| Library | SPICE-Compatible Semiconductors |
| 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 2-122 "Gate-Drain Current-Voltage Model" on page 2-123 |

- "Drain-Source Current-Voltage Model" on page 2-124
- "Junction Charge Model" on page 2-125
- "Temperature Dependence" on page 2-127

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 |
|---|--|
| $V_{gs} > 80 * V_t$ | $I_{gs} = IS * \left(\left(\frac{V_{gs}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{gs} * G \min$ |
| $80 * V_t \ge V_{gs}$ | $I_{gs} = IS * (e^{V_{gs}/V_t} - 1) + V_{gs} * G \min$ |

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} - $V_{to} \leq 0$ | $I_{ds} = 0$ |

| Applicable Range of V _{gs} and V _{gd} Values | Corresponding I _{ds} Equation |
|--|--|
| $0 < V_{gd} - V_{to} \leq -V_{ds}$ | $I_{ds} = -\beta \left(V_{gd} - V_{to} \right)^2 \left(1 - \lambda V_{ds} \right)$ |
| $0 < -V_{ds} < V_{gs} - V_{to}$ | $I_{ds} = \beta V_{ds} \left(2 \left(V_{gd} - V_{to} \right) + V_{ds} \right) \left(1 - \lambda V_{ds} \right)$ |

Junction Charge Model

The block provides the following relationship between the gate-source charge Q_{gs} and the gate-source voltage V_{gs} after adjusting the applicable model parameters for temperature.



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 |
|--|--|
| $V_{gd} < FC * VJ$ | $Q_{gd} = \frac{CGD * VJ * \left(1 - \left(1 - \frac{V_{gd}}{VJ}\right)^{1 - MG}\right)}{1 - MG}$ |
| $V_{gd} \ge FC * VJ$ | $Q_{gd} = CGD * \left(F1 + \frac{F3 * (V_{gd} - FC * VJ) + \frac{MG * (V_{gd}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$ |

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:

$$IS(T) = IS * \left(T/T_{meas}\right)^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}}\right)^{\frac{EG}{V_{t}}}}$$

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:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T_{meas}}$$

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 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 $\boldsymbol{\beta}$ 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.

Dialog Box and Parameters

Main Tab

| 51 - 1 | | |
|--|---|---|
| his model approximates a S arameters as instance para arameters KE and AE are p | PICE N-channel JFET. You specify be ameters on this mask. The instance p of supported. Additional instance pa | oth model card and instance parameter OFF and noise me prometers are SCALE |
| OFFSET, ND, MG, XTI and | EG. | |
| CALE is the number of para urrent and device charge d | Illel JFET instances for this device. S irectly. This differs from the AREA p CGS_CGD_and divides PS and PD | CALE multiplies the output arameter, which multiples t |
| evice parameters bit in, 15, | | |
| ou can set the JFET temper ne Custom Electrical Enviror djust temperature sensitive | ature to a fixed temperature or to t nment block) plus TOFFSET. The par e parameters. | ameters ND, MG, XTI and E |
| he block lets you include or | exclude capacitance modeling and i | nitial conditions. The |
| apacitance modeling uses the second sec | he published temperature equations or capacitance. The initial conditions | , which may yield a slightly ICVDS and ICVGS are the |
| oltages across the internal | junctions, and are only effective wh | hen the corresponding junct |
| apacitances are present. | | |
| arameters | | |
| Main Junction Capacit | ance Temperature | |
| Device area (ABEA) | 1 | m42 |
| Number of parallel | | 111 2 |
| devices, SCALE: | 1 | |
| | | |
| Threshold voltage, VTO: | -2 | ۷ 💌 |
| Threshold voltage, VTO: Transconductance, BETA: | -2 1e-04 | V × A/m^2/V^2 × |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: | -2 1e-04 0 | V • • • • • • • • • • • • • • • • • • • |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: | -2 1e-04 0 1e-14 | V ▼ A/m^2/V^2 ▼ 1/V ▼ A/m^2 ▼ |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: | -2 1e-04 0 1e-14 1 | V ▼ A/m^2/V^2 ▼ 1/V ▼ A/m^2 ▼ |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: | -2 1e-04 0 1e-14 1 0 | V • • • • • • • • • • • • • • • • • • • |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: Drain resistance, RD: | -2 1e-04 0 1e-14 1 0 0 | V A/m^2/V^2 1/V A/m^2 m^2*Ohm m^2*Ohm V |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: Drain resistance, RD: | -2 1e-04 0 1e-14 1 0 0 | V ▼ A/m^2/V^2 ▼ 1/V ▼ A/m^2 ▼ m^2*Ohm ▼ m^2*Ohm ▼ |
| Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: Drain resistance, RD: | -2 1e-04 0 1e-14 1 0 0 | V ▼ A/m^2/V^2 ▼ 1/V ▼ A/m^2 ▼ m^2*Ohm ▼ 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 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.

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 $0 \text{ m}^{2*}\Omega$ The value must be greater than or equal to 0.

Drain resistance, RD

The transistor drain resistance. The default value is $0\ m^{2*}\Omega$ The value must be greater than or equal to 0.

Junction Capacitance Tab

| NJFET | |
|---|-----------------|
| This model approximates a SPICE N-channel JFET. You specify both model card and instan parameters as instance parameters on this mask. The instance parameter OFF and noise r parameters KF and AF are not supported. Additional instance parameters are SCALE, TOFFSET, ND, MG, XTI and EG. | ce node |
| SCALE is the number of parallel JFET instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples device parameters BETA, IS, CGS, CGD, and divides RS and RD. | : the |
| You can set the JFET temperature to a fixed temperature or to the circuit temperature (fr the Custom Electrical Environment block) plus TOFFSET. The parameters ND, MG, XTI and adjust temperature sensitive parameters. | om EG |
| 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 ICVDS and ICVGS are the voltages across the internal junctions, and are only effective when the corresponding juncapacitances are present. | / ; :tion |
| Parameters | |
| 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: NJFET | | | | |
|---|---|--|---|--|
| JJFET- | | | | |
| his model approximates a SPICE N- arameters as instance parameters o parameters KF and AF are not suppo FOFFSET, ND, MG, XTI and EG. | channel JFET on this mask, orted, Additio | . You specify bo The instance panal instance panal | oth model card a arameter OFF a rameters are SC | and instance Ind noise mod IALE, |
| CALE is the number of parallel JFET urrent and device charge directly. T device parameters BETA, IS, CGS, C | instances for This differs fro GD, and divid | r this device. So om the AREA pa es RS and RD. | CALE multiplies t arameter, which | he output multiples the |
| 'ou can set the JFET temperature to he Custom Electrical Environment blo adjust temperature sensitive parame | a fixed temp ock) plus TOF sters. | erature or to th FSET. The para | ne circuit tempe ameters ND, MG | rature (from i, XTI and EG |
| The block lets you include or exclude apacitance modeling uses the publis different value than SPICE for capac voltages across the internal junction: apacitances are present | capacitance hed tempera itance. The ir s, and are on | modeling and ir ture equations, nitial conditions ly effective wh | itial conditions, which may yiel ICVDS and ICV en the correspo | The d a slightly GS are the Inding junction |
| apacitantes are present. | | | | |
| 'arameters | | _, | | |
| Main Junction Capacitance | Temperatur | e | | |
| Model temperature dependence | Device te | mperature | | • |
| using: Saturation current temperature exponent, XTI: | 0 | | | |
| Activation energy, EG: | 1.11 | | eV | • |
| Offset local circuit temperature, TOFFSET: | 0 | | K | • |
| Parameter extraction temperature TMEAS: | ^{e,} 300.15 | | К | • |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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| | | | | |
| | | | 1 | |

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.

NJFET

| 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. Semiconductor Device Modeling with SPICE. 2nd Edition, McGraw-Hill, 1993. Chapter 3. |
| See Also | N-Channel JFET, PJFET |

Purpose Model Gummel-Poon NPN Transistor

Library SPICE-Compatible Semiconductors

Description

κť: NPN 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 2-139
- "Base Resistance Model" on page 2-143
- "Transit Charge Modulation Model" on page 2-143
- "Junction Charge Model" on page 2-144
- "Temperature Dependence" on page 2-146

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 139
- Terminal Currents on page 142
- Base Charge Model on page 142

Base-Emitter and Base-Collector Junction Currents

The base-emitter junction current is calculated using the following equations:

• When $V_{BE} > 80 * V_{TE}$:

$$I_{bef} = IS * \left(\left(\frac{V_{BE}}{V_{TF}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{BE}$$
$$I_{bee} = ISE * \left(\left(V_{BE} - 80 * V_{TF} + V_{TE} \right) * \frac{e^{(80*V_{TF}/V_{TE})}}{V_{TE}} - 1 \right)$$

• 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.

$$V_{TE} = NE * k * T / q, V_{TC} = NC * k * T / q, V_{TF} = NF * k * T / q, \text{ and}$$

 $V_{TR} = NR * k * T / q.$

- *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:

$$\begin{split} I_B &= -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)\\ I_C &= -\left(\frac{I_{ebf}}{q_b} - \frac{I_{cbr}}{BR} - I_{cbc}\right) \end{split}$$

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:

$$TF_{\rm mod} = \frac{TF * \left[1 + XTF * e^{V_{BC} / (1.44V_{TF})} \left(\frac{I_{BE}}{I_{BE} + ITF} \right)^2 \right]}{q_b}$$



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:

$$Q_{be} = TF_{mod} * I_{be} + Q_{dep}$$

• For the internal base-collector junctions:

$$Q_{bc} = TR * I_{bc} + XCJC * Q_{det}$$

• For the external base-collector junctions:

$$Q_{b_{ext}c} = (1 - XCJC) * Q_{dep}$$

 $Q_{\it dep}$ depends on the junction voltage, $V_{\it jct}$ ($V_{\it BE}$ for the base-emitter junction and $V_{\it BC}$ for the base-collector junction) as follows.



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*_{*ict*} 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 $Q_{\scriptscriptstyle cs}$ 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 |
|--|---|
| $V_{cs} < 0$ | $Q_{cs} = CJS * VJS * \left(\frac{1 - \left(1 - V_{cs} / VJS\right)^{(1 - MJS)}}{1 - MJS}\right)$ |
| $V_{cs} \ge 0$ | $Q_{cs} = CJS * (1 + MJS * V_{cs} / (2 * VJS)) * V_{cs}$ |
| | whore |

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.

•
$$EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4 * T_{meas}^2) / (T_{meas} + 1108)$$

• $EG_T = 1.16eV - (7.02e - 4 * T^2) / (T + 1108)$

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 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:

and not across the block ports.

Basic Assumptions and Limitations

The NPN block does not support noise analysis.The NPN block applies initial conditions across junction capacitors

Dialog Box and Parameters

Main Tab

| 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 RB, RBM, RE and RC. You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Imperature Number of parallel 1 M^2 Imperature | Block Para | meters: 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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVEE and ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Main Forward Gain Reverse Gain Resistors Capacitance Temperature Devices, SCALE: 1 | NPN | | | | | |
| 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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVEE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: Number of parallel devices, SCALE: OK Cancel Help And/v | This model ap parameters a noise model p | proximates a SP is instance parar parameters KF a | PICE NPN transisto meters on this ma: ind AF are not sup | r. You specify bo k. The instance p ported. | th model card and parameters PTF a | d instance nd OFF and |
| You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Image: I | SCALE is the current and o device param parameters R | number of paral Jevice charge dir Jeters IS, IKF, IS RB, RBM, RE and | llel BJT instances f rectly. This differs SE, IKR, ISC, IRB, d RC. | or this device. SC from the AREA p CJE, ITF, CJC ar | ALE multiplies the arameter, which id CJS, and divide | e output multiples the es the |
| 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Image: Image | You can set t Custom Elect temperature | he BJT temperat rical Environmen sensitive param | ture to a fixed ten nt block) plus TOFF leters. | perature or to th SET. The parame | e circuit tempera ters XTB, XTI and | ture (from the d EG adjust |
| Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Image: Capacitance | The block lets capacitance r different valu voltages acro capacitances | s you include or modeling uses th ue than SPICE fo oss the internal j are present. | exclude capacitan ne published tempe or capacitance. Th junctions, and are | ce modeling and i rature equations e initial conditions only effective wh | nitial conditions. , which may yield : ICVBE and ICVC nen the correspor | The I a slightly E are the nding junction |
| Main Forward Gain Reverse Gain Resistors Capacitance Temperature Device area, AREA: 1 m^2 Image: Capacitance Ima | Parameters – | • | | | | |
| Device area, AREA: 1 m^2 v Number of parallel devices, SCALE: 1 | Main F | orward Gain 丨 | Reverse Gain | Resistors C | apacitance Te | emperature |
| Number of parallel devices, SCALE: | Device are | ea, AREA: | 1 | | m^2 | _ |
| | Number of | [:] parallel | 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

🖥 Block Parameters: NPN X -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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Forward Gain Reverse Gain Resistors Capacitance Main. Temperature Transport saturation 1e-16 A/m^2 • current, IS: Forward beta, BF: 100 Forward emission 1 coefficient, NF: B-E leakage current, ISE: 0 A/m^2 -B-E emission coefficient, 1.5 NE: Forward knee current, Inf A/m^2 ▼ IKF: Forward Early voltage, Inf ۷ • VAE: OK. Cancel Help Apply

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/m². 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

| 🙀 Block Parameters: NPN | | | | | × |
|---|--|--|--|---|----|
| NPN | | | | | |
| This model approximates a S parameters as instance para noise model parameters KF a | PICE NPN transist meters on this ma and AF are not sup | or. You specify sk. The instand ported. | both model card ce parameters P1 | and instance 'F and OFF and | |
| SCALE is the number of para current and device charge di device parameters IS, IKF, I parameters RB, RBM, RE and | illel BJT instances f irectly. This differs SE, IKR, ISC, IRB, d RC. | or this device. from the ARE CJE, ITF, CJC | SCALE multiplies A parameter, wh I and CJS, and d | the output ich multiples the vides the | • |
| You can set the BJT tempera Custom Electrical Environmer temperature sensitive param | iture to a fixed ter nt block) plus TOFf neters. | nperature or to FSET. The para | o the circuit temp ameters XTB, XTI | erature (from t and EG adjust | ne |
| The block lets you include or capacitance modeling uses the different value than SPICE for voltages across the internal capacitances are present. | exclude capacitar he published temp or capacitance. Th junctions, and are | ice modeling a erature equati ie initial conditi only effective | nd initial conditior ons, which may y ions ICVBE and IC when the corres | ns, The rield a slightly EVCE are the sponding junctic | n |
| -Parameters | | | | | |
| Main Forward Gain | Reverse Gain | Resistors | Capacitance | Temperature | 1 |
| Reverse beta, BR: | 1 | | | | |
| Reverse emission | 1 | | | | |
| B-C leakage current, ISC: | 0 | | A/m^2 | • | |
| B-C emission coefficient, | 2 | | | | |
| Reverse knee current, TKR: | Inf | | A/m^2 | • | |
| Reverse Early voltage, VAR: | Inf | | V | - | |
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| | 04 | Cance | | (inclu | 1 |
| | | | | | |

