SimElectronics™ 1
Reference

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SimElectronics™ Reference

Revision History

April 2008	Online only	New for Version 1.0 (Release 2008a+)

Contents

1 Block Reference

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Block Reference

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

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
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Thermistor	Model NTC thermistor using B-parameter equation
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Sources

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

SPICE-Compatible Sources

DC Current Source	Model constant current source
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Exponential Voltage Source	Model exponential pulse voltage source
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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
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SFFM Current Source	Model single-frequency FM current source
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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

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Blocks — Alphabetical List

Band-Limited Op-Amp

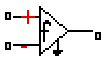
Purpose

Model band-limited operational amplifier

Library

Integrated Circuits

Description



Band-Limited Op-Amp

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

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

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.

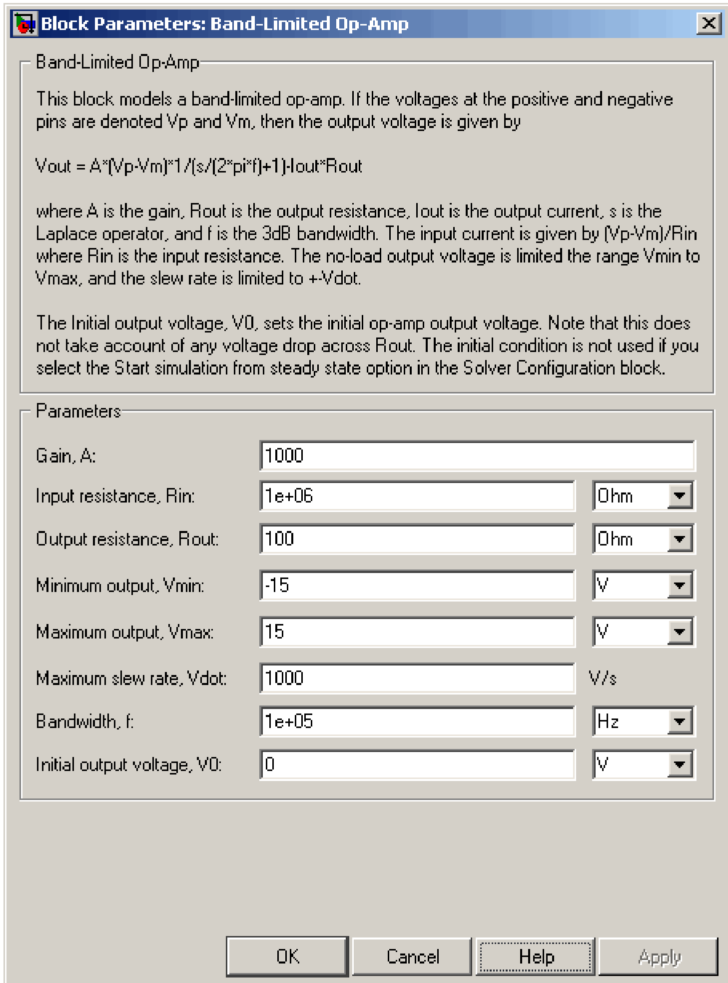
The input current is:

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

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



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

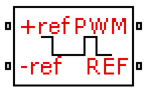
Purpose

Model pulse-width modulated voltage source

Library

Actuators & Drivers

Description



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

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

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.

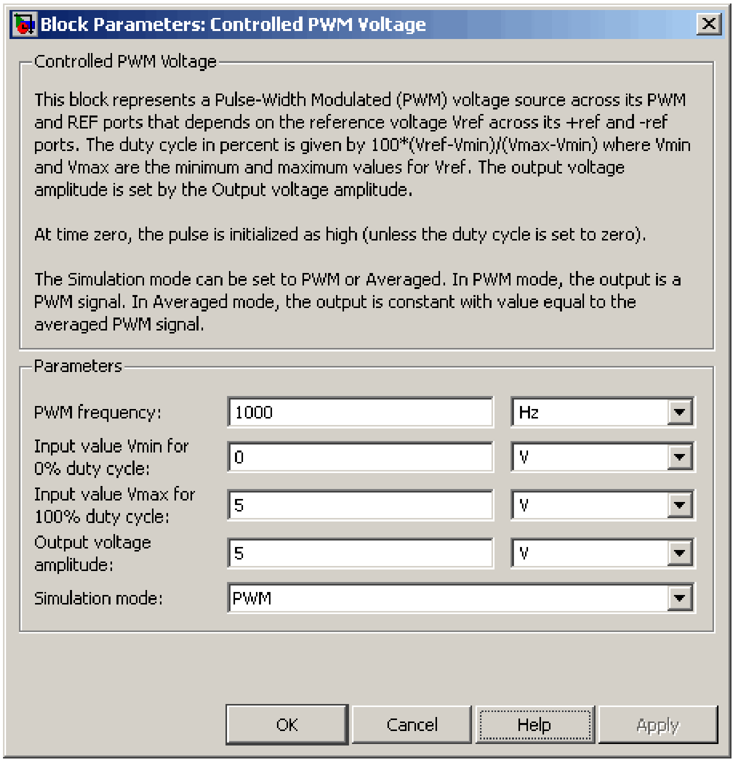
Basic Assumptions and Limitations

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

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



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

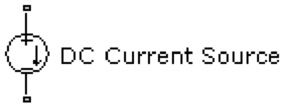
Purpose

Model constant current source

Library

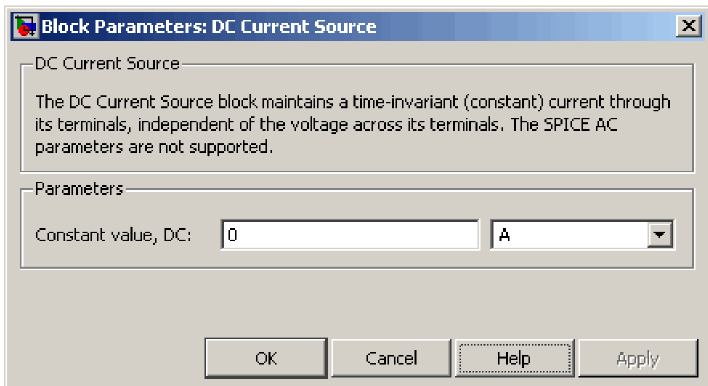
SPICE-Compatible Sources

Description



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



Constant value, DC

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

Ports

The block has the following ports:

+

Positive electrical voltage.

-

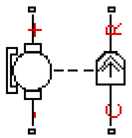
Negative electrical voltage.

See Also DC Voltage Source

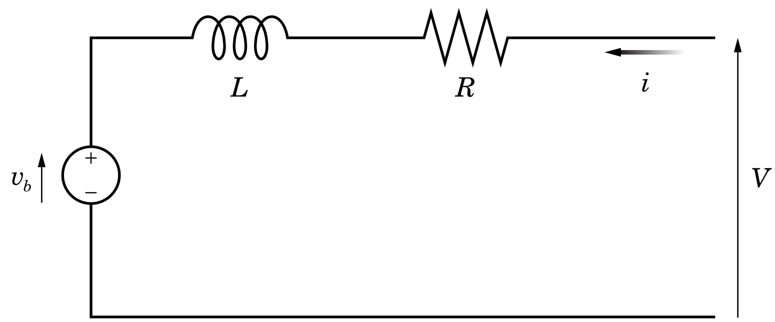
Purpose Model electrical and torque characteristics of DC motor

Library Actuators & Drivers

Description



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.

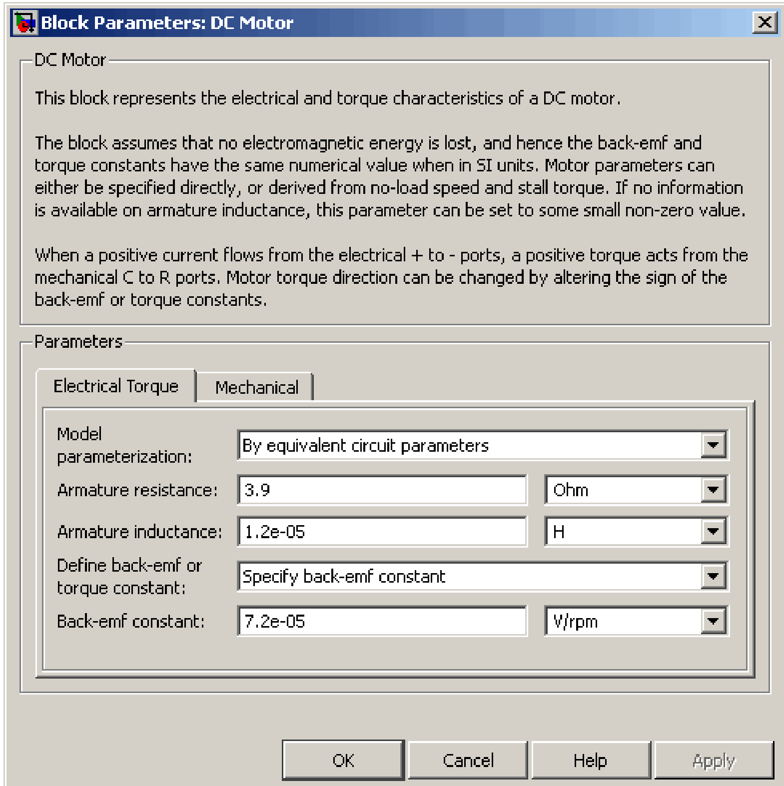
The block models motor inertia J and damping B for all values of the **Model parameterization** parameter. The output torque is:

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

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

Dialog Box and Parameters

Electrical Torque Tab



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` Ω.

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.

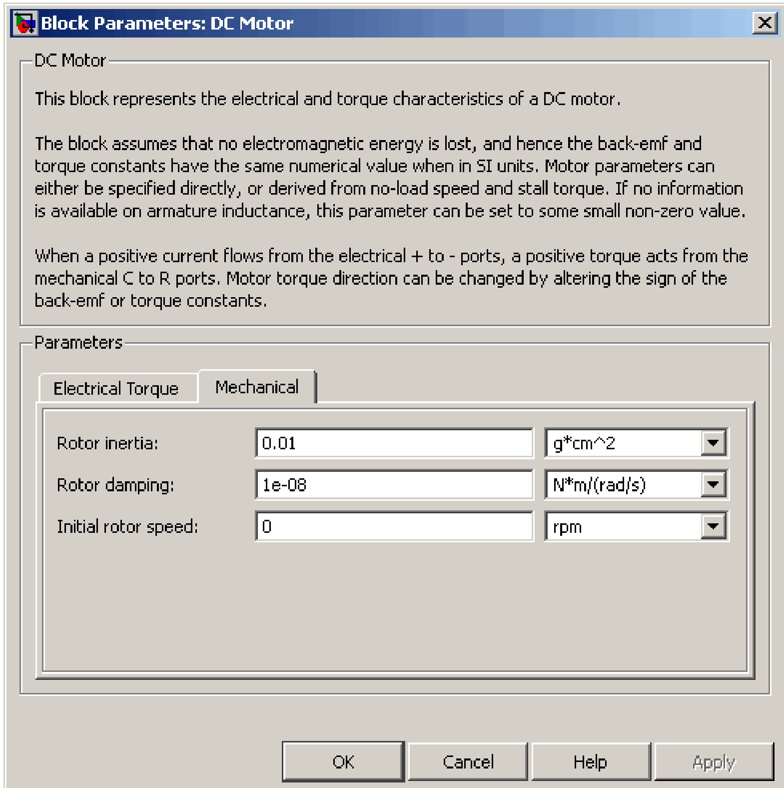
No-load speed
Speed of the motor when not driving a load. This parameter is only visible when you select `By stall torque & no-load speed` or `By rated power, rated speed & no-load speed` for the **Model parameterization** parameter. The default value is `1.91e+04` rpm.

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



Rotor inertia
Resistance of the rotor to change in motor motion. The default value is `0.01` g*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

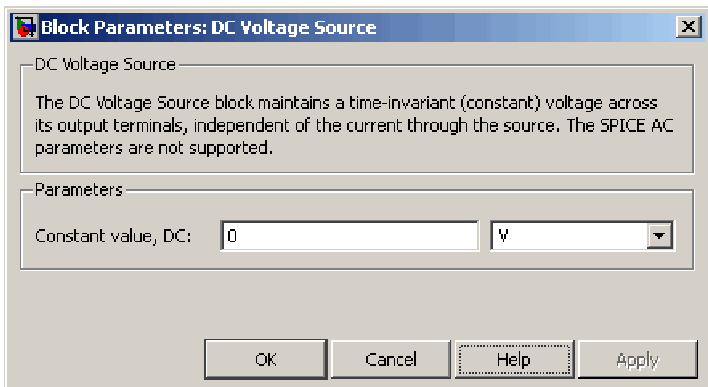
Library

SPICE-Compatible Sources

Description

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



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.

See Also DC Current Source

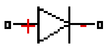
Purpose

Model piecewise linear, piecewise linear zener, or exponential diode

Library

Semiconductor Devices

Description



Diode

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

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

Piecewise Linear Zener

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

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

Exponential

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

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

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

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:

- $\mathrm{N} = ((V_1 - V_2)/V_t)/(\log(I_1) - \log(I_2))$
- $\mathrm{IS} = \left(I_1/(\exp(V_1/(\mathrm{N}V_t)) - 1) + I_2/(\exp(V_2/(\mathrm{N}V_t)) - 1)\right)/2$

where:

- $V_t = kT/q$.
- V_1 and V_2 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.
- C_1, C_2, and C_3 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_j as:

- For $V < FC \times VJ$:

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

- For $V \geq FC \times VJ$:

$$Q_j = CJ0 \times F_1 + (CJ0/F_2) \times (F_3 \times (V - FC \times VJ) + 0.5*(M/VJ)*(V^2 - (FC \times VJ)^2))$$

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.

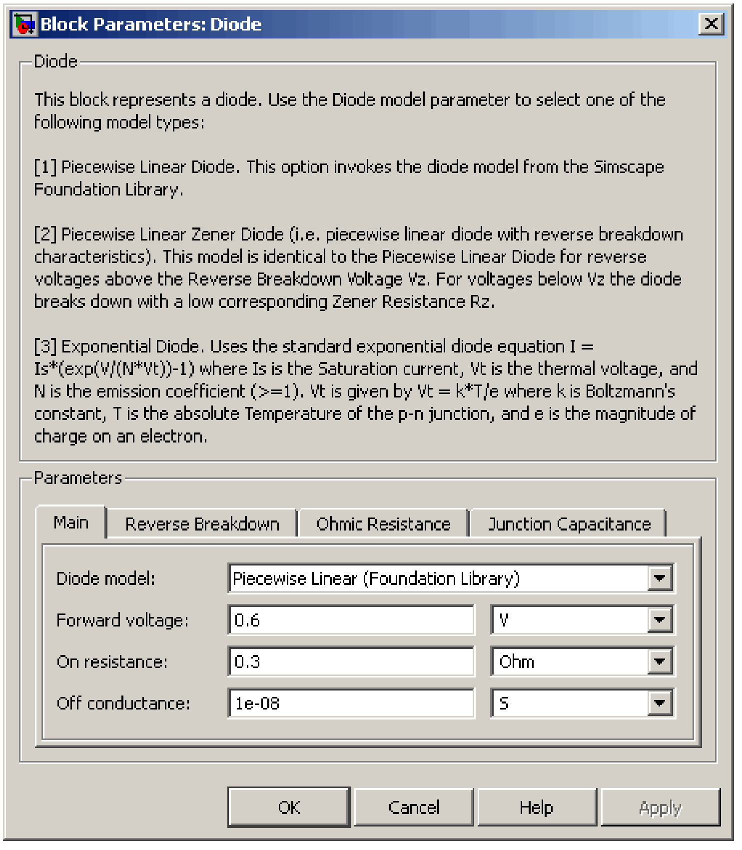
Basic Assumptions and Limitations

The Exponential diode model has the following limitations:

- When you select `Use I-V curve data points` for the **Parameterization** parameter, choose a pair of voltages near the diode turn-on voltage. Typically, this is in the range from 0.05 to 1 Volt. Using values outside of this region may lead to numerical 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

Main Tab



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/Ω

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.
- `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.

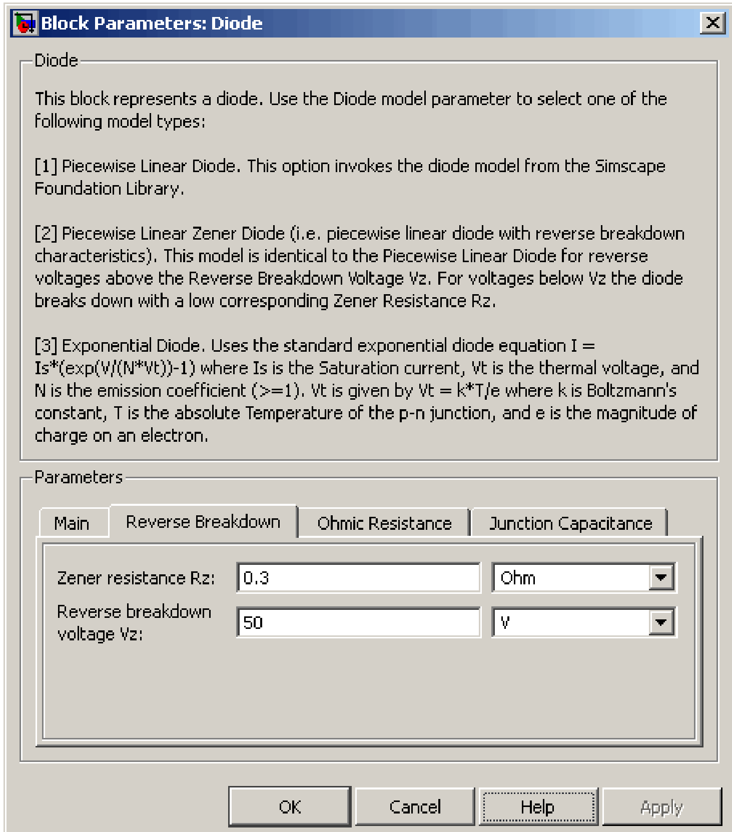
Voltages [V1 V2]
A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select `Exponential` for the **Diode model** parameter and `Use I-V curve data points` for the **Parameterization** parameter. 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` °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



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.

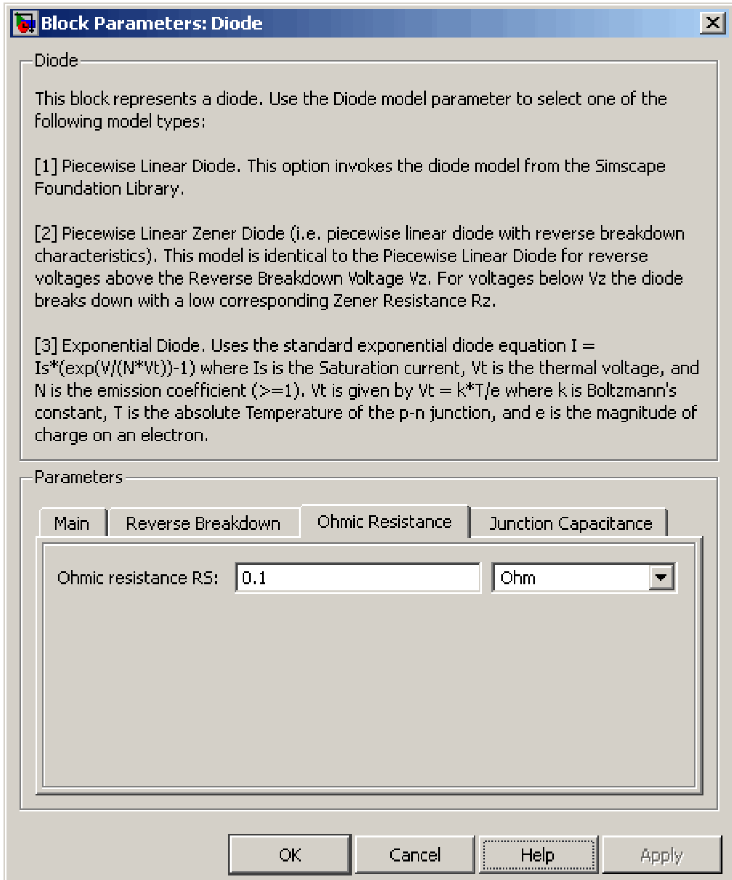
Reverse breakdown voltage Vz

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.

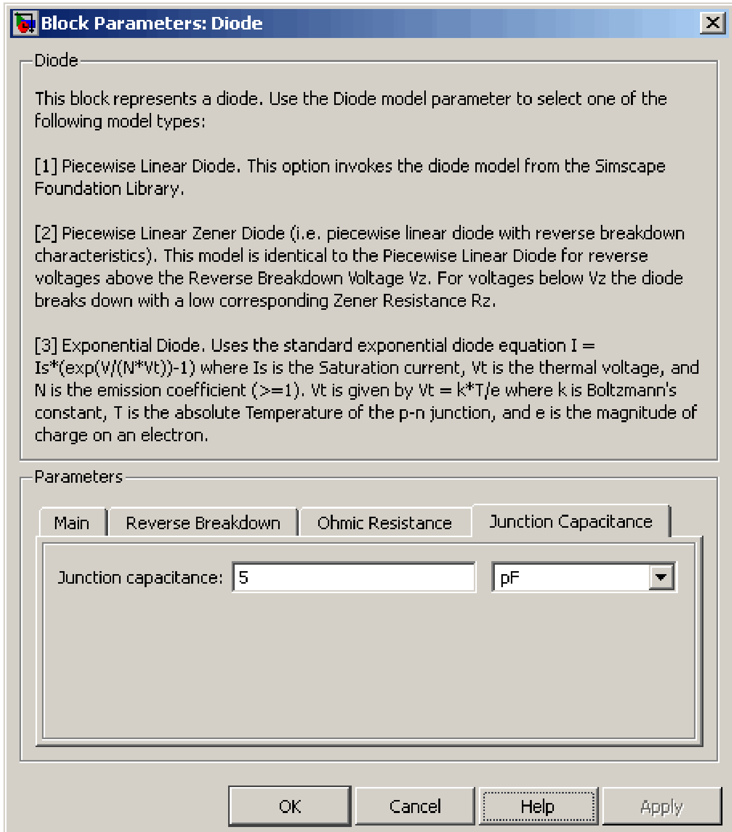
Ohmic Resistance Tab



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



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 *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 0.1 10 100 ]` V.

Corresponding capacitances [C1 C2 C3]
A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 3.5 1 0.4 ]` pF.

Junction potential VJ
The junction potential. This parameter is only visible when you select `Exponential` for the **Diode model** parameter and `Use`

parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 1 V.

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

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

Ports

The block has the following ports:

+
Electrical conserving port associated with the diode positive terminal.

-
Electrical conserving port associated with the diode negative terminal.

References

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

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

See Also

Simscape Diode, Diode (SPICE)

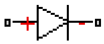
Purpose

Model SPICE-compatible diode

Library

SPICE-Compatible Semiconductors

Description


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
$V_d > 80 * V_t$	$I_d = IS\left(\left(\frac{V_d}{V_t} - 79\right)e^{80} - 1\right) + V_d * G\min$
$80 * V_t \geq V_d \geq -3 * V_t$	$I_d = IS * (e^{V_d/V_t} - 1) + V_d * G\min$

Applicable Range of V_d Values	Corresponding I_d Equation
$-3*V_t > V_d \geq -BV$	$I_d = -IS\left(1+\frac{27}{(V_d/V_t)^3 e^3}\right) + V_d * G\min$
$V_d < -BV$	$I_d = -IBV*\left(e^{(-(BV+V_d)/V_t} - 1\right) - IS*\left(1-\left(\frac{3}{e*BV/V_t}\right)^3\right) + V_d * G\min$

Where:

- IS is the **Saturation current, IS** parameter value.
- $V_t = N * k * T/q$
- N is the **Emission coefficient, ND** parameter value.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- T is the diode temperature:
  - If you select `Device temperature` for the **Model temperature dependence using** parameter, T is the sum of the **Circuit temperature** value plus the **Offset local circuit temperature, TOFFSET** parameter value. The **Circuit temperature** value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
  - If you select `Fixed temperature` for the **Model temperature dependence using** parameter, T is the **Fixed circuit temperature, TFIXED** parameter value.

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

Junction Charge Model

The block provides the following relationship between the diode charge Q_d and the diode voltage V_d after adjusting the applicable model parameters for temperature.

Applicable Range of V_d Values	Corresponding Q_d Equation
$V_d < FC*VJ$	$Q_d = TT*I_d + CJO*VJ*\dfrac{1-\left(1-\dfrac{V_d}{VJ}\right)^{1-MG}}{1-MG}$
$V_d \geq FC*VJ$	$Q_d = TT*I_d + CJO*\left(F1+\dfrac{F3*\left(V_d - FC*VJ\right)+\left(\dfrac{MG}{2*VJ}\right)*\left(V_d^2 - \left(FC*VJ\right)^2\right)}{F2}\right)$

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is the **Junction potential VJ** parameter value.

- *TT* is the **Transit time, TT** parameter value.
- *CJ0* is the **Zero-bias junction capacitance CJ0** parameter value.
- *MG* is the **Grading coefficient MG** parameter value.
- $F1 = VJ * (1 - (1 - FC)^{(1-MG)})/(1 - MG)$
- $F2 = (1 - FC)^{(1+MG)}$
- $F3 = 1 - FC * (1 + MG)$

Temperature Dependence

Several diode parameters depend on temperature. There are two ways to specify the diode temperature:

- When you select `Device temperature` for the **Model temperature dependence using** parameter, the diode temperature is

  $$T = T_C + T_O$$

  where:

  - T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
  - T_O is the **Offset local circuit temperature, TOFFSET** parameter value.
- When you select `Fixed temperature` for the **Model temperature dependence using** parameter, the diode temperature is the **Fixed circuit temperature, TFIXED** parameter value.

The block provides the following relationship between the saturation current *IS* and the diode temperature *T*:

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

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.
- $EG_{T_{meas}} = 1.16eV - \left(7.02e-4 * T_{meas}{}^2\right) / \left(T_{meas} + 1108\right)$
- $EG_T = 1.16eV - \left(7.02e-4 * T^2\right) / \left(T + 1108\right)$

The block provides the following relationship between the junction capacitance *CJO* and the diode temperature *T*:

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

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

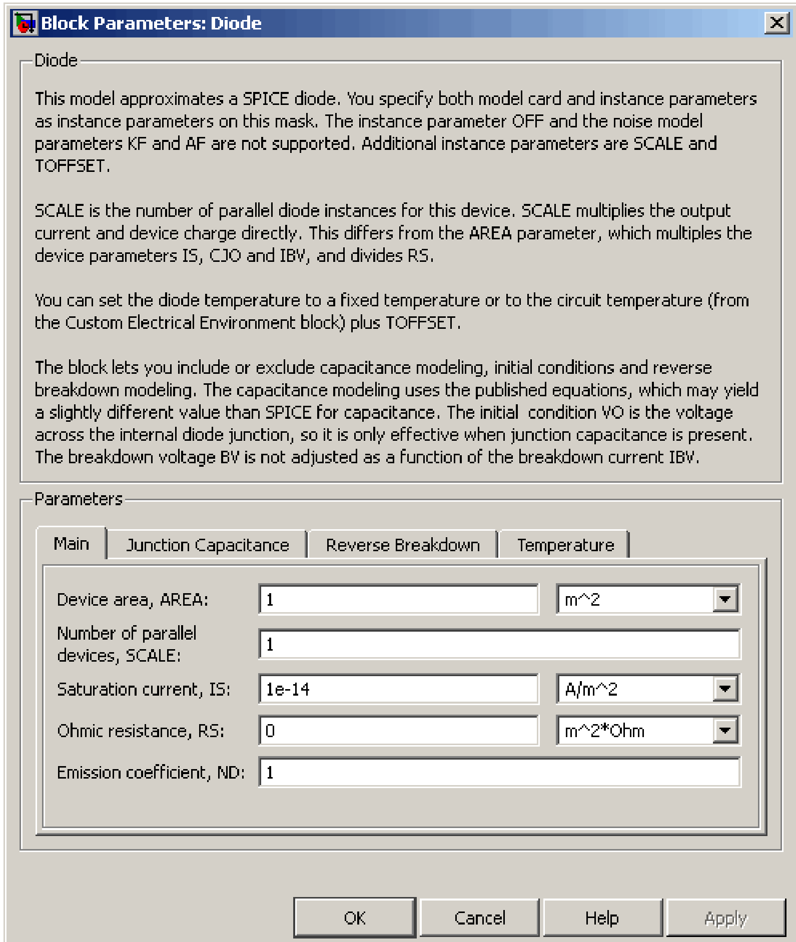
Basic Assumptions and Limitations

The model is based on the following assumptions:

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

Dialog Box and Parameters

Main Tab



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.