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 Paramete | ers: NPN | | | | | | x |
|--|---|--|--|--|--|--|---|
| NPN | | | | | | | |
| This model approxi parameters as inst noise model param | mates a SPIC ance paramel eters KF and | E NPN transisto ters on this mas AF are not supp | r, You specif :k, The instar ported, | y both i nce para | model card and ameters PTF ar | l instance nd OFF and | |
| SCALE is the numb current and device device parameters parameters RB, RB | er of parallel charge direc IS, IKF, ISE, M, RE and R(| BJT instances fo tly. This differs IKR, ISC, IRB, C. | or this device from the ARI CJE, ITF, CJ | e. SCALI EA para IC and (| E multiplies the ameter, which n IJS, and divide | output nultiples the s the | |
| You can set the BJ Custom Electrical E temperature sensit | T temperatum nvironment b ive paramete | e to a fixed tem lock) plus TOFF ers. | perature or I SET. The par | to the c rameter | ircuit temperat 's XTB, XTI and | ure (from th EG adjust | e |
| The block lets you i capacitance modeli different value tha voltages across the capacitances are p | include or exc ng uses the p n SPICE for c e internal jun resent. | clude capacitan oublished tempe apacitance. The ctions, and are | ce modeling a rature equat e initial condit only effectiv | and initi ions, w tions IC e when | al conditions. T hich may yield VBE and ICVCE the correspon | he a slightly are the ding junctior | 1 |
| Parameters | | | | | | | |
| Main Forwar | d Gain 🗍 Ri | everse Gain | Resistors | Сара | acitance Te | mperature | |
| Emitter resistan | ce, RE: 0 | | | | m^2*Ohm | • | |
| Collector resista | ince, RC: 0 | | | | m^2*Ohm | - | |
| Zero-bias base resistance, RB: | 0 | | | | m^2*Ohm | • | |
| Minimum base re RBM: | esistance, 0 | | | | m^2*Ohm | • | |
| Half base resist | ance cur, 🛛 Ir | nf | | | A/m^2 | • | |
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Emitter resistance, RE

The resistance of the emitter. The default value is 0 $m^{2*}\Omega$ The value must be greater than or equal to 0.

Collector resistance, RC

The resistance of the collector. The default value is 0 $m^{2*}\Omega\,$ The value must be greater than or equal to 0.

Zero-bias base resistance, RB

The resistance of the collector. The default value is $0\ m^{2*}\Omega$ The value must be greater than or equal to 0.

Minimum base resistance, RBM

The resistance of the collector. The default value is 0 $m^{2*}\Omega$ 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

| 5 | Block Parameters: NPN | × |
|---|--|---|
| Г | 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 temperature or to the circuit temperature (from th Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. | e |
| | 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. | |
| | Parameters | |
| | Main Forward Gain Reverse Gain Resistors Capacitance Temperature | |
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| | 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.
- 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 ${\bf Specify\ initial\ condition\ }$ 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: NPN | | | × |
|---|---|---|---|
| NPN | | | |
| This model approximates a SPICE NPN parameters as instance parameters on noise model parameters KF and AF are | transistor. You specif this mask. The instar not supported. | y both model card nce parameters PT | and instance F and OFF and |
| SCALE is the number of parallel BJT ins current and device charge directly. Thi device parameters IS, IKF, ISE, IKR, I: parameters RB, RBM, RE and RC. | tances for this device s differs from the ARI 5C, IRB, CJE, ITF, CJ | :. SCALE multiplies EA parameter, wh C and CJS, and di | the output ich multiples the vides the |
| You can set the BJT temperature to a f Custom Electrical Environment block) pi temperature sensitive parameters. | ixed temperature or I lus TOFFSET. The par | to the circuit temp ameters XTB, XTI | erature (from the and EG adjust |
| The block lets you include or exclude conception of the published different value than SPICE for capacitation voltages across the internal junctions, capacitances are present. | apacitance modeling a ed temperature equat ance. The initial condi and are only effectiv | and initial condition ions, which may y tions ICVBE and IC e when the corres | is, The ield a slightly WCE are the ponding junction |
| Parameters | | | |
| Main Forward Gain Reverse | Gain 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 | К | • |
| Parameter extraction temperature, TMEAS: | 300.15 | K | • |
| | | | |
| | | | |
| | | | |
| | | | |
| | OK Cano | 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. |
| Examples | See the Creating a SPICE-Compatible Circuit with the Extended Electrical Library demo. |
| 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 |

Purpose Model NPN bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



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:

$$\begin{split} I_{C} &= I_{S} \left[\left(e^{qV_{BE}/(kT)} - e^{qV_{BC}/(kT)} \right) \left(1 - \frac{V_{BC}}{V_{A}} \right) - \frac{1}{\beta_{R}} \left(e^{qV_{BC}/(kT)} - 1 \right) \right] \\ I_{B} &= I_{S} \left[\frac{1}{\beta_{F}} \left(e^{qV_{BE}/(kT)} - 1 \right) + \frac{1}{\beta_{R}} \left(e^{qV_{BC}/(kT)} - 1 \right) \right] \end{split}$$

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- 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* 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 $qV_{_{BC}}/(kT) > 40$ or $qV_{_{BE}}/(kT) > 40$, the corresponding exponential

terms in the equations are replaced with $\left(q V_{_{BC}} \, / (kT) - 39
ight) e^{_{40}}$ and

 $\left(qV_{\scriptscriptstyle BE}\,/(kT)-39\right)e^{40}$, respectively. This helps prevent numerical issues associated with the steep gradient of the exponential function e^x at large

values of x. Similarly, if $qV_{\rm BC}/(kT) < -39$ or $qV_{\rm BE}/(kT) < -39$ then the corresponding exponential terms in the equations are replaced with

 $(qV_{\scriptscriptstyle BC}/(kT)+40)e^{-39}$ and $(qV_{\scriptscriptstyle BE}/(kT)+40)e^{-39}$, respectively.

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.

The NPN Bipolar Transistor model has the following limitations:

Basic Assumptions and 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.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

X

Dialog Box and Parameters

Main 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

| Forward current transfer ratio h fe: | 100 | | |
|--|-------|-------|---|
| Output admittance h_oe: | 5e-05 | 1/Ohm | - |
| Collector current at which h-parameter are defined: | /s 1 | mA | • |
| Voltage Vbe: | 0.55 | V | - |
| Current Ib for voltage Vbe: | 0.5 | mA | • |
| Reverse current transfer ratio BR: | 1 | | |
| Measurement 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-05 1/ Ω

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.

Voltage Vbe

Base-emitter voltage when the collector current is zero and the base current is Ib. 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* and the collector current is zero. 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 at which *Vbe* and *Ib* or *IS* are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 25 $^{\circ}$ C.

Ohmic Resistance Tab

| ed bas e equa | e-emitter and base-col tion parameters can ei | ect, and gives the lector capacitance: ther be specified d | option to includ s. For full detail lirectly, or are d | e base, emitter a s of the equation lerived from stan | and emitter resist s, consult the do dard datasheet p | ances plu cumentat parameter |
|-------------------------------|--|--|--|---|---|------------------------------------|
| ramete | rs | | | | | |
| Main | Ohmic Resistance | Junction Capacil | tance | | | |
| Collect | or resistance RC: | 0.1 | | | Ohm | - |
| Emitte | r resistance RE: | 0.1 | | | Ohm | • |
| Zero bias base resistance RB: | | : 0.1 | | | Ohm | - |
| | | | | | | |
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Collector resistance RC

Resistance at the collector. The default value is $0.1\ \Omega$

Emitter resistance RE

Resistance at the emitter. The default value is $0.1\ \Omega$

Zero bias base resistance RB

Resistance at the base at zero bias. The default value is $0.1\ \Omega$

Junction Capacitance Tab

| The equation parameters car | collector capacitances. For a either be specified directly | ruil details of the equ , or are derived from | ations, consult the doc standard datasheet pa | umenta aramete |
|-----------------------------|---|--|--|-------------------|
| Main Ohmic Resistance | g Junction Capacitance |] | | |
| Base-collector capacitance | : 5 | | pF | - |
| Base-emitter capacitance: | 5 | | pF | • |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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| | | | | |
| | | | | |

Base-collector capacitance

Parasitic capacitance across the base-collector junction. The default value is 5 pF.

Base-emitter capacitance

Parasitic capacitance across the base-emitter junction. The default value is 5 pF.

NPN Bipolar Transistor

| 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 Bipolar Transistor Characteristics demo. |
| 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, PNP Bipolar Transistor |

Purpose Model optocoupler as LED, current sensor, and controlled current source

Semiconductor Devices

Description

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 $CTR*I_d$, 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 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.
- This block does not model temperature-dependent effects. SimElectronicsTM simulates the block at the temperature at which the component behavior was measured, as specified by the **Measurement temperature** parameter value.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Optocoupler

Dialog Box and Parameters

Main Tab

| Detocoupler Optocoupler This block represents a model consists of an ex side, and a controlled of from the collector to en current and CTR is the | Dptocoupler simplified implementation of an opt ponential diode in series with a cur urrent source on the output side. T itter junction, and is equal to CTR ¹ Current Transfer Ratio. | cocoupler. Structurally the rrent sensor on the input- The output side current flows *Id where Id is the diode |
|---|--|---|
| Parameters Main Ohmic Resis Current transfer ratio: Diode parameterization: Currents [I1 I2]: Voltages [V1 V2]: Measurement | Interview Junction Capacitance 0.2 Use I-V curve data points [0.001 0.015] [[0.9 1.05] [| |
| | 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 $^{\circ}\mathrm{C}.$

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 |
| 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 |
|---|
| Coptocoupler |
| 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 |
| Junction capacitance: Fixed or zero junction capacitance Zero-bias junction capacitance Image: Second s |
| 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.

Optocoupler

| 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. |
| 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, Simscape [™] Controlled Current Source |

Purpose Model P-Channel JFET

Library

Semiconductor Devices

Description

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P-Channel JFET

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-source current, I_{ds} , 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-source current I_{ds} and the drain-source voltage V_{ds} .

| Region | Applicable Range of V _{gs} and V _{gd} Values | Corresponding I _{ds} Equation |
|--------|--|--|
| Off | $-V_{gs} < -V_{t0}$ | $I_{ds} = 0$ |

| Region | Applicable Range of V _{gs} and V _{gd} Values | Corresponding I _{ds} Equation |
|-----------|--|--|
| Linear | $\begin{array}{l} 0 < -V_{ds} < -V_{gs} + \\ V_{t0} \end{array}$ | $I_{ds} = \beta V_{ds} \left(2(-V_{gs} + V_{t0}) + V_{ds} \right) (1 - \lambda V_{ds})$ |
| Saturated | $\begin{array}{l} 0 < -V_{gs} + V_{t0} < \\ -V_{ds} \end{array}$ | $I_{ds} = -\beta (-V_{gs} + V_{t0})^2 (1 - \lambda V_{ds})$ |

• In inverse mode ($V_{ds} < 0$), the block provides the following relationship between the drain-source current I_{ds} and the drain-source voltage V_{ds} .

| Region | Applicable Range of V _{gd} and V _{ds} Values | Corresponding I _{ds} Equation |
|-----------|--|--|
| Off | $-V_{gd} < -V_{t0}$ | $I_{ds} = 0$ |
| Linear | $0 < V_{ds} < -V_{gd} + V_{t0}$ | $I_{ds} = \beta V_{ds} \left(2(-V_{gd} + V_{t0}) - V_{ds} \right) (1 + \lambda V_{ds})$ |
| Saturated | $0 < -V_{gd} + V_{t0} < V_{ds}$ | $I_{ds} = \beta (-V_{gd} + V_{t0})^2 (1 + \lambda V_{ds})$ |

In the preceding equations:

- V_{gs} is the gate-source voltage.
- V_{gd} is the gate-drain voltage.
- V_{t0} is the threshold voltage. If you select Specify using equation parameters directly for the **Parameterization** parameter, V_{to}

is the **Threshold voltage** parameter value. Otherwise, the block calculates V_{to} 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

$$\begin{split} I_{gd} &= I_S \times \left(e^{\frac{qV_{gd}}{kT}} - 1 \right) \\ I_{gs} &= I_S \times \left(e^{\frac{qV_{gs}}{kT}} - 1 \right) \end{split}$$

Where:

- I_S is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, I_S is the **Saturation current** parameter value. Otherwise, the block calculates I_S from the datasheet parameters you specify.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode 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** C_iss and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = Ciss Crss$

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.
 - 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.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Basic Assumptions and Limitations

P-Channel JFET

Dialog Box and Parameters

Main Tab

| IH – Dif A | /as.//t0 / 0 (off) | | |
|------------------|---------------------------------------|---|--------------------|
| | · · · · · · · · · · · · · · · · · · · | | |
| lds = -B*∖ | /ds*[2*(-Vgs - Vt0) + Vds]*(1-L*Vc | ls) if 0 < -Vds < -Vgs - Vt0] (linear regin | on) |
| lds = -B*(| -Vgs - Vt0)^2*(1-L*Vds) if 0 < -Vg: | s - Vt0 < -Vds (saturated region) | |
| where B i | is the Transconductance parame | ter, Vt0 is the Threshold voltage, L is | the Channel-length |
| modulatio | on, Vgs is the gate-source voltage | e and Vds is the drain-source voltage. | |
| Paramete | ers | | |
| Main | Ohmic Resistance Junctio | on Capacitance | |
| Param | eterization: | Specifu from a datasheet | • |
| Calar | | | |
| Gater | everse current i_gss: | 5 | |
| Satura | ated 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+03 75] | uS 💌 |
| Small- V_ds]: | signal measurement point [V_gs | [0-15] | V |
| Measu | urement 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. This is the default method.

• Specify using equation parameters directly — Provide equation parameters V_{to} , β , λ , and I_S .

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_{gs} and V_{ds} at which I_{dss} is measured. Normally V_{gs} is zero. V_{ds} should be less 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, i.e. the conductance for a fixed drain-source voltage. g_{os} is the output conductance, i.e. 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+03 75] uS.

Small-signal measurement point [V_gs V_ds]

A vector of the values of V_{gs} and V_{ds} at which g_{fs} and g_{os} are measured. V_{ds} should be less than zero. For depletion-mode devices, V_{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.

Measurement temperature

The temperature for which the datasheet parameters are quoted. It is also the temperature at which the device is simulated. The default value is 25 C.

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.

Ohmic Resistance Tab

| P-Channel This block | I JFET | | | | | |
|-------------------------|-------------------------|-----------------|---------------------|----------------------|------------------|---------------|
| his block | | | | | | |
| | represents a P-Chann | el JFET. The c | drain current Id fo | or negative Vds (r | ormal operation) |) is given by |
| d = 0 if -1 | Vgs-VtO < 0 (off) | | | | | |
| ds = -B*\ | /ds*[2*(-Vgs - VtO) + | Vds]*(1-L*Vds | s) if 0 < -Vds < -V | /gs - Vt0] (linear r | egion) | |
| ds = -B*(| (-Vgs - Vt0)^2*(1-L*V | ds) if 0 < -Vgs | - Vt0 < -Vds (sat | urated region) | | |
| vhere B is | s the Transconductanc | e parameter, ' | VtO is the Thresh | old voltage, L is th | ne Channel-lengt | h |
| nodulatior | n, Vgs is the gate-sour | rce voltage an | id Vds is the drain | -source voltage. | | |
| 'arameter | rs | | | | | |
| Main | Ohmic Resistance | Junction Ca | pacitance | | | |
| Source | ohmic resistance: | 0.1 | | | Ohm | • |
| Drain o | hmic resistance: | 0.1 | | | Ohm | - |
| | | , | | | | _ |
| | | | | | | |
| | | | | | | |
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| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Source ohmic resistance

The transistor source resistance. The default value is $0.1\ \Omega$ The value must be greater than or equal to 0.

Drain ohmic resistance

The transistor drain resistance. The default value is $0.1\ \Omega$ The value must be greater than or equal to 0.

Junction Capacitance Tab

| 🙀 Block Parameters: P-Chann | el JFET | | × |
|---|--|---------------------------------------|-----------------|
| P-Channel JFET | | | |
| This block represents a P-Channe | IJFET. The drain current Id for negati | ve Vds (normal operation | n) is given by: |
| Id = 0 if -Vgs-Vt0 < 0 (off) | | | |
| lds = -B*Vds*(2*(-Vgs - Vt0) + Vds | *(1-L*Vds) if 0 < -Vds < -Vgs - Vt0] (line | ear region) | |
| lds = -B*(-Vgs - Vt0)^2*(1-L*Vds) ii | 0 < -Vgs - Vt0 < -Vds (saturated region | n) | |
| where B is the Transconductance modulation, Vgs is the gate-source | e parameter, Vt0 is the Threshold voltage e voltage and Vds is the drain-source v | ge, L is the Channel-leng voltage. | jth |
| - Parameters | | | |
| Main Ohmic Resistance | Junction Capacitance | | |
| Parameterization: | Specify from a datasheet | | • |
| Input capacitance C_iss: | 5 | pF | - |
| Reverse transfer capacitance | 1 | pF | - |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | OK Can | cel Help | Apply |

Parameterization

Select one of the following methods for block parameterization:

| • | Specify | from | а | datasheet — Provide param | neters that the |
|---|-----------|--------|----|------------------------------|-----------------|
| | block con | verts | to | junction capacitance values. | This is the |
| | default n | nethod | l. | | |

• Specify using equation parameters directly — Provide junction capacitance parameters directly.

Input capacitance C_iss

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 C_rss

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.

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.

Ports

| | 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

Purpose Model P-Channel MOSFET using Shichman-Hodges equation

Library Semiconductor Devices

DescriptionThe P-Channel MOSFET block uses the Shichman and Hodges
equations [1] for an insulated-gate field-effect transistor to represent an
P-Channel MOSFET.

The drain-source current, I_{DS} , depends on the region of operation:

P-Channel MOSFET

• 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:

$$I_{DS} = -K \left((V_{GS} - V_{th}) V_{DS} - V_{DS}^{2} / 2 \right)$$

- In the saturated region ($0 < -V_{\rm GS} + V_{\rm th} < -V_{\rm DS}$) the drain-source current is:

$$I_{DS} = -(K/2)(V_{GS} - V_{th})^2$$

In the preceding equations:

- *K* is the transistor gain.
- V_{DS} is the negative drain-source voltage.
- V_{GS} is the gate-source voltage.
- V_{th} is the threshold voltage.

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 in the **Junction Capacitance** tab, 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 C_iss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

- $C_{GD} = Crss$
- $C_{GS} = C_{iss} Crss$

P-Channel MOSFET

Dialog Box and Parameters

Main Tab

| 🙀 Block Parameters: F | P-Cha | nnel MOSFET | | | × |
|---|--|-------------------|------------------|--------------------|------------|
| P-Channel MOSFET | | | | | |
| This block represents a negative Vds is given by | P-cha '' | nnel MOSFET (o | r IGFET). The dr | ain-source curre | nt Ids for |
| Ids = 0 if -Vgs < -Vth (o | ff) | | | | |
| Ids = -K*[(Vgs - Vth)*Ve | ds - V | ds^2/2] if 0 < -\ | /ds < -Vgs + Vth | i] (linear region) | |
| Ids = -(K/2)*(Vgs - Vth) | $Ids = -(K/2)^*(Vgs - Vth)^2 \ if \ 0 < -Vgs + Vth < -Vds \ (saturated \ region)$ | | | | |
| where K is a constant, V Vds is the drain-source v | where K is a constant, Vth is the Threshold voltage, Vgs is the gate-source voltage and Vds is the drain-source voltage. | | | | |
| -Parameters | | | | | |
| Main Ohmic Resis | Main Ohmic Resistance Junction Capacitance | | | | |
| Parameterization: | Spe | ecify from a data | asheet | | _ |
| Drain-source on resistance R_DS(on): | 0.1 | 167 | | Ohm | • |
| Drain current, Ids, for R_DS(on): | -2. | 5 | | A | • |
| Gate-source voltage, Vgs, for R_DS(on): | -4. | 5 | | V | _ |
| Gate-source threshold voltage | -1. | 4 | | V | |
| Vth: | , | | | | |
| | | | | | |
| | | | | | |
| | | ОК | Cancel | Help | Apply |

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.

Ohmic Resistance 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) | | | | |
| $Ids = -K^*[(Vgs - Vth)^*Vds - Vds^2/2] \ if \ 0 < -Vds < -Vgs + Vth] \ (linear \ region)$ | | | | |
| $Ids = -(K/2)^*(Vgs - Vth)^2 \ if \ 0 < -Vgs + Vth < -Vds \ (saturated \ region)$ | | | | |
| where K is a constant, Vth is the Threshold voltage, Vgs is the gate-source voltage and Vds is the drain-source voltage. | | | | |
| Parameters | | | | |
| Main Ohmic Resistance Junction Capacitance | | | | |
| Source ohmic resistance: 0.001 Ohm | | | | |
| Drain ohmic resistance: 0.001 Ohm 💌 | | | | |
| | | | | |
| | | | | |
| | | | | |
| OK Cancel Help Apply | | | | |

Source ohmic resistance

The transistor source resistance. The default value is 0.001Ω . 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: 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) | |
| $Ids = -K^*[(Vgs - Vth)^*Vds - Vds^2/2] \ if \ 0 < -Vds < -Vgs + Vth] \ (linear \ region)$ | |
| $Ids = -(K/2)^*(Vgs - Vth)^2 \ if \ 0 < -Vgs + Vth < -Vds \ (saturated \ region)$ | |
| where K is a constant, $\forall th$ is the Threshold voltage, $\forall gs$ is the gate-source voltage and $\forall ds$ is the drain-source voltage. | |
| Parameters | |
| Main Ohmic Resistance Junction Capacitance | |
| Parameterization: Specify from a datasheet | |
| C iss: | |
| Reverse transfer 45 pF | |
| | |
| 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 C_iss

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 C_rss

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.

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.

Ports

- **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

PCCCS

Purpose Model polynomial current-controlled current source

Library SPICE-Compatible Sources

Description

PCCCS

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.

Dialog Box and Parameters

| 🙀 Block Parameters: PCCCS 🛛 🛛 🔀 | | | |
|--|--|--|--|
| PCCCS | | | |
| The Polynomial Current-Controlled Current Source (PCCCS) block generates a current waveform, Iout, 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: | | | |
| $Iout = p(0) + p(1)*Iin + + p(n-1)*Iin^{(n-1)} + p(n)*Iin^{n}$ | | | |
| If you specify a scalar coefficient, p, the block creates a linearly dependent output current. | | | |
| Iout = p * Iin | | | |
| | | | |
| Parameters | | | |
| Polynomial coefficients: [0 1] | | | |
| | | | |
| | | | |
| OK 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 $[0\ 1]$.

Ports 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 PCCVS, PVCCS, and PVCVS

Purpose Model polynomial current-controlled voltage source

Library SPICE-Compatible 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:

$$V_{out} = p(0) + p(1) * I_{in} + \dots + p(n-1) * I_{in}^{n-1} + p(n) * I_{in}^{n}$$

• 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: PCCV5 | | | | |
|--|--|--|--|--|
| PCCV5 | | | | |
| 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: | | | | |
| $\label{eq:Vout} Vout = p(0) + p(1)^*Iin + \ldots + p(n{-}1)^*Iin^{(n-1)} + p(n)^*Iin^n$ | | | | |
| 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, PVCCS, and PVCVS

Photodiode

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:

Photodiode

 $I_{p} = DeviceSensitivity \times RadiantFluxDensity$

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:

$$I = IS \times \left(e^{\frac{qV}{NkT}} - 1 \right)$$

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* is the temperature at which the diode parameters are specified, as defined by the **Measurement temperature** parameter value.

When $\frac{qV}{NkT} > 40$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} - 39\right)e^{40}$, which matches the gradient of the diode current at qV/(NkT) = 40 and extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, 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.

- $V_t = kT/q$.
- *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 $V < FC \times VJ$:

$$Q_j = CJ0 \times (VJ/(M-1)) \times ((1-V/VJ)^{1-M}-1)$$

• For $V \ge FC \times VJ$:

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

where:

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

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.

Photodiode

| Basic Assumptions and Limitations | 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 <i>N</i>. |
|--|--|
| | • 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. |

• You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Photodiode

Dialog Box and Parameters

| | • | - | |
|---|-----|----|---|
| M | aın | la | b |

| his block represents a ph | otodiode. Structurally it | consists of a cor | trolled current s | ource an |
|----------------------------|---------------------------|--------------------|--------------------|------------|
| xponential diode connect | ed in parallel. The contr | olled current sou | rce produces a (| current Ip |
| hat is proportional to the | Radiant flux density pre | esented at the ph | nysical signal por | tD: |
| = Device sensitivity * R | adiant flux density | | | |
| order to model dupamic | response time, the dias | le junction canac | itance can cet t | o a cuitab |
| alue. | response ame, crie aloc | unction capac | itance can set o | u a suitau |
| arameters | | | | |
| 1 | x. | , | | |
| Main Ohmic Resista | nce Junction Capaci | itance | | |
| Sensitivity | C : E | | | |
| parameterization: | Specify measured cur | rent for given flu | x density | |
| Measured current: | 25 | | μA | <u> </u> |
| Flux density: | 5 | | W/m^2 | • |
| Diode | Lice dark current plus | a forward bias I. | V data point | |
| parameterization: | Jose dark current plus | a forward blas r | -v data point | |
| voltage VF: | 0.08 | | A | - |
| Forward voltage VF: | 1.3 | | V | |
| Dark current: | 5e-09 | | 4 | |
| Meacurement | 100.05 | | | |
| temperature: | 25 | | C | - |
| | | | | |

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 0.08 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 - 09 A.

Measurement temperature

The temperature at which the I-V curve or dark current was measured. The default value is 25 $^{\circ}\mathrm{C}.$

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 📃 🔀 | | |
|---|--|--|
| 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 set to a suitable value. | | |
| Parameters | | |
| Main Ohmic Resistance Junction Capacitance | | |
| Ohmic resistance RS: 0.1 Ohm V | | |
| OK Cancel Help Apply | | |

Ohmic resistance RS

The series diode connection resistance. The default value is $0.1\ \Omega$

Junction Capacitance Tab

| hotodiode his block represents a photodiode. Structurally it consists of a controlled current source and a xponential diode connected in parallel. The controlled current source produces a current Ip hat is proportional to the Radiant flux density p = Device sensitivity * Radiant flux density n order to model dynamic response time, the diode junction capacitance can set to a suitable falue. Yarameters Main Ohmic Resistance Junction Capacitance Junction capacitance: Fixed or zero junction capacitance Zero-bias junction capacitance CJ0: OK Capcel Hab | Block Parameters: Pho | todiode | |
|--|--|--|------------------------------|
| his block represents a photodiode. Structurally it consists of a controlled current source and a xponential diode connected in parallel. The controlled current source produces a current Ip hat is proportional to the Radiant flux density presented at the physical signal port D: p = Device sensitivity * Radiant flux density n order to model dynamic response time, the diode junction capacitance can set to a suitable alue. arameters | hotodiode | | |
| Main Ohmic Resistance Junction Capacitance Junction capacitance: Fixed or zero junction capacitance Zero-bias junction 60 pF | This block represents a phi exponential diode connect hat is proportional to the p = Device sensitivity * R in order to model dynamic value | Itodiode. Structurally it consists of a controlled current source of in parallel. The controlled current source produces a curre Radiant flux density presented at the physical signal port D: adiant flux density response time, the diode junction capacitance can set to a su | e and an nt Ip uitable |
| Main Ohmic Resistance Junction Capacitance Junction capacitance: Fixed or zero junction capacitance Zero-bias junction capacitance CJ0: 60 pF Image: Complexity of the second secon | Parameters | | |
| Junction capacitance: Fixed or zero junction capacitance Zero-bias junction capacitance CJ0: 60 PF C | Main Ohmic Resistar | ce Junction Capacitance | |
| Zero-bias junction capacitance CJO: | Junction capacitance: | Fixed or zero junction capacitance | • |
| | Zero-bias junction capacitance CJO; | 60 pF | - |
| | | | |
| | | | |
| | | | |
| | | | |
| OK Capcel Help Apply | | | |
| OK Capcel Help Apply | | | |
| OK Capcel Help Apply | | | |
| OK Capcel Help Apply | | | |
| | | OK Cancel Help | Annly |

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 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 [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. |
|------------|---|
| Ports | The block has the following ports: |
| | D Physical port representing incident flux. + 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. <i>Analogue and digital electronics</i> for engineers. 2nd Edition, Cambridge University Press, 1984. |
| | [2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. |
| See Also | Diode, Light-Emitting Diode, Optocoupler |

PJFET

| Purpose | Model SPICE-compatible P-Channel JFET | |
|-------------|---|--|
| Library | SPICE-Compatible Semiconductors | |
| Description | The PJFET block represents a SPICE-compatible P-channel JFET. | |
| ┉┿┥╗ | The PJFET block model includes the following components: | |
| PJFET | • "Source-Gate Current-Voltage Model" on page 2-220 | |
| | • "Drain-Gate Current-Voltage Model" on page 2-221 | |
| | • "Source-Drain Current-Voltage Model" on page 2-222 | |

- "Junction Charge Model" on page 2-223
- "Temperature Dependence" on page 2-225

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} - $V_{to} \leq 0$ | $I_{sd} = 0$ |
| $0 < V_{dg} - V_{to} \leq -V_{sd}$ | $I_{sd} = \beta * \left(V_{dg} - V_{to} \right)^2 * \left(1 - \lambda * V_{sd} \right)$ |
| $0 < -V_{sd} < V_{dg} - V_{to}$ | $I_{sd} = \beta * V_{sd} * (2 * (V_{dg} - V_{to}) + V_{sd}) * (1 - \lambda * V_{sd})$ |

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:

$$IS(T) = IS * \left(T/T_{meas}\right)^{\frac{XTI}{ND}} * e^{\left(\frac{T}{T_{meas}} - 1\right)^{*}\frac{EG}{V_{t}}}$$

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:

$$VJ(T) = VJ * \left(\frac{T}{T_{meas}}\right) - \frac{3 * k * T}{q} * \log\left(\frac{T}{T_{meas}}\right) - \left(\frac{T}{T_{meas}}\right) * EG_{T_{meas}} + EG_{T_{meas}}$$

where:

• *VJ* is the **Junction potential VJ** parameter value.