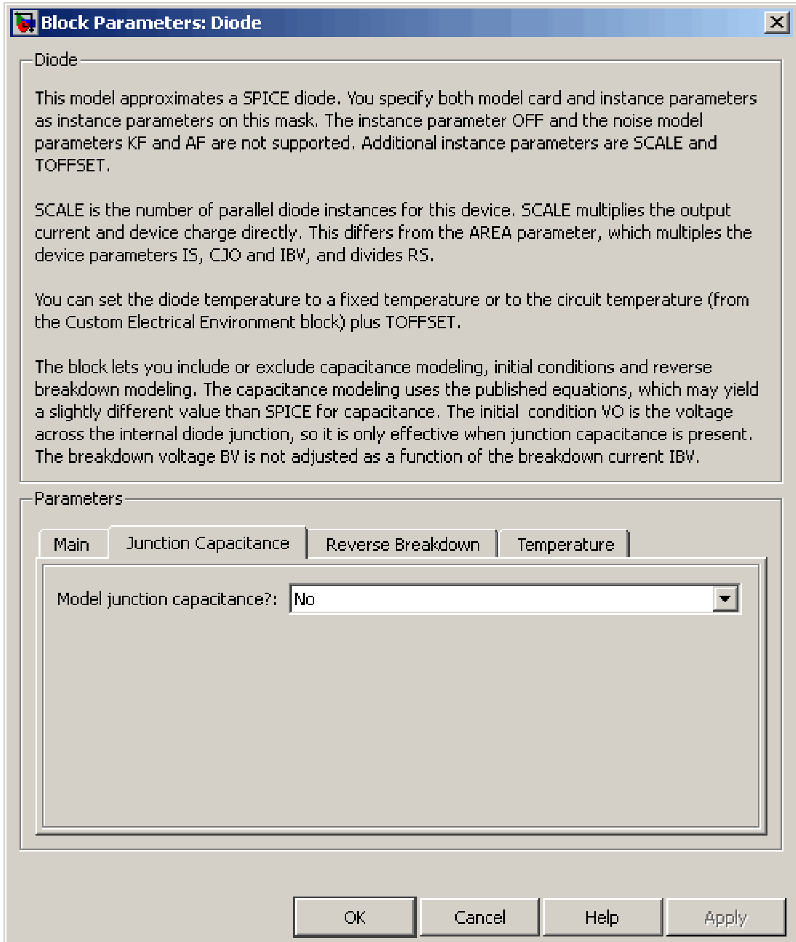
Number of parallel devices, SCALE
The number of parallel diodes the block represents. This value multiplies the output current and device charges. The default value is 1. The value must be greater than 0.

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 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



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.

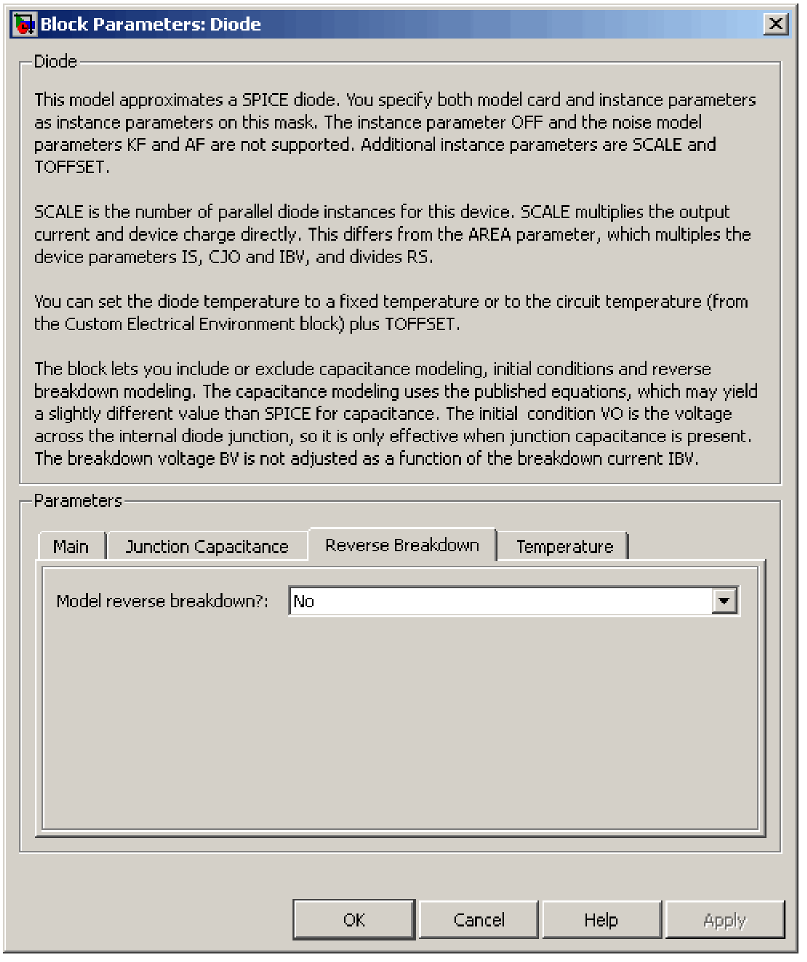
Note The Diode block applies the initial diode voltage across the junction capacitors and not across the ports.

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



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

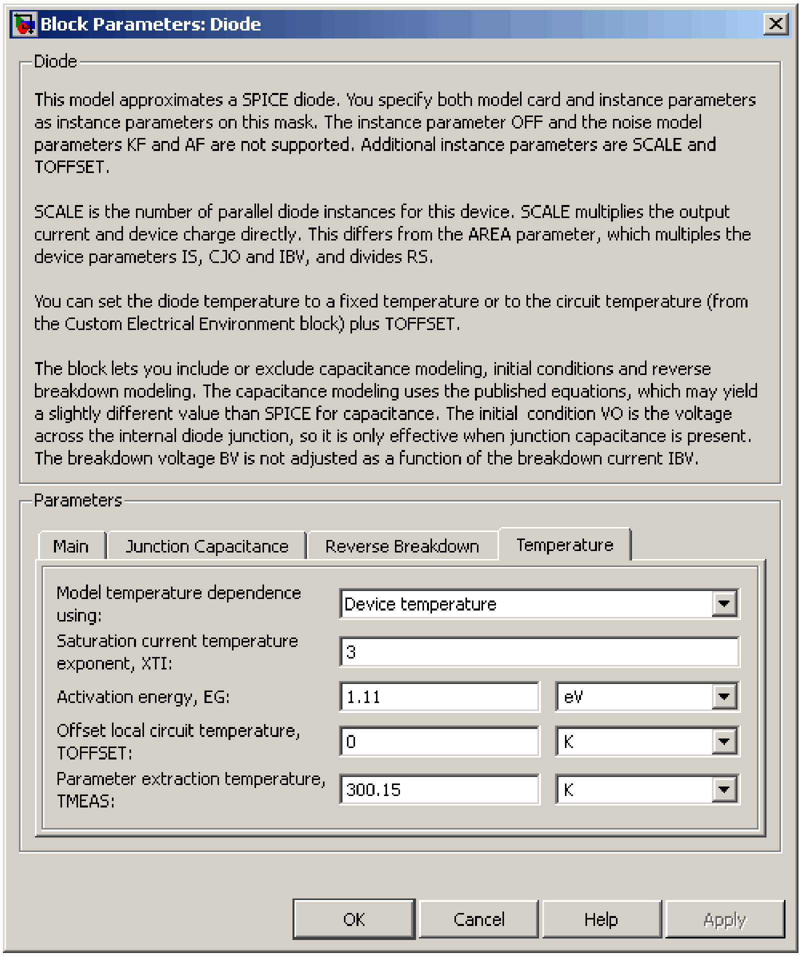
The diode current that corresponds to the **Reverse breakdown voltage, BV** value. This parameter is only visible when you select Yes for the **Model reverse breakdown** parameter. The default value is 0.001 A/m_2. The value must be greater than 0.

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



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.

See Also

Diode

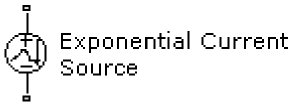
Purpose

Model exponential pulse current source

Library

SPICE-Compatible Sources

Description



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

$$I_{out}\left(0 \le Time \le TDR\right) = I1$$

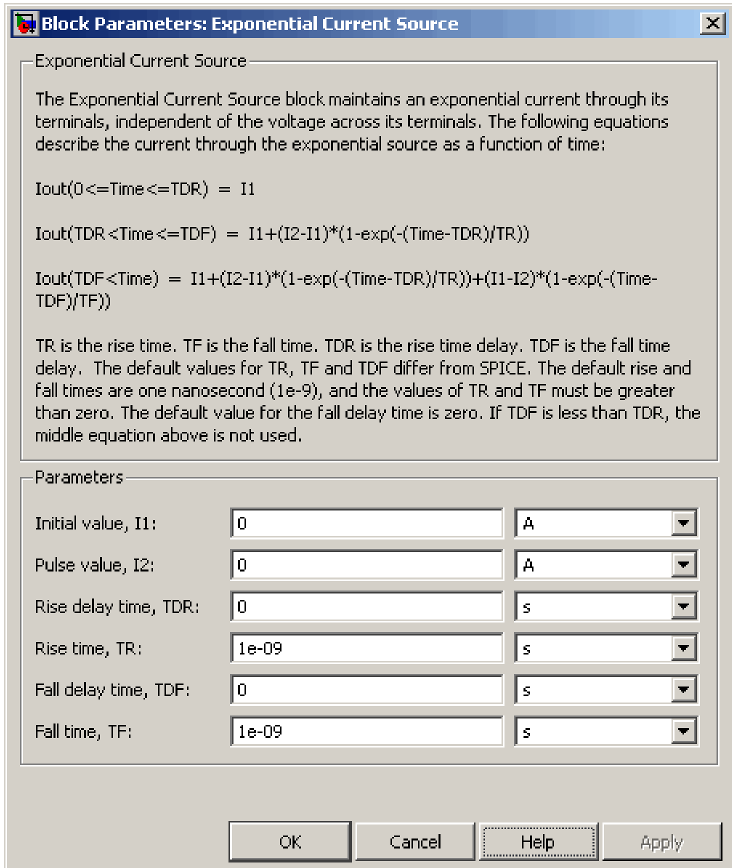
$$I_{out}\left(TDR < Time \le TDF\right) = I1 + \left(I2 - I1\right) * \left(1 - e^{-(Time-TDR)/TR}\right)$$

$$I_{out}\left(TDF < Time\right) = I1 + \left(I2 - I1\right) * \left(e^{-(Time-TDF)/TF} - e^{-(Time-TDR)/TR}\right)$$

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



Initial value, I1

The value of the output current at time zero. The default value is 0 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

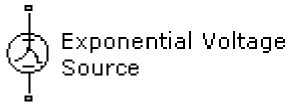
Purpose

Model exponential pulse voltage source

Library

SPICE-Compatible Sources

Description



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

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

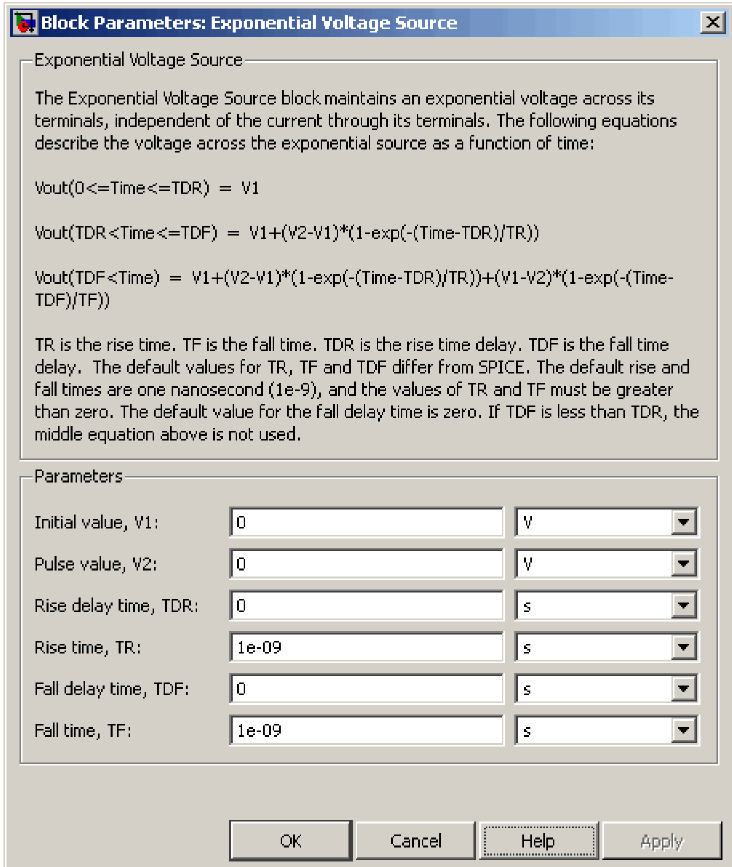
$$V_{out}\left(TDR < Time \le TDF\right) = V1 + \left(V2 - V1\right) * \left(1 - e^{-(Time-TDR)/TR}\right)$$

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

where:

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

Dialog Box and Parameters



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

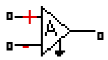
Purpose

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:

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

where:

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

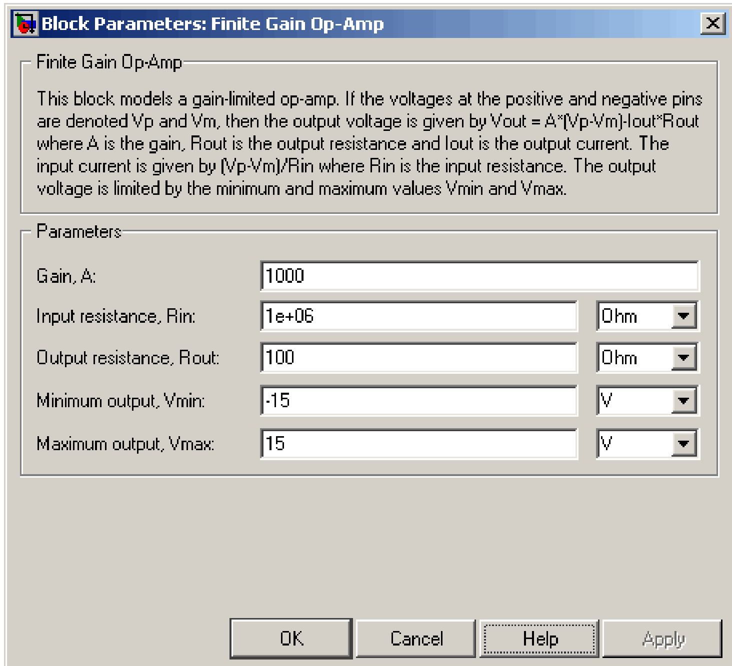
The input current is:

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

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



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

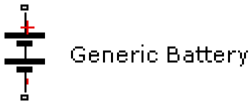
Purpose

Model simple battery

Library

Sources

Description



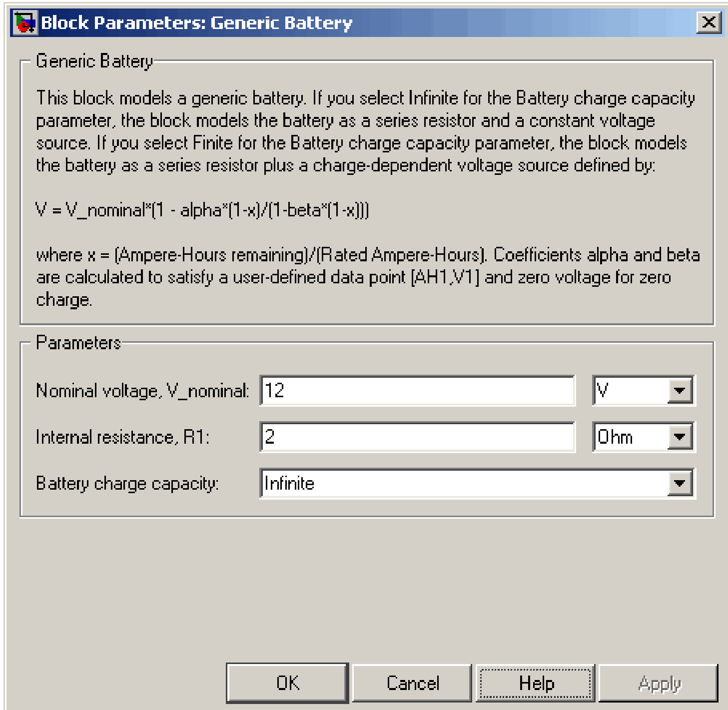
The Generic Battery block represents a simple battery. If you select `Infinite` for the **Battery charge capacity** parameter, the block models the battery as a series resistor and a constant voltage source. If you select `Finite` for the **Battery charge capacity** parameter, the block models the battery 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.
- V_0 is the voltage when the battery is fully charged, as defined by the **Nominal voltage, V_nominal** parameter.
- The block calculates the constants 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



Nominal voltage, V_nominal

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

Internal resistance, R1

Internal connection resistance. The default value is 2 Ω

Battery charge capacity

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

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

Ampere-Hour rating, AH

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

Initial charge

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

Voltage V1 < V_nominal when charge is AH1

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

Charge AH1 when no-load volts are V1

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

Self-discharge resistance, R2

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

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

R2

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

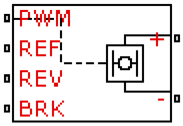
Purpose

Model H-bridge motor driver

Library

Actuators & Drivers

Description



H-Bridge

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

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

  where:

  - V_O 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.

Basic Assumptions and Limitations

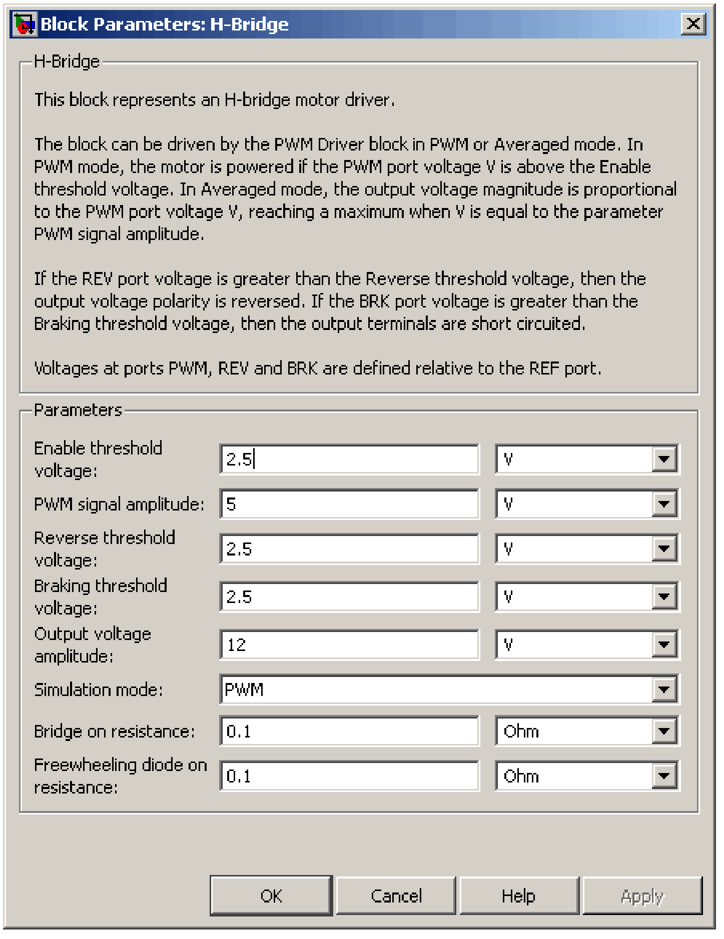
The model is based on the following assumptions:

- 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



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 `0.1` Ω

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` Ω

Ports

The block has the following ports:

`+ref`
: Positive electrical output voltage.

`-ref`
: Negative electrical output voltage.

`PWM`
: Pulse-width modulated signal. The voltage is defined relative to the REF port.

`REF`
: Floating zero volt reference.

`REV`
: Voltage that controls when to reverse the polarity of the H-Bridge output. The voltage is defined relative to the REF port.

`BRK`
: Voltage that controls when to short circuit the H-Bridge output. The voltage is defined relative to the REF port.

Examples

See the Controlled DC Motor, Linear Electrical Actuator (System-Level Model) and Linear Electrical Actuator (Implementation Model) demos.

Incremental Shaft Encoder

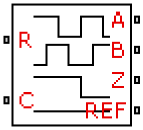
Purpose

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

Library

Sensors

Description



Incremental Shaft 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.

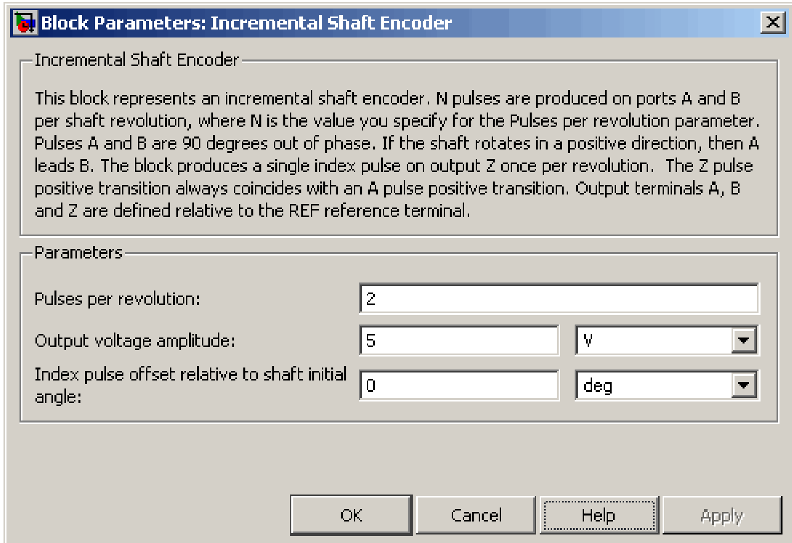
Use this block if you need to model the shaft encoder signals, either to support development of a decoding algorithm, or to include the quantization effects. Otherwise, use the Simscape™ Ideal Rotational Motion Sensor block.

Basic Assumptions and Limitations

The Incremental Shaft Encoder block has the following 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



Pulses per revolution
: The number of pulses produced on each of the A and B phases per revolution of the shaft. The default value is `2`.

Output voltage amplitude
: The amplitude of the shaft encoder output voltage when the output is high. The default value is `5` V.

Index pulse offset relative to shaft initial angle
: The offset of the index pulse Z relative to the angle of the shaft at the start of the simulation. This parameter lets you set the initial location of the index pulse. The default value is `0`°.

Ports

The block has the following ports:

`R`
: Mechanical rotational conserving port associated with the sensor positive probe.

C
: Mechanical rotational conserving port associated with the sensor negative (reference) probe.

A
: Encoded electrical output.

B
: Encoded electrical output.

Z
: Index, or synchronization, electrical output.

REF
: Floating zero volt reference.

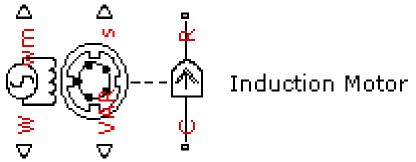
See Also

Simscape Ideal Rotational Motion Sensor

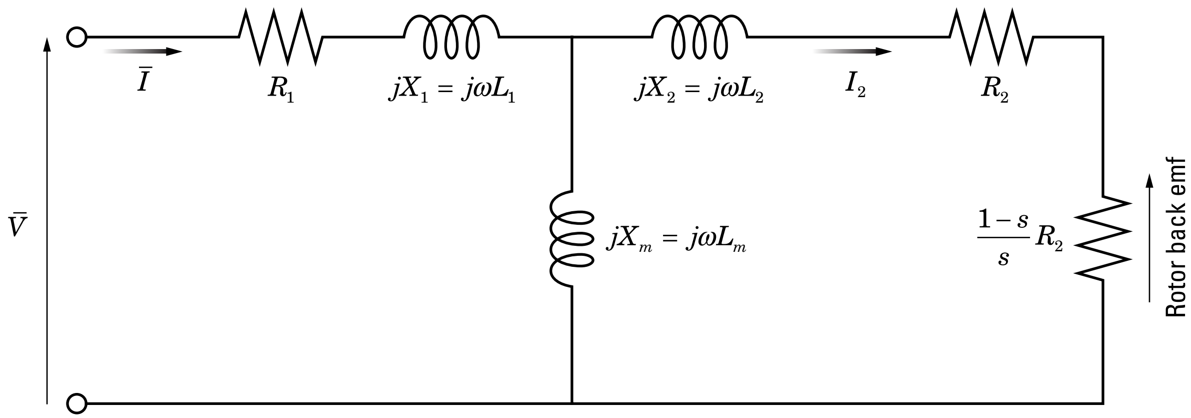
Purpose Model induction motor powered by ideal AC supply

Library Actuators & Drivers

Description



The Induction Motor block represents the electrical and torque characteristics of an induction motor powered by an ideal AC supply. The following figure shows the equivalent circuit model of the Induction Motor block.



In the figure:

- R_1 is the stator resistance.
- R_2 is the rotor resistance with respect to the stator.
- L_1 is the stator inductance.
- L_2 is the rotor inductance with respect to the stator.

- L_m is magnetizing inductance.
- s is the rotor slip.
- $\bar{V}$ and $\bar{I}$ 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.

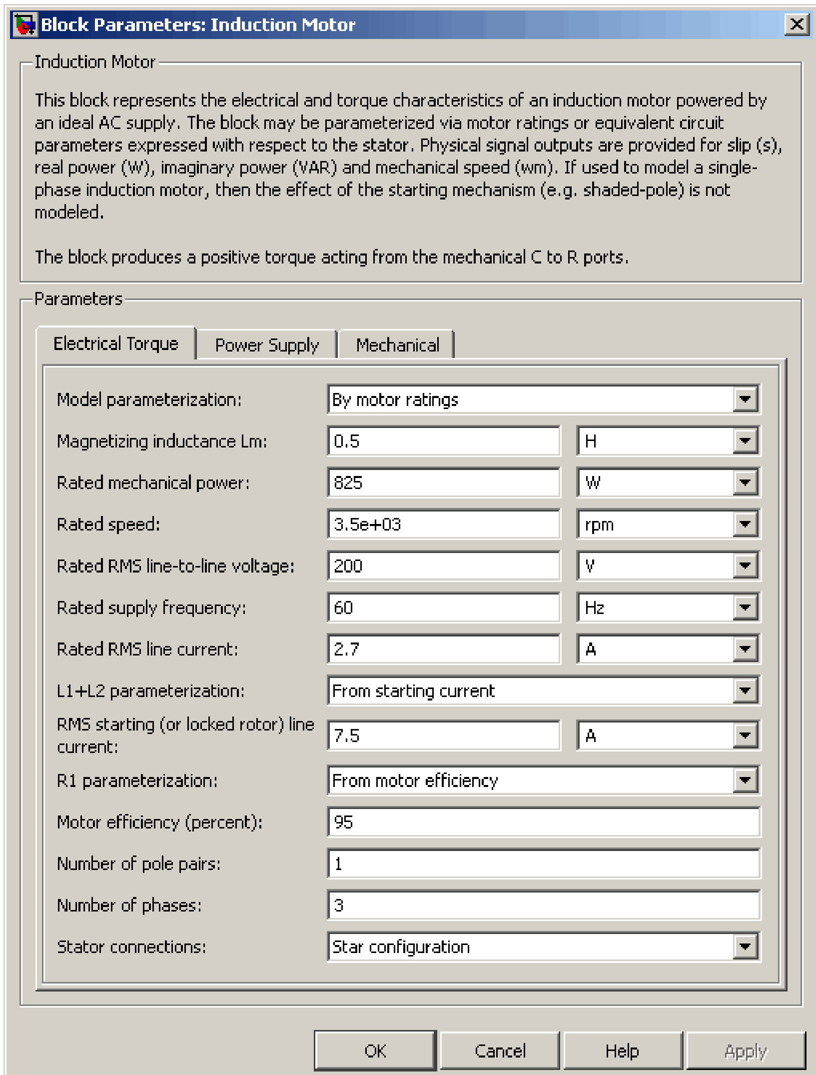
Basic Assumptions and Limitations

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.

Dialog Box and Parameters

Electrical Torque Tab



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 R_1 from the motor efficiency. This is the default method.
- `From power factor` — Calculate R_1 from the motor power factor.
- `Use measured stator resistance R1` — Measure R_1 directly.

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

Motor efficiency (percent)
the percentage of input power to the motor that gets delivered to the mechanical load when running at the **Rated speed** value. The default value is `95`. This parameter is only visible when you select `By motor ratings` for the **Model parameterization** parameter and `From motor efficiency` for the **R1 parameterization** parameter.

Motor power factor
The cosine of the angle by which the supply current lags the supply voltage when running at the **Rated mechanical power** value. The default value is `0.93`. This parameter is only visible when you select `By motor ratings` for the **Model parameterization** parameter and `From power factor` for the **R1 parameterization** parameter.

Measured stator resistance R1
the measured stator resistance. The default value is `1` Ω. This parameter is only visible when you select `By motor ratings` for the **Model parameterization** parameter and `Use measured stator resistance R1` for the **R1 parameterization** parameter.

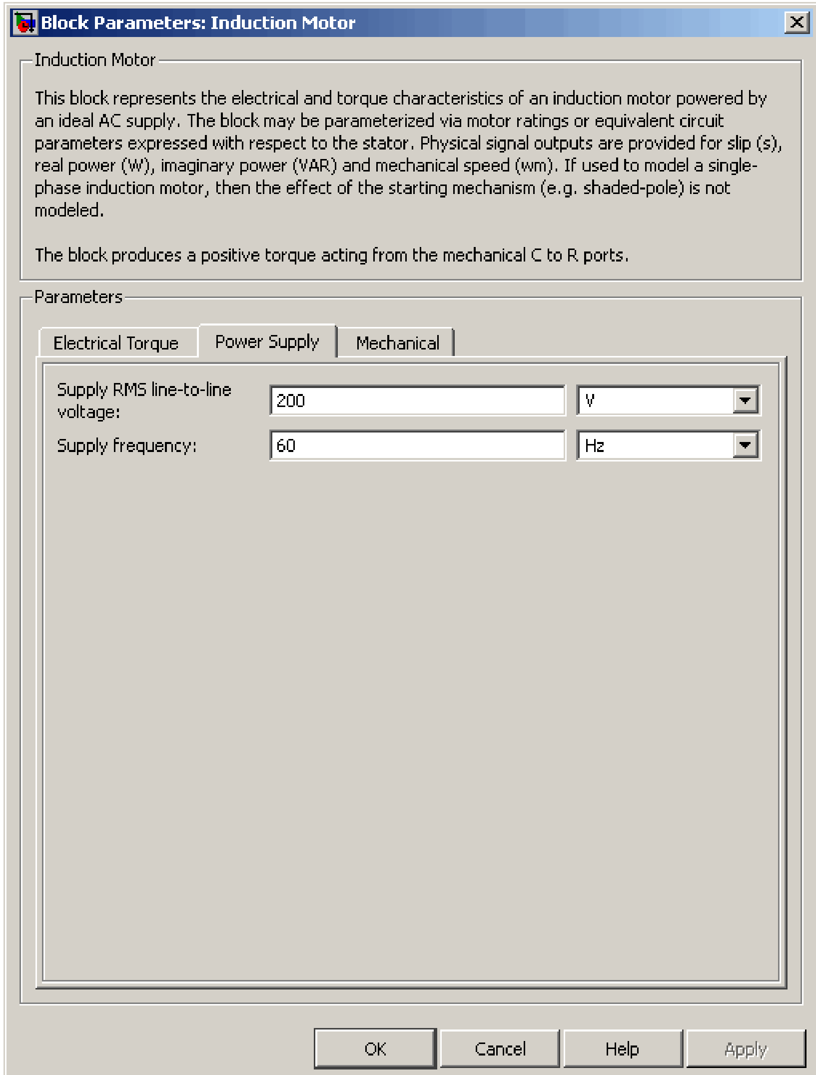
Number of pole pairs
Total number of pole pairs for the motor. The default value is `1`.