•
$$EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4 * T_{meas}^{2}) / (T_{meas} + 1108)$$

•
$$EG_T = 1.16eV \cdot (7.02e \cdot 4*T^2)/(T+1108)$$

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 $\boldsymbol{\beta}$ 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.

Dialog Box and Parameters

Main Tab

| is model approximates a S | PICE P-channel JEET. You specify I | ooth model card and instanc | | |
|---|--|---|--|--|
| rameters as instance para | ameters on this mask. The instance | parameter OFF and noise n | | |
| rameters KF and AF are n)FFSET, ND, MG, XTI and | ot supported. Additional instance p EG. | arameters are SCALE, | | |
| ALT :- the | | | | |
| LALE is the number of parallel JFET instances for this device. SCALE multiplies the output urrent and device charge directly. This differs from the AREA parameter, which multiples the | | | | |
| evice parameters BETA, IS, CGS, CGD, and divides RS and RD. | | | | |
| u can set the JFET temper | rature to a fixed temperature or to | the circuit temperature (fro | | |
| e Custom Electrical Envirol Ijust temperature sensitive | nment block) plus TOFF5ET. The pa e parameters. | rameters ND, MG, X11 and | | |
| e block lets vou include or | exclude capacitance modeling and | initial conditions. The | | |
| pacitance modeling uses t | he published temperature equation | s, which may yield a slightly | | |
| ferent value than SPICE f Itages across the internal | or capacitance. The initial condition junctions, and are only effective w | is ICVDS and ICVGS are the iben the corresponding junc | | |
| pacitances are present. | janciono, ana aro oniy orrocaro n | non cho con osponaling jane | | |
| rameters | | | | |
| Main I Institut Casadi | Tono and Tono and the second | | | |
| Main Junction Capacit | | | | |
| Device area, AREA: | 1 | m^2 | | |
| | | | | |
| Number of parallel | 1 | | | |
| Number of parallel devices, SCALE: | 1 | | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance | -2 | V | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: | 1 -2 1e-04 | V A/m^2/V^2 | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: | 1 -2 1e-04 0 | V A/m^2/V^2 | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: | 1 -2 1e-04 0 1e-14 | V A/m^2/V^2 1/V A/m^2 | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient ND: | 1 -2 1e-04 0 1e-14 | V A/m^2/V^2 | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: | 1 -2 1e-04 0 1e-14 1 0 | V A/m^2/V^2 1/V A/m^2 | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: | 1 -2 1e-04 0 1e-14 1 0 | V A/m^2/V^2 1/V A/m^2 m^2*Ohm | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: Drain resistance, RD: | 1 -2 1e-04 0 1e-14 1 0 0 | V A/m^2/V^2 1/V A/m^2 m^2*Ohm m^2*Ohm | | |
| Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS: Drain resistance, RD: | 1 -2 1e-04 0 1e-14 1 0 0 0 | V A/m^2/V^2 1/V A/m^2 m^2*Ohm 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 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.

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 0 m²* Ω The value must be greater than or equal to 0.

Drain resistance, RD

The transistor drain resistance. The default value is $0\ m^{2*}\Omega$ The value must be greater than or equal to 0.

Junction Capacitance Tab

| PJFET | |
|---|--|
| This model approximates a SPICE P-channel JFET. You specify both model card an parameters as instance parameters on this mask. The instance parameter OFF an parameters KF and AF are not supported. Additional instance parameters are SC/ TOFFSET, ND, MG, XTI and EG. | d instance d noise mode ALE, |
| SCALE is the number of parallel JFET instances for this device. SCALE multiplies th current and device charge directly. This differs from the AREA parameter, which r device parameters BETA, IS, CGS, CGD, and divides RS and RD. | e output multiples the |
| You can set the JFET temperature to a fixed temperature or to the circuit tempera the Custom Electrical Environment block) plus TOFFSET. The parameters ND, MG, adjust temperature sensitive parameters. | ature (from XTI and EG |
| The block lets you include or exclude capacitance modeling and initial conditions. T capacitance modeling uses the published temperature equations, which may yield different value than SPICE for capacitance. The initial conditions ICVDS and ICVG voltages across the internal junctions, and are only effective when the correspon capacitances are present. | he a slightly 5 are the ding junction |
| Parameters | |
| Main Junction Canacitance Tomporative | |
| model janea on capacitances. The | • |
| | T |
| | T |

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: PJFET | | |
|---|--|--------|
| PJFET | | |
| This model approximates a SPICE P-ch parameters as instance parameters or parameters KF and AF are not suppor TOFFSET, ND, MG, XTI and EG. | hannel JFET. You specify both model card and instance in this mask. The instance parameter OFF and noise mo rted. Additional instance parameters are SCALE, | idel |
| SCALE is the number of parallel JFET i current and device charge directly. Th device parameters BETA, IS, CGS, CG | instances for this device. SCALE multiplies the output his differs from the AREA parameter, which multiples th 5D, and divides RS and RD. | e |
| You can set the JFET temperature to the Custom Electrical Environment blo adjust temperature sensitive paramet | a fixed temperature or to the circuit temperature (from ock) plus TOFFSET. The parameters ND, MG, XTI and E0 ters. |) 3 |
| The block lets you include or exclude or capacitance modeling uses the publish different value than SPICE for capacit voltages across the internal junctions, capacitances are present. | capacitance modeling and initial conditions. The hed temperature equations, which may yield a slightly itance. The initial conditions ICVDS and ICVGS are the s, and are only effective when the corresponding juncti | on |
| Parameters | | |
| Main Junction Canacitance | Temperature | |
| Model temperature dependence using: Saturation current temperature | Device temperature | |
| Activation energy, EG: | 1 11 eV | |
| Offset local circuit temperature, TOFFSET: | | |
| Parameter extraction temperature TMEAS: | ³ / 300.15 | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | OK Cancel Help Appl | 1 |

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.

PJFET

| 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. Semiconductor Device Modeling with SPICE. 2nd Edition, McGraw-Hill, 1993. Chapter 3. | | |
| See Also | NJFET, P-Channel JFET | | |

Purpose Model Gummel-Poon PNP Transistor

Library SPICE-Compatible Semiconductors

Description

κ: PNP 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 2-237
- "Base Resistance Model" on page 2-241
- "Transit Charge Modulation Model" on page 2-241
- "Junction Charge Model" on page 2-242
- "Temperature Dependence" on page 2-244

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 237
- Terminal Currents on page 240
- Base Charge Model on page 240

Emitter-Base and Collector-Base Junction Currents

The base-emitter junction current is calculated using the following equations:

• When $V_{EB} > 80 * V_{TF}$:

$$I_{ebf} = IS * \left(\left(\frac{V_{EB}}{V_{TF}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{EB}$$
$$I_{ebe} = ISE * \left((V_{EB} - 80 * V_{TF} + V_{TE}) * \frac{e^{(80*V_{TF}/V_{TE})}}{V_{TE}} - 1 \right)$$

• 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 $V_{CB} \le 80 * V_{TR}$

$$I_{cbr} = IS * (e^{(V_{CB}/V_{TR})} - 1) + G_{\min} * V_{CB}$$
$$I_{cbc} = ISC * (e^{(V_{CB}/V_{TC})} - 1)$$

In the preceding equations:

• V_{EB} is the emitter-base voltage and V_{CB} is the collector-base voltage.

$$V_{TE} = NE * k * T / q, V_{TC} = NC * k * T / q, V_{TF} = NF * k * T / q, \text{ and}$$

 $V_{TR} = NR * k * T / q.$

- *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:

$$\begin{split} I_B &= -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)\\ I_C &= -\left(\frac{I_{ebf}}{q_b} - \frac{I_{cbr}}{BR} - I_{cbc}\right) \end{split}$$

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:

$$TF_{\rm mod} = \frac{TF * \left[1 + XTF * e^{V_{CB} / (1.44V_{TF})} \left(\frac{I_{EB}}{I_{EB} + ITF} \right)^2 \right]}{q_b}$$



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:

$$Q_{cb} = TR * I_{cb} + XCJC * Q_{dep}$$

• For the external base-collector junctions:

$$Q_{cb_{ext}} = (1 - XCJC) * Q_{dep}$$

 $Q_{\it dep}$ depends on the junction voltage, $V_{\it jct}$ ($V_{\it EB}$ for the emitter-base junction and $V_{\it CB}$ for the collector-base junction) as follows.


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*_{*ict*} 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 $Q_{\rm sc}$ 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 |
|--|--|
| $V_{sc} < 0$ | $Q_{sc} = CJS * VJS * \left(\frac{1 - (1 - V_{sc} / VJS)^{(1 - MJS)}}{1 - MJS}\right)$ |
| $V_{sc} \ge 0$ | $Q_{sc} = CJS * (1 + MJS * V_{sc} / (2 * VJS)) * V_{sc}$ |
| | whore |

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.

•
$$EG_{T_{meas}} = 1.16eV \cdot (7.02e \cdot 4 * T_{meas}^{2}) / (T_{meas} + 1108)$$

• $EG_T = 1.16eV - (7.02e - 4 * T^2) / (T + 1108)$

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:

Basic Assumptions and Limitations

- The PNP block does not support noise analysis.
- The PNP block applies initial conditions across junction capacitors and not across the block ports.

Dialog Box and Parameters

Main Tab

| | arameters: PNP | | | | |
|--|--|---|---|--|--|
| PNP | | | | | |
| This mode paramete noise mod | l approximates a s rs as instance par- lel parameters KF | 5PICE PNP transisto ameters on this ma: and AF are not sup | or. You specify sk. The instanc ported. | both model card and e parameters PTF a | l instance nd OFF and |
| SCALE is t current ar device pa paramete | the number of para nd device charge of rameters IS, IKF, rs RB, RBM, RE an | allel BJT instances f directly. This differs ISE, IKR, ISC, IRB, Id RC. | or this device. from the ARE/ CJE, ITF, CJC | SCALE multiplies the A parameter, which i and CJS, and divide | e output multiples the es the |
| You can s Custom El temperati | et the BJT temper- ectrical Environme ure sensitive parar | ature to a fixed ten ent block) plus TOFF meters. | nperature or to SET. The para | the circuit temperal meters XTB, XTI and | ture (from th I EG adjust |
| The block capacitan different voltages a capacitan | lets you include or ce modeling uses t value than SPICE I across the internal ces are present. | r exclude capacitan the published tempe for capacitance. Th junctions, and are | ce modeling an erature equation e initial condition only effective | d initial conditions. 1 ons, which may yield ons ICVBE and ICVCI when the correspon | The a slightly E are the Iding junction |
| Paramete | rs | | | | |
| Main | Forward Gain | Deverce Gain | Peristors | Capacitance Te | moerature |
| Device | area, AREA: | 1 | · | m^2 | _ |
| Numbe | s SCALE: | 1 | | | |
| Numbe device: | s, SCALE: |]1 | | | |
| Numbe device: | s, SCALE: | 1 | | | |
| Numbe device: | s, SCALE: | 1 | | | |
| Numbe device | s, SCALE: | 1 | | | |
| Numbe device: | s, SCALE: | <u>1</u> | | | |
| Numbe device: | s, SCALE: | J <u>1</u> | | | |
| Numbe device: | s, SCALE: | J <u> </u> | | | |
| Numbe device: | s, SCALE: | | | | |

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

🐱 Block Parameters: PNP X PNP-This model approximates a SPICE PNP 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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Forward Gain Reverse Gain Main. Resistors Capacitance Temperature Transport saturation 1e-16 A/m^2 • current, IS: Forward beta, BF: 100 Forward emission 1 coefficient, NF: B-E leakage current, ISE: 0 A/m^2 -B-E emission coefficient, 1.5 NE: Forward knee current, Inf A/m^2 • IKF: Forward Early voltage, Inf ۷ • VAE: OK. Cancel Help Apply

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 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

| 🙀 Block Parameters: PNP | | | | × | | |
|--|--|-----------|-------------|-------------|--|--|
| PNP | | | | | | |
| This model approximates a SPICE PNP 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 tempera Custom Electrical Environmer temperature sensitive param | You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. | | | | | |
| The block lets you include or capacitance modeling uses the different value than SPICE for voltages across the internal capacitances are present. | 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. | | | | | |
| Parameters | | | | | | |
| Main Forward Gain | Reverse Gain | Resistors | Capacitance | Temperature | | |
| Reverse beta, BR: | 1 | | | | | |
| Reverse emission | 1 | | | | | |
| B-C leakage current, ISC: | 0 | | A/m^2 | • | | |
| B-C emission coefficient, NC: | 2 | | | | | |
| Reverse knee current, | Inf | | A/m^2 | | | |
| Reverse Early voltage, VAR: | Inf | | V | • | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | ОК | Cance | I Help | Apply | | |
| | | | | | | |

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/m². 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

🖥 Block Parameters: PNP X PNP-This model approximates a SPICE PNP 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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. 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 ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Reverse Gain Resistors Main Forward Gain Capacitance Temperature Emitter resistance, RE: 0 m^2*Ohm • Collector resistance, RC: 0 • m^2*Ohm Zero-bias base • 0 m^2*Ohm resistance, RB: Minimum base resistance, 0 m^2*Ohm • RBM: Half base resistance cur, Inf A/m^2 Ŧ IRB: OK. Cancel Help Apply

Emitter resistance, RE

The resistance of the emitter. The default value is 0 $m^{2*}\Omega$ The value must be greater than or equal to 0.

Collector resistance, RC

The resistance of the collector. The default value is 0 $m^{2*}\Omega\,$ The value must be greater than or equal to 0.

Zero-bias base resistance, RB

The resistance of the collector. The default value is $0\ m^{2*}\Omega$ The value must be greater than or equal to 0.

Minimum base resistance, RBM

The resistance of the collector. The default value is 0 m^{2*} Ω 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: PNP | × |
|--|--------------------------------|
| PNP This model approximates a SPICE PNP transistor. You specify both model card and ins parameters as instance parameters on this mask. The instance parameters PTF and (pairs model parameters (FE) and (FE) are a prepared. | tance SFF and |
| SCALE is the number of parallel BJT instances for this device. SCALE multiplies the ou current and device charge directly. This differs from the AREA parameter, which mult device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides th parameters RB, RBM, RE and RC. | tput :iples the ne |
| You can set the BJT temperature to a fixed temperature or to the circuit temperature Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG temperature sensitive parameters. | ; (from the ; adjust |
| The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a s different value than SPICE for capacitance. The initial conditions ICVBE and ICVCE ar voltages across the internal junctions, and are only effective when the correspondin capacitances are present. | lightly e the g junction |
| Parameters Main Forward Gain Reverse Gain Resistors Capacitance Temp | erature |
| 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.
- 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/m². 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

| 🙀 Block Parameters: PNP | × | | | | |
|--|---|--|--|--|--|
| PNP | | | | | |
| This model approximates a SPICE PNP 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 temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. | | | | | |
| The block lets you include or exclude capacitance mo capacitance modeling uses the published temperatur different value than SPICE for capacitance. The initi voltages across the internal junctions, and are only capacitances are present. | deling and initial conditions. The e equations, which may yield a slightly al conditions ICVBE and ICVCE are the effective when the corresponding junction | | | | |
| Parameters | | | | | |
| Main Forward Gain Reverse Gain Res | stors Capacitance Temperature | | | | |
| Model temperature dependence Device tem | perature 💌 | | | | |
| Beta temperature exponent, XTB: 0 | | | | | |
| Energy gap, EG: 1.11 | eV | | | | |
| Temperature exponent for IS, XTI: 3 | | | | | |
| Offset local circuit temperature 0 TOFFSET: | K | | | | |
| Parameter extraction temperature, 300.15 | K | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| ок | Cancel 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 | PNP Bipolar Transistor |

Purpose Model PNP bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



The 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]:

$$\begin{split} I_{C} &= -I_{S} \left[\left(e^{-qV_{BE}/(kT)} - e^{-qV_{BC}/(kT)} \right) \left(1 + \frac{V_{BC}}{V_{A}} \right) - \frac{1}{\beta_{R}} \left(e^{-qV_{BC}/(kT)} - 1 \right) \right] \\ I_{B} &= -I_{S} \left[\frac{1}{\beta_{F}} \left(e^{-qV_{BE}/(kT)} - 1 \right) + \frac{1}{\beta_{R}} \left(e^{-qV_{BC}/(kT)} - 1 \right) \right] \end{split}$$

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- 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).

PNP Bipolar Transistor • *T* 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 $-qV_{_{BC}}/(kT) > 40$ or $-qV_{_{BE}}/(kT) > 40$, the corresponding exponential terms in the equations are replaced with

 $(-qV_{BC}/(kT)-39)e^{40}$ and $(-qV_{BE}/(kT)-39)e^{40}$, respectively. This helps prevent numerical issues associated with the steep gradient of the exponential function e^x at large values of x.

Similarly, if $-qV_{BC}/(kT) < -39$ or $-qV_{BE}/(kT) < -39$ then the corresponding exponential terms in the equations are replaced with

 $\left(-qV_{_{BC}}\,/(kT)+40\right)e^{-39}$ and $\left(-qV_{_{BE}}\,/(kT)+40\right)e^{-39}$, respectively.

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.

The PNP Bipolar Transistor model 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.
- You may need to use nonzero ohmic resistance and junction capacitance values to prevent numerical simulation problems, but the simulation may run faster with these values set to zero.

Basic Assumptions and Limitations

X

Dialog Box and Parameters

Main Tab

🙀 Block Parameters: 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

| Output admittance billoer | 50-05 | 1/Ohm | |
|---|--------|-------|--|
| Collector current at which b-parameters | J36-03 | | |
| are defined: | 1 | ImA 💌 | |
| Voltage Vbe: | 0.55 | V | |
| Current Ib for voltage Vbe: | 0.5 | mA 💌 | |
| Reverse current transfer ratio BR: | 1 | | |
| Measurement 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-05 1/ Ω

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.

Voltage Vbe

Base-emitter voltage when the collector current is zero and the base current is Ib. 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* and the collector current is zero. 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 at which *Vbe* and *Ib* or *IS* are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 25 $^{\circ}$ C.

Ohmic Resistance Tab

| ed bas | s the Early voltage err e-emitter and base-col | ect, and gives the ector capacitance | e option to includ es. For full detail: | e base, emitter a s of the equation | nd emitter resist s, consult the do | tances plu ocumentat |
|------------------|---|---|--|--|--|-------------------------|
| e equa ramete | tion parameters can ei rs | ther be specified | directly, or are d | erived from stan | dard datasheet p | parameter |
| Main | Ohmic Resistance | Junction Capac | itance | | | |
| Collect | or resistance RC: | 0.1 | | | Ohm | • |
| Emitter | r resistance RE: | 0.1 | | | Ohm | - |
| Zero b | ias base resistance RB | 0.1 | | | Ohm | - |
| | | | | | | |
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| | | | | | | |

Collector resistance RC

Resistance at the collector. The default value is $0.1\ \Omega$

Emitter resistance RE

Resistance at the emitter. The default value is $0.1\ \Omega$

Zero bias base resistance RB

Resistance at the base at zero bias. The default value is $0.1\ \Omega$

Junction Capacitance Tab

| block adds the Early voltage eff fixed base-emitter and base-co The equation parameters can e | fect, and gives the option Ilector capacitances. For f ither be specified directly | to include base, emit full details of the equa or are derived from : | ter and emitter resistan ations, consult the docu standard datasheet pa | nces plu umentat rameter |
|---|--|--|---|--------------------------------|
| Parameters | icher be specified directry, | | | Tamocol |
| Main Ohmic Resistance | Junction Capacitance |] | | |
| Base-collector capacitance: | 5 | | pF | • |
| Base-emitter capacitance: | 5 | | pF | - |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Base-collector capacitance

Parasitic capacitance across the base-collector junction. The default value is 5 pF.

Base-emitter capacitance

Parasitic capacitance across the base-emitter junction. The default value is 5 pF.

PNP Bipolar Transistor

| 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 Bipolar Transistor Characteristics demo. |
| 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 |

 Purpose
 Model ideal positive supply rail

Library Sources

Description

V+ Positive Supply Rail ┇

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 | 🙀 Block Parameters: Positive Supply Rail |
|-----------------------|--|
| Box and Parameters | 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 which must be positive. Do not attach more than one Positive Supply Rail block to any connected line. |
| | Parameters Constant voltage: |

| | Constant voltage The voltage at the output port relative to the Electrical Reference block ground port. The value must be greater than zero. 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 |

- Purpose
 Model simple distance sensor
- Library

Sensors

Description



Proximity Sensor

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: Prox | imity 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.D.) or Normally Closed (N.C.) when no object is detected. | | | | | |
| Parameters | | | | | |
| Vector of radial offset distances R: | [-25-20-15- | 10-50510 | 15 20 25] | mm | • |
| Corresponding sensing distances Z: | 00589.5 | 109.5850 | 0] | mm | • |
| Output when not detected: | Normally Oper | n (N.O.) | | | ▪ |
| Closed resistance R_closed: | 0.01 | | | Ohm | ◄ |
| Open conductance G_open: | 1e-08 | | | 1/0hm | |
| | | | | | |
| | | | | | |
| | | | | | |
| | ОК | Cancel | Help | App | y |

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:

- PS Sensor
- 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 | Sensor > |
|---|--|
| PS Sensor | |
| This block implements a ge into an electrical output vo ports, depending on the se equation: | eneric linear sensor. The physical signal input U is converted Itage Y, output current Y or resistance Y across the + and - lected Output type. Y is related to U with the following |
| Y = max(min(A*U + B,Ymax |),Ymin) |
| where Ymin and Ymax are resistance in ohms, depend Variable resistance, then th | limits on the output voltage in volts, current in amps or ding on the selected Output type. If the Output type is set to ne 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 $Y_{\rm max}$ and $Y_{\rm min}$. 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_{\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 periodic square pulse current source

Library SPICE-Compatible Sources

Description

Dulse Current Source

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.
- *I2* 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.

Dialog Box and Parameters

| 🙀 Block Parameters: P | ulse Current Source | × |
|--|---|---|
| Pulse Current Source— | | |
| The Pulse Current Source independent of the volta current through the bloc | e block maintains a pulsed current thi age across its terminals. The following k as a function of time: | rough its terminals,) table describes the |
| Iout(0) = I1 | | |
| Iout(TD) = I1 | | |
| Iout(TD+TR) = I2 | | |
| Iout(TD+TR+PW) = I2 | | |
| Iout(TD+TR+PW+TF) = | II | |
| Iout(TD+PER) = I1 | | |
| The block determines the is the delay time. TR is t | e values at intermediate time points b he rise time. TF is the fall time. PW is | y linear interpolation. TD the pulse width. |
| The default values for T times are one nanoseco | R, TF, PW and PER differ from SPICE nd (1e-9), and the values of TR and 1 | . The default rise and fall IF 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 | s 💌 |
| | | |
| | | |
| | OK Cancel | Help Apply |

Initial value, I1

The value of the output current at time zero. The default value is 0 $\ensuremath{A}\xspace$

| | 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 Sources

Description

Pulse Voltage Source

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: P | ulse Voltage S | ource | | × |
|--|---|--|---|----------------|
| Pulse Voltage Source- | | | | |
| The Pulse Voltage Source independent of the curre voltage across the block | e block maintains ent through its te as a function of | a pulsed voltage . rminals. The follow time: | across its terminals, wing table describes th | ne |
| 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 is the delay time. TR is t | e values at intern he rise time. TF is | nediate time point: ; the fall time. PW | s by linear interpolatio is the pulse width. | n. TD |
| The default values for T times are one nanoseco | R, TF, PW and Pf nd (1e-9), and th | R differ from SPI e values of TR an | CE. The default rise ar d TF can be set to zer | nd fall :o. |
| -Parameters | | | | |
| Initial value, V1: | 0 | | V | • |
| Pulse value, V2: | 0 | | V | • |
| 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 | | s | • |
| | | | | |
| | | | | |
| | ОК | Cancel | Help A | pply |

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 Model polynomial voltage-controlled current source

Library SPICE-Compatible 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.

Dialog Box and Parameters

| 🙀 Block Parameters: PVCC5 |
|---|
| -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: [0 1] |
| |
| |
| 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.

Ports

See Also PCCCS, PCCVS, and PVCVS

PVCVS

Purpose Model polynomial voltage-controlled voltage source

Library SPICE-Compatible Sources

Description



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

Ports

| 🙀 Block Parameters: PVCVS 🛛 🔀 |
|---|
| 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: |
| $\label{eq:Vout} {\sf Vout} = {\sf p}(0) + {\sf p}(1)^* {\sf Vin} + \ldots + {\sf p}(n{\text{-}}1)^* {\sf Vin}^{(n{\text{-}}1)} + {\sf p}(n)^* {\sf Vin}^n$ |
| 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.

See Also PCCCS, PCCVS, and PVCCS

 Purpose
 Model lookup table current source

Library SPICE-Compatible Sources

Description

PWL Current Source

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.

| Dialog | Block Parameters: F | PWL Current Source | × |
|------------|---|---|--|
| Box and | PWL Current Source- | | |
| Parameters | The Piecewise Lookup C (Time, Current) to speci equivalent, this source determine output currer last point or last two po | urrent Source (PWL) block uses time- fy a time dependent current wavefor can use linear, cubic or spline interpol nt values at intermediate time points. ints method for extrapolation. | current pairs of the form m. Like its SPICE ation methods to The block can use either |
| | 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 [01234] 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 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 Voltage Source

PWL Voltage Source

 Purpose
 Model lookup table voltage source

Library SPICE-Compatible Sources

Description

PWL Voltage Source

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.

| nd eters | Block Parameters: PWL Voltage Source PWL Voltage Source The Piecewise Lookup Voltage Source (PWL) block uses time-voltage pairs of the form (Time, Voltage) to specify a time dependent voltage waveform. Like its SPICE equivalent, this source can use linear, cubic or spline interpolation methods to determine output voltage values at intermediate time points. The block can use either last point or last two points method for extrapolation. Parameters Time specification: [01234] s Voltage at specified [00000] V Interpolation method: Linear | |
|-------------|---|--|
| | OK Cancel Help Apply | |

Dialog Box and Parameters

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 [01234] 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 brushless motor with closed-loop torque control

Library

Actuators & Drivers

Description



Servomotor

The Servomotor block represents a brushless motor 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 allows the range of torques and speeds defined by the torque-speed envelope that comes from the motor manufacturer. You specify this data in the block dialog box as a set of speed data points and the corresponding maximum torque values. The one in the following figure shows a typical torque-speed envelope for a servomotor.



The block limits any demand applied to its reference demand port Tr to values within the defined torque-speed envelope.

Note For numerical reasons, you must not specify an infinite slope at $N_{\max}{\cdot}$

The block models the electrical losses in the motor using an equivalent resistance R in series with the DC supply to the motor and driver. Compute the equivalent resistance for your motor in terms of the manufacturer-quoted efficiency level E at some rated torque T and speed ω as follows:

1 Equate the power used by the servomotor to the mechanical power plus the electrical losses. In terms of the DC supply voltage (V) and current (I), this means

$$VI = T\omega + I^2 R$$

2 Define the efficiency of the servomotor as the mechanical power into the motor divided by the total electrical power supplied:

$$E = \frac{T\omega}{VI}$$

3 Solve the preceding equations for R:

$$R = \frac{EV^2}{T\omega} (1 - E)$$

The block produces a positive torque acting from the mechanical C to R ports.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The motor driver tracks a torque demand with a time constant Tc.
- The motor torque tracking is not affected by motor speed fluctuations due to mechanical load.
- Motor electrical losses are proportional to the square of the DC supply current.