Number of phases
Number of supply phases. The default value is `3`.

Stator connections
Select one of the following motor configurations:

- `Delta configuration` — Connect the motor stator windings in delta configuration. This is the default method.
- `Star configuration` — Connect the motor stator windings in star configuration.

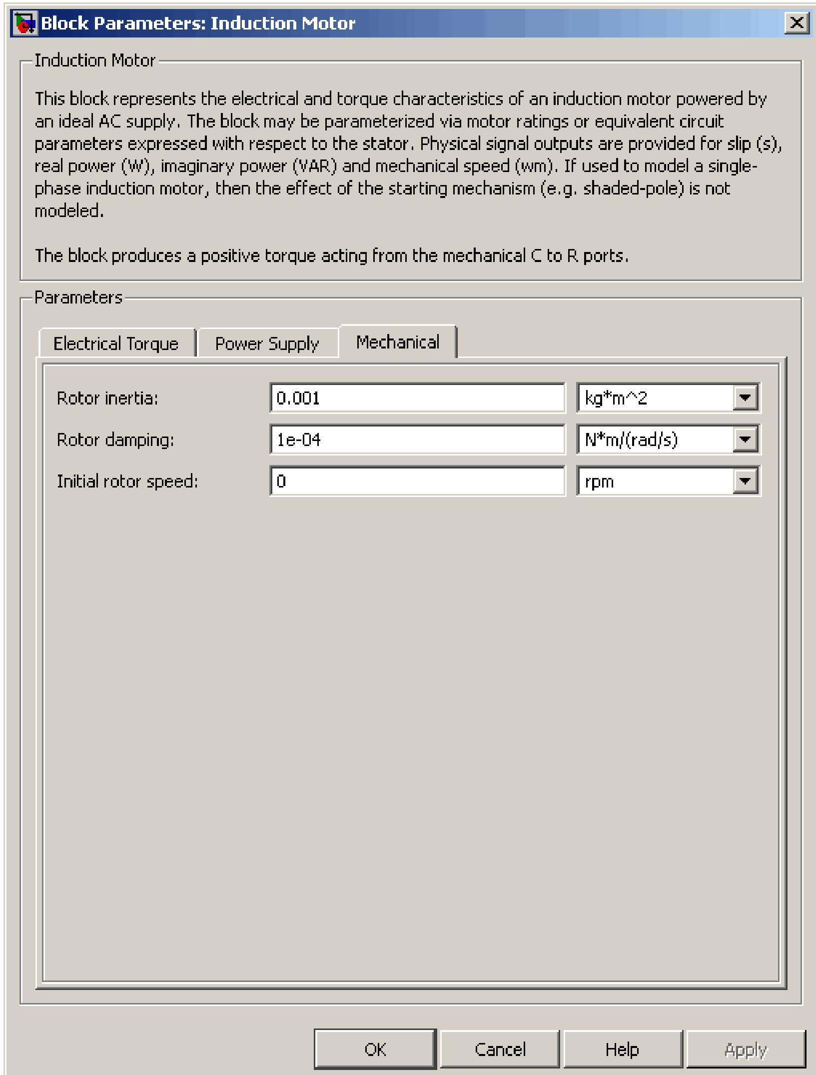
Power Supply Tab



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



Rotor inertia
Rotor inertia. The default value is `0.1` kg*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.

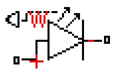
Purpose

Model light-emitting diode as exponential diode and current sensor in series

Library

Sensors

Description



Light-Emitting Diode

The Light-Emitting Diode block represents a light-emitting diode as an exponential diode in series with a current sensor. The optical power presented at the signal port W is equal to the product of the current flowing through the diode and the **Optical power per unit current** parameter value.

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

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

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

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:

- $\mathrm{N} = ((V_1 - V_2)/V_t)/(\log(I_1) - \log(I_2))$
- $\mathrm{IS} = \left(I_1/(\exp(V_1/(\mathrm{N}V_t)) - 1) + I_2/(\exp(V_2/(\mathrm{N}V_t)) - 1)\right)/2$

where:

- $V_t = kT/q$
- V_1 and V_2 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.
  - C_1, C_2, and C_3 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_j as:

- For $V < FC \times VJ$:

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

- For $V \geq FC \times VJ$:

$$Q_j = CJ0 \times F_1 + (CJ0/F_2) \times (F_3 \times (V - FC \times VJ) + 0.5 * (M/VJ) * (V^2 - (FC \times VJ)^2))$$

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.

Basic Assumptions and Limitations

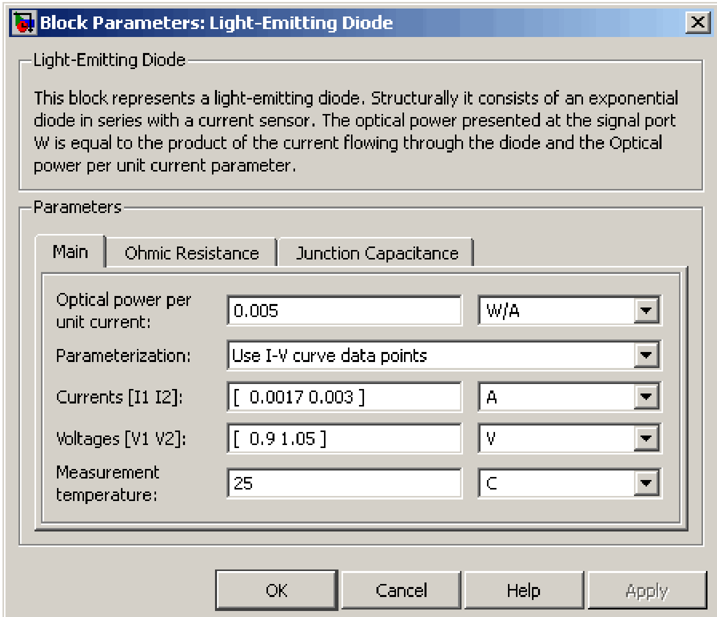
The Light-Emitting Diode block has the following limitations:

- When you select `Use I-V curve data points` for the **Parameterization** parameter, choose a pair of voltages near the diode turn-on voltage. Typically this is in the range from 0.05 to 1 Volt. Using values outside of this region may lead to numerical 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

Main Tab



Optical power per unit current

The amount of optical power the light-emitting diode generates per unit of current flowing through the diode. The default value is `0.005` W/A.

Parameterization

Select one of the following methods for model parameterization:

- `Use I-V curve data points` — Specify measured data at two points on the diode I-V curve. This is the default method.

- `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.

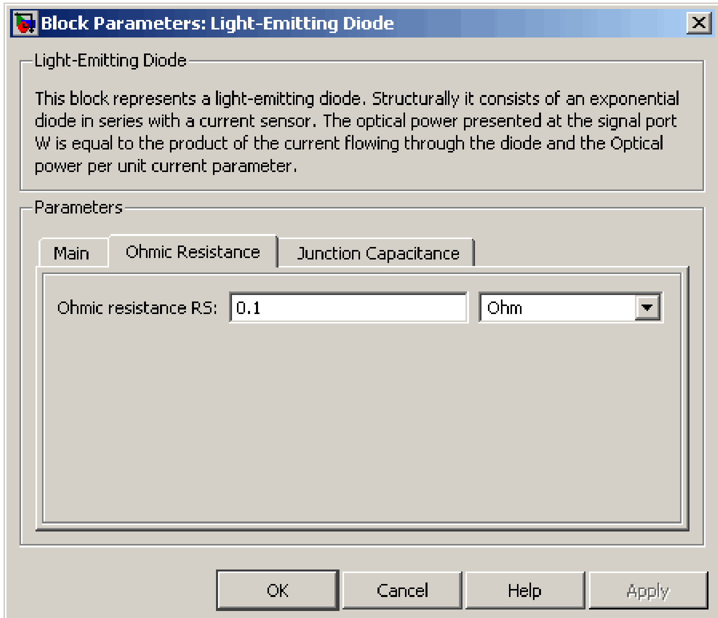
Voltages [V1 V2]
A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select `Use I-V curve data points` for the **Parameterization** parameter. The default value is `[ 0.9 1.05 ]` V.

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`.

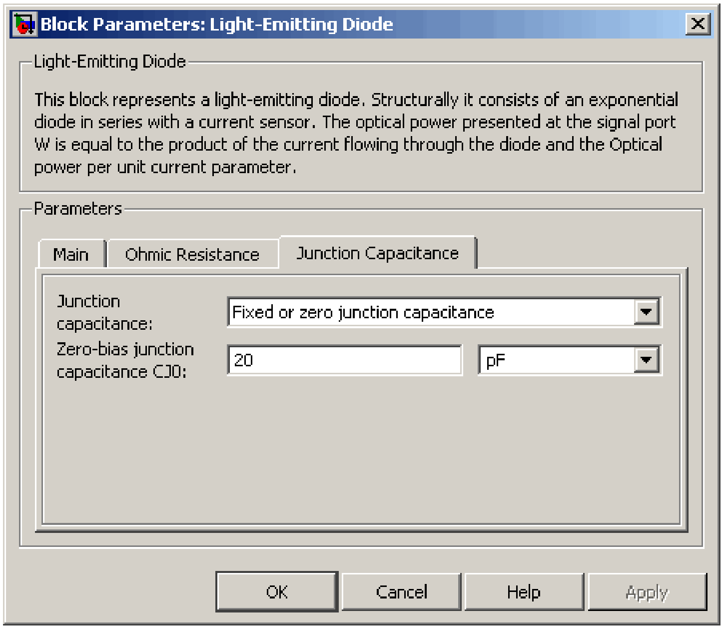
Ohmic Resistance Tab



Ohmic resistance RS

The series diode connection resistance. The default value is `0.1` Ω

Junction Capacitance Tab



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 CJ0, 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 *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 0.1 10 100 ]` V.

Corresponding capacitances [C1 C2 C3]
: A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 15 10 2 ]` pF.

Junction potential VJ
: The junction potential. This parameter is only visible when you select `Use parameters CJ0, 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 CJ0, 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 CJ0, 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. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

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

See Also

Diode, Optocoupler, Photodiode

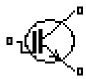
Purpose

Model N-Channel IGBT

Library

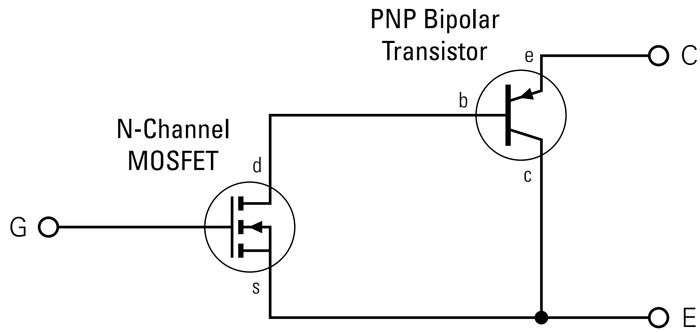
Semiconductor Devices

Description



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_{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:

$$I_b = 0 = I_s\left[\frac{1}{\beta_F}(e^{-qV_{be}/(NkT)} - 1) - \frac{1}{\beta_R}\right]$$

$$I_c = I_s\left[e^{-qV_{be}/(NkT)} + 1/\beta_R\right]$$

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:

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

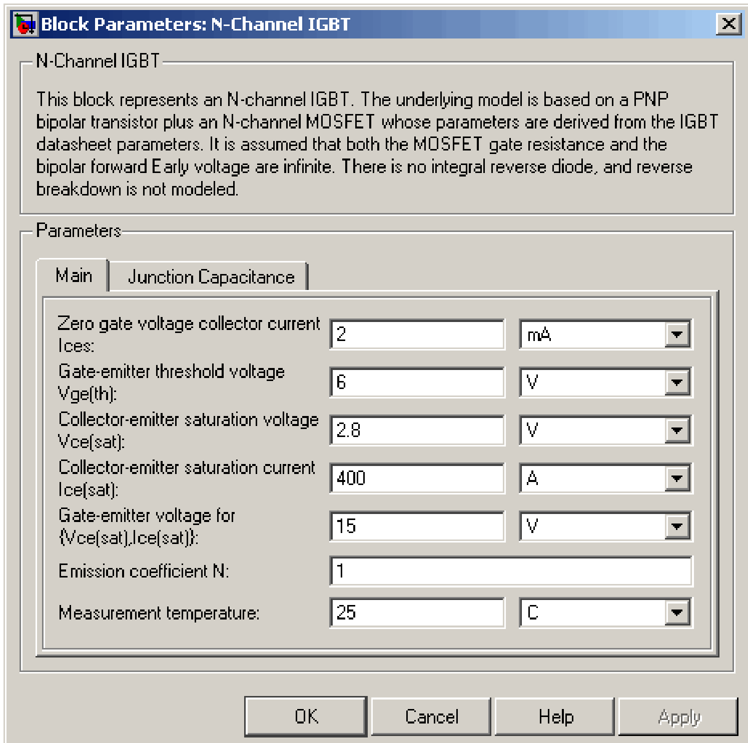
Basic Assumptions and Limitations

The model is based on the following assumptions:

- This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.
- 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.

Dialog Box and Parameters

Main Tab



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.

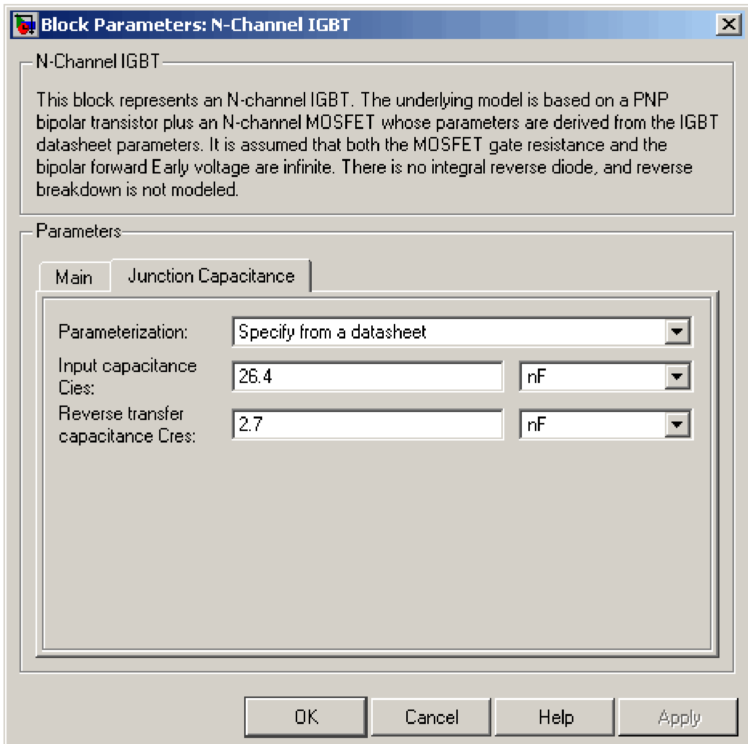
Collector-emitter saturation current Ice(sat)
The collector-emitter current when the gate-emitter voltage is $V_{ge(sat)}$ and collector-emitter voltage is $V_{ce(sat)}$. The default value is 400 A.

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



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.

Ports

The block has the following ports:

`C`

Electrical conserving port associated with the PNP emitter terminal.

`G`

Electrical conserving port associated with the MOSFET gate terminal.

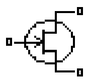
`E`

Electrical conserving port associated with the PNP collector terminal.

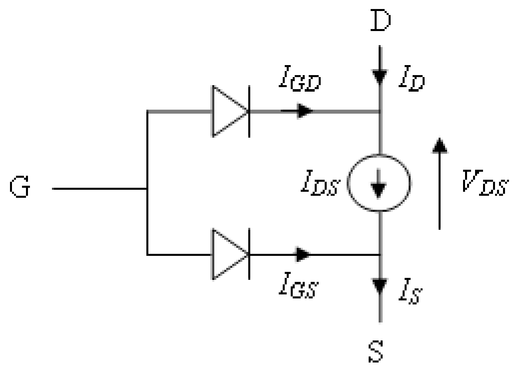
Purpose Model N-Channel JFET

Library Semiconductor Devices

Description 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 ($V_{ds} \geq 0$), 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	$0 < V_{ds} < V_{gs} - V_{to}$	$I_{ds} = \beta V_{ds}\left(2\left(V_{gs} - V_{to}\right) - V_{ds}\right)(1+\lambda V_{ds})$
Saturated	$0 < V_{gs} - V_{to} \le V_{ds}$	$I_{ds} = \beta\left(V_{gs} - V_{to}\right)^2(1+\lambda V_{ds})$

- 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_{gs} and V_{ds} Values	Corresponding I_{ds} Equation
Off	$V_{gd} - V_{to} \le 0$	$I_{ds} = 0$
Linear	$0 < -V_{ds} < V_{gs} - V_{to}$	$I_{ds} = \beta V_{ds}\left(2\left(V_{gd} - V_{to}\right) + V_{ds}\right)(1-\lambda V_{ds})$
Saturated	$0 < V_{gd} - V_{to} \le -V_{ds}$	$I_{ds} = -\beta\left(V_{gd} - V_{to}\right)^2(1-\lambda V_{ds})$

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

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

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

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:

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

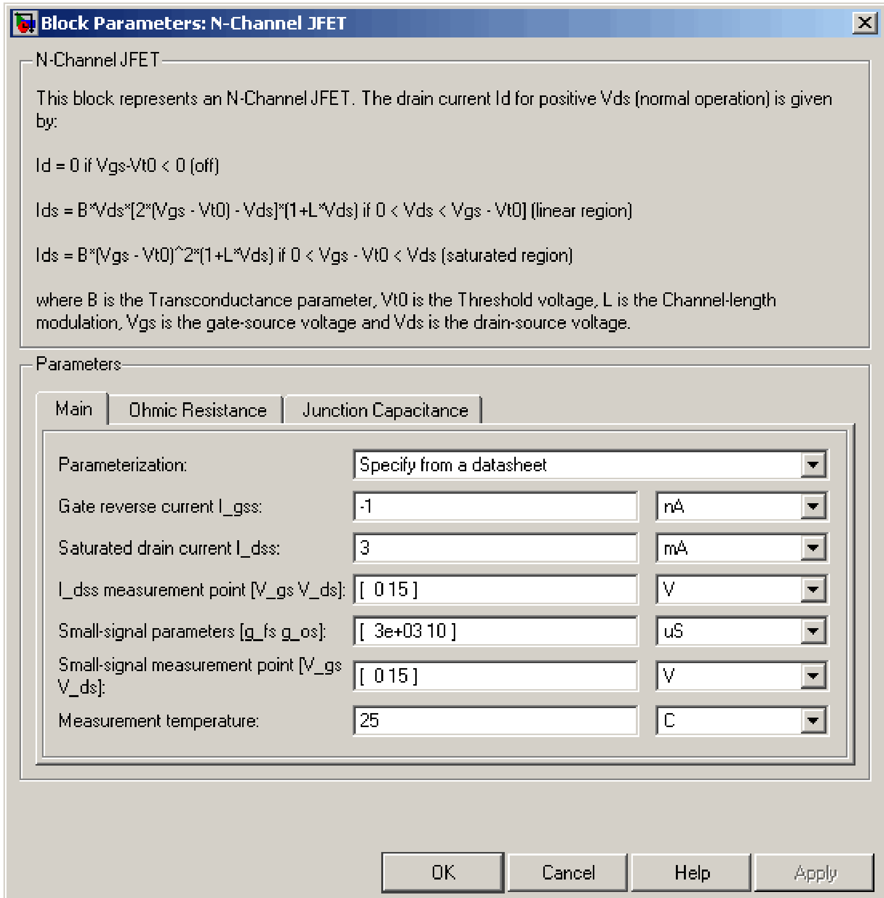
Basic Assumptions and Limitations

The model is based on the following assumptions:

- This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.
- 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

Main Tab



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_{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` A/V^2.

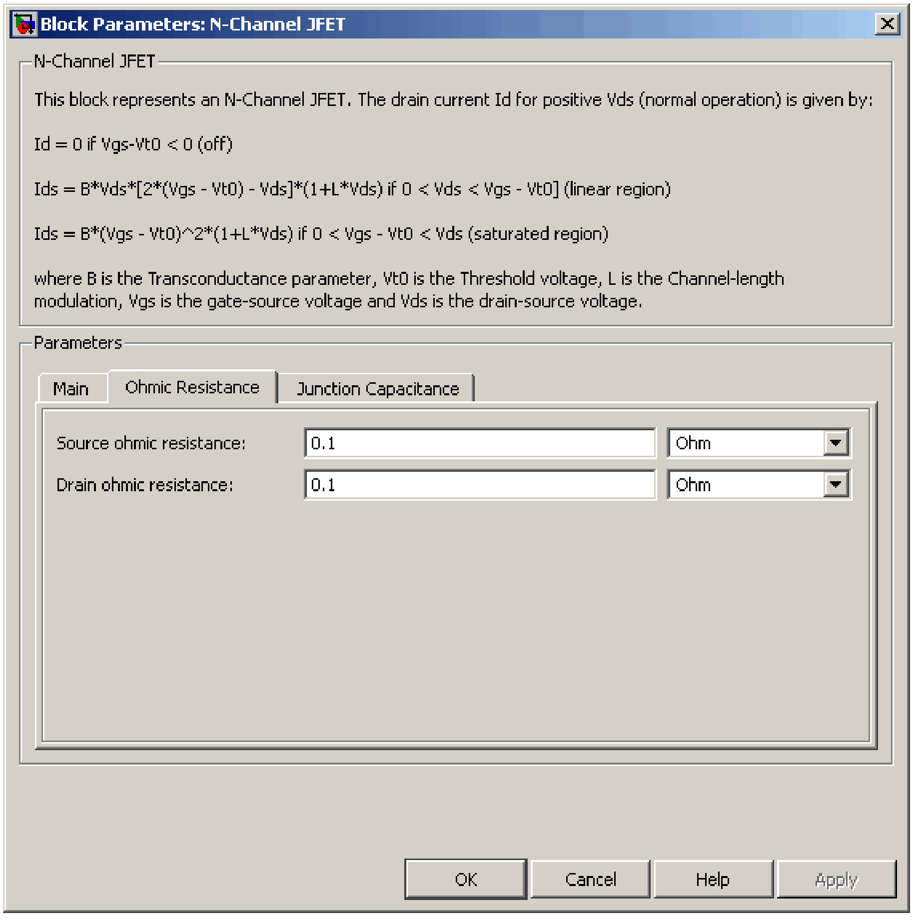
Saturation current
The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select `Specify using equation parameters directly` for the **Parameterization** parameter. The default value is `1e-14` 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



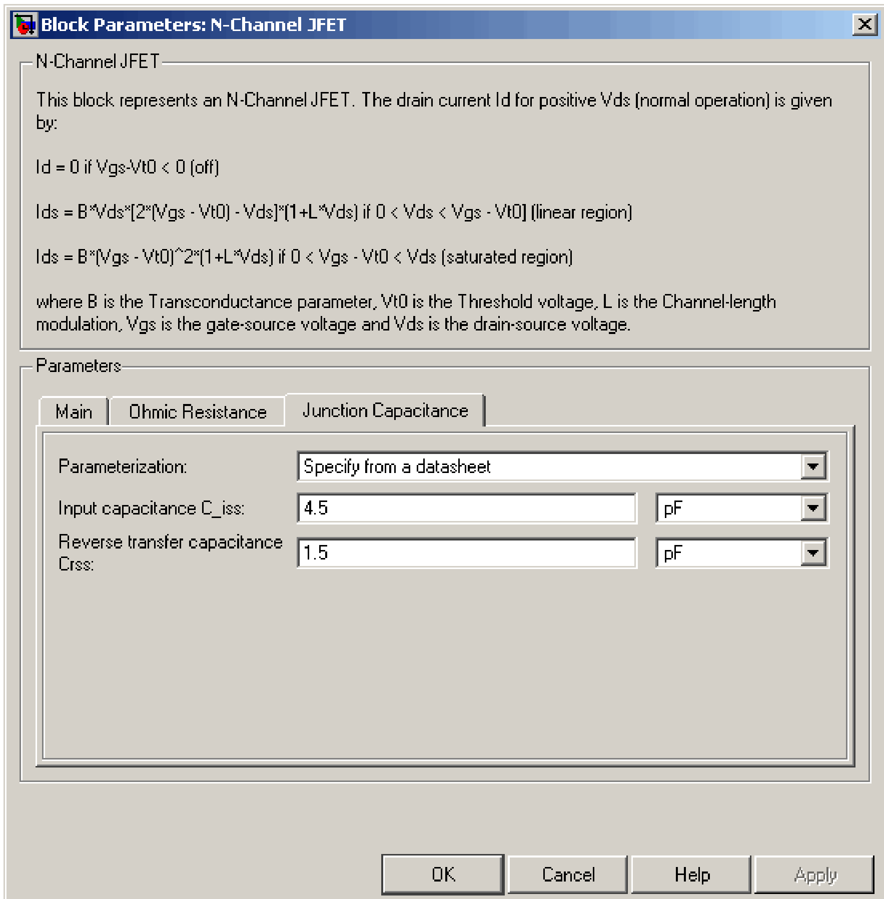
Source ohmic resistance

The transistor source resistance. The default value is `0.1` Ω. The value must be greater than or equal to `0`.

Drain ohmic resistance

The transistor drain resistance. The default value is `0.1` Ω. The value must be greater than or equal to `0`.

Junction Capacitance Tab



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 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.

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.

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

See Also

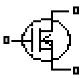
P-Channel JFET

N-Channel MOSFET

Purpose Model N-Channel MOSFET using Shichman-Hodges equation

Library Semiconductor Devices

Description



N-Channel MOSFET

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

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

- In the off region ($V_{GS} < V_{th}$) 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.

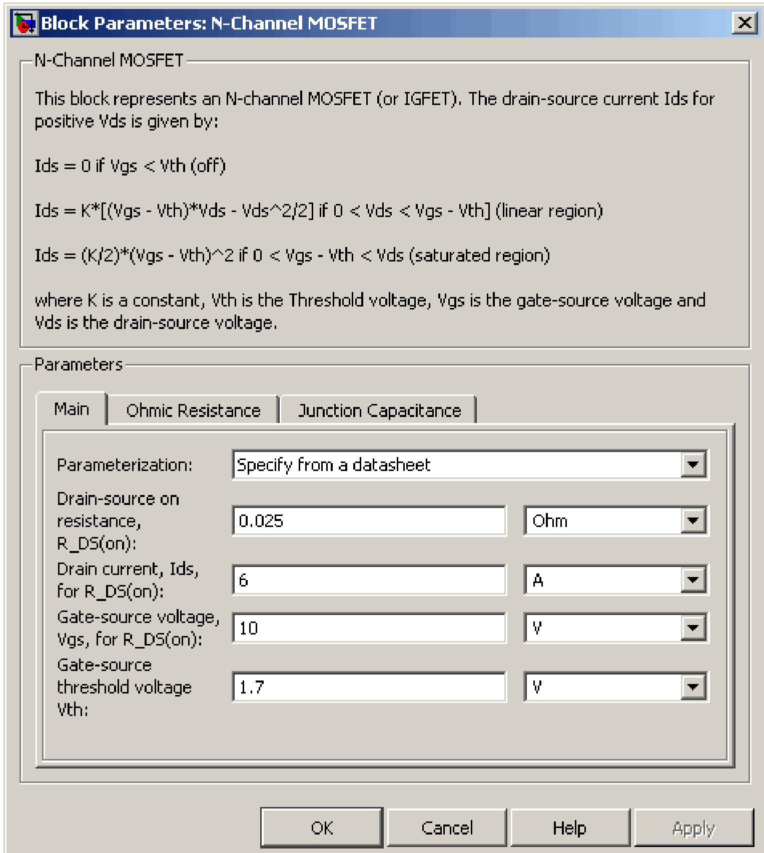
The block models gate junction capacitance as a fixed gate-drain capacitance C_{GD} and a fixed gate-source capacitance C_{GS}. If you select `Specify using equation parameters directly` for the

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:

- $C_{GD} = Crss$
- $C_{GS} = C\_iss - Crss$

Dialog Box and Parameters

Main Tab



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.

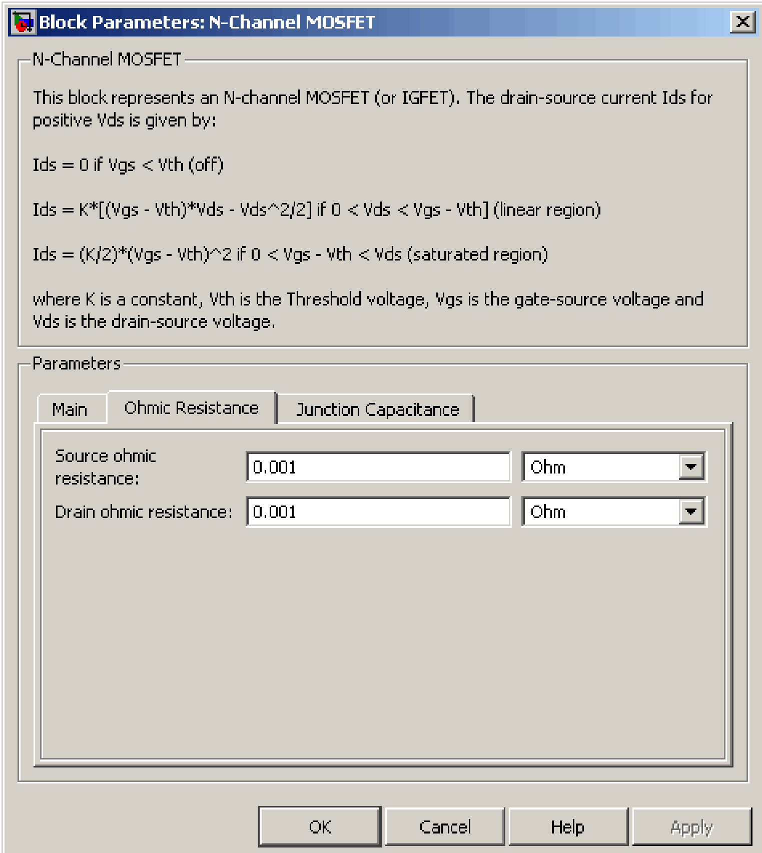
Gain K

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.