Servomotor

Dialog Box and Parameters

Electrical Torque Tab

| _ | | | | | | | |
|--|--|--|--|---|--|---|---|
| Servo | motor — | | | | | | |
| This b range outpu motor value: 2*wm RPM a | lock represents of torques and t torque is assu manufacturer (s to [Tmax Tma ax] where Tma and ens is a sma | a servom speeds is med to tra does not o × 0 0] and × is the ra all nositive | notor with s defined ack the t define an d the vec ated maxis | h closed-lo l by the ma corque refe n envelope tor of RPM imum conti e.g. 0.01. | op torque contr nufacturer toro rence demand , then set the v 1 values to [0 (1 nuous torque, v | ol. The motor's p que-speed envelor Tr with time cons rector of maximu (-eps)*wmax (1- wmax is the max | oermissible ope, and t stant Tc. If m torque Feps)*wma imum spee |
| The co repres chose inform | ontrolled servor sented by I^2* n to match man nation on how to | motor sho R where I hufacturer o determir | uld be co I is the D r defined ne R. | onnected to C supply c motor loss | o a DC supply. I urrent and R is es. Consult the | Motor electrical lo a series resistan documentation | osses are ce with va for further |
| The bl | lock produces a | i positive t | torque ac | ting from | the mechanical | C to R ports. | |
| | | | | | | | |
| Param | eters | | | | | | |
| ^p aram Fler | eters | Mechan | pical Ì | | | | |
| Param Elec | eters ctrical Torque | Mechar | nical | | | | |
| Param Elec Vec | ieters :trical Torque | Mechar al speeds i | nical in RPM: | [03.75 | e+03 7.5e+03 | 8e+03] | |
| Param Elec Vec Vec | eters trical Torque tor of rotationation tor of maximun | Mechar al speeds i n torque v | nical in RPM: values in | [0 3.75 [0.09 0 | e+03 7.5e+03 .08 0.07 0] | 8e+03] | |
| Param Elec Vec Vec Nm Tor | eters strical Torque stor of rotationa tor of maximun s que control tim | Mechar al speeds i n torque v e constan | nical in RPM: values in it, Tc: | [0 3.75 [0.09 0 0.02 | e+03 7.5e+03 .08 0.07 0] | 8e+03] | |
| Param Elec Vec Nm Tor Sup ele | eters ctrical Torque ctor of rotationa ctor of maximun ctor of maximun ctrical control tim poply series resis ctrical losses: | Mechar al speeds i n torque v e constan stance R to | nical in RPM: values in it, Tc: o model | [0 3.75 [0.09 0 0.02 3.5 | e+03 7.5e+03 .08 0.07 0] | 8e+03] 5 Ohm | |
| Param Elec Vec Nm Tor Sup ele | eters ctrical Torque ctor of rotationa ctor of maximun ctor of maximun ctrical losses; | Mechar al speeds i n torque v e constan stance R to | nical in RPM: values in it, Tc: o model | [0 3.75 [0.09 0 [0.02 [3.5 | e+03 7.5e+03 .08 0.07 0] | 8e+03] s Ohm | Ţ |
| Param Elec Vec Vec Nm Tor Sup ele | eters trical Torque tor of rotationa tor of maximum que control tim oply series resis ctrical losses: | Mechar al speeds i n torque v e constan stance R to | nical in RPM: values in it, Tc: o model | [0 3.75 [0.09 0 [0.02 [3.5 | e+03 7.5e+03 .08 0.07 0] | 8e+03] 5 Ohm | Ţ |
| Param Elec Vec Nm Tor Sup ele | eters ctrical Torque ctor of rotations ctor of maximum c que control tim oply series resis ctrical losses: | Mechar al speeds i n torque v e constan stance R to | nical in RPM: values in it, Tc: o model | [03.75 [0.090 [0.02 [3.5 | e+03 7.5e+03 .08 0.07 0] | 8e+03] 5 Ohm | x |

Vector of rotational speeds in RPM

Rotational speeds for permissible steady-state operation. The default value is [0 3.75e+03 7.5e+03 8e+03].

Vector of maximum torque values in Nm

Maximum torque values for permissible steady-state operation. These values correspond to the speeds in the **Vector of rotational** **speeds in RPM** parameter and define the torque-speed envelope for the motor. The default value is $[0.09\ 0.08\ 0.07\ 0]$.

Torque Control time constant, Tc

Time constant with which the motor driver tracks a torque demand. The default value is 0.02 s.

Supply series resistance R to model electrical losses

The equivalent resistance used in series with the DC supply to model electrical losses in the motor. The default value is $3.5~\Omega$

Mechanical Tab

| ange of torques and spec output torque is assumed | eds is defined by the manu to track the torque refere | ifacturer torqu nce demand T | ue-speed envelope, and the r with time constant Tc. If th |
|--|---|-----------------------------------|--|
| notor manufacturer does values to [Tmax Tmax 0 0 | not define an envelope, th] and the vector of RPM v. | hen set the ve alues to [0 (1- | ector of maximum torque eps)*wmax (1+eps)*wmax |
| 2*wmax] where Tmax is t RPM and eps is a small po: | he rated maximum continu sitive number e.g. 0.01. | ous torque, w | max is the maximum speed i |
| The controlled servomotor | r should be connected to a | DC supply. M | otor electrical losses are |
| epresented by I^2*R wh hosen to match manufac | ere I is the DC supply curr turer defined motor losses | ent and R is a . Consult the i | series resistance with value documentation for further |
| nformation on how to det | ermine R. | | |
| The block produces a posi | tive torque acting from the | e mechanical C | to R ports. |
| arameters | | | |
| Electrical Torque M® | echanical | | |
| Listingar inique | | | |
| Rotor inertia: | 5e-06 | | kg*m^2 💌 |
| Rotor inertia: Rotor damping: | 5e-06 1e-05 | | kg*m^2 |
| Rotor inertia: Rotor damping: Initial rotor speed: | 5e-06 1e-05 0 | | kg*m^2 |
| Rotor inertia: Rotor damping: Initial rotor speed: | 5e-06 1e-05 0 | | kg*m^2 N*m/(rad/s) rpm |
| Rotor inertia: Rotor damping: Initial rotor speed: | 5e-06 1e-05 0 | | kg*m^2 |

Rotor inertia

Rotor inertia. The default value is $5e\mathchar`e\mar$

Rotor damping

Rotor damping. The default value is $1e\,{-}\,05$ 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 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 | DC Motor, Induction Motor, Shunt Motor, and Universal Motor. |

SFFM Current Source

 Purpose
 Model single-frequency FM current source

Library SPICE-Compatible Sources

Description

SFFM Current Source

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.

| Dialog | |
|-------------------|---|
| Box and | |
| Parameters | 6 |

| modulated current throu terminals. The following | ugh its terminals, independent of th equation describes the current thro | e voltage across its bugh the SFFM source as a |
|---|---|---|
| function of time: | | - |
| Iout = IO + IA*sin((2*pi)) | *FC*Time)+MI*sin(2*pi*FS*Time)) | |
| IO is the current offset carrier frequency. MI is default values for carrie equal to zero. | value. IA is the magnitude of the si the signal modulation index. FS is tl r (FC) and signal (FS) frequencies o | gnal current. FC is the he signal frequency. The differ from SPICE, and are |
| Parameters | | |
| Current offset, IO: | 0 | A |
| Current amplitude, IA: | 0 | A |
| Carrier frequency, FC: | 0 | Hz |
| | 0 | |
| Modulation index, MI: | | Hz |
| Modulation index, MI: | 0 | |

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 Sources

Description

SFFM Voltage Source

The 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 | × | | | | |
|--|--|---|--|--|--|--|
| -SFFM Voltage Source- | | _ | | | | |
| The Single-Frequency FM Voltage (SFFM) Source block maintains a frequency- modulated voltage across its terminals, independent of the current through its terminals. The following equation describes the voltage across the SFFM source as a function of time: | | | | | | |
| Vout = VO+VA*sin((2*p | *FC*Time)+MI*sin(2*pi*FS*Time)) | | | | | |
| VO is the voltage offset carrier frequency. MI is default values for carrie equal to zero. | 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 | I | | | | |
| Voltage amplitude, VA: | 0 V 💌 | I | | | | |
| Carrier frequency, FC: | 0 Hz 💌 | 1 | | | | |
| Modulation index, MI: | 0 | | | | | |
| Signal frequency, FS: | 0 Hz 💌 | I | | | | |
| | | | | | | |
| | | | | | | |
| | 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. - Nogative electrical voltage |
| See Also | SFFM Current Source |

Shunt Motor

Purpose Model electrical and torque characteristics of shunt motor

Library

Actuators & Drivers

Description

shur

Shunt Motor

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_{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 :

$$\begin{split} i_f &= \frac{V}{R_f} \\ i_a &= \frac{V}{R_a} \Biggl(1 - \frac{L_{af} w}{R_f} \Biggr) \end{split}$$

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.

Shunt Motor

Dialog Box and Parameters

| hunt Motor his block represents the el esitance), La (armature inc iductance) and Laf (back-e b = Laf * If * W where If i Iteratively, the motor char speed, nominal voltage, s rmature or field winding in | ectrical and torque ch e defined in terms of Juctance), Rf (field w mf constant). The ba s the field current an "acteristics can be del tarting current, La ar Juctance, these para | haracteristics of equivalent circui inding resistanc ack emf induced id W is the mech fined in terms of nd Lf. If no infoi ameters can be s | a shunt motor. It parameters Ra e), Lf (field wind in the armature ianical angular sp i no-load speed, rmation is availat set to a small nor |) (armature ing is given by peed. rated powe ple on 1-zero value |
|---|--|---|---|--|
| his block represents the el lotor characteristics can be esitance), La (armature inc iductance) and Laf (back-e b = Laf * If * W where If i literatively, the motor char speed, nominal voltage, s rmature or field winding in | ectrical and torque ch a defined in terms of Juctance), Rf (field w mf constant). The ba s the field current an "acteristics can be del tarting current, La ar Juctance, these para | haracteristics of equivalent circui inding resistance ack emf induced id W is the mech fined in terms of nd Lf. If no infor ameters can be s | a shunt motor. It parameters Ra e), Lf (field wind in the armature anical angular sp i no-load speed, rmation is availat set to a small nor |) (armature ing is given by peed. rated powe ple on 1-zero value |
| lotor characteristics can be esitance), La (armature inc iductance) and Laf (back-e b = Laf * If * W where If i literatively, the motor char speed, nominal voltage, s rmature or field winding in | e defined in terms of a Juctance), Rf (field w emf constant). The ba s the field current an acteristics can be del tarting current, La ar Juctance, these para | equivalent circui inding resistance ack emf induced id W is the mech fined in terms of nd Lf. If no infor ameters can be s | it parameters Ra e), Lf (field wind in the armature anical angular sp i no-load speed, rmation is availat iet to a small nor | a (armature ing is given by peed. rated powe ple on n-zero value |
| he block produces a positiv | e torgue acting from | the mechanical | C to R ports. | |
| ne block produces a posici | /e corque acting from | n the mechanical | C to R ports. | |
| arameters | | | | |
| Electrical Torque Mec | hanical | | | |
| Model parameterization: | 3y equivalent circuit p | parameters | | ~ |
| Armature resistance: | 110 | | Ohm | - |
| Field winding resistance: | 2.5e+03 | | Ohm | • |
| Back-emf constant: | 5.11 | | s*V/rad/A | - |
| Armature inductance: | 0.1 | | н | - |
| Field winding | 0.1 | | Н | • |
| | | | | |
| | | | | |
| | | | | |
| | | | 1 | |

Model parameterization

Electrical Torque Tab

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 110 Ω

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 Ω

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

| 당 Block Parameters: | Shunt Motor | | | × | | |
|--|-----------------------------|-------------------|----------------|-------|--|--|
| Shunt Motor | | | | | | |
| This block represents th | ne electrical and torque ch | haracteristics of | a shunt motor. | | | |
| This block represents the electrical and torque characteristics or 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 | | | | | | |
| | Machanical | | | | | |
| Electrical lorque | | | | | | |
| Rotor inertia: | 2e-04 | | kg*m^2 | • | | |
| Rotor damping: | 1e-06 | | N*m/(rad/s) | • | | |
| Initial rotor speed: | 0 | | rpm | • | | |
| | | | | | | |
| | ОК | Cancel | Help | Apply | | |

Rotor inertia

Rotor inertia. The default value is $2e\mbox{-}04\ kg^*m^2$. The value can be zero.

Rotor damping

Rotor damping. The default value is $1e\,\text{-}\,06$ 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. |
|------------|---|
| Ports | The block has the following ports: |
| | + Positive electrical input. |
| | - Negative electrical input. |
| | C Mechanical rotational conserving port. |
| | R Mechanical rotational conserving port. |
| References | [1] Bolton, W. Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 3rd edition Pearson Education, 2004. |
| See Also | DC Motor, Induction Motor, Servomotor, and Universal Motor. |

Sinusoidal Current Source

Purpose Model damped sinusoidal current source

Library SPICE-Compatible Sources

Description

Sinusoidal Current Source

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:

$$I_{out} (Time < TD) = IO$$
$$I_{out} (Time \ge TD) = IO + IA * e^{-(Time - TD)*DF} * \sin(2\pi * FREQ * (Time - TD))$$

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.

Dialog Box and Parameters

| 🙀 Block Parameters: Si | nusoidal Current Source | × | | | | |
|--|--|--|--|--|--|--|
| -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 | -TD)*DF)*sin(2*pi*FREQ*(Time-TD) |) | | | | |
| IO is the current offset va frequency of the signal. 1 The default value for free | alue. IA is the magnitude of the sign: D is the signal time delay. DF is the juency (FREQ) differs from SPICE, a | al current. FREQ is the signal damping factor. nd 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, DF The amount by which to amplify or reduce the exponential damping term that multiples the sine wave to produce the outp 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. |

output

See Also Sinusoidal Voltage Source Purpose Model damped sinusoidal voltage source

Library SPICE-Compatible Sources

Description

Sinusoidal Voltage Source

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.

Dialog Box and Parameters

| 당 Block Parameters: 1 | Sinusoidal Volta | age Source | | x | | |
|--|--|--|--|-----------------------------------|--|--|
| Sinusoidal Voltage Sour | ce | | | | | |
| 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 frequency of the signal The default value for fr | t value. VA is the . TD is the signal equency (FREQ) | magnitude of the time delay. DF is tl differs from SPICE | signal voltage. FF ne signal damping , and is equal to | REQ is the factor. 1 MHz. | | |
| -Parameters | | | | | | |
| Voltage offset, VO: | 0 | | V | • | | |
| Sinusoidal amplitude, VA: | 0 | | V | - | | |
| 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 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 $0 ext{ s. The value can be less than } 0.$

| | 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

| Model | single | solar | cell |
|-------|--------|--------------|-----------------------|
| | Model | Model single | Model single solar |

Library Sources

Solar Cell

Description

The Solar Cell block represents a single solar cell as a parallel current source and exponential diode that are connected in series with a resistance Rs. The output current I is:

$$I = I_{ph} - Is \times \left(e^{(V+I \times R_S)/(NV_t)} - 1\right)$$

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} .
- *Is* is the diode saturation current.
- V_t is the thermal voltage, kT/q, where:
 - k is the Boltzmann constant (1.3806503e-23 J/K).
 - *T* is the **Measurement temperature** parameter value.
 - q is the elementary charge on an electron (1.602176e–19 Coulombs).
- N is the quality factor (diode emission coefficient).
- *V* is the voltage across the solar cell electrical ports.