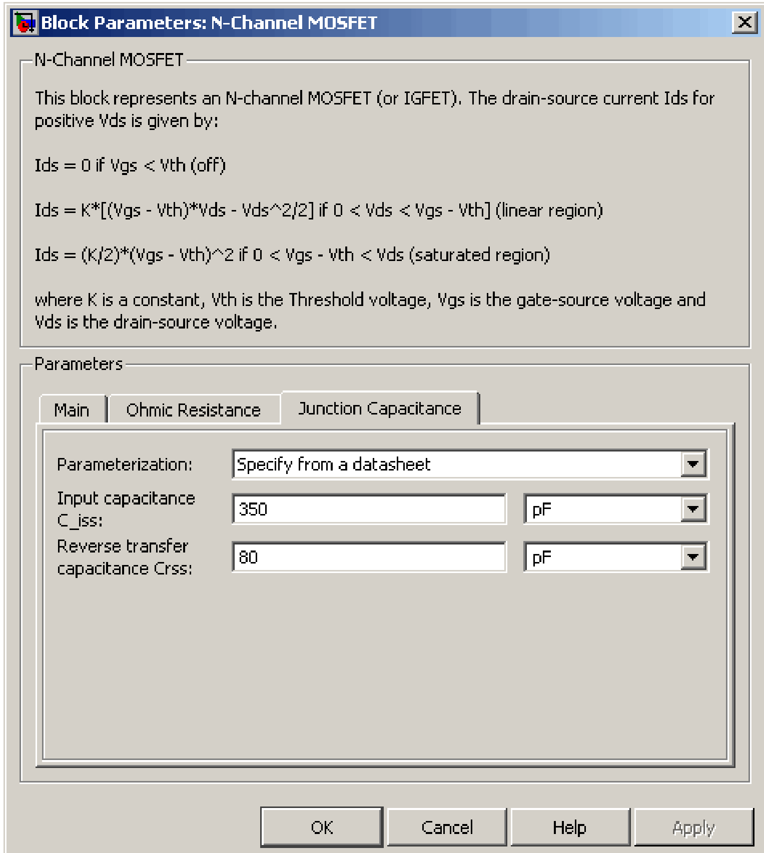
Ohmic Resistance Tab



Source ohmic resistance
: The transistor source resistance. The default value is `0.001` Ω. The value must be greater than or equal to `0`.

Drain ohmic resistance
: The transistor drain resistance. The default value is `0.001` Ω. The value must be greater than or equal to `0`.

Junction Capacitance Tab



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 `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

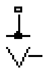
Purpose

Model ideal negative supply rail

Library

Sources

Description

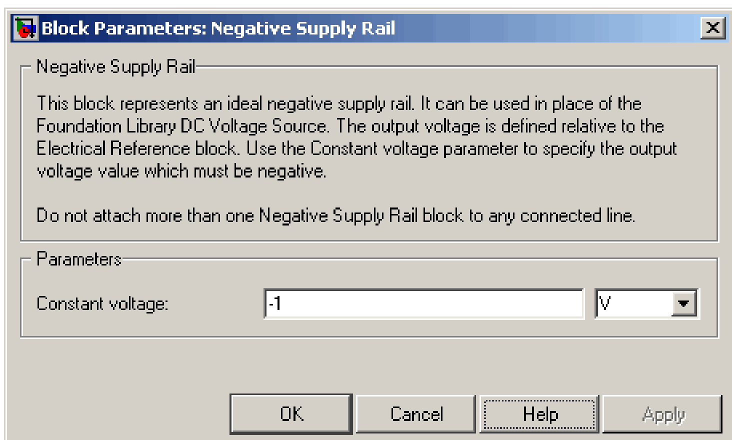


Negative Supply Rail

The Negative Supply Rail block represents an ideal negative supply rail. Use this block instead of the Simscape™ DC Voltage Source block to define the output voltage relative to the Simscape Electrical Reference block that must appear in each model.

Note Do not attach more than one Negative Supply Rail block to any connected line.

Dialog Box and Parameters



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

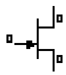
Purpose

Model SPICE-compatible N-Channel JFET

Library

SPICE-Compatible Semiconductors

Description



NJFET

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

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

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 ($V_{ds} \geq 0$) 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.

Applicable Range of V_{gs} Values	Corresponding Q_{gs} Equation
$V_{gs} < FC * VJ$	$Q_{gs} = \dfrac{CGS * VJ * \left(1 - \left(1 - \dfrac{V_{gs}}{VJ}\right)^{1-MG}\right)}{1 - MG}$
$V_{gs} \geq FC * VJ$	$Q_{gs} = CGS * \left(F1 + \dfrac{F3 * \left(V_{gs} - FC * VJ\right) + \dfrac{MG * \left(V_{gs}^2 - \left(FC * VJ\right)^2\right)}{2 * VJ}}{F2}\right)$

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.

- $F1 = \frac{VJ*\left(1-(1-FC)^{1-MG}\right)}{1-MG}$
- $F2 = (1-FC)^{1+MG}$
- $F3 = 1-FC*(1+MG)$

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

Where:

- *CGD* is the **Zero-bias GD capacitance, CGD** parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

- When you select `Device temperature` for the **Model temperature dependence using** parameter, the transistor temperature is

  $$T = T_C + T_O$$

  where:

  - T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
  - T_O is the **Offset local circuit temperature, TOFFSET** parameter value.
- When you select `Fixed temperature` for the **Model temperature dependence using** parameter, the transistor temperature is the **Fixed circuit temperature, TFIXED** parameter value.

The block provides the following relationship between the saturation current *IS* and the transistor temperature *T*:

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

where:

- *IS* is the **Saturation current, IS** parameter value.
- T_{meas} is the **Parameter extraction temperature, TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent, XTI** parameter value.
- *EG* is the **Energy gap, EG** parameter value.

- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient, ND** parameter value.

The block provides the following relationship between the junction potential *VJ* and the transistor temperature *T*:

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

where:

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

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

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

The block provides the following relationship between the gate-source junction capacitance *CGS* and the transistor temperature *T*:

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

where:

- *CGS* is the **Zero-bias GS capacitance, CGS** parameter value.

The block uses the *CGS(T)* equation to calculate the gate-drain junction capacitance by substituting *CGD* (the **Zero-bias GD capacitance, CGD** parameter value) for *CGS*.

The block provides the following relationship between the forward and reverse beta and the transistor temperature *T*:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}} \right)$$

where β is the **Transconductance, BETA** parameter value.

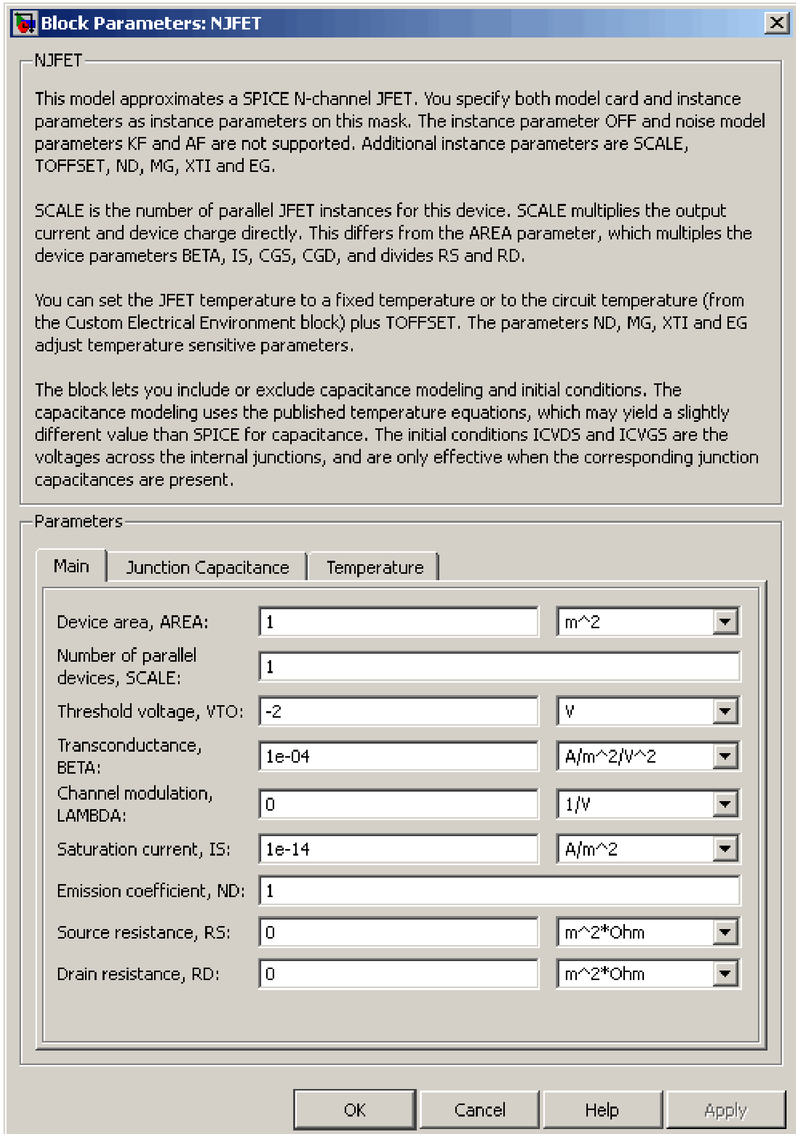
Basic Assumptions and Limitations

The model is based on the following assumptions:

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

Dialog Box and Parameters

Main Tab



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 $A/m^2/V^2$. 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 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.

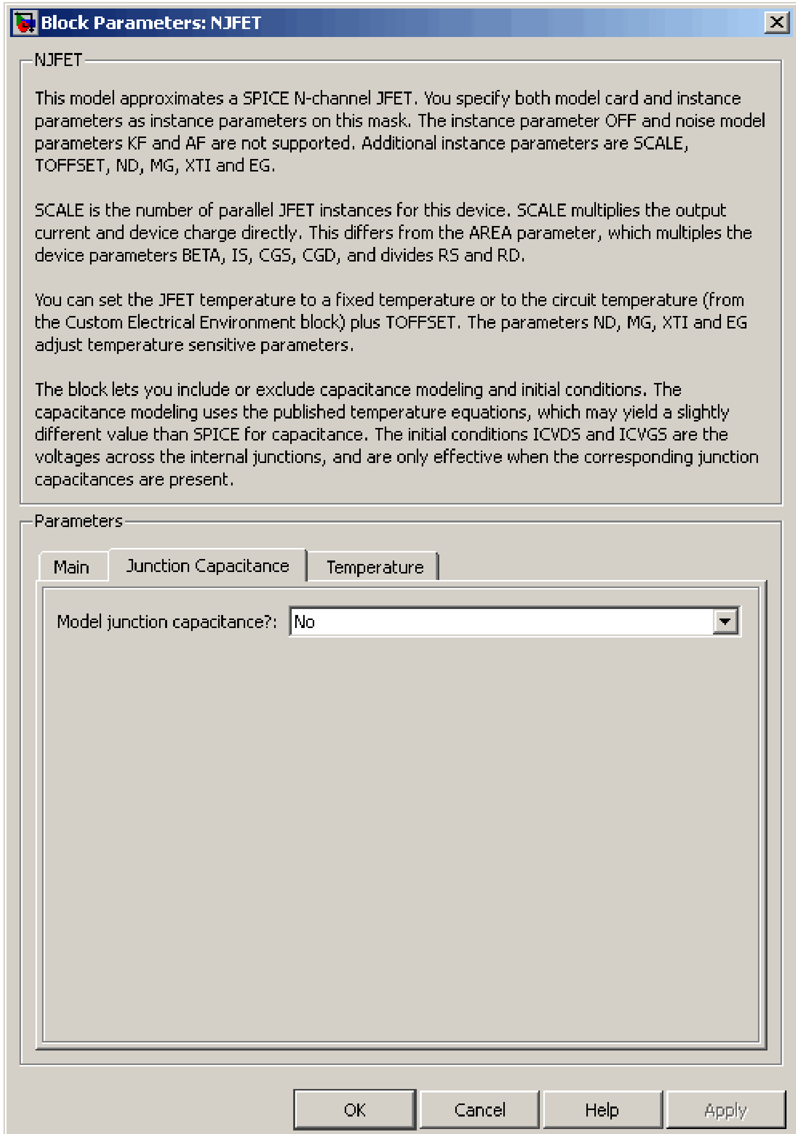
Source resistance, RS

The transistor source resistance. The default value is 0 $m^2*\Omega$ 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



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.

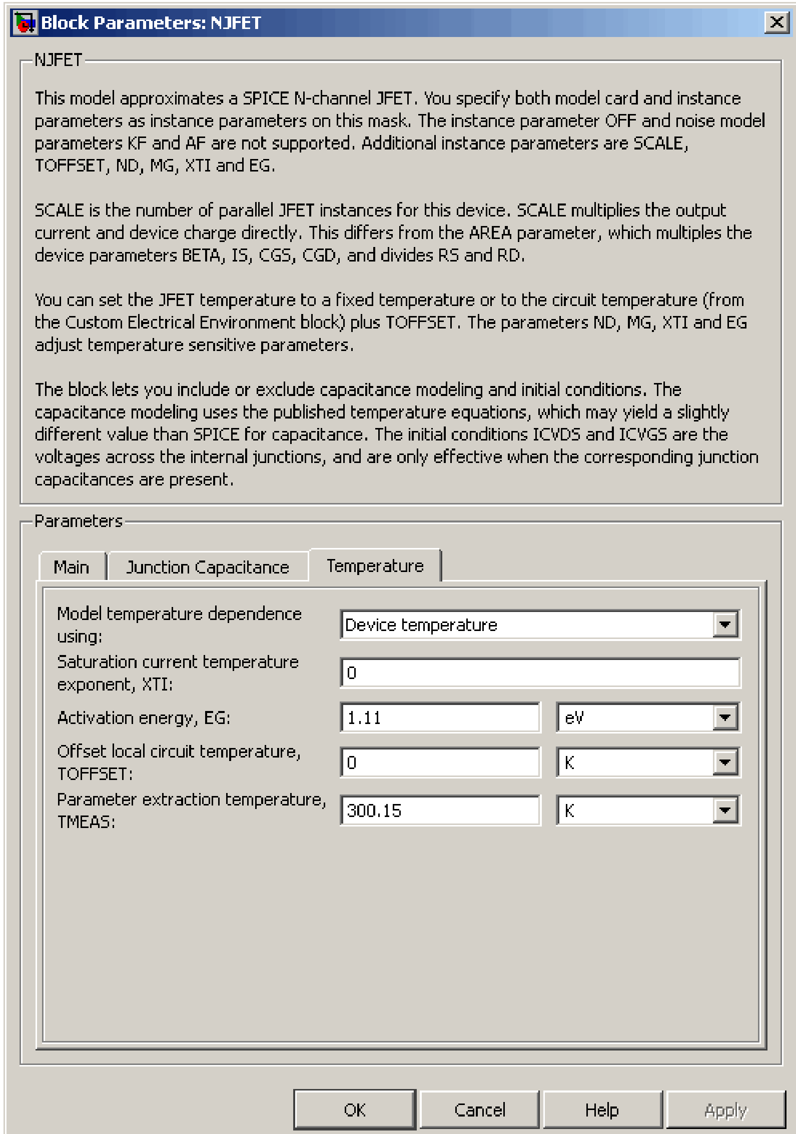
Initial condition voltage ICVDS

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



Model temperature dependence using
Select one of the following options for modeling the diode temperature dependence:

- `Device temperature` — Use the device temperature, which is the **Circuit temperature** value plus the **Offset local circuit temperature, TOFFSET** value. The **Circuit temperature** value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
- `Fixed temperature` — Use a temperature that is independent of the circuit temperature to model temperature dependence.

Saturation current temperature exponent, XTI
The order of the exponential increase in the saturation current as temperature increases. The default value is `0`. The value must be greater than or equal to `0`.

Activation energy, EG
The energy gap that affects the increase in the saturation current as temperature increases. The default value is `1.11` eV. The value must be greater than `0.1` eV.

Offset local circuit temperature, TOFFSET
The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select `Device temperature` for the **Model temperature dependence using** parameter. The default value is `0` K.

Fixed circuit temperature, TFIXED
The temperature at which to simulate the transistor. This parameter is only visible when you select `Fixed temperature` for the **Model temperature dependence using** parameter. The default value is `300.15` K. The value must be greater than `0`.

Parameter extraction temperature, TMEAS
The temperature at which the transistor parameters were measured. The default value is `300.15` K. The value must be greater than `0`.

Ports

The block has the following ports:

G
: Electrical conserving port associated with the transistor gate terminal.

D
: Electrical conserving port associated with the transistor drain terminal.

S
: Electrical conserving port associated with the transistor source terminal.

References

[1] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993. Chapter 3.

See Also

N-Channel JFET, PJFET

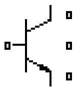
Purpose

Model Gummel-Poon NPN Transistor

Library

SPICE-Compatible Semiconductors

Description



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 $V_{BE} > 80 * V_{TF}$:

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

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

- When $V_{BE} \le 80 * V_{TF}$

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

$$I_{bee} = ISE * \left(e^{(V_{BE}/V_{TE})} - 1 \right)$$

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

- When $V_{BC} > 80 * V_{TR}$:

$$I_{bcr} = IS * \left(\left(\frac{V_{BC}}{V_{TR}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{BC}$$

$$I_{bcc} = ISC * \left((V_{BC} - 80 * V_{TR} + V_{TC}) * \frac{e^{(80 * V_{TR} / V_{TC})}}{V_{TC}} - 1 \right)$$

- When $V_{BC} \le 80 * V_{TR}$

$$I_{bcr} = IS * \left(e^{(V_{BC}/V_{TR})} - 1 \right) + G_{\min} * V_{BC}$$

$$I_{bcc} = ISC * \left(e^{(V_{BC}/V_{TC})} - 1 \right)$$

In the preceding equations:

- V_{BE} is the base-emitter voltage and V_{BC} is the base-collector voltage.
- $V_{TE} = NE * k * T / q$, $V_{TC} = NC * k * T / q$, $V_{TF} = NF * k * T / q$, and $V_{TR} = NR * k * T / q$.
- *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:

$$I_B = -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)$$

$$I_C = -\left(\frac{I_{ebf} - I_{cbr}}{q_b} - \frac{I_{cbr}}{BR} - I_{\mathrm{cbc}}\right)$$

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:

$$q_b = \frac{q_1}{2}\left(1 + \sqrt{0.5 * \left(\sqrt{(1 + 4 * q_2 - eps)^2 + eps^2} + 1 + 4 * q_2 - eps\right) + eps}\right)$$

$$q_1 = \left(1 - \frac{V_{BC}}{VAF} - \frac{V_{BE}}{VAR}\right)^{-1}$$

$$q_2 = \frac{I_{bef}}{IKF} + \frac{I_{bcr}}{IKR}$$

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

  $$z = \frac{\sqrt{1 + 144 I_B / (\pi^2 IRB)} - 1}{(24/\pi^2)\sqrt{(I_B / IRB)}}$$

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:

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

where *ITF* is the **Coefficient of TF, ITF** parameter value.

Junction Charge Model

The block lets you model junction charge. The base-collector charge Q_{bc} and the base-emitter charge Q_{be} depend on an intermediate value, Q_{dep} as follows, after adjusting the applicable model parameters for temperature:

- For the internal base-emitter junctions:

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

- For the internal base-collector junctions:

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

- For the external base-collector junctions:

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

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

Applicable Range of V_{jct} Values	Corresponding Q_{dep} Equation
$V_{jct} < FC * VJ$	$Q_{dep} = C_{jct} * VJ * \frac{1 - \left(1 - V_{jct}/VJ\right)^{(1-MJ)}}{1 - MJ}$
$V_{jct} \geq FC * VJ$	$Q_{dep} = C_{jct} * \left[F1 + \frac{F3 * \left(V_{jct} - FC * VJ\right) + \frac{MJ * \left[V_{jct}^{2} - \left(FC * VJ\right)^{2}\right]}{2 * VJ}}{F2} \right]$

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is:
  - The **B-E built-in potential, VJE** parameter value for the base-emitter junction.
  - The **B-C built-in potential, VJC** parameter value for the base-collector junction.
- *MJ* is:
  - The **B-E exponential factor, MJE** parameter value for the base-emitter junction.
  - The **B-C exponential factor, MJC** parameter value for the base-collector junction.
- C_{jct} is:
  - The **B-E depletion capacitance, CJE** parameter value for the base-emitter junction.

- The **B-C depletion capacitance, CJC** parameter value for the base-collector junction.

- $F1 = VJ*\left(1-\left(1-FC\right)^{(1-MJ)}\right)/\left(1-MJ\right)$
- $F2 = \left(1-FC\right)^{(1+MJ)}$
- $F3 = 1-FC*\left(1+MJ\right)$

The collector-substrate charge Q_{cs} depends on the collector-substrate voltage V_{cs} as follows, after adjusting the applicable model parameters for temperature.

Applicable Range of V_{cs} Values	Corresponding Q_{cs} Equation
$V_{cs} < 0$	$Q_{cs} = CJS*VJS*\left(\dfrac{1-\left(1-V_{cs}/VJS\right)^{(1-MJS)}}{1-MJS}\right)$
$V_{cs} \geq 0$	$Q_{cs} = CJS*\left(1+MJS*V_{cs}/(2*VJS)\right)*V_{cs}$

where:

- *CJS* is the **C-S junction capacitance, CJS** parameter value.
- *VJS* is the **Substrate built-in potential, VJS** parameter value.
- *MJS* is the **Substrate exponential factor, MJS** parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

- When you select `Device temperature` for the **Model temperature dependence using** parameter, the transistor temperature is

  $$T = T_C + T_O$$

  where:

  - T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
  - T_O is the **Offset local circuit temperature, TOFFSET** parameter value.

- When you select `Fixed temperature` for the **Model temperature dependence using** parameter, the transistor temperature is the **Fixed circuit temperature, TFIXED** parameter value.

The block provides the following relationship between the saturation current *IS* and the transistor temperature *T*:

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

where:

- *IS* is the **Transport saturation current, IS** parameter value.
- T_{meas} is the **Parameter extraction temperature, TMEAS** parameter value.
- *XTI* is the **Temperature exponent for IS, XTI** parameter value.
- *EG* is the **Energy gap, EG** parameter value.
- $V_t = kT/q$.

The block provides the following relationship between the base-emitter junction potential *VJE* and the transistor temperature *T*:

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

where:

- *VJE* is the **B-E built-in potential, VJE** parameter value.
- $EG_{T_{meas}} = 1.16eV - \left(7.02e-4 * T_{meas}{}^2\right) / \left(T_{meas} + 1108\right)$
- $EG_T = 1.16eV - \left(7.02e-4 * T^2\right) / \left(T + 1108\right)$

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*.

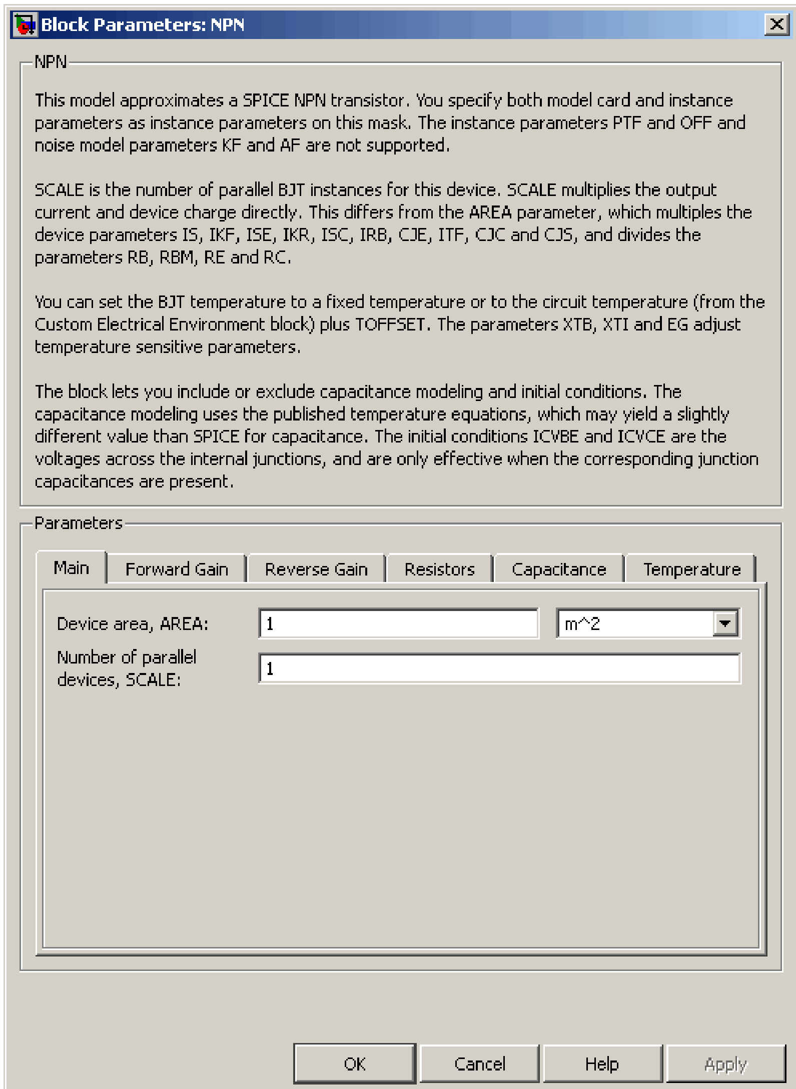
Basic Assumptions and Limitations

The model is based on the following assumptions:

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

Dialog Box and Parameters

Main Tab



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:

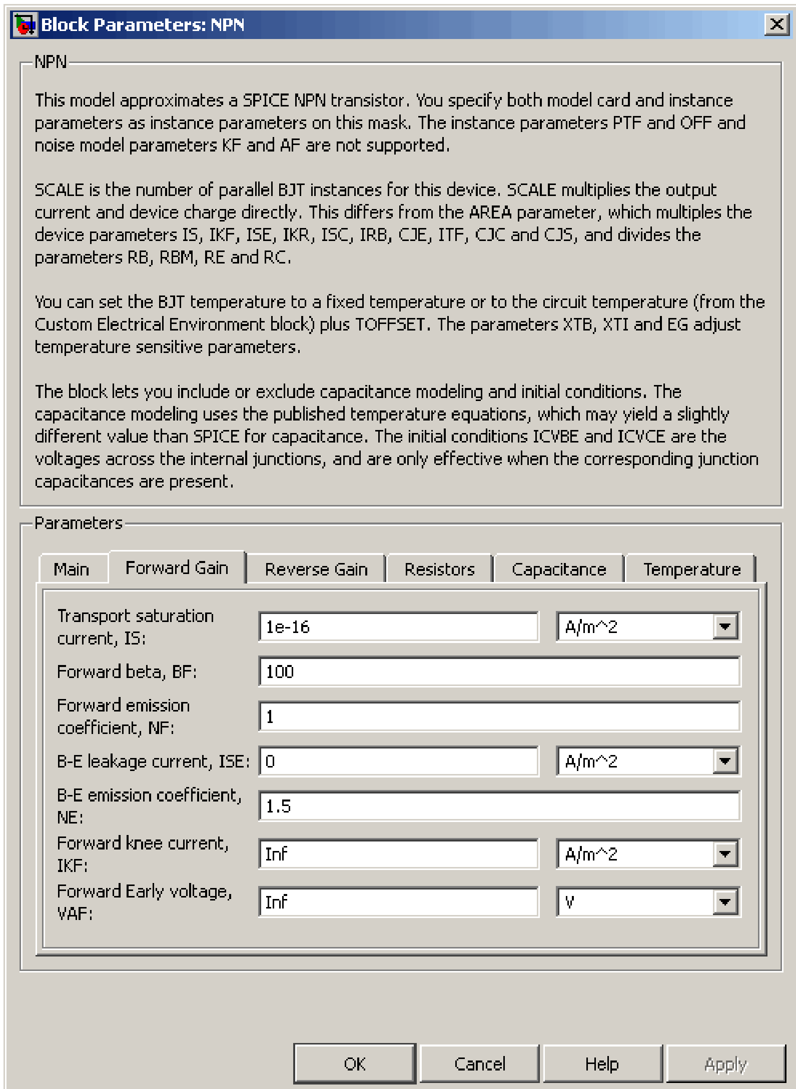
- **Zero-bias base resistance, RB**
- **Minimum base resistance, RBM**
- **Emitter resistance, RE**
- **Collector resistance, RC**

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



Transport saturation current, IS

The magnitude of the current at which the transistor saturates. The default value is `1e-16` A/m^2. The value must be greater than or equal to `0`.

Forward beta, BF

The ideal maximum reverse beta. The default value is `100`. The value must be greater than `0`.

Forward emission coefficient, NF

The reverse emission coefficient or ideality factor. The default value is `1`. The value must be greater than `0`.

B-E leakage current, ISE

The base-emitter leakage current. The default value is `0` A/m^2. The value must be greater than or equal to `0`.

B-E emission coefficient, NE

The base-collector emission coefficient or ideality factor. The default value is `1.5`. The value must be greater than `0`.

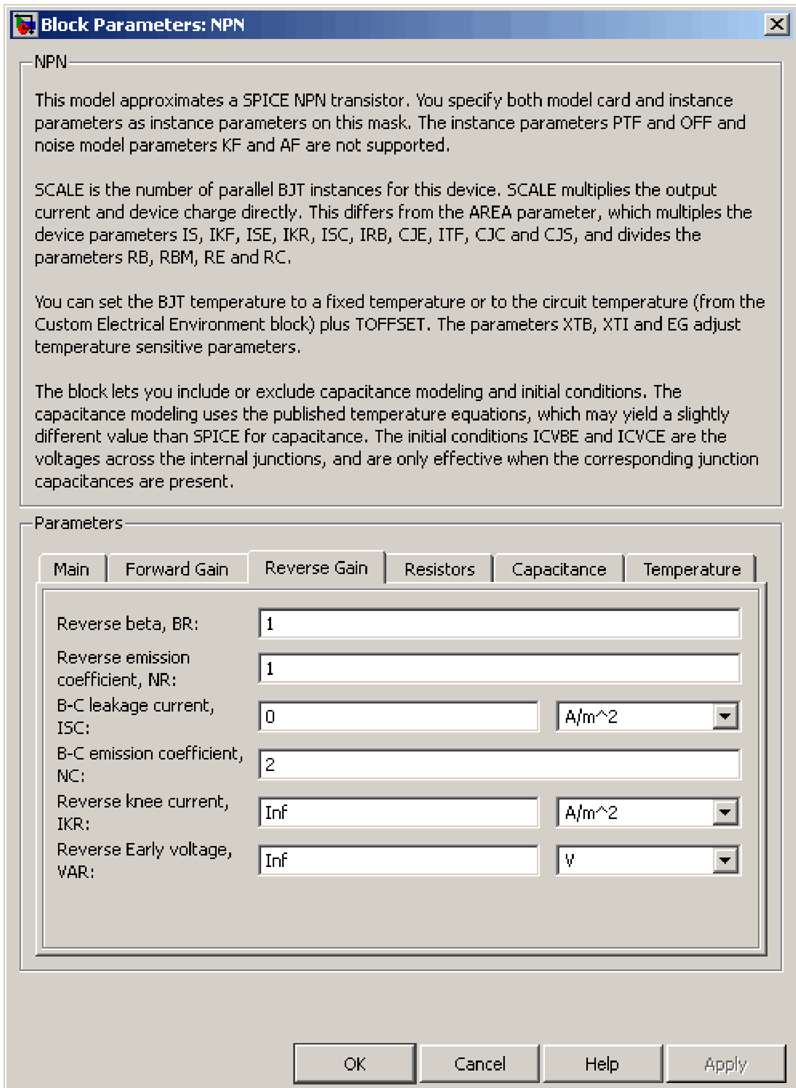
Forward knee current, IKF

The current value at which forward-beta high-current roll-off occurs. The default value is `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



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`.

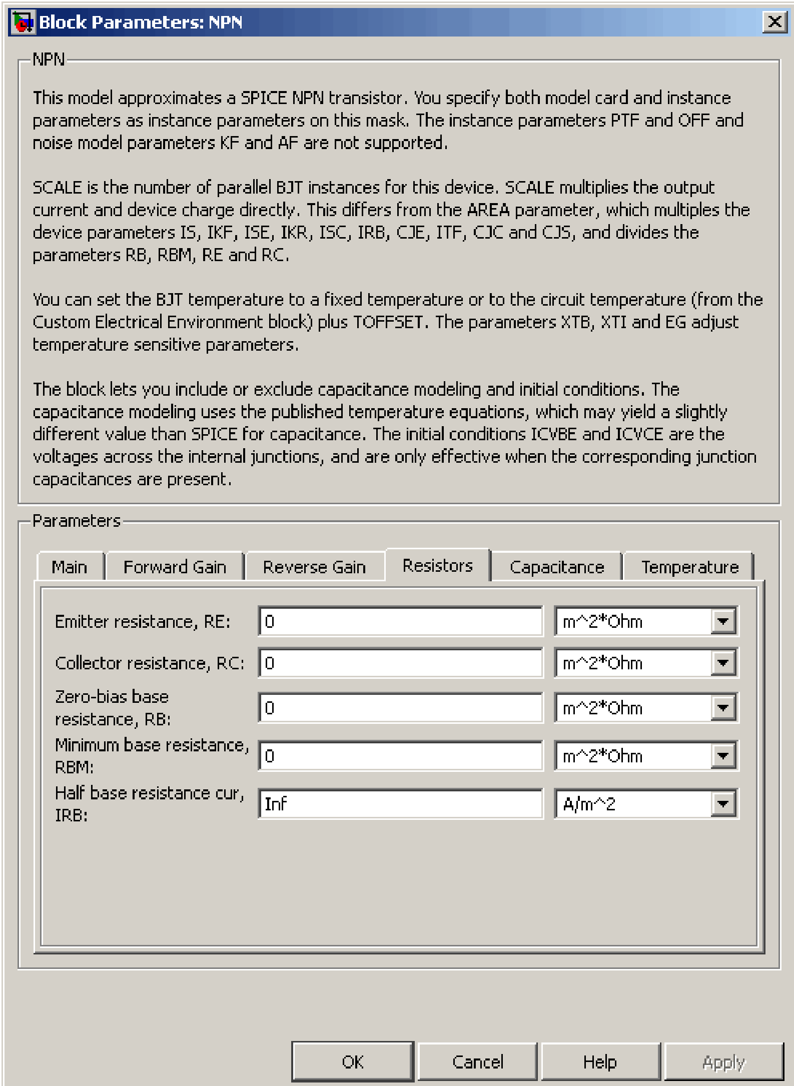
Reverse knee current, IKR

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



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`.

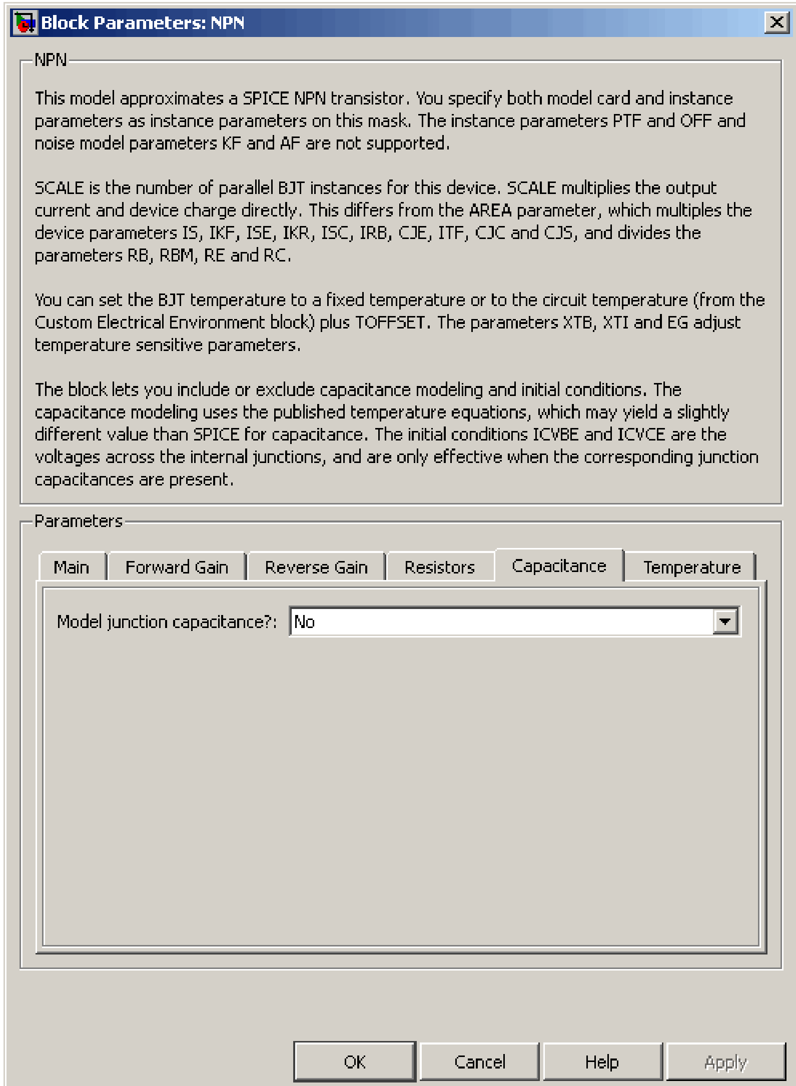
Minimum base resistance, RBM

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



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 Inf V. The value must be greater than or equal to 0.

Coefficient of TF, ITF
The coefficient for the dependence of the transit time on collector current. This parameter is only visible when you select B-E

Capacitance for the **Model junction capacitance** parameter. The default value is 0 A/m^2. The value must be greater than or equal to 0. Use the default value of 0 if you do not want to model the effect of collector current on transit time.

B-C depletion capacitance, CJC
The depletion capacitance across the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m^2. The value must be greater than 0.

B-C built-in potential, VJC
The base-collector junction potential. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.75 V. The value must be greater than or equal to 0.01 V.

B-C exponential factor, MJC
The grading coefficient for the base-collector junction. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.33. The value must be greater than or equal to 0 and less than or equal to 0.9.

B-C capacitance fraction, XCJC
The fraction of the base-collector depletion capacitance that is connected between the internal base and the internal collector. The rest of the base-collector depletion capacitance is connected between the external base and the internal collector. This parameter is only visible when you select B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0. The value must be greater than or equal to 0 and less than or equal to 1.

Reverse transit time, TR
The transit time of the minority carriers that cause diffusion capacitance when the base-collector junction is reverse-biased. This parameter is only visible when you select B-C Capacitance

for the **Model junction capacitance** parameter. The default value is 0 s. The value must be greater than or equal to 0.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than or equal to 0 and less than or equal to 0.95.

Specify initial condition

Select one of the following options for specifying an initial condition:

- No — Do not specify an initial condition for the model. This is the default option.
- Yes — Specify the initial transistor conditions.

Note The NPN block applies the initial transistor voltages across the junction capacitors and not across the ports.

This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** parameter.

Initial condition voltage ICVBE

Base-emitter voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Initial condition voltage ICVCE

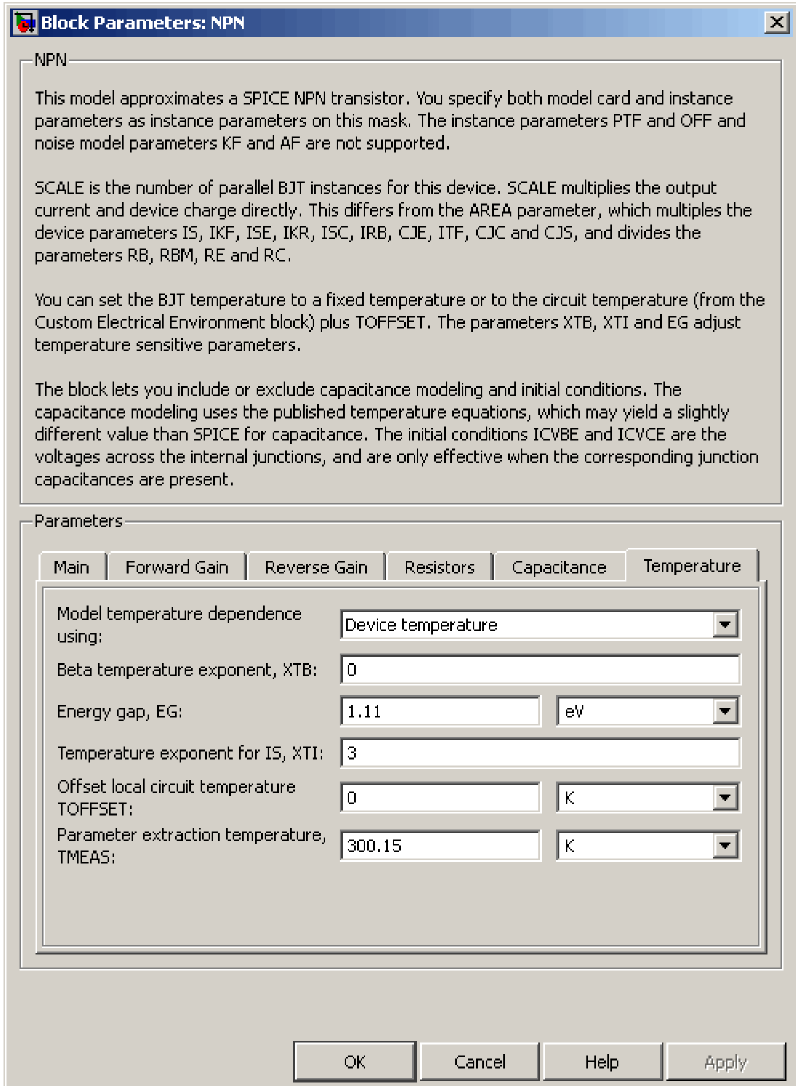
Base-collector voltage at the start of the simulation. This parameter is only visible when you select B-E Capacitance or B-C Capacitance for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is `0` V.

C-S junction capacitance, CJS
The collector-substrate junction capacitance. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0` F/m^2. The value must be greater than or equal to `0`.

Substrate built-in potential, VJS
The potential of the substrate. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0.75` V.

Substrate exponential factor, MJS
The grading coefficient for the collector-substrate junction. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0`. The value must be greater than or equal to `0` and less than or equal to `0.9`.

Temperature Tab



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. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993. Chapter 2.

See Also

NPN Bipolar Transistor

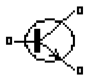
Purpose

Model NPN bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



NPN Bipolar Transistor

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:

$$I_C = I_S\left[\left(e^{qV_{BE}/(kT)} - e^{qV_{BC}/(kT)}\right)\left(1-\frac{V_{BC}}{V_A}\right)-\frac{1}{\beta_R}\left(e^{qV_{BC}/(kT)}-1\right)\right]$$

$$I_B = I_S\left[\frac{1}{\beta_F}\left(e^{qV_{BE}/(kT)}-1\right)+\frac{1}{\beta_R}\left(e^{qV_{BC}/(kT)}-1\right)\right]$$

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

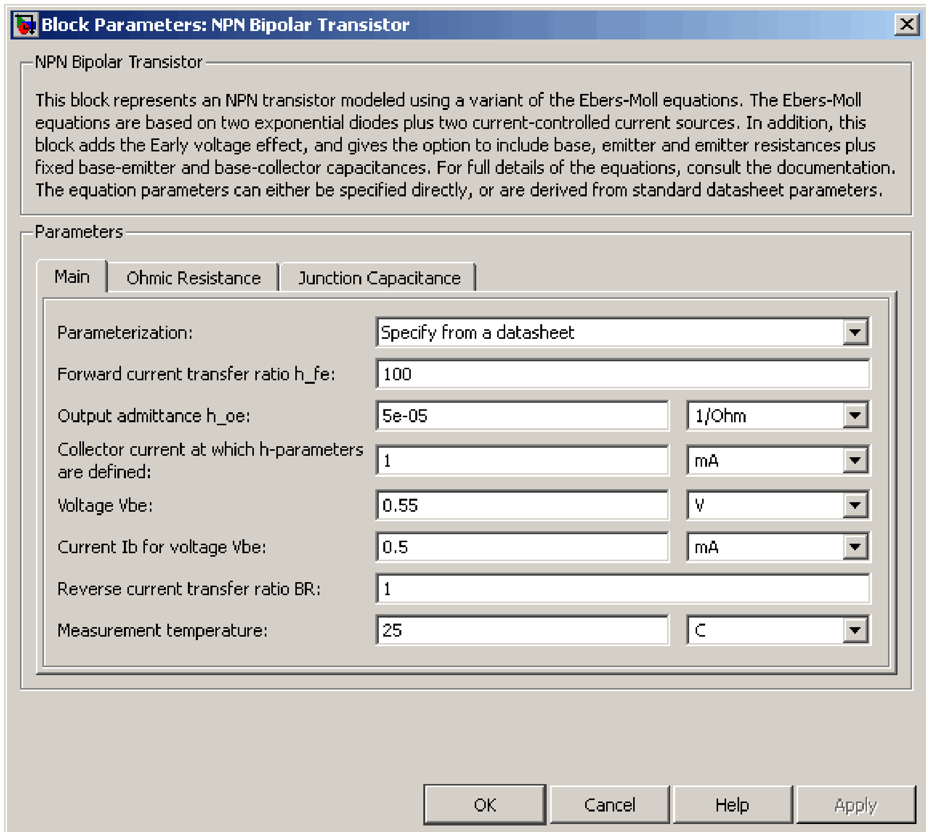
Basic Assumptions and Limitations

The NPN 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.

Dialog Box and Parameters

Main Tab



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.

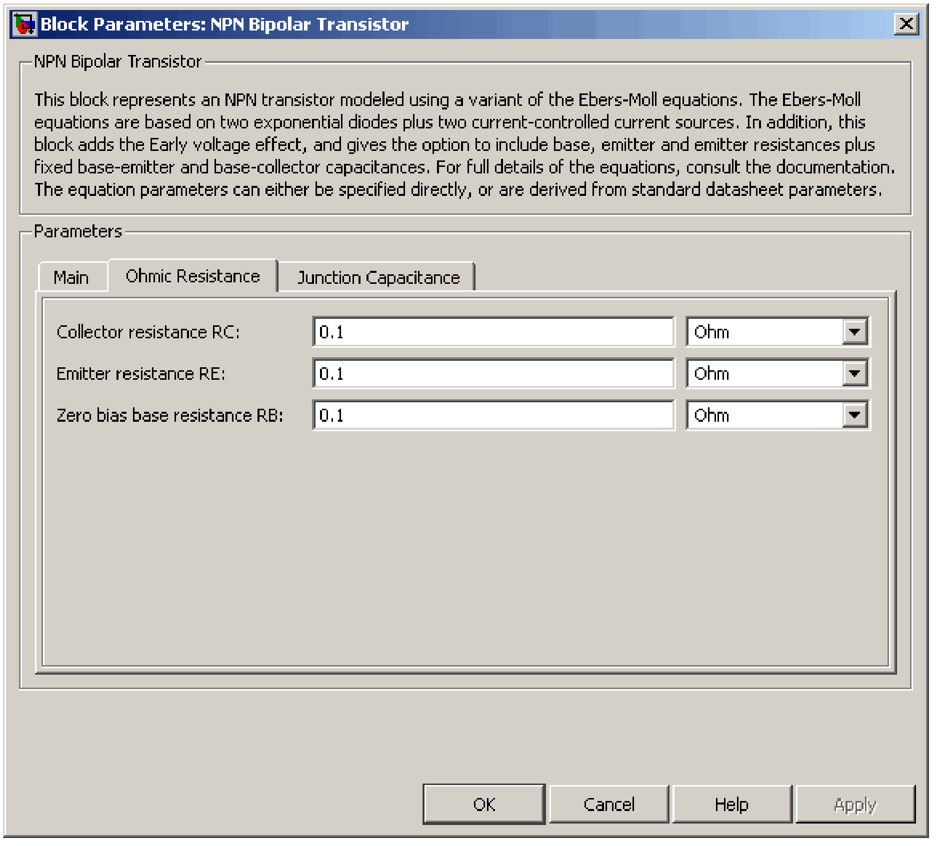
Reverse current transfer ratio BR

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` °C.

Ohmic Resistance Tab

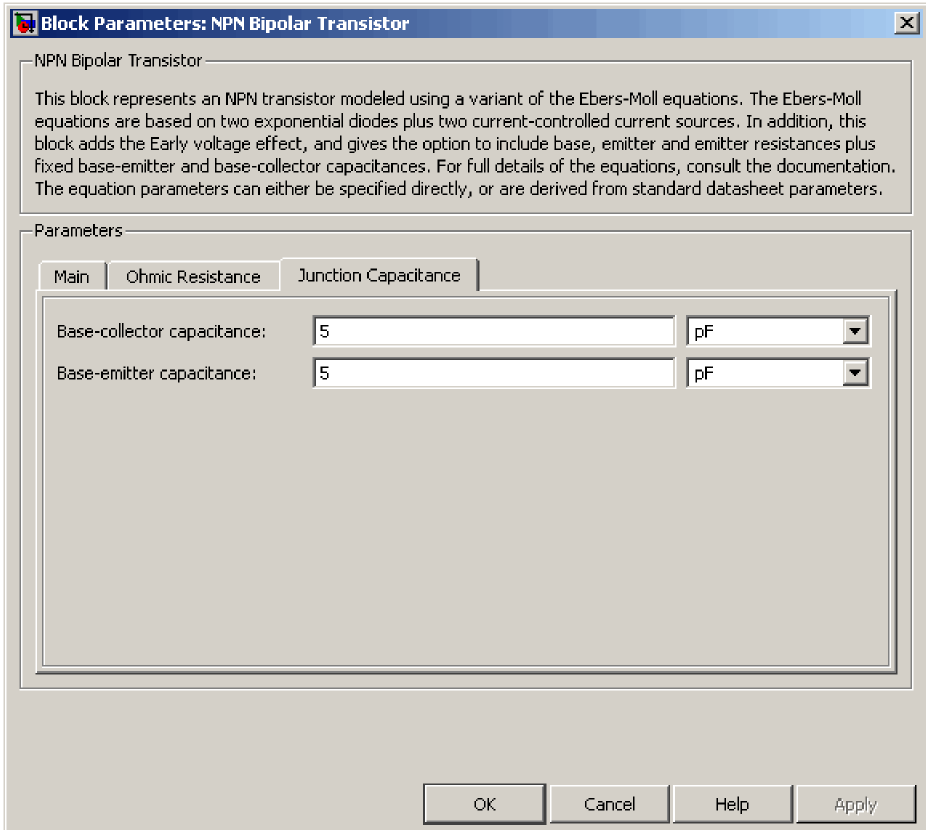


Collector resistance RC
: Resistance at the collector. The default value is `0.1` Ω.

Emitter resistance RE
: Resistance at the emitter. The default value is `0.1` Ω.

Zero bias base resistance RB
: Resistance at the base at zero bias. The default value is `0.1` Ω.

Junction Capacitance Tab



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.

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. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

See Also

Diode, PNP Bipolar Transistor

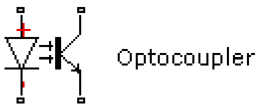
Purpose

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

Library

Semiconductor Devices

Description



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.

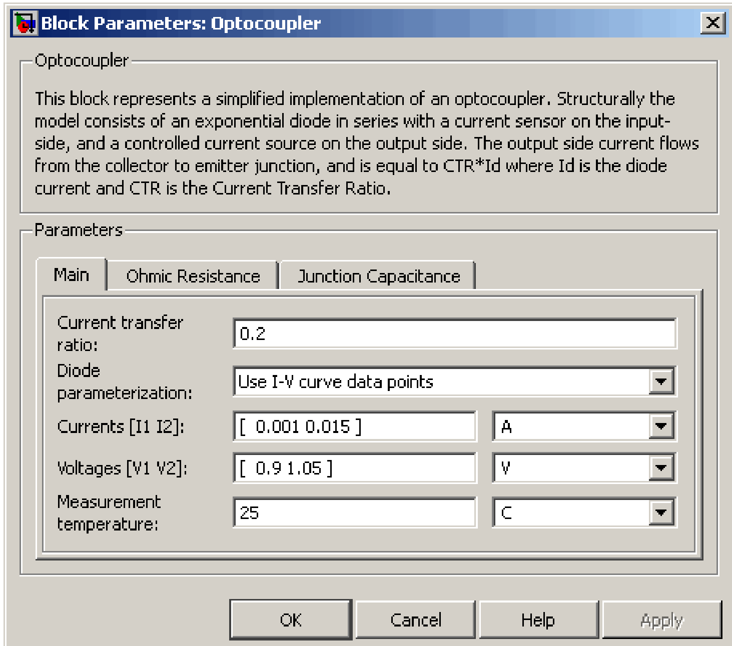
Basic Assumptions and Limitations

The Optocoupler block has the following 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. 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

Main Tab



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.
- `Use parameters IS and N` — Specify saturation current and emission coefficient.

Currents [I1 I2]
: A vector of the current values at the two points on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select `Use I-V curve data points` for the **Diode parameterization** parameter. The default value is `[ 0.001 0.015 ]` A.

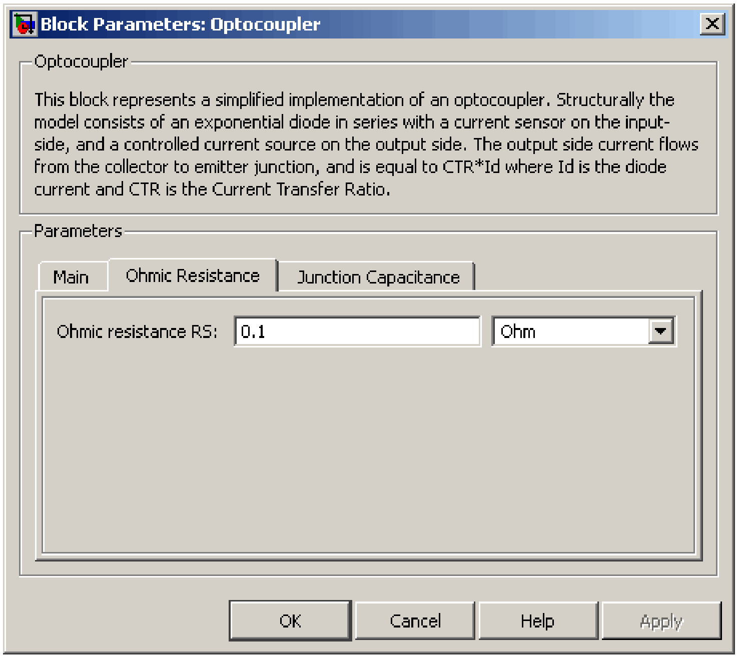
Voltages [V1 V2]
: A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select `Use I-V curve data points` for the **Diode parameterization** parameter. The default value is `[ 0.9 1.05 ]` V.

Saturation current IS
: The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select `Use parameters IS and N` for the **Diode parameterization** parameter. The default value is `1e-10` A.

Measurement temperature
: The temperature at which IS or the I-V curve was measured. The default value is `25` °C.

Emission coefficient N
: The diode emission coefficient or ideality factor. This parameter is only visible when you select `Use parameters IS and N` for the **Diode parameterization** parameter. The default value is `2`.

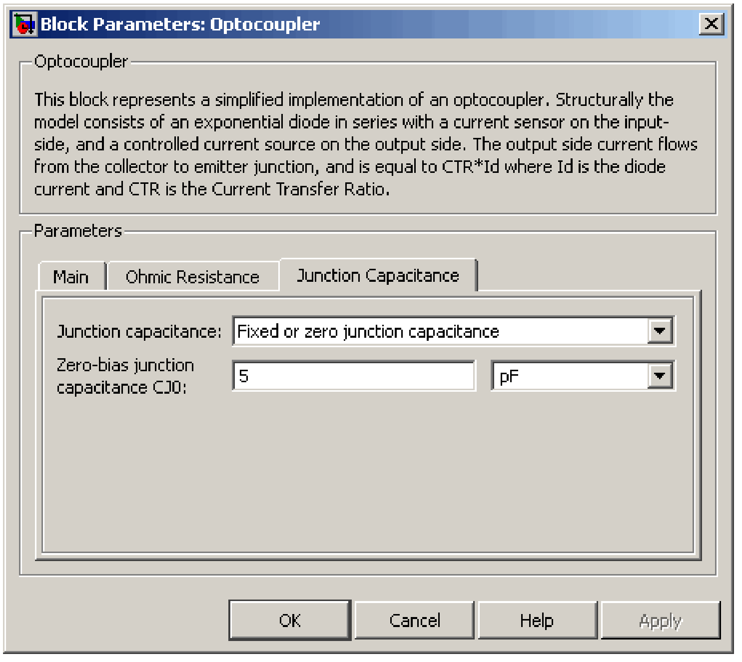
Ohmic Resistance Tab



Ohmic resistance RS

The series diode connection resistance. The default value is `0.1` Ω

Junction Capacitance Tab



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 CJ0, 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 CJ0, 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 CJ0, 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 CJ0, 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 *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 0.1 10 100 ]` V.

Corresponding capacitances [C1 C2 C3]
A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 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 CJ0, VJ, M & FC` for the **Junction capacitance** parameter. The default value is `0.5`.