The quality factor varies for amorphous cells, and is typically 2 for polycrystalline cells.



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.

Basic Assumptions and Limitations

The Solar Cell model 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.

Solar Cell

Dialog Box and **Parameters**

| 🙀 Block Parameters: 9 | õolar Cell | × | | | |
|--|---|--|--|--|--|
| – Solar Cell – | | | | | |
| This block models a sing that are connected in se | le solar cell as a parallel current sourc eries with a resistance Rs. The output | e and exponential diode current I is given by | | | |
| I = Iph - Is*(e^((V+I*f | Rs)/(N*Vt)) -1) | | | | |
| where Is is the diode saturation current, Vt is the thermal voltage, N is the quality factor (diode emission coefficient) and Iph is the solar-generated current. The quality factor varies for amorphous cells, and is typically 2 for polycrystalline cells. 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 Iph0*Ir/Ir0 where Iph0 is the measured solar-generated current for irradiance Ir0. | | | | | |
| -Parameters | | | | | |
| Parameterize by: | By s/c current and o/c voltage | | | | |
| Short-circuit current, Isc: | 7.34 | A | | | |
| Open-circuit voltage, Voc: | 0.6 | V | | | |
| Measurement temperature: | 25 | C 💌 | | | |
| Irradiance used for measurements, Ir0: | 1000 | W/m^2 | | | |
| Quality factor, N: | 1.5 | | | | |
| Series resistance, Rs: | 0 | Ohm 💌 | | | |
| | | | | | |
| | | | | | |
| | OK Cancel | Help Apply | | | |

Parameterize by

Select one of the following methods for block parameterization:

- By s/c current and o/c voltage 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 method.
- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor.

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 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 for the **Parameterize by** parameter. The default value is 0.6 V.

Diode saturation current, Is

The asymptotic reverse current for increasing reverse bias in the absence of any incident light. This parameter is only visible when you select By equivalent circuit parameters for the **Parameterize by** parameter. The default value is 1e-06 A.

Measurement temperature

The temperature at which Is is measured and at which the solar cell is simulated. The default value is 25 C.

Solar-generated current, Iph0

The solar-induced current when the irradiance is I_{r0} . This parameter is only visible when you select By equivalent circuit parameters 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 diode emission coefficient. The default value is 1.5.

Series resistance, Rs

The series terminal resistance. The default value is 0 Ω

Ports The block has the following ports:

Solar Cell

Ir Incident irradiance.

+

_

Positive electrical voltage.

Negative electrical voltage.

Purpose Model electrical characteristics and generated force of solenoid

Library Actuators & Drivers

Description

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 α 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 α and β by taking the two specified force and stroke measurements and substituting them into the preceding equation. It solves the resulting equations for α 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.

Dialog Box and Parameters

| Magnetic | Force | Tab |
|----------|-------|-----|
|----------|-------|-----|

| 🙀 Block Parameters: S | olenoid | | | X | | |
|--|------------------|---------------|------|-------|--|--|
| 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>0 are stoke values and F1>F2>0 are corresponding forces. The plunger fully in (i.e. air gap closed) corresponds to X=0, 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 the electrical + to - ports results in a negative force (i.e. pulling force) acting force the mechanical C to B ports. | | | | | | |
| pulling force) acting from | the mechanical (| C to R ports. | | | | |
| Parameters | | | | | | |
| Magnetic Force M | echanical 📔 | | | 1 | | |
| Forces [F1 F2]: | [7.5 0.75] | | N | • | | |
| Stroke [X1 X2]: | [15] | | mm | • | | |
| Rated voltage Vdc: | 50 | | V | • | | |
| 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 | X | | | |
|---|---|------------|--|--|--|
| 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>0 are stoke values and F1>F2>0 are corresponding forces. The plunger fully in (i.e. air gap closed) corresponds to X=0, 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 str set by the Contact stiffne are used to model the cor constant parameter is use can be set to zero. A positive current from th pulling force) acting from | 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 the electrical + to - ports results in a negative force (i.e. pulling force) acting from the mechanical C to R ports. | | | | |
| Parameters | | | | | |
| Magnetic Force Me | Magnetic Force Mechanical | | | | |
| Spring constant: | 200 | N/m 💌 | | | |
| Stroke for zero spring force: | 5 | mm | | | |
| Damping: | 1 | N/(m/s) | | | |
| 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) | | | |
| | | | | | |
| | OK 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 150 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 | [1] S Appl | .E. Lyshevski. Electromechanical Systems, Electric Machines, and ied MechatronicsCRC, 1999. |

SPICE Environment Parameters

PurposeSet parameters that apply to all connected SPICE-compatible blocksLibraryUtilitiesDescriptionThe SPICE Environment Parameters block lets you set parameters that
apply to all SPICE-compatible blocks in an electrical network:SPICE Environment
ParametersCircuit temperature
• Minimum conductanceIf your Simulipl® model does not contain a SPICE Environment

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

| SPICE Environment Para SPICE Environment Para This block controls the SI in the electrical network parameters have a direc Solver parameters and/o | PICE Environment Parameters meters PICE environment parameters of to which it is connected. Not all it t equivalent in SimElectronics, ar or parameters in the Solver Conf | all SPICE-compatible blocks SPICE environment nd many relate to Simulink iguration block. |
|---|---|--|
| Parameters SPICE | | 1 |
| Circuit temperature: Minimum conductance, GMIN: | 300.15 1e-12 | K I/Ohm |
| | OK 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.

Stepper Motor

| Purpose | Model stepper motor |
|---------|---------------------|
|---------|---------------------|

Library

Actuators & Drivers

Description

Stepper Motor

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:

$$\frac{di_A}{dt} = \left(v_A - Ri_A + K_m \omega \sin(N_r \theta)\right) / L$$

$$\frac{di_B}{dt} = \left(v_B - Ri_B + K_m \omega \cos(N_r \theta)\right) / L$$

$$\frac{d\omega}{dt} = \left(-K_m i_a \sin(N_r \theta) + K_m i_b \cos(N_r \theta) - B\omega\right) / J$$

$$\frac{d\theta}{dt} = \omega$$

where:

- i_A and i_B are the A and B phase winding currents.
- v_A and v_B are the A and B phase winding voltages.
- K_m is the motor torque constant.
- N_r is the number of rotor teeth. The **Full step size** parameter is $2\pi/N_r$.
- *R* is the winding resistance.
- *L* is the winding inductance.
- *B* is the rotational damping.
- *J* is the inertia.



If the initial rotor is zero or some multiple of $2\pi/N_r$, 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.

The model is based on the following assumptions:

Basic 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 SimscapeTM Solver Configuration block, this block will not initialize an **Initial rotor angle** value between −π and π.

Stepper Motor

Dialog Box and Parameters

Electrical Torque Tab

| Block Parameter | rs: Stepper Moto | or | | × |
|--|------------------|--------|-------|----------|
| This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The block 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 2*pi/Nr, then the rotor is aligned with the A-phase winding, a condition that 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- | | | | |
| -Parameters | | | | |
| Electrical Torque | Mechanical | | | 1 |
| Phase winding resistance: | 0.55 | | Ohm | • |
| Phase winding inductance: | 0.0015 | | н | · |
| Motor torque constant: | 0.19 | | N*m/A | • |
| Full step size: | 1.8 | | deg | • |
| | | | | |
| | ОК | Cancel | Help | Apply |

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 $0.0015\ \mathrm{H}.$

Motor torque constant

Motor torque constant K_m . The default value is 0.19 N*m/A.

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 Moto | or 👘 | | × |
|---|----------------|--------|-------------|-------|
| Stepper Motor | | | | |
| This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The block 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 2*pi/Nr, then the rotor is aligned with the A-phase winding, a condition that 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 | | | | |
| Rotor inertia: | 4.5e-05 | | kg*m^2 | |
| Rotor damping: | 8e-04 | | N*m/(rad/s) | - I |
| Initial rotor speed: | 0 | | rpm | • |
| Initial rotor angle: | 0 | | deg | • |
| | | | | |
| | | | | |
| | ОК | Cancel | Help | Apply |

Rotor inertia

Resistance of the rotor to change in motor motion. The default value is $4.5e{-}05~kg^{*}m^{2}.$ 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.

Stepper Motor

| | Initial rotor speed Speed of the rotor at the start of the simulation. The default value is 0 rpm. | | | |
|------------|---|--|--|--|
| | Initial rotor angle Angle of the rotor at the start of the simulation. The default value is 0 rad. | | | |
| Ports | The block has the following ports: | | | |
| | A+ Positive electrical output of pulse A. | | | |
| | A- Negative electrical output of pulse A | | | |
| | B+ Positive electrical output of pulse B. | | | |
| | B- Negative electrical output of pulse B. | | | |
| | C Mechanical rotational conserving port. | | | |
| | R Mechanical rotational conserving port. | | | |
| Examples | See the Controlled Stepper Motor demo. | | | |
| 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. <i>Stepping Motors: A Guide to Modern Theory and Practice</i> . New York: Peregrinus, 1982. | | | |

[3] S.E. Lyshevski. *Electromechanical Systems, Electric Machines, and Applied Mechatronics*. CRC, 1999.

See Also Stepper Motor Driver

Stepper Motor Driver

| Purpose Model stepper moto | or driver |
|----------------------------|-----------|
|----------------------------|-----------|

Library Actuators & 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**.

REW If the voltage at the REV port is less than or equal to the **Reverse** Stepper Motor Driver **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, which is controlled by Simulink[®], you need to set a suitably small time step for the simulation. For information about specifying the Simulink step size, see "Choosing a Solver" in the Simulink User's Guide.
| Dial | bg |
|------|---------|
| Box | and |
| Para | imeters |

| 🙀 Block Parameters | : Stepper Motor Driv | ver | | X | |
|---|--|-------------------|-----------|-------|--|
| 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 voltag pulse A leads pulse B B leads pulse A by 90 A is initialized positive | 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 | 1 and REF are defined i | relative to the F | 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 - | 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 demo. |
| See Also | Cont | rolled PWM Voltage and Stepper Motor. |

Strain Gauge

 Purpose
 Model deformation sensor

Sensors

Library

Description

▷ █<mark>ॖ</mark> ₽

Strain Gauge

 $\frac{\Delta R}{R} = K\varepsilon$

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

| Strain Gauge This block models a physical signal input unstressed gauge res | strain gauge. The port and change ir sistance and K is t | relationship be n resistance dF he gauge facto | tween strain Epre: 3 is dR/R = K*Ewł or. | sented at the here R is the |
|--|--|--|--|--------------------------------|
| Parameters | | | | |
| Gauge resistance: | 100 | | Ohm | • |
| Gauge factor: | 2 | | | |
| | | | | |
| | | | | |
| | | | | |

Gauge resistance

The unstressed gauge resistance. The default value is 100 $\boldsymbol{\Omega}$

The Strain Gauge block represents a sensor that generates a change in

resistance as a function of strain using the following equation:

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

▫+₽⊤ ₀_┎╯╲╲╲╱╌[┍]╵

 $R = R_0(1 + \alpha(T - T_0))$

Thermal Resistor where:

• R_0 is the nominal resistance at the reference temperature T_0 .

The Thermal Resistor block represents a temperature-dependent resistor. The resistance when the temperature at the thermal port is T is

• α is the temperature coefficient.

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.

Thermal Resistor

Dialog Box and Parameters

Electrical Tab

| Block Parameters: Thermal Resistor 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 = $Q + i 2^{R}(T)$ 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 | | 1 | | | |
| Nominal resistance: | 1 | Ohm 💌 | | | |
| Reference temperature: | 25 | C 🔽 | | | |
| Temperature coefficient: | 5e-05 | 1/K | | | |
| | | | | | |
| | OK Cancel | Help Apply | | | |

Nominal resistance

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 1 Ω

Reference temperature

The temperature at which the nominal resistance was measured. The default value is 25 °C.

Temperature coefficient

The coefficient α in the equation that describes resistance as a function of temperature. The default value is 5e-05 1/K.

Thermal Tab

| Block Parameters: T Thermal Resistor This block represents a r given by R(T) = R0*(1+ Reference temperature T of the resistor is gover the net heat flow into po i is the current. The ther and the Dissipation factor | Block Parameters: Thermal Resistor Thermal Resistor This block represents a resistor with a thermal port. The resistance at temperature T is given by $R(T) = RO^*(1+a pha(T-TO))$ 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 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 | Parameters Electrical Thermal | | | | |
| Thermal time constant: | 10 | s 💌 | | | |
| Dissipation factor: | 0.001 | W/K 💽 | | | |
| Initial temperature: 25 C 💌 | | | | | |
| | | | | | |
| | | | | | |
| | OK Cancel | 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 25 °C.

Ports The block has the following ports:

| A | Resistor thermal port. |
|---|---------------------------|
| + | Positive electrical port. |
| - | Negative electrical port. |

See Also

Thermistor, Thermocouple.

Purpose Model NTC thermistor using B-parameter equation

Library Sensors

Description

▫♣D⊤ ▫₄┎┎╱══┶╴╸ The Thermistor block represents an NTC thermistor using the B-parameter equation. The resistance at temperature T is

$$R = R_0 (e^{B(1/T - 1/T_0)} - 1)$$

Thermistor

- 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:

where:

- *Q* is the net heat flow into port A.
- *K_d* is the **Dissipation factor K_d** parameter value.
- *t_c* is the **Thermal time constant t_c** parameter value.
- dT/dt is the rate of change of the temperature.

To model the thermistor in free space:

- 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} .

Electrical Tab

| Thermistor This block represents an NTC thermisitemperature T is given by $R(T) = R0^4$ the reference temperature T0, and B temperature T of the thermistor is go net heat flow into port A, m is the ma- mass m*c is calculated from the Thermistor the equation m*c = K d*t c. | tor using the B-parame "exp(B*(1/T-1/T0)) whe is the Characteristic te verned by the equation iss and c is the lumped mal time constant t_c a | ter equation. The res ere R0 is the Nominal imperature constant. n m*c*dT/dt = Q whe specific heat capacity nd the Dissipation fac | istance at resistance at The ere Q is the 7. The thermal ctor K_d using |
|--|--|---|--|
| Parameters Electrical Thermal | | | 1 |
| Nominal resistance R0 at reference temperature T0: | e 1000 | Ohm | • |
| | 25 | C C | |
| Reference temperature TO: | 120 | | |
| Reference temperature TO: Characteristic temperature constant B: | 3.5e+03 | K K | |
| Reference temperature TO: Characteristic temperature constant B: | 3.5e+03 | K | |

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

Dialog Box and Parameters

Reference temperature T0

The temperature at which the nominal resistance was measured. The default value is 25 $^{\circ}\mathrm{C}.$

Characteristic temperature constant B

The coefficient B in the equation that describes resistance as a function of temperature. The default value is 3.5e+03 K.