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. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

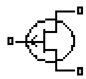
See Also

Diode, NPN Bipolar Transistor, Simscape™ Controlled Current Source

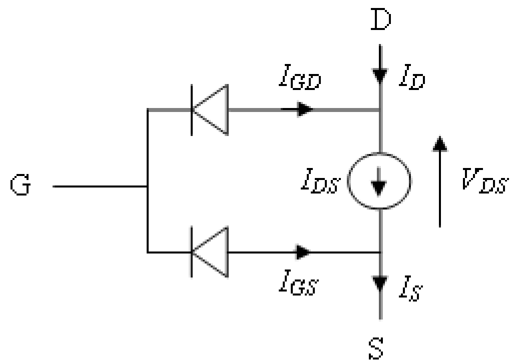
Purpose Model P-Channel JFET

Library Semiconductor Devices

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



P-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 ($-V_{ds} \geq 0$), 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	$0 < -V_{ds} < -V_{gs} + V_{t0}$	$I_{ds} = \beta V_{ds}\left(2(-V_{gs} + V_{t0}) + V_{ds}\right)(1 - \lambda V_{ds})$
Saturated	$0 < -V_{gs} + V_{t0} < -V_{ds}$	$I_{ds} = -\beta(-V_{gs} + V_{t0})^2(1 - \lambda V_{ds})$

- 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

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

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

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:

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

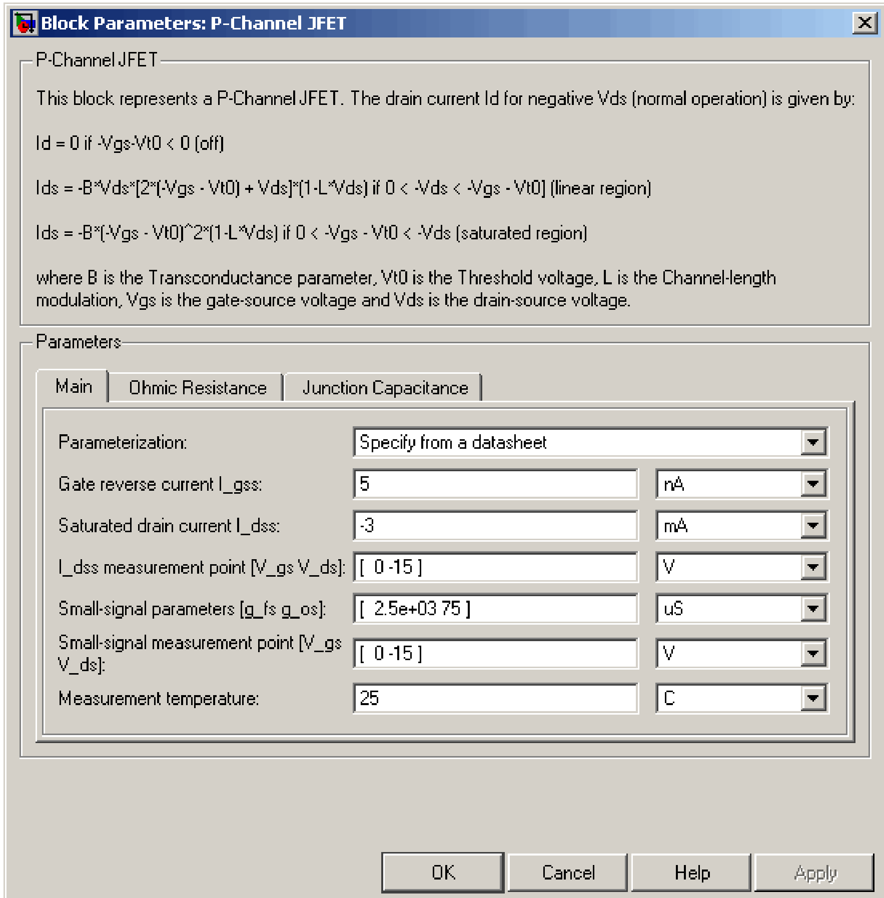
Basic Assumptions and Limitations

The model is based on the following assumptions:

- This block does not allow you to specify initial conditions on the junction capacitances. If you select the **Start simulation from steady state** option in the Solver Configuration block, the block solves the initial voltages to be consistent with the calculated steady state. Otherwise, voltages are zero at the start of the simulation.
- 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

Main Tab



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` A/V^2.

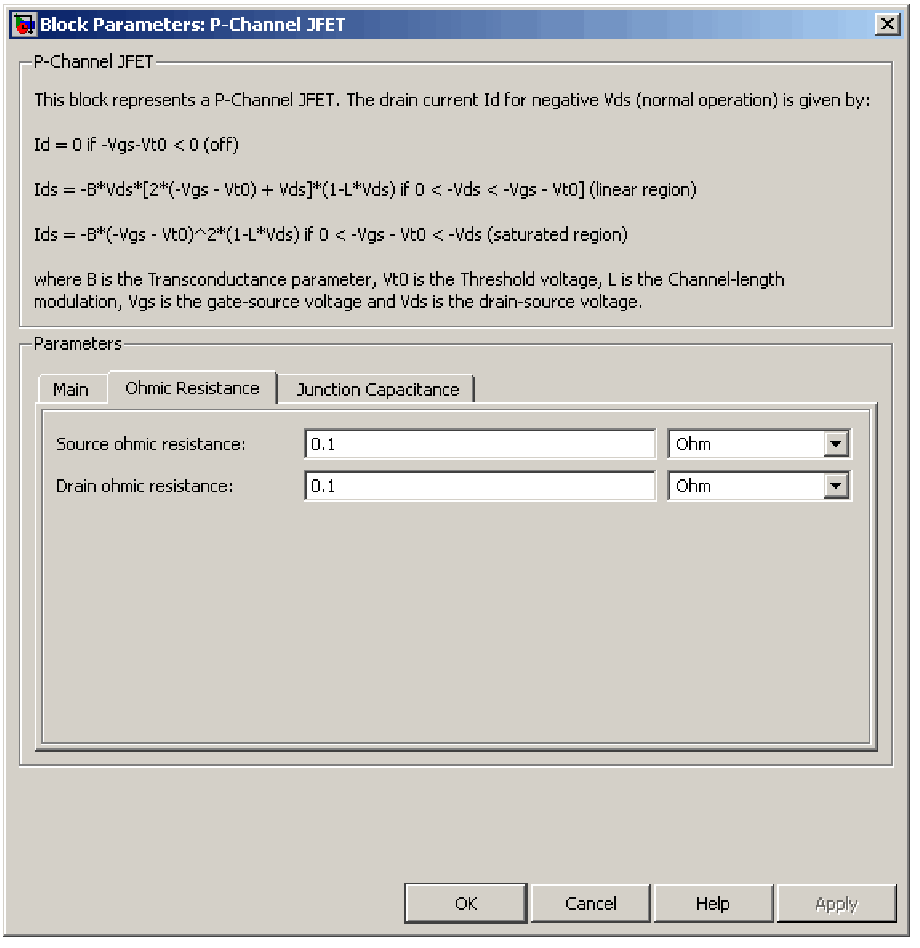
Saturation current
The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select `Specify using equation parameters directly` for the **Parameterization** parameter. The default value is `1e-14` 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

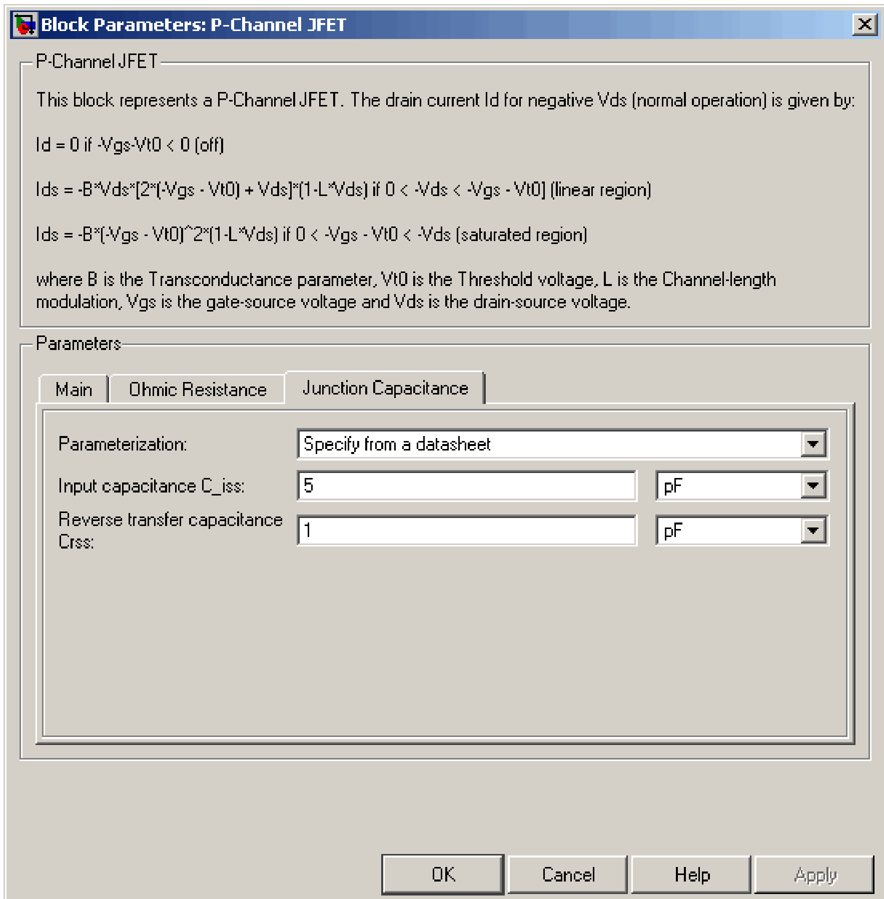


Source ohmic resistance

The transistor source resistance. The default value is `0.1` Ω. The value must be greater than or equal to `0`.

Drain ohmic resistance
The transistor drain resistance. The default value is `0.1` Ω. The value must be greater than or equal to `0`.

Junction Capacitance Tab



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 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.

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.

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

See Also

N-Channel JFET

P-Channel MOSFET

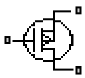
Purpose

Model P-Channel MOSFET using Shichman-Hodges equation

Library

Semiconductor Devices

Description



P-Channel MOSFET

The 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:

- 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:

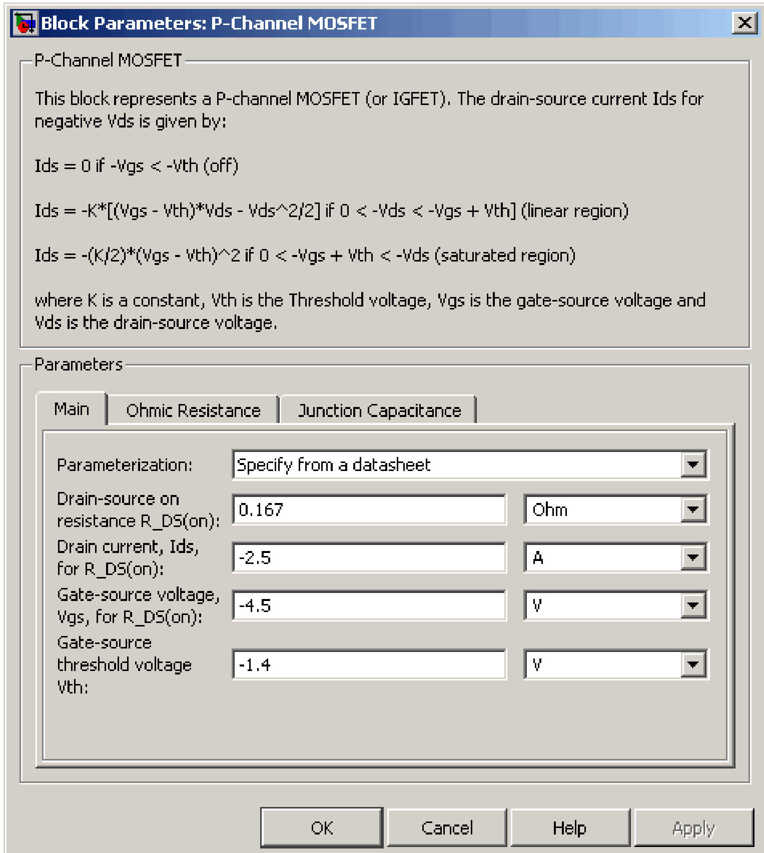
- K is the transistor gain.
- V_{DS} is the negative drain-source voltage.
- V_{GS} is the gate-source voltage.
- V_{th} is the threshold voltage.

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:

- $C_{GD} = Crss$
- $C_{GS} = C\_iss - Crss$

Dialog Box and Parameters

Main Tab



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

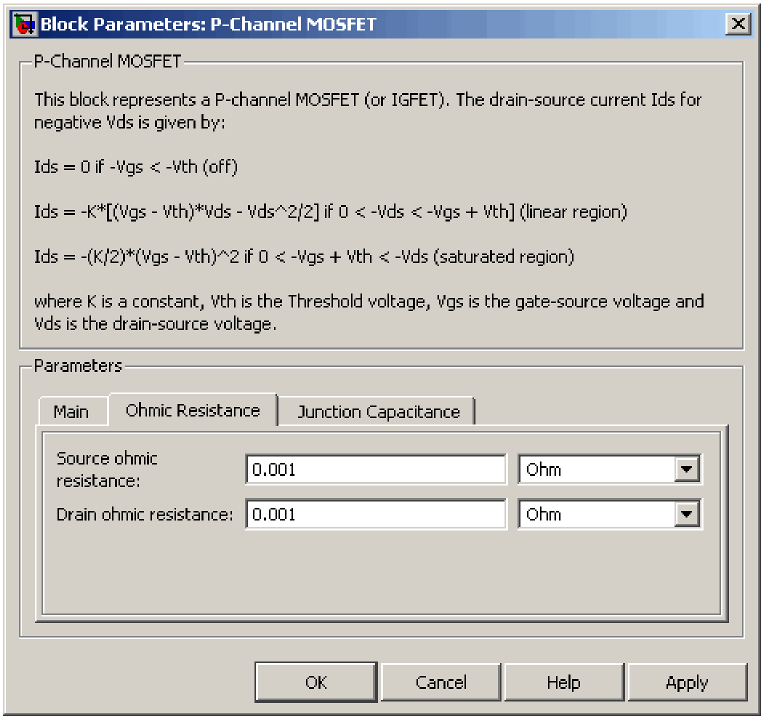
Drain current, Ids, for R_DS(on)
The drain current the block uses to calculate the value of the drain-source resistance. I_{DS} should have a negative value. This parameter is only visible when you select `Specify from a datasheet` for the **Parameterization** parameter. The default value is `-2.5` A.

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.

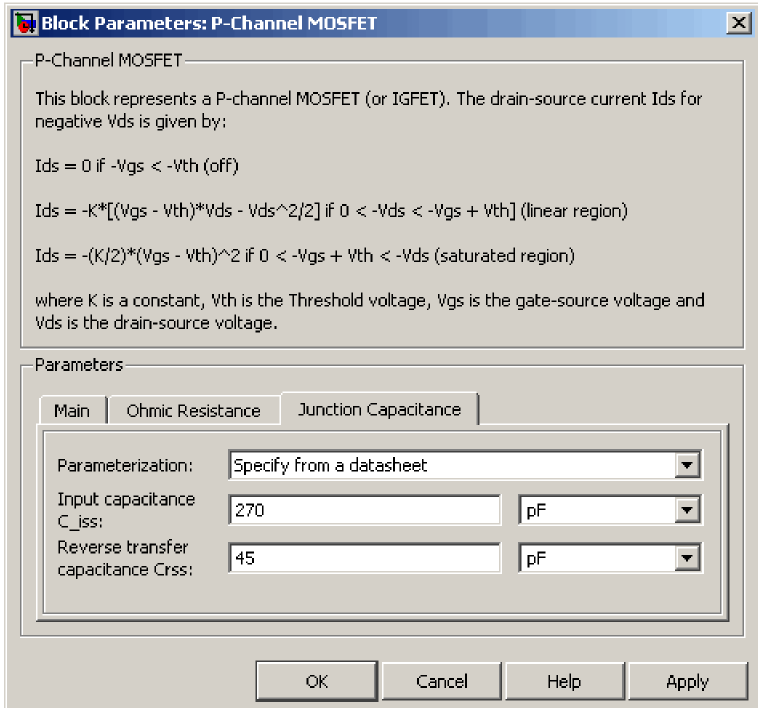
Ohmic Resistance Tab



Source ohmic resistance
: The transistor source resistance. The default value is `0.001` Ω. The value must be greater than or equal to `0`.

Drain ohmic resistance
: The transistor drain resistance. The default value is `0.001` Ω. The value must be greater than or equal to `0`.

Junction Capacitance Tab



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.

Ports

The block has the following ports:

`G`
: Electrical conserving port associated with the transistor gate terminal.

`D`
: Electrical conserving port associated with the transistor drain terminal.

`S`
: Electrical conserving port associated with the transistor source terminal.

References

[1] H. Shichman and D. A. Hodges. "Modeling and simulation of insulated-gate field-effect transistor switching circuits." IEEE J. Solid State Circuits, SC-3, 1968.

See Also

N-Channel MOSFET

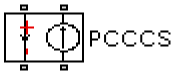
Purpose

Model polynomial current-controlled current source

Library

SPICE-Compatible Sources

Description



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:

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

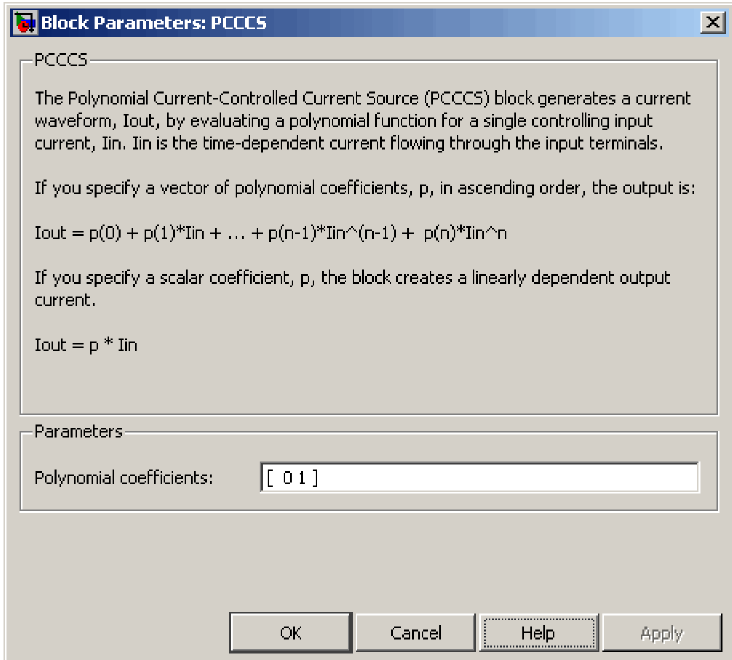
- If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$I_{out} = p * I_{in}$$

where:

- I_{in} is the current through the input ports.
- p is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters



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

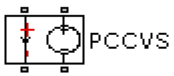
Purpose

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:

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

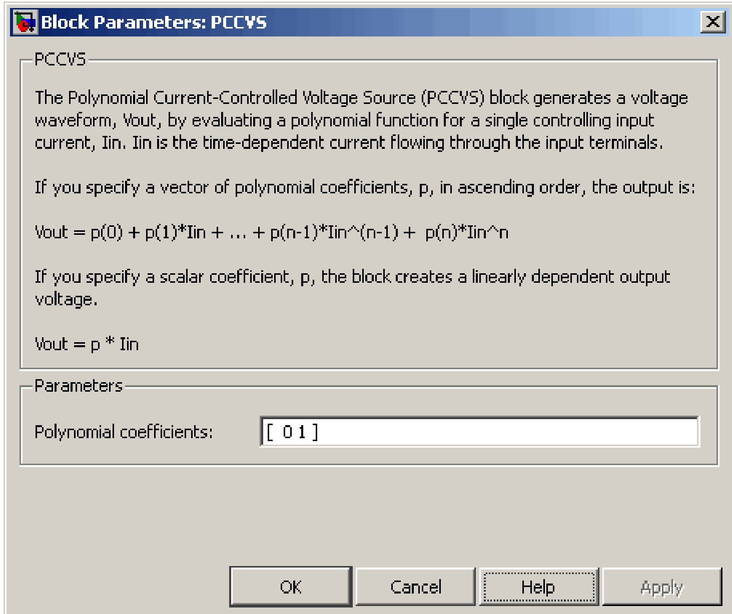
- If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$V_{out} = p * I_{in}$$

where:

- I_{in} is the current through the input ports.
- p is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters



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 ]`.

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 PCCCS, PVCCS, and PVCVS

Photodiode

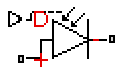
Purpose

Model photodiode as parallel controlled current source and exponential diode

Library

Sensors

Description



Photodiode

The Photodiode block represents a photodiode as a controlled current source and an exponential diode connected in parallel. The controlled current source produces a current I_p that is proportional to the radiant flux density:

$$I_p = DeviceSensitivity \times RadiantFluxDensity$$

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.
  - C_1, C_2, and C_3 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_j as:

- For $V < FC \times VJ$:

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

- For $V \geq FC \times VJ$:

$$Q_j = CJ0 \times F_1 + (CJ0/F_2) \times (F_3 \times (V - FC \times VJ) + 0.5 * (M/VJ) * (V^2 - (FC \times VJ)^2))$$

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.

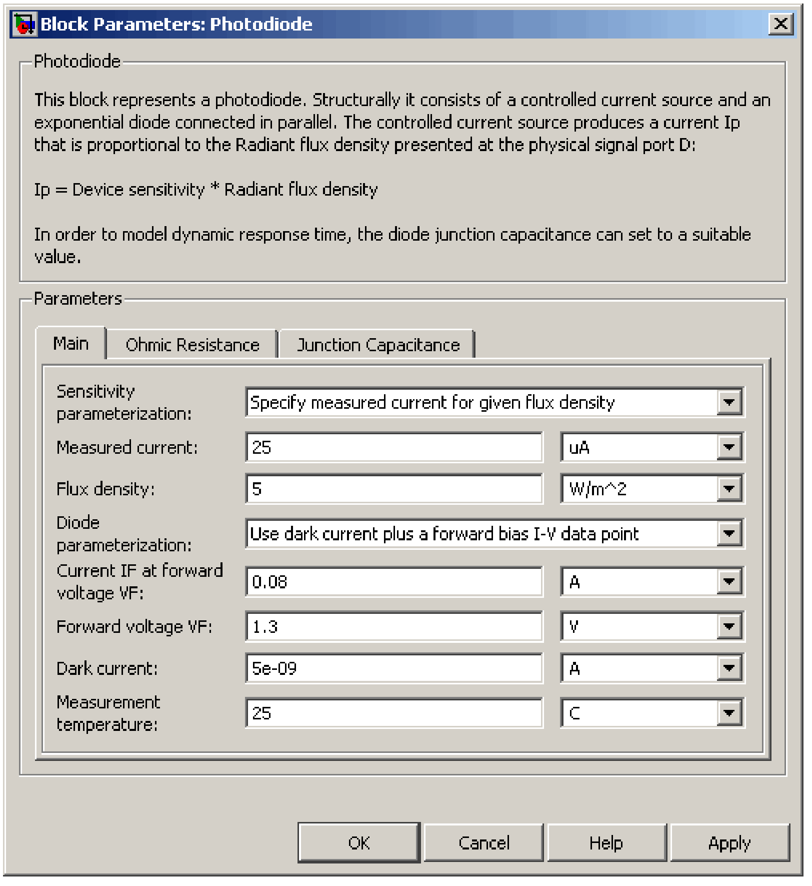
Basic Assumptions and Limitations

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 *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

Main Tab



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 `25` μA.

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/m^2.

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` m^2*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.
- `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.

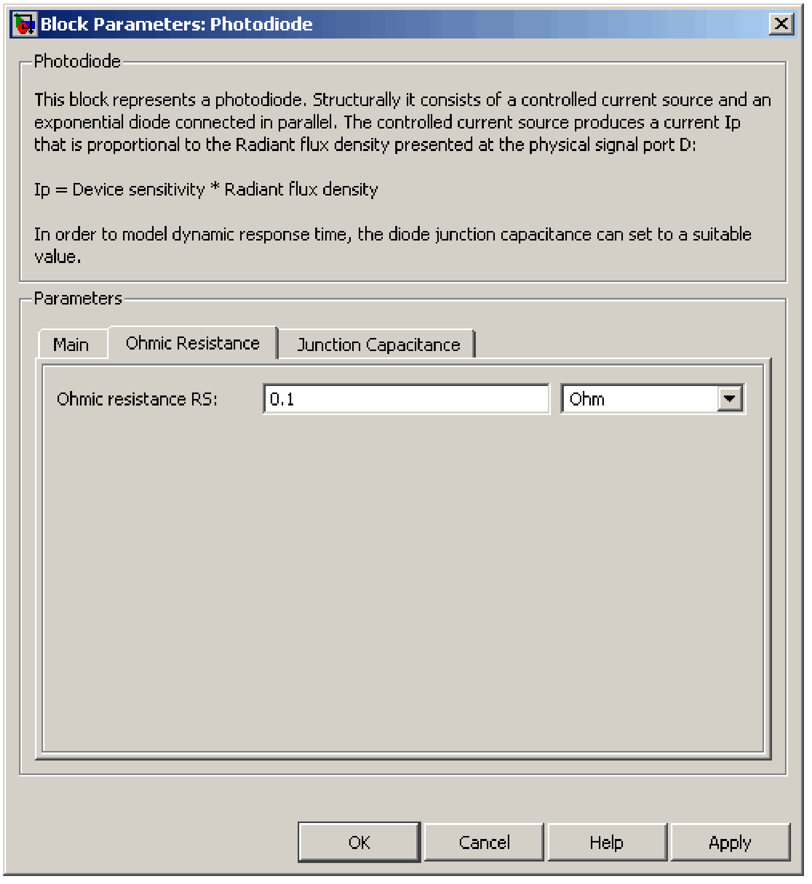
Forward voltage VF
The corresponding voltage at the forward-biased point on the diode I-V curve that the block uses to calculate *IS* and *N*. This parameter is only visible when you select and `Use dark current plus a forward bias I-V data point` for the **Diode parameterization** parameter. The default 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` °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`.

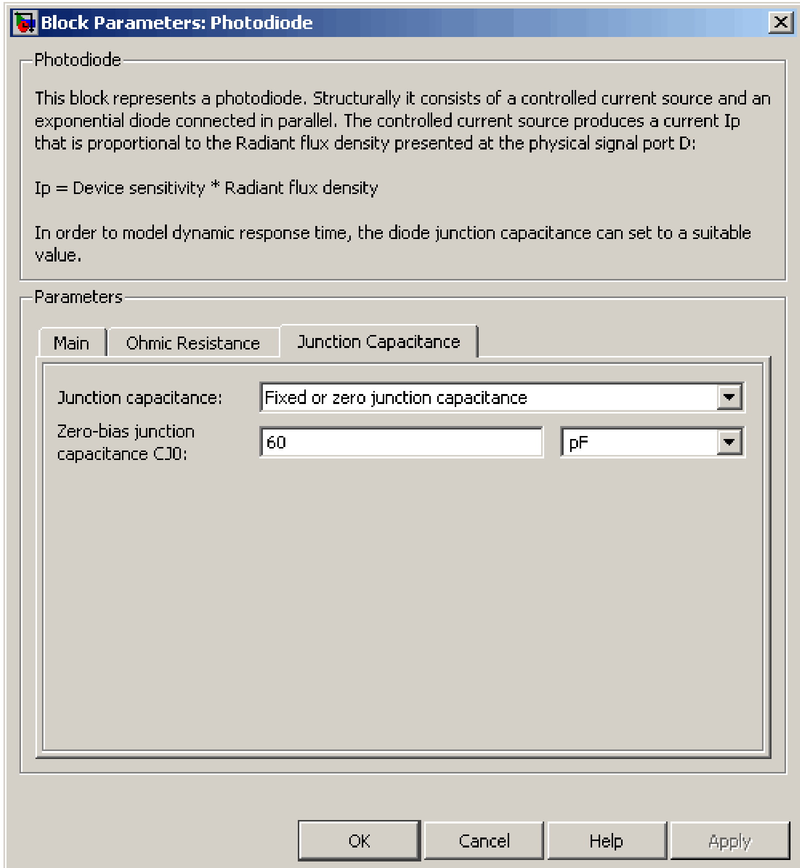
Ohmic Resistance Tab



Ohmic resistance RS

The series diode connection resistance. The default value is `0.1` Ω

Junction Capacitance Tab



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 CJ0, 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 CJ0, 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 *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 0.1 10 100 ]` V.

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate *CJ0*, *VJ*, and *M*. This parameter is only visible when you select `Use C-V curve data points` for the **Junction capacitance** parameter. The default value is `[ 45 30 6 ]` pF.

Junction potential VJ

The junction potential. This parameter is only visible when you select `Use parameters CJ0, 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 CJ0, 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. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

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

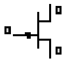
See Also

Diode, Light-Emitting Diode, Optocoupler

Purpose Model SPICE-compatible P-Channel JFET

Library SPICE-Compatible Semiconductors

Description The PJFET block represents a SPICE-compatible P-channel JFET.



PJFET

The PJFET block model includes the following components:

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

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

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 ($V_{sd} \geq 0$) after adjusting the applicable model parameters for temperature.

Applicable Range of V_{sg} and V_{dg} Values	Corresponding I_{sd} Equation
$V_{sg} - V_{to} \leq 0$	$I_{sd} = 0$
$0 < V_{sg} - V_{to} \leq V_{sd}$	$I_{sd} = -\beta * \left(V_{sg} - V_{to} \right)^2 * \left(1 + \lambda * V_{sd} \right)$
$0 < V_{sd} < V_{sg} - V_{to}$	$I_{sd} = \beta * V_{sd} * \left(2 * \left(V_{sg} - V_{to} \right) - V_{sd} \right) * \left(1 + \lambda * V_{sd} \right)$

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

Junction Charge Model

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

Applicable Range of V_{sg} Values	Corresponding Q_{sg} Equation
$V_{sg} < FC * VJ$	$Q_{sg} = \dfrac{CGS * VJ * \left(1 - \left(1 - \dfrac{V_{sg}}{VJ}\right)^{1-MG}\right)}{1 - MG}$
$V_{sg} \ge FC * VJ$	$Q_{sg} = CGS * \left(F1 + \dfrac{F3 * \left(V_{sg} - FC * VJ\right) + \dfrac{MG * \left(V_{sg}^2 - \left(FC * VJ\right)^2\right)}{2 * VJ}}{F2}\right)$

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.

- $F1 = \dfrac{VJ * \left(1 - (1 - FC)^{1-MG}\right)}{1 - MG}$
- $F2 = (1 - FC)^{1+MG}$
- $F3 = 1 - FC * (1 + MG)$

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
$V_{dg} < FC * VJ$	$Q_{dg} = \dfrac{CGD * VJ * \left(1 - \left(1 - \dfrac{V_{dg}}{VJ}\right)^{1-MG}\right)}{1 - MG}$
$V_{dg} \geq FC * VJ$	$Q_{dg} = CGD * \left(F1 + \dfrac{F3 * (V_{dg} - FC * VJ) + \dfrac{MG * \left(V_{dg}^2 - (FC * VJ)^2\right)}{2 * VJ}}{F2}\right)$

Where:

- *CGD* is the **Zero-bias GD capacitance, CGD** parameter value.

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature:

- When you select `Device temperature` for the **Model temperature dependence using** parameter, the transistor temperature is

  $$T = T_C + T_O$$

  where:

  - T_C is the **Circuit temperature** parameter value from the SPICE Environment Parameters block. If this block doesn't exist in the circuit, T_C is the default value of this parameter.
  - T_O is the **Offset local circuit temperature, TOFFSET** parameter value.

- When you select `Fixed temperature` for the **Model temperature dependence using** parameter, the transistor temperature is the **Fixed circuit temperature, TFIXED** parameter value.

The block provides the following relationship between the saturation current *IS* and the transistor temperature *T*:

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

where:

- *IS* is the **Saturation current, IS** parameter value.
- T_{meas} is the **Parameter extraction temperature, TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent, XTI** parameter value.
- *EG* is the **Energy gap, EG** parameter value.

- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient, ND** parameter value.

The block provides the following relationship between the junction potential *VJ* and the transistor temperature *T*:

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

where:

- *VJ* is the **Junction potential VJ** parameter value.
- $EG_{T_{meas}} = 1.16eV - \left(7.02e - 4 * T_{meas}{}^2\right) / \left(T_{meas} + 1108\right)$
- $EG_T = 1.16eV - \left(7.02e - 4 * T^2\right) / \left(T + 1108\right)$

The block provides the following relationship between the gate-source junction capacitance *CGS* and the transistor temperature *T*:

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

where:

- *CGS* is the **Zero-bias GS capacitance, CGS** parameter value.

The block uses the *CGS(T)* equation to calculate the gate-drain junction capacitance by substituting *CGD* (the **Zero-bias GD capacitance, CGD** parameter value) for *CGS*.

The block provides the following relationship between the forward and reverse beta and the transistor temperature *T*:

$$\beta(T) = \beta * \left(\frac{T}{T_{meas}} \right)$$

where β is the **Transconductance, BETA** parameter value.

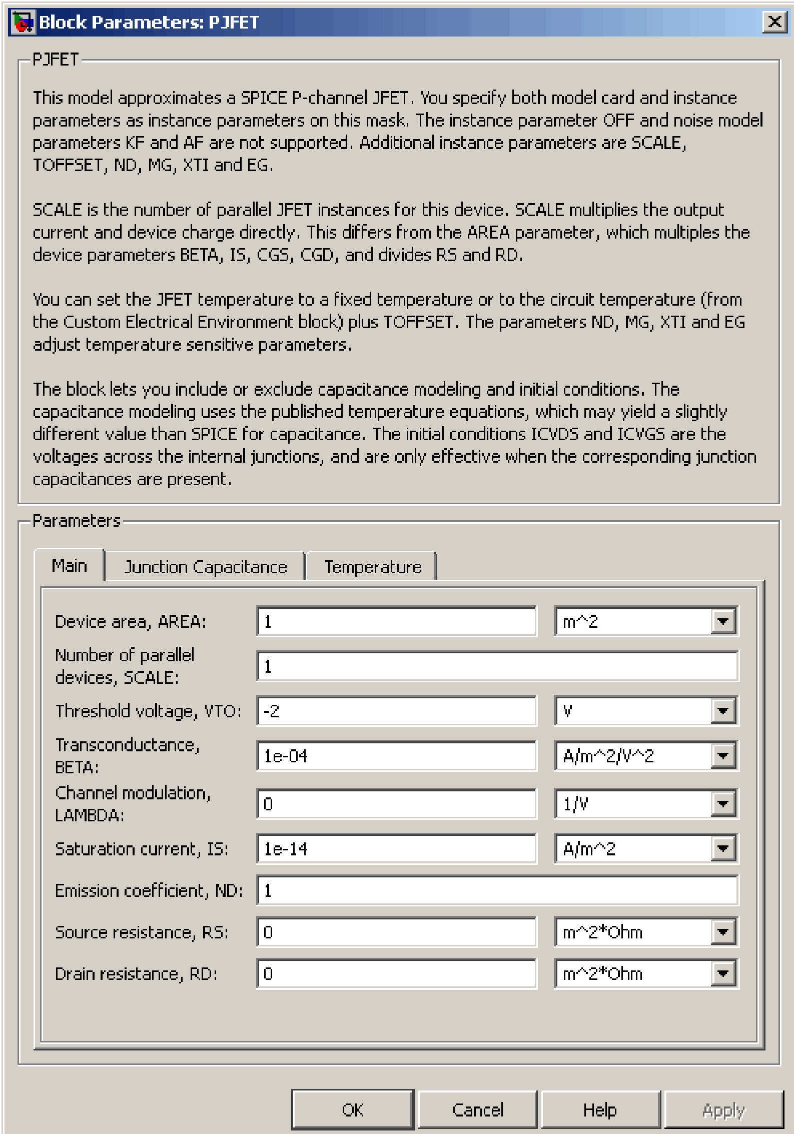
Basic Assumptions and Limitations

The model is based on the following assumptions:

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

Dialog Box and Parameters

Main Tab



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` $A/m^2/V^2$. 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` 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`.

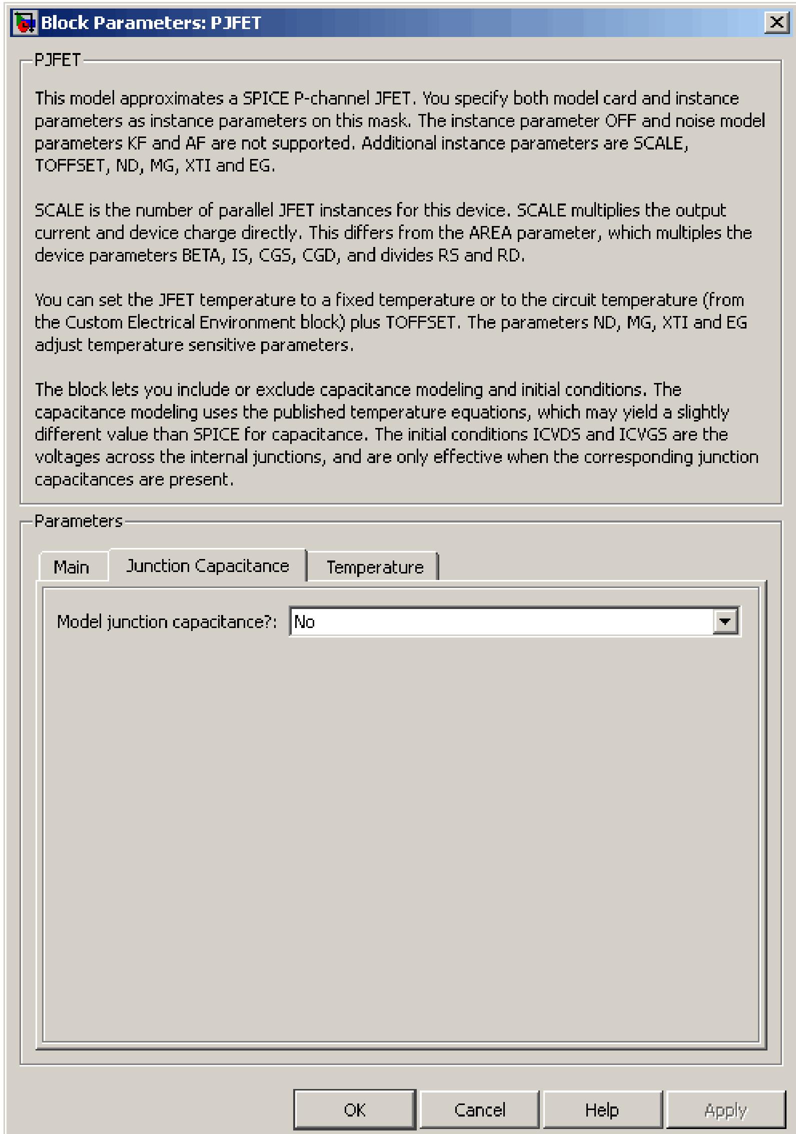
Source resistance, RS

The transistor source resistance. The default value is `0` $m^2*\Omega$ 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



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.

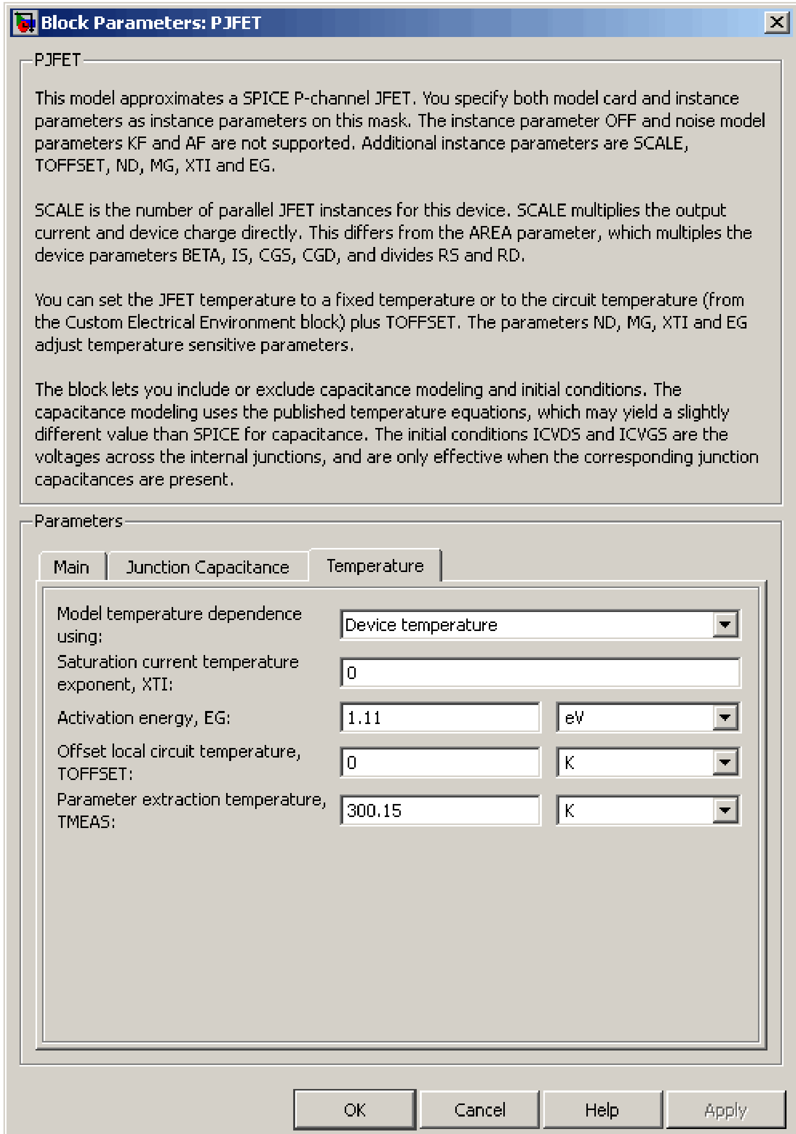
Initial condition voltage ICVDS

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



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` eVi.

Offset local circuit temperature, TOFFSET

The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select `Device temperature` for the **Model temperature dependence using** parameter. The default value is `0` K.

Fixed circuit temperature, TFIXED

The temperature at which to simulate the transistor. This parameter is only visible when you select `Fixed temperature` for the **Model temperature dependence using** parameter. The default value is `300.15` K. The value must be greater than `0`.

Parameter extraction temperature, TMEAS

The temperature at which the transistor parameters were measured. The default value is `300.15` K. The value must be greater than `0`.

Ports

The block has the following ports:

`G`
: Electrical conserving port associated with the transistor gate terminal.

`D`
: Electrical conserving port associated with the transistor drain terminal.

`S`
: Electrical conserving port associated with the transistor source terminal.

References

[1] G. Massobrio and P. Antognetti. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993. Chapter 3.

See Also

NJFET, P-Channel JFET

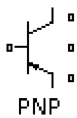
Purpose

Model Gummel-Poon PNP Transistor

Library

SPICE-Compatible Semiconductors

Description



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 $V_{EB} \leq 80 * V_{TF}$

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

$$I_{ebe} = ISE * \left(e^{(V_{EB}/V_{TE})} - 1 \right)$$

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

- When $V_{CB} > 80 * V_{TR}$:

$$I_{cbr} = IS * \left(\left(\frac{V_{CB}}{V_{TR}} - 79 \right) * e^{80} - 1 \right) + G_{\min} * V_{CB}$$

$$I_{cbc} = ISC * \left((V_{CB} - 80 * V_{TR} + V_{TC}) * \frac{e^{(80 * V_{TR} / V_{TC})}}{V_{TC}} - 1 \right)$$

- When $V_{CB} \leq 80 * V_{TR}$

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

$$I_{cbc} = ISC * \left(e^{(V_{CB}/V_{TC})} - 1 \right)$$

In the preceding equations:

- V_{EB} is the emitter-base voltage and V_{CB} is the collector-base voltage.
- $V_{TE} = NE * k * T / q$, $V_{TC} = NC * k * T / q$, $V_{TF} = NF * k * T / q$, and $V_{TR} = NR * k * T / q$.
- *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:

$$I_B = -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc} \right)$$

$$I_C = -\left(\frac{I_{ebf} - I_{cbr}}{q_b} - \frac{I_{cbr}}{BR} - I_{\text{cbc}} \right)$$

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:

$$q_b = \frac{q_1}{2}\left(1 + \sqrt{0.5 * \left(\sqrt{(1 + 4 * q_2 - eps)^2 + eps^2} + 1 + 4 * q_2 - eps \right) + eps} \right)$$

$$q_1 = \left(1 - \frac{V_{CB}}{VAF} - \frac{V_{EB}}{VAR} \right)^{-1}$$

$$q_2 = \frac{I_{ebf}}{IKF} + \frac{I_{cbr}}{IKR}$$

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

  $$r_{bb} = RBM + 3*\left(RB - RBM\right)*\left(\frac{\tan z - z}{z*\tan^2 z}\right)$$

  where:

  $$z = \frac{\sqrt{1+144 I_B/\left(\pi^2 IRB\right)} - 1}{\left(24/\pi^2\right)\sqrt{\left(I_B/IRB\right)}}$$

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:

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

where *ITF* is the **Coefficient of TF, ITF** parameter value.

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:

$$Q_{eb} = TF_{\text{mod}} * I_{eb} + Q_{dep}$$

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

Applicable Range of V_{jct} Values	Corresponding Q_{dep} Equation
$V_{jct} < FC*VJ$	$Q_{dep} = C_{jct} * VJ * \frac{1-\left(1-V_{jct}/VJ\right)^{(1-MJ)}}{1-MJ}$
$V_{jct} \geq FC*VJ$	$Q_{dep} = C_{jct} * \left[F1 + \frac{F3*\left(V_{jct} - FC*VJ\right) + \frac{MJ*\left[V_{jct}^{2} - \left(FC*VJ\right)^{2}\right]}{2*VJ}}{F2} \right]$

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is:
  - The **B-E built-in potential, VJE** parameter value for the emitter-base junction.
  - The **B-C built-in potential, VJC** parameter value for the collector-base junction.
- *MJ* is:
  - The **B-E exponential factor, MJE** parameter value for the emitter-base junction.
  - The **B-C exponential factor, MJC** parameter value for the collector-base junction.
- C_{jct} is:
  - The **B-E depletion capacitance, CJE** parameter value for the emitter-base junction.

- The **B-C depletion capacitance, CJC** parameter value for the collector-base junction.

- $F1 = VJ * \left(1 - (1 - FC)^{(1-MJ)}\right) / (1 - MJ)$
- $F2 = (1 - FC)^{(1+MJ)}$
- $F3 = 1 - FC * (1 + MJ)$

The collector-substrate charge Q_{sc} depends on the collector-substrate voltage V_{sc} as follows, after adjusting the applicable model parameters for temperature.

Applicable Range of V_{sc} Values	Corresponding Q_{sc} Equation
$V_{sc} < 0$	$Q_{sc} = CJS * VJS * \left(\frac{1 - (1 - V_{sc}/VJS)^{(1-MJS)}}{1 - MJS} \right)$
$V_{sc} \geq 0$	$Q_{sc} = CJS * (1 + MJS * V_{sc} / (2 * VJS)) * V_{sc}$

where:

- *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.
- $EG_{T_{meas}} = 1.16eV - \left(7.02e-4 * T_{meas}{}^2\right) / \left(T_{meas} + 1108\right)$
- $EG_T = 1.16eV - \left(7.02e-4 * T^2\right) / \left(T + 1108\right)$

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*.

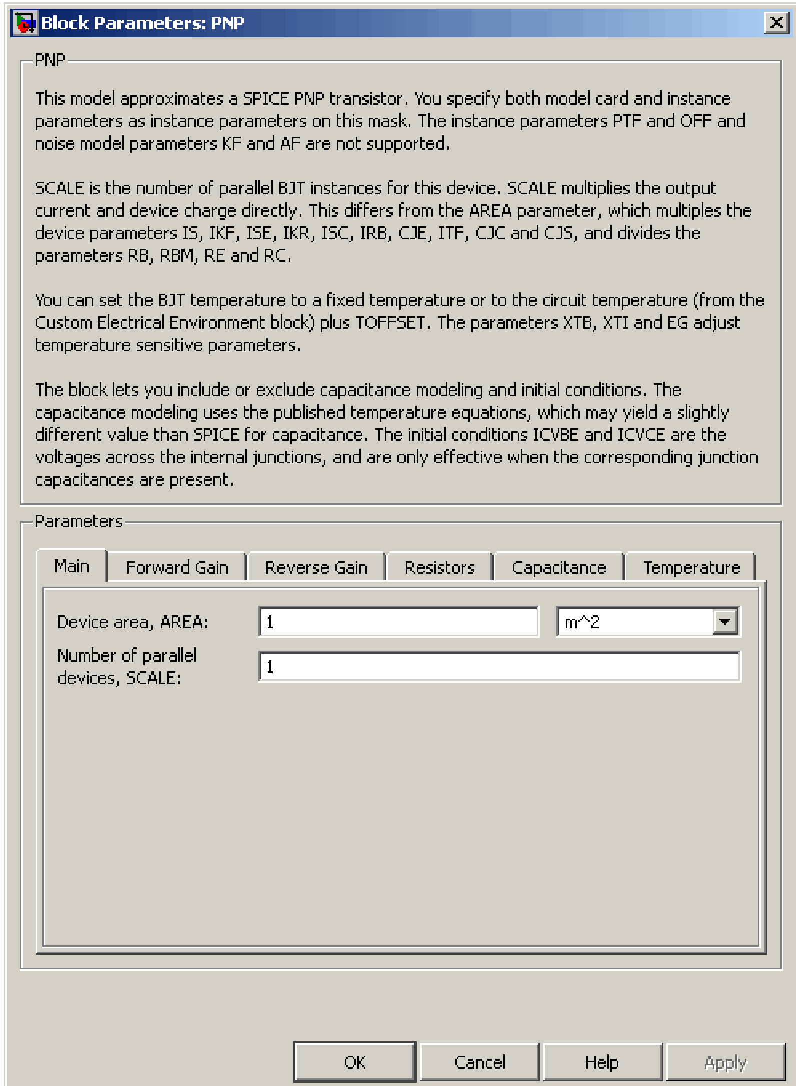
Basic Assumptions and Limitations

The model is based on the following assumptions:

- 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



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:

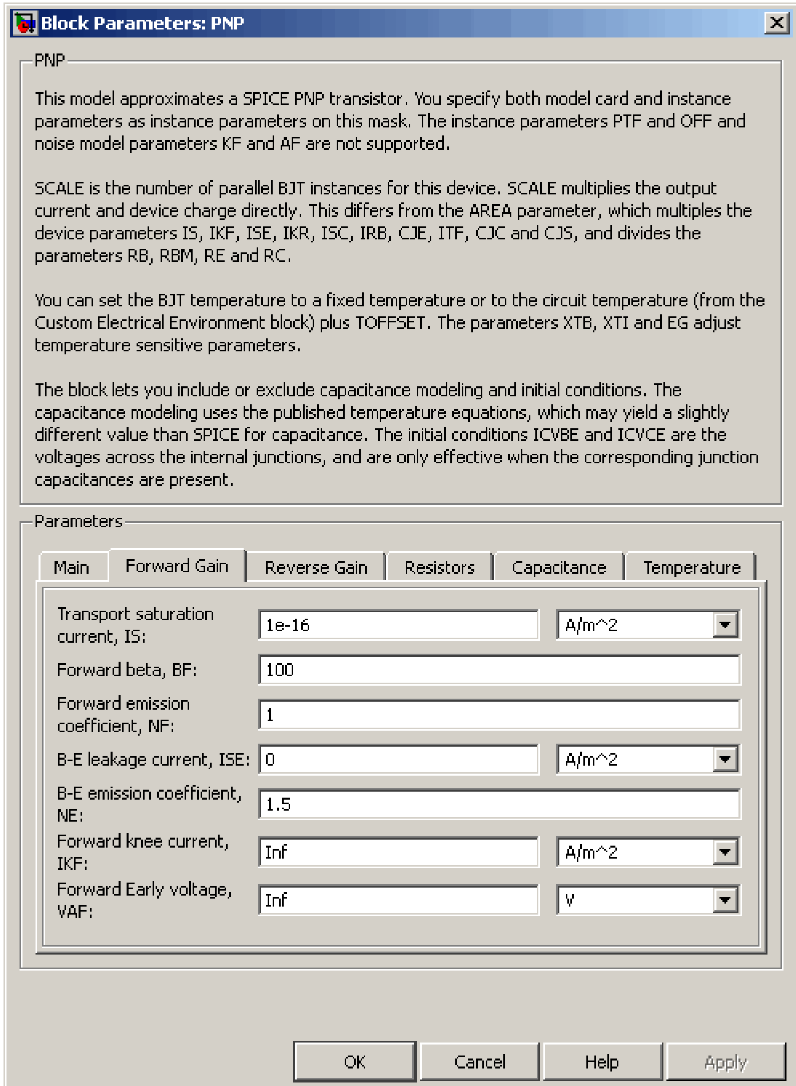
- **Zero-bias base resistance, RB**
- **Minimum base resistance, RBM**
- **Emitter resistance, RE**
- **Collector resistance, RC**

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



Transport saturation current, IS

The magnitude of the current at which the transistor saturates. The default value is `1e-16` A/m^2. The value must be greater than or equal to `0`.

Forward beta, BF

The ideal maximum reverse beta. The default value is `100`. The value must be greater than `0`.

Forward emission coefficient, NF

The reverse emission coefficient or ideality factor. The default value is `1`. The value must be greater than `0`.

B-E leakage current, ISE

The base-emitter leakage current. The default value is `0` A/m^2. The value must be greater than or equal to `0`.

B-E emission coefficient, NE

The base-collector emission coefficient or ideality factor. The default value is `1.5`. The value must be greater than `0`.

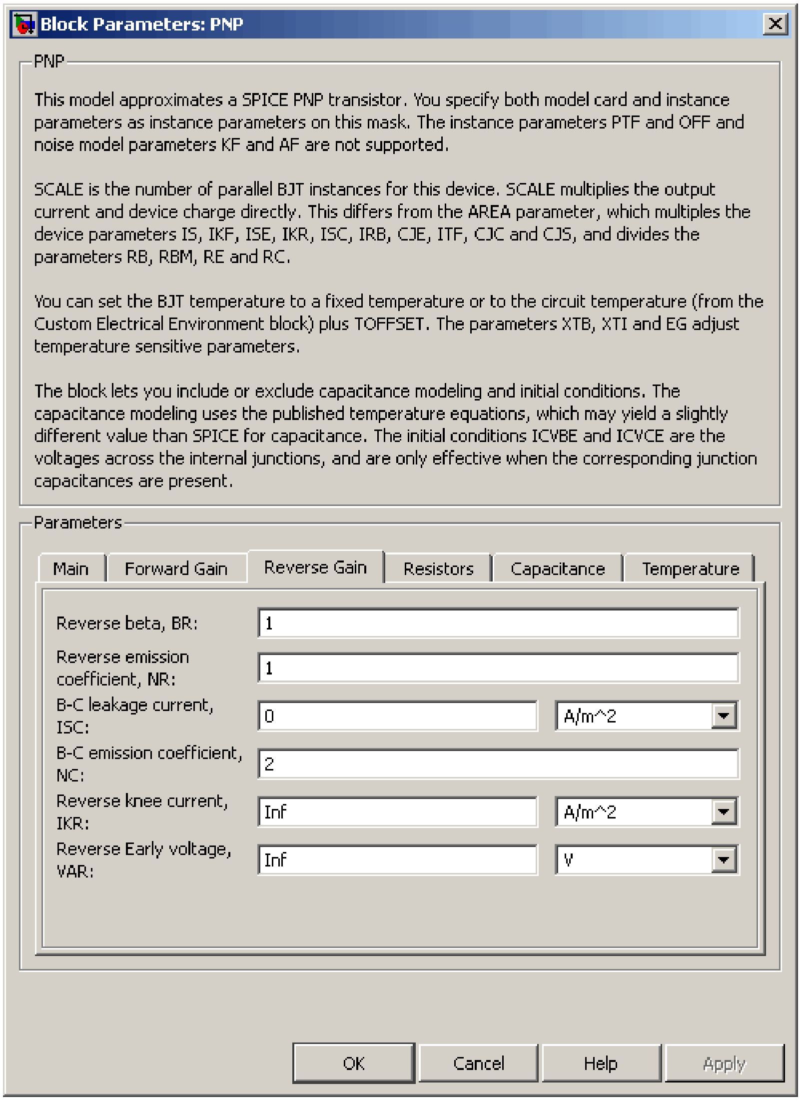
Forward knee current, IKF

The current value at which forward-beta high-current roll-off occurs. The default value is `0` A/m^2. The value must be greater than or equal to `0`. For this parameter, the software interprets a value of `0` as infinity.

Forward Early voltage, VAF

The forward Early voltage. The default value is `0` V. The value must be greater than or equal to `0`. For this parameter, the software interprets a value of `0` as infinity.

Reverse Gain Tab



Reverse beta, BR

The ideal maximum reverse beta. The default value is 1. The value must be greater than 0.

Reverse emission coefficient, NR

The reverse emission coefficient or ideality factor. The default value is 1. The value must be greater than 0.

B-C leakage current, ISC

The base-collector leakage current. The default value is 0 A/m^2. The value must be greater than or equal to 0.

B-C emission coefficient, NC

The base-collector emission coefficient or ideality factor. The default value is 2. The value must be greater than 0.

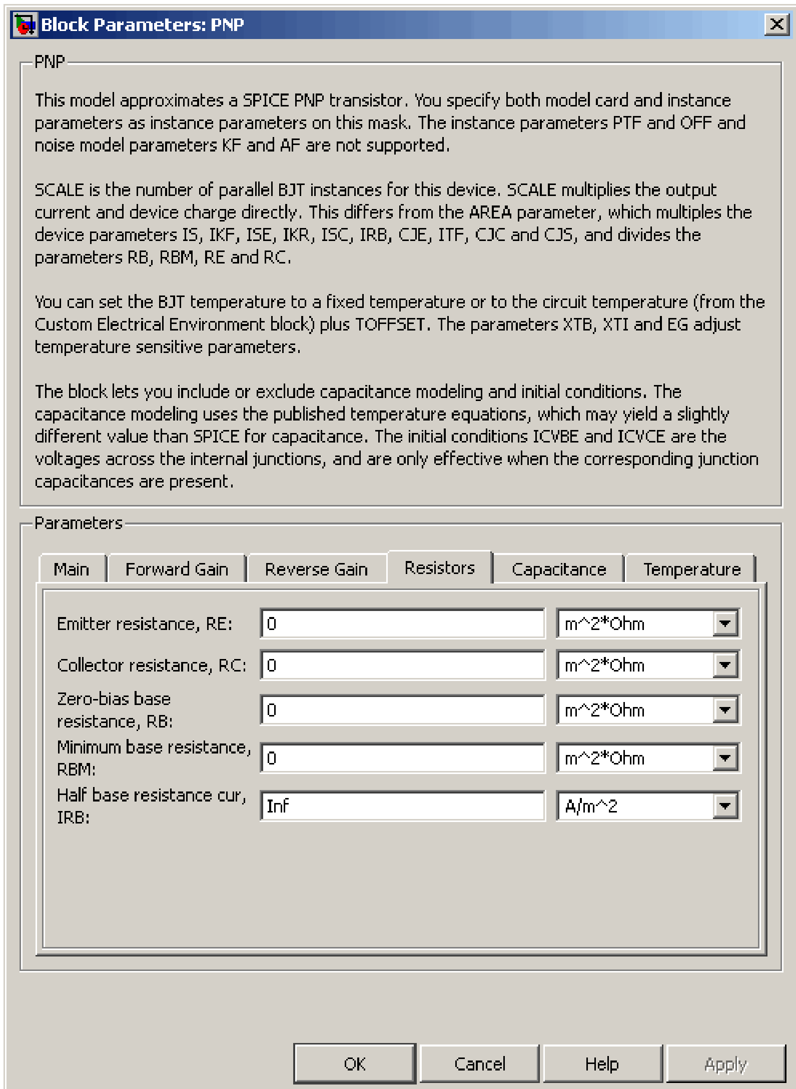
Reverse knee current, IKR

The current value at which reverse-beta high-current roll-off occurs. The default value is 0 A/m^2. The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Reverse Early voltage, VAR

The reverse Early voltage. The default value is 0 V. The value must be greater than or equal to 0. For this parameter, the software interprets a value of 0 as infinity.

Resistors Tab



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`.