Thermal Tab

| 🙀 Block Parameters: The | mistor | × |
|---|--|---|
| Thermistor | | |
| This block represents an NT temperature T is given by R the reference temperature temperature T of the thermi net heat flow into port A, m mass m*c is calculated from the equation m*c = K_d*t_c | C thermistor using the B-paramete (T) = R0*exp(B*(1/T-1/T0)) where T0, and B is the Characteristic tem stor is governed by the equation n is the mass and c is the lumped sp the Thermal time constant t_c and t | r equation. The resistance at 9 RO is the Nominal resistance at perature constant. The n*c*dT/dt = Q where Q is the ecific heat capacity. The thermal I the Dissipation factor K_d using |
| Parameters | | |
| Electrical Thermal | | 1 |
| Thermal time constant: | 5 | s • |
| Dissipation factor: | 7.5e-04 | W/K 💌 |
| Initial temperature: | 25 | C 💽 |
| | | |
| | | |
| | | |
| | 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.

Thermistor

| | Dissipation factor The thermal power required to raise the thermistor temperature by one K. The default value is 7.5e-04 W/K. |
|----------|--|
| | Initial temperature The temperature of the thermistor at the start of the simulation. The default value is 25 °C. |
| Ports | The block has the following ports: |
| | A Thermal port. |
| | + Positive electrical port. |
| | - Negative electrical port. |
| See Also | Thermal Resistor |

Purpose Model sensor that converts thermal potential difference into electrical potential difference

Library

Sensors

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

Thermocouple

 $E(mV) = c0 + c1^{*}t + \dots + cn^{*}t^{n}$

where:

- *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:
Connect the thermocouple to the B port of a Simscape™ Convective Heat Transfer block.
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.
Set the Area parameter of the Convective Heat Transfer block to an approximate area A_{nom}.
Set the Heat transfer coefficient parameter of the Convective Heat Transfer block to an approximate area A_{nom}.

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

| Block Parameters: Thermocouple | X |
|--|---|
| - Thermocouple | |
| This block implements a thermocouple model. The thermocouple voltage is given by $E(mV)=c0+c1^*t+\ldots,cn^*t^n$ where t is the temperature difference in degrees Celcius between the temperature presented at thermal port A and the Reference temperature. The voltage presented across the output terminals is in units of volts. The default parameters are for a Type S thermocouple. | |
| The absolute temperature T of the thermocouple 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 capacity. 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 | |
| | |
| Coefficients [c0 c1 cn]: -3.315e-14 2.5574e-17 -1.2507e-20 2.7144e-24] | |
| | |
| | _ |
| | |
| OK Cancel Help Apply | |

Coefficients [c0 c1 ... cn]

Electrical Tab

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 a demo of how to do this, see the Simulink[®] Approximating Nonlinear Relationships: Type S Thermocouple demo, sldemo_tc_script.m, and the associated model file, sldemo_tc.mdl.

Thermal Tab

| 🙀 Block Parameters: T | hermocouple | | | × | | |
|---|---|--------|------|----------|--|--|
| - Thermocouple | | | | | | |
| This block implements a thermocouple model. The thermocouple voltage is given by $E(mV) = c0 + c1^*t + \dots cn^*t^n$ where t is the temperature difference in degrees Celcius between the temperature presented at thermal port A and the Reference temperature. The voltage presented across the output terminals is in units of volts. The default parameters are for a Type S thermocouple. | | | | | | |
| The absolute temperatur m*c*dT/dt = Q where Q lumped specific heat cap time constant t_c and th | The absolute temperature T of the thermocouple 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 capacity. 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 | | | | | | |
| Reference temperature: | 0 | | с | - | | |
| Thermal time constant: | Thermaltime 1 s | | | | | |
| Dissipation factor: | 0.001 | | W/K | • | | |
| Initial temperature: | 25 | | c | • | | |
| | | | | | | |
| | | | | | | |
| | ОК | Cancel | 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. |
| 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. |

Three-Winding Mutual Inductor

Purpose

Model three coupled inductors

Library Passive Devices

Description



Three-Winding Mutual Inductor

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 | Block Parameters: Three-Winding Mutual Inductor | | | | | |
|------------|---|-----------|------------|---|--|--|
| Box and | Three-Winding Mutual Inductor | | | | | |
| Parameters | 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 | | | 5 | | |
| | Inductance L1: | 0.001 | H | 1 | | |
| | Inductance L2: | 0.001 | H | 1 | | |
| | Inductance L3: | 0.001 | Н | 1 | | |
| | Coefficient of coupling, K12: | 0.9 | | | | |
| | Coefficient of coupling, K13: | 0.9 | | | | |
| | Coefficient of coupling, 0.9 | | | | | |
| | Specify initial condition?: | No | • | 1 | | |
| | | OK Cancel | Help Apply | | | |

Inductance L1

Dialog Box and

> The self inductance of the first winding. The default value is 0.001 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 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. |

Universal Motor

Purpose Model electrical and torque characteristics of a universal (or series) motor

Library Actuators & Drivers

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 $\operatorname{emf} v_b$ 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.

Dialog Box and Parameters

Electrical Torque Tab

| niversal Motor | | | | | |
|---|---|-------------------------------------|--------------------------------------|---|------------------------|
| is block represents the electrical ar ound motor). | nd torque characteris | tics of a unive | rsal motor (also | o sometimes calle | ed a serie |
| | | | | | |
|)tor characteristics can be defined sistance), L (total armature and fie | in terms of equivaler eld winding inductance | it circuit param e) and Laf (bai | neters R (total a ck-emf constant | armature and he t), The back emf | id windin induced |
| e armature is given by Vb = Laf * 1 | I * W where I is the n | notor current a | and W is the me | chanical angular | speed. |
| ernatively, the motor characteristie ectrical power, nominal DC voltage | ics can be defined in , and L. If no informa | terms of rated ition is availabl | i mechanical poi le on armature (| wer & speed, sta or field winding ir | all torque nductanc |
| in be set to a suitably small non-zer | ro value when driving | ; the motor wit | h DC. | - | |
| ne block produces a positive torque | acting from the med | hanical C to R | ports. | | |
| arameters | | | | | |
| | | | | | |
| Electrical Torque Mechanical | | | | | |
| Model parameterization: | By DC rated power | , rated speed | & electrical pow | ver | |
| Rated speed (at rated load): | 6.5e+03 | | | rpm | |
| Rated load (mechanical power): | 75 | | W | | |
| Rated DC supply voltage: | 200 | | V | | |
| Electrical power in at rated load: | 160 | | W | | |
| Total armature and field winding | 0.525 | | | | 1 |
| inductance: | 10.020 | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

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

| | s. oniversurri | 10001 | | | | |
|--|--|--|--|--|---|---|
| Jniversal Motor —— | | | | | | |
| This block represents wound motor). | the electrical a | ind torque charact | eristics of a unive | ersal motor (also | sometimes called | l a serie |
| Motor characteristics resistance), L (total the armature is giver Alternatively, the mo electrical power, non can be set to a suita | can be defined armature and fie) by Vb = Laf *) (tor characterist inal DC voltage, bly small non-ze | l in terms of equiv. eld winding inducta I * W where I is th tics can be defined a, and L. If no info ro value when dri | alent circuit paran ance) and Laf (ba ne motor current d in terms of rated rmation is availab ving the motor wi | neters R (total a ck-emf constant and W is the mer d mechanical pow le on armature o ch DC. | rmature and field). The back emf i chanical angular s ver & speed, stall r field winding ind | l windin nduced speed. l torque ductanc |
| he block produces a | positive torque | e acting from the r | nechanical C to R | ports. | | |
| arameters | | , | | | | |
| Electrical Torque | Mechanical | | | | | |
| Rotor inertia: | | 2e-04 | | | kg*m^2 | |
| Rotor damping: | | 1e-06 | | | N*m/(rad/s) | |
| Initial rotor speed | : | 0 | | | rpm | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
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| | | | | | | |
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| | | | | | | |

Rotor inertia

Rotor inertia. The default value is $2e\,\text{-}\,04~\text{kg}^*\text{m}^2.$ 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. | | | | |
| Ports | The block has the following ports: | | | | |
| | + Positive electrical port. | | | | |
| | - Negative electrical port. | | | | |
| | C Mechanical rotational conserving port. | | | | |
| | R Mechanical rotational conserving port. | | | | |
| References | [1] Bolton, W. Mechatronics: <i>Electronic Control Systems in Mechanical and Electrical Engineering</i> 3rd edition, Pearson Education, 2004. | | | | |
| See Also | DC Motor, Induction Motor, Servomotor, and Shunt Motor. | | | | |

Purpose Model linear time-varying capacitor

Library

Passive Devices

Description

□ □ Variable Capacitor The Variable Capacitor block represents a linear time-varying capacitor. The current i through the device when the capacitance at port C is C is governed by the following equation:

 $i = \frac{dC}{dt}v + C\frac{dv}{dt}$

where v is the voltage across the capacitor.

The block includes a resistor in series with the variable capacitor. This resistor can be used to represent the total ohmic connection resistance of the capacitor. It may be required to prevent numerical problems for some circuit topologies, such as one where a Variable Capacitor block is connected in parallel with another capacitor block that doesn't have a series resistance.

| | Block Parameters: Variable Capacitor |
|-------|---|
| nd | Variable Capacitor |
| eters | This block models a linear time-varying capacitor. The relationship between current I and voltage V is I=C*dV/dt+dC/dt*V where C is the value of the physical input signal C. The Minimum capacitance parameter prevents zero or negative capacitance values. The Series resistance parameter can be used to represent component internal resistance, and may be needed for simulation of some circuit topologies such as when the block is connected in parallel with another capacitor. |
| | Parameters Minimum capacitance 1e-09 F |
| | Series resistance: 1e-06 Ohm |
| | OK Cancel Help Apply |

Dialog Box and Parameters

| | 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 Ω | | | | |
| Ports | The block has the following ports: | | | | |
| | C 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 voltage *v* across the device when the inductance at port L is L is governed by the following set of equations:

$$v = \frac{dL}{dt}i + L\frac{di}{dt}$$

where *i* is the current through the inductor.

The block includes a conductor in series with the variable inductor. This conductor can be used to represent the total insulation conductance of the inductor. It may be required to prevent numerical problems for some circuit topologies, such as one where a Variable Inductor block is connected in series with another inductor block that doesn't have a parallel conductance.



Dialog Box and **Parameters**

Variable Inductor

| | 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. | | | | |
|----------|--|--|--|--|--|
| | $\begin{array}{llllllllllllllllllllllllllllllllllll$ | | | | |
| Ports | The block has the following ports: | | | | |
| | L Inductance. L must be finite and greater than zero. | | | | |
| | + Positive electrical port. | | | | |
| | - Negative electrical port. | | | | |
| See Also | Variable Capacitor, Simscape [™] Variable Resistor | | | | |

Functions — Alphabetical List

netlist2sl

| Purpose | Convert SPICE netlist to library of Simulink® blocks | | | | | |
|-------------|--|--|--|--|--|--|
| Syntax | <pre>modelname = netlist2sl(filename, libraryname) modelname = netlist2sl(filename, options)</pre> | | | | | |
| Description | <pre>modelname = netlist2sl(filename, libraryname) maps the circuit elements listed in the SPICE netlist file filename to a Simulink library called libraryname that contains one or more blocks.</pre> | | | | | |
| | • filename is the full name of the netlist file; it can also include the path name. | | | | | |
| | • libraryname is the optional Simulink library name. | | | | | |
| | netlist2sl can import either subcircuit information or model card information into a block: | | | | | |
| | When you import subcircuit data from a SPICE netlist, SimElectronics[™] creates a block that represents the netlist. | | | | | |
| | The block dialog box for each imported block contains the following information: | | | | | |
| | Subcircuit name | | | | | |
| | Netlist file name | | | | | |
| | Time the netlist2s1 function created the block You can look at a snapshot of the netlist the function used to create the block by clicking Help in the block dialog box. | | | | | |
| | • When you import model card data from a SPICE netlist, SimElectronics uses the data to populate the parameter values of the corresponding SPICE-compatible SimElectronics block. | | | | | |
| | modelname = netlist2sl(filename, options) uses the information in the structure options to map the circuit elements in filename to a Simulink library. The structure has the following fields: | | | | | |
- LibName A string that specifies the name of the Simulink library where netlist2s1 puts the blocks.
- ModelOnly A boolean value. True tells netlist2s1 to generate a library that contains only blocks representing the model cards that appear in the SPICE file. False (the default value) tells netlist2s1 to generate a library that contains all circuit information that appears in the SPICE file.

The netlist file must define one or more SPICE subcircuits or model cards. To import a netlist that is not a subcircuit into a Simulink library, add a subcircuit wrapper before using the netlist2s1 function. "Example 2" on page 3-4 shows this procedure.

The output library has one block that represents the top-level subcircuit, and a block for each subcircuit that this subcircuit references. The block names match the subcircuit names, except that slashes (/) are replaced by underscores (_).

If the library already exists in the specified directory, netlist2s1 adds new blocks to this library. If a subcircuit name conflicts with an existing block name in the library, netlist2s1 prompts you to either overwrite the existing block or rename the new block.

The model name, subcircuit name, instance name, and node name are all case insensitive.

After you create the library, you can drag and drop the blocks into any Simulink model. If you make any change to the library, Simulink applies the change to all instances of the affected block or blocks.

Note You cannot make changes directly to the library blocks that you create with the netlist2s1 function. To update the blocks, you must change the netlist and then re-run the netlist2s1 function.

Examples Example 1

Suppose you have a netlist file, SimpleDiode.cir as follows:

```
.SUBCKT SimpleDiode 1 2
R1 1 3 100
D1 3 2 DMOD1
.model DMOD1 D(Is=1e-13 Rs=0.1)
.ENDS SimpleDiode
```

To import this netlist and create a library called mylib that contains a block called SimpleDiode, type the following at the MATLAB[®] prompt:

```
netlist2sl(`SimpleDiode.cir', `mylib')
```

Example 2

Suppose you have a netlist that is not a subcircuit. To use the netlist2s1 function, add a subcircuit wrapper to the netlist. Consider the following netlist file:

R1 1 3 100 D1 3 2 DMOD1 .model DMOD1 D(Is=1e-13 Rs=0.1)

If you want to probe nodes 1 and 2 in Simulink, add the subcircuit wrapper as follows:

```
.SUBCKT mydiode 1 2
R1 1 3 100
D1 3 2 DMOD1
.model DMOD1 D(Is=1e-13 Rs=0.1)
.ENDS mydiode
```

Then, apply the netlist2s1 function to the modified netlist, as described in the preceding example.

Example 3

See the Creating a Library Block from a Netlist demo.

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