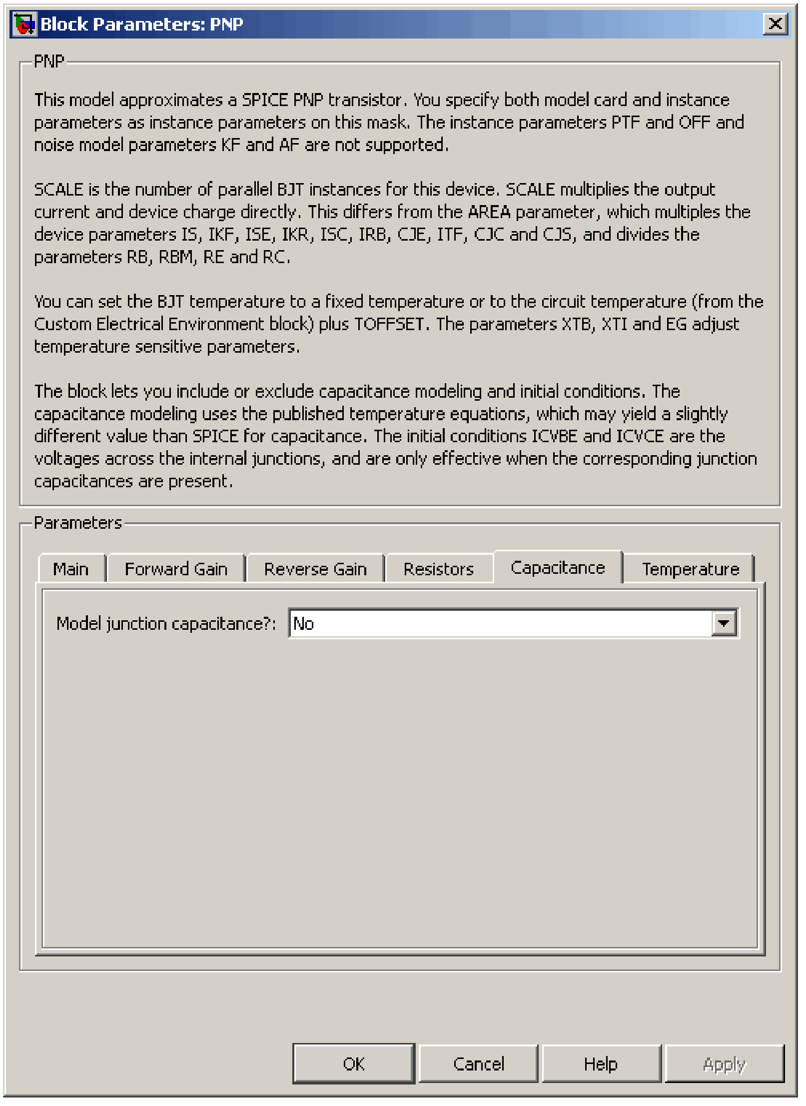
Minimum base resistance, RBM

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



Model junction capacitance

Select one of the following options for modeling the junction capacitance:

- `No` — Do not include junction capacitance in the model. This is the default option.
- `B-E Capacitance` — Model the junction capacitance across the base-emitter junction.
- `B-C Capacitance` — Model the junction capacitance across the base-collector junction.
- `C-S Capacitance` — Model the junction capacitance across the collector-substrate junction.

Note To include junction capacitance in the model:

1. Select `B-E Capacitance` and specify the base-emitter junction capacitance parameters.
2. Select `B-C Capacitance` and specify the base-collector junction capacitance parameters.
3. Select `C-S Capacitance` and specify the collector-substrate junction capacitance parameters.

You can specify or change any of the common parameters when you select any of the preceding options for the **Model junction capacitance** parameter.

B-E depletion capacitance, CJE

The depletion capacitance across the base-emitter junction. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0` F/m^2. The value must be greater than or equal to `0`.

B-E built-in potential, VJE
The base-emitter junction potential. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0.75` V. The value must be greater than or equal to `0.01` V.

B-E exponential factor, MJE
The grading coefficient for the base-emitter junction. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0.33`. The value must be greater than or equal to `0` and less than or equal to `0.9`.

Forward transit time, TF
The transit time of the minority carriers that cause diffusion capacitance when the base-emitter junction is forward-biased. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0`. The value must be greater than or equal to `0`.

Coefficient of TF, XTF
The coefficient for the base-emitter and base-collector bias dependence of the transit time, which produces a charge across the base-emitter junction. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0`. The value must be greater than or equal to `0`. Use the default value of `0` if you do not want to model the effect of base-emitter bias on transit time.

VBC dependence of TF, VTF
The coefficient for the base-emitter bias dependence of the transit time. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0` V. The value must be greater than or equal to `0`. For this parameter, the software interprets a value of `0` as infinity.

Coefficient of TF, ITF

The coefficient for the dependence of the transit time on collector current. This parameter is only visible when you select `B-E Capacitance` for the **Model junction capacitance** parameter. The default value is `0` A/m^2. The value must be greater than or equal to `0`. Use the default value of `0` if you do not want to model the effect of collector current on transit time.

B-C depletion capacitance, CJC

The depletion capacitance across the base-collector junction. This parameter is only visible when you select `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0` F/m^2. The value must be greater than `0`.

B-C built-in potential, VJC

The base-collector junction potential. This parameter is only visible when you select `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0.75` V. The value must be greater than or equal to `0.01` V.

B-C exponential factor, MJC

The grading coefficient for the base-collector junction. This parameter is only visible when you select `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0.33`. The value must be greater than or equal to `0` and less than or equal to `0.9`.

B-C capacitance fraction, XCJC

The fraction of the base-collector depletion capacitance that is connected between the internal base and the internal collector. The rest of the base-collector depletion capacitance is connected between the external base and the internal collector. This parameter is only visible when you select `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0`. The value must be greater than or equal to `0` and less than or equal to `1`.

Reverse transit time, TR

The transit time of the minority carriers that cause diffusion capacitance when the base-collector junction is reverse-biased. This parameter is only visible when you select `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0` s. The value must be greater than or equal to `0`.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select `B-E Capacitance` or `B-C Capacitance` for the **Model junction capacitance** parameter. The default value is `0.5`. The value must be greater than or equal to `0` and less than or equal to `0.95`.

Specify initial condition

Select one of the following options for specifying an initial condition:

- `No` — Do not specify an initial condition for the model. This is the default option.
- `Yes` — Specify the initial transistor conditions.

Note The PNP block applies the initial transistor voltages across the junction capacitors and not across the ports.

This parameter is only visible when you select `B-E Capacitance` or `B-C Capacitance` for the **Model junction capacitance** parameter.

Initial condition voltage ICVBE

Base-emitter voltage at the start of the simulation. This parameter is only visible when you select `B-E Capacitance` or `B-C Capacitance` for the **Model junction capacitance** and `Yes` for the **Specify initial condition** parameter. The default value is `0` V.

Initial condition voltage ICVCE

Base-collector voltage at the start of the simulation. This parameter is only visible when you select `B-E Capacitance` or `B-C Capacitance` for the **Model junction capacitance** and `Yes` for the **Specify initial condition** parameter. The default value is `0` V.

C-S junction capacitance, CJS

The collector-substrate junction capacitance. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0` F/m^2. The value must be greater than or equal to `0`.

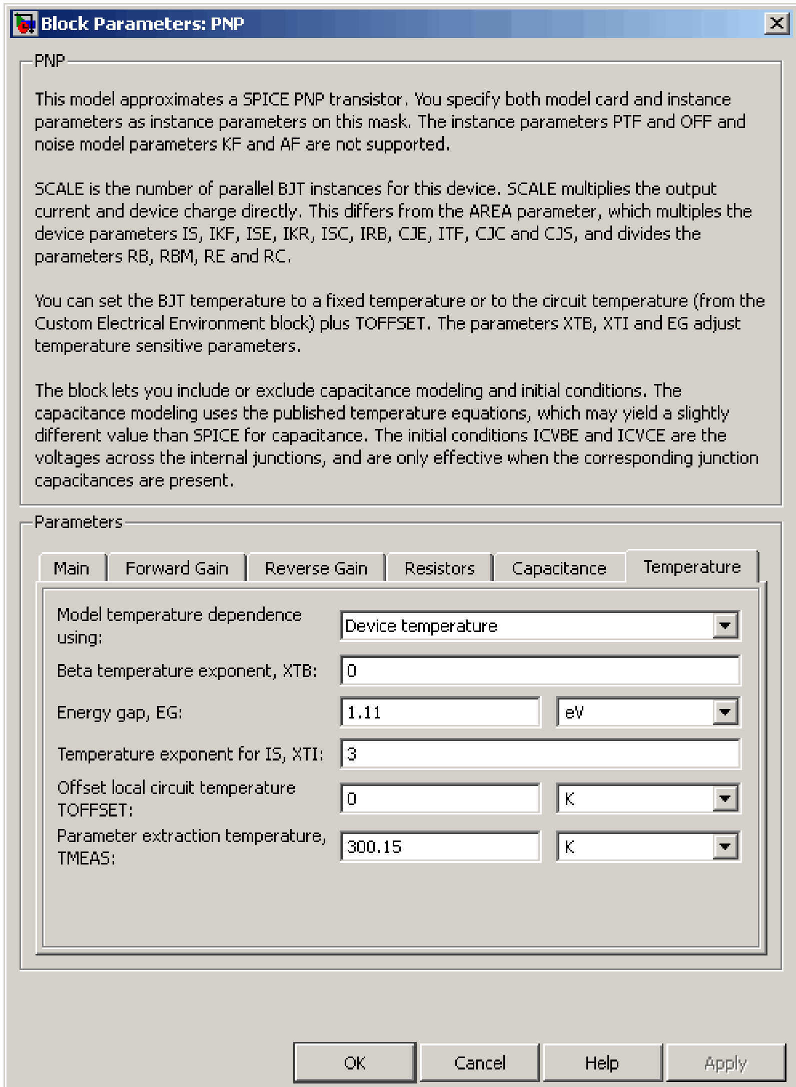
Substrate built-in potential, VJS

The potential of the substrate. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0.75` V.

Substrate exponential factor, MJS

The grading coefficient for the collector-substrate junction. This parameter is only visible when you select `C-S Capacitance` for the **Model junction capacitance** parameter. The default value is `0`. The value must be greater than or equal to `0` and less than or equal to `0.9`.

Temperature Tab



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. *Semiconductor Device Modeling with SPICE*. 2nd Edition, McGraw-Hill, 1993. Chapter 2.

See Also

PNP Bipolar Transistor

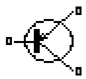
Purpose

Model PNP bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



PNP Bipolar Transistor

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]:

$$I_C = -I_S\left[\left(e^{-qV_{BE}/(kT)} - e^{-qV_{BC}/(kT)}\right)\left(1+\frac{V_{BC}}{V_A}\right) - \frac{1}{\beta_R}\left(e^{-qV_{BC}/(kT)}-1\right)\right]$$

$$I_B = -I_S\left[\frac{1}{\beta_F}\left(e^{-qV_{BE}/(kT)}-1\right)+\frac{1}{\beta_R}\left(e^{-qV_{BC}/(kT)}-1\right)\right]$$

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

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

Similarly, if $-qV_{BC}/(kT) < -39$ 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.

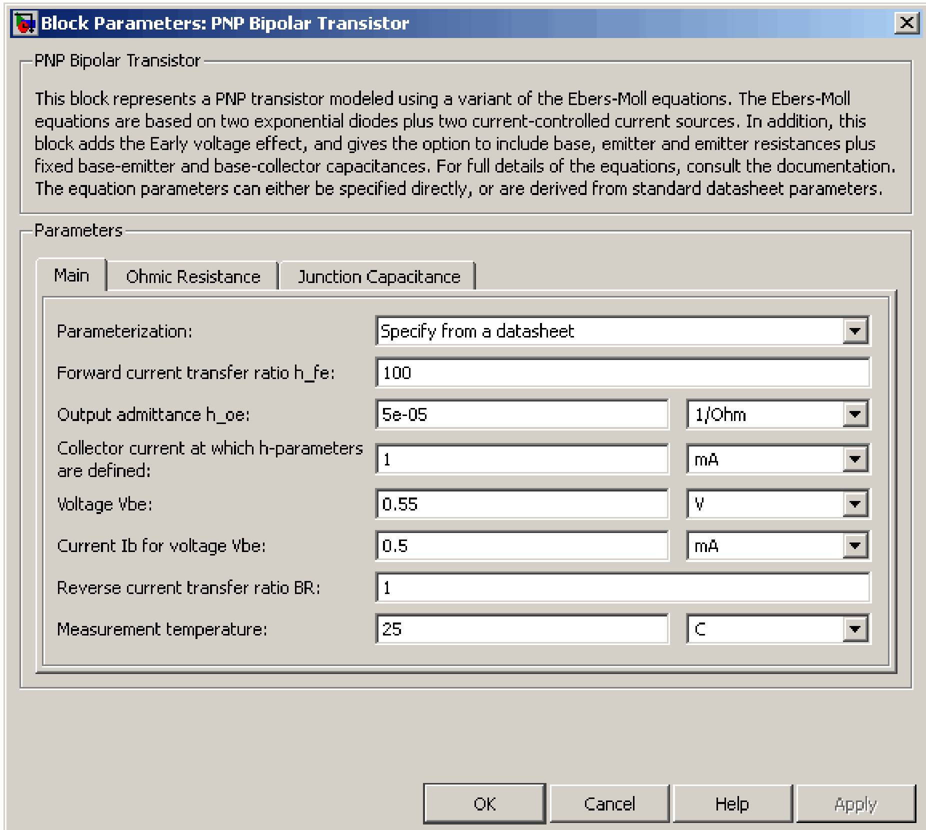
Basic Assumptions and Limitations

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.

Dialog Box and Parameters

Main Tab



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.

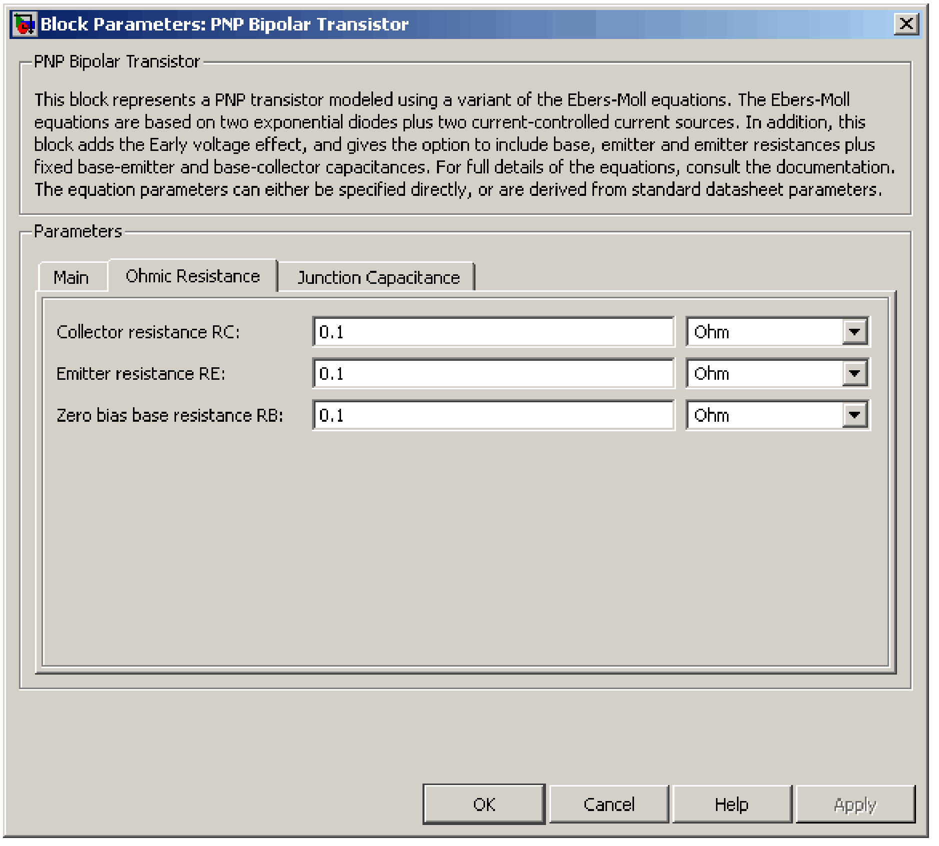
Reverse current transfer ratio BR

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` °C.

Ohmic Resistance Tab



Collector resistance RC

Resistance at the collector. The default value is `0.1` Ω.

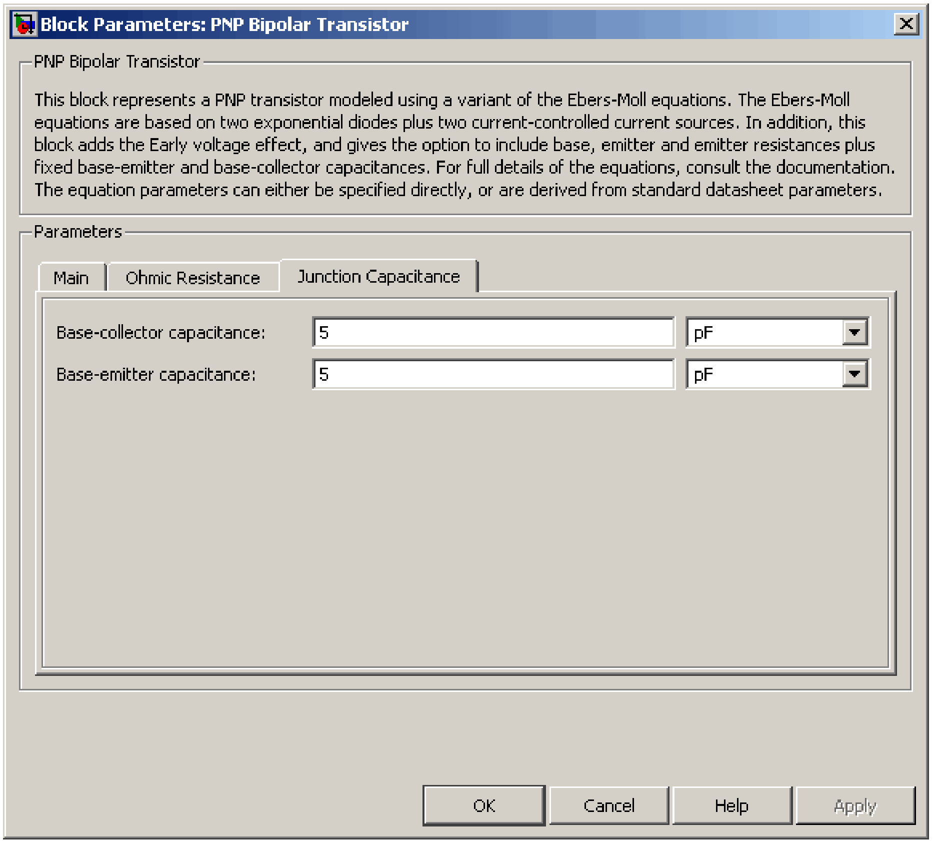
Emitter resistance RE

Resistance at the emitter. The default value is `0.1` Ω.

Zero bias base resistance RB

Resistance at the base at zero bias. The default value is `0.1` Ω.

Junction Capacitance Tab



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.

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. *Analogue and digital electronics for engineers*. 2nd Edition, Cambridge University Press, 1984.

See Also

Diode, NPN Bipolar Transistor

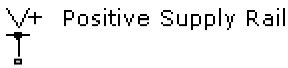
Purpose

Model ideal positive supply rail

Library

Sources

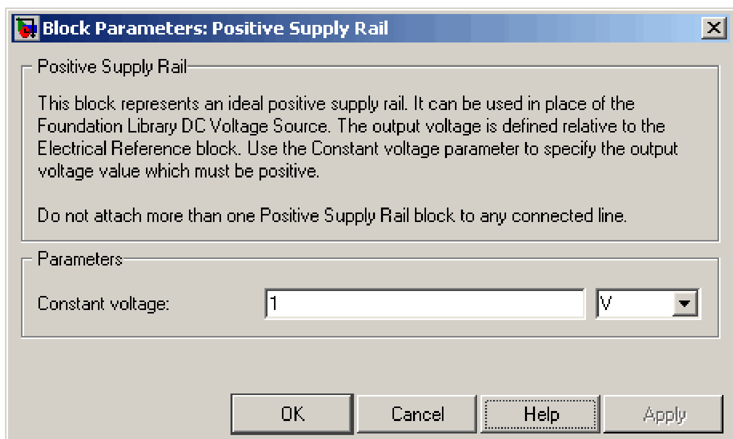
Description



The Positive Supply Rail block represents an ideal positive supply rail. Use this block instead of the Simscape™ DC Voltage Source block to define the output voltage relative to the Simscape Electrical Reference block that must appear in each model.

Note Do not attach more than one Positive Supply Rail block to any connected line.

Dialog Box and Parameters



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

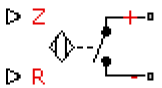
Purpose

Model simple distance sensor

Library

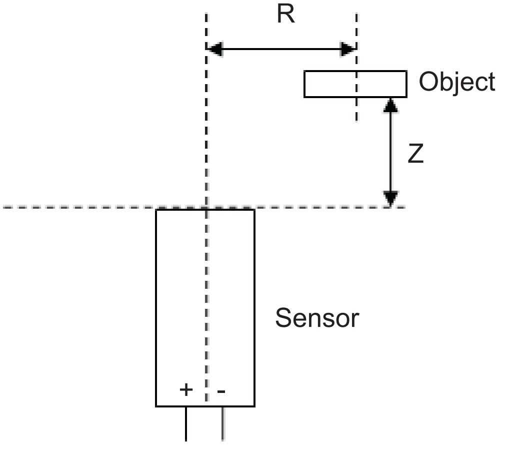
Sensors

Description

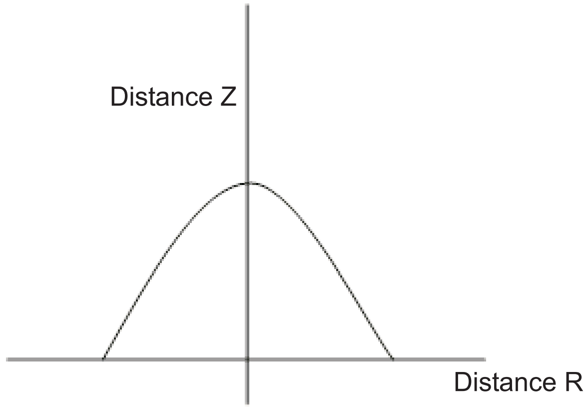


Proximity Sensor

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.

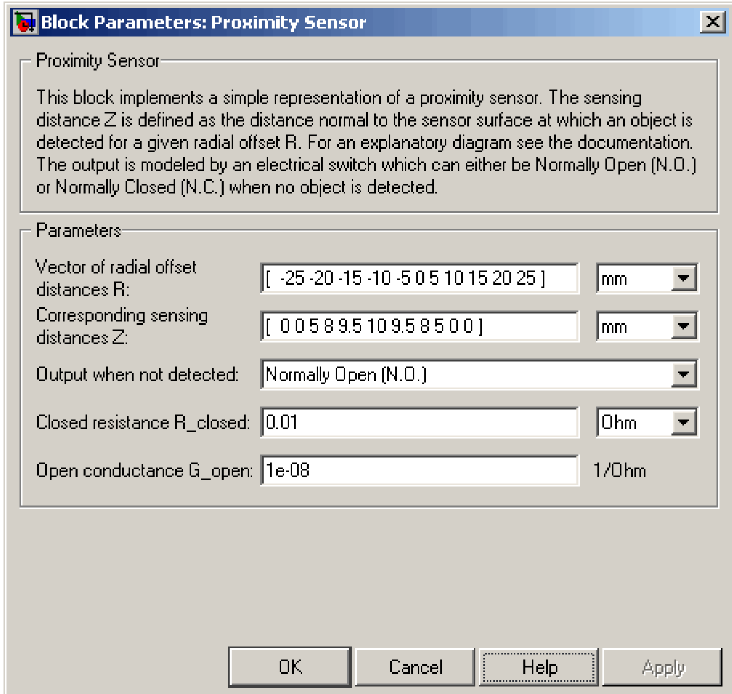


A typical sensing distance curve is shown in the following figure.



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



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/Ω

Ports

The block has the following ports:

`R`
Radial distance to the sensor.

`Z`
Perpendicular distance to the sensor.

`+`
Positive electrical voltage.

`-`
Negative electrical voltage.

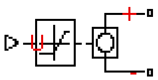
Purpose

Model generic linear sensor

Library

Sensors

Description

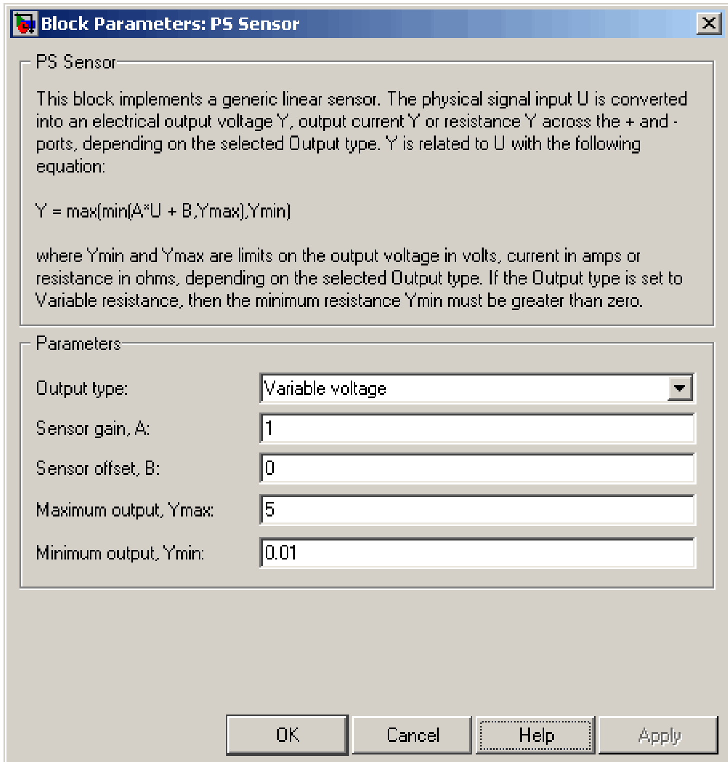


The PS Sensor block represents a generic linear sensor. The block converts the physical signal input *U* into an electrical output *Y* across the + and - ports. The **Output type** parameter value determines which of the following electrical outputs the block produces:

- Output voltage
- Output current
- Output resistance

Y is related to U as $Y = \max(\min(A*U + B, Y_{\max}), Y_{\min})$ where $Y_{\min}$ and $Y_{\max}$ are minimum and maximum limits on the output, respectively.

Dialog Box and Parameters



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 Ω. The default value is `Variable voltage`.

Sensor gain, A

The sensitivity of the output Y with respect to the input U, dY/dU. The default value is `1`.

Sensor offset, B

The output when the input U is zero. The output does not exceed the limits Y_{max} and Y_{min}. The default value is `0`.

Maximum output, Ymax

The upper limit on the sensor output. The following table shows the units of this parameter, which depend on the selected value of the **Output type** parameter.

Output type	Units
`Variable voltage`	V
`Variable current`	A
`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`	A
`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.

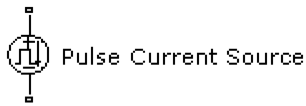
See Also

Simscape™ Controlled Voltage Source, Simscape Controlled Current Source, and Simscape Variable Resistor

Purpose Model periodic square pulse current source

Library SPICE-Compatible Sources

Description



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.

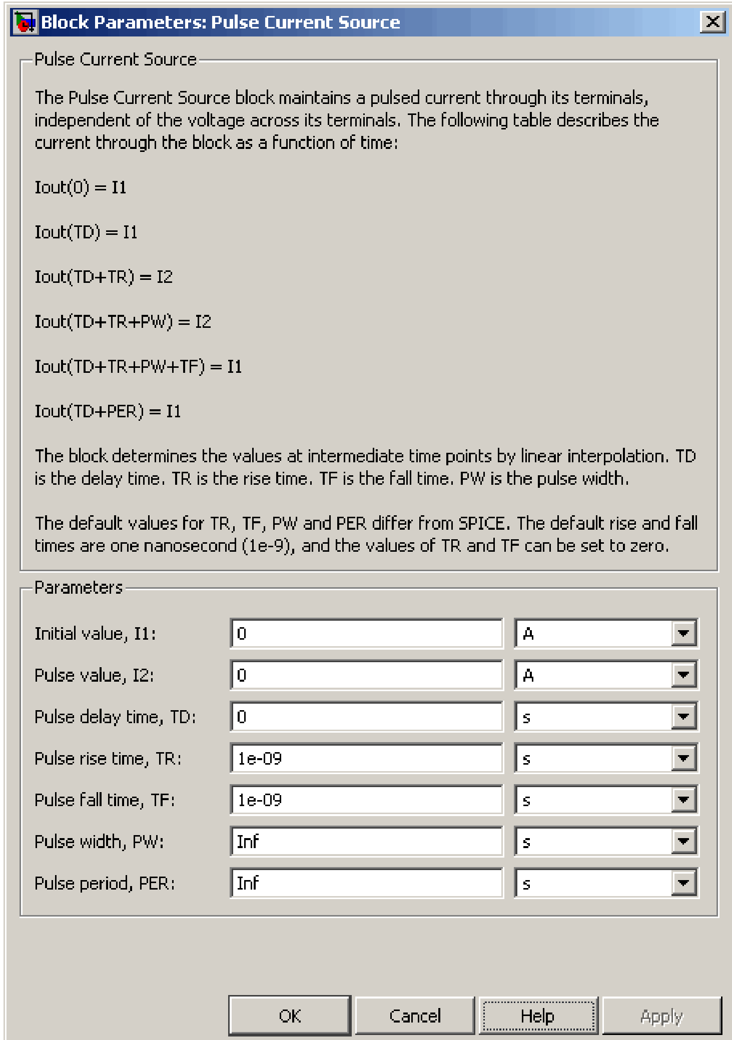
- *PER* is the **Pulse period, PER** parameter value.

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



Initial value, I1

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

Pulse value, I2
: The value of the output current when the output is high. The default value is `0` A.

Pulse delay time, TD
: The time at which the pulse first starts. The default value is `0` s.

Pulse rise time, TR
: The time it takes the output current to rise from the **Initial value, I1** value to the **Pulse value, I2** value. The default value is `1e-09` s. The value must be greater than or equal to `0`.

Pulse fall time, TF
: The time it takes the output current to fall from the **Pulse value, I2** value to the **Initial value, I1** value. The default value is `1e-09` s. The value must be greater than or equal to `0`.

Pulse width, PW
: The time width of the output pulse. The default value is `Inf` s. The value must be greater than `0`.

Pulse period, PER
: The period of the output pulse. The default value is `Inf` s. This value means that the block produces a single pulse with an infinite period. The value must be greater than `0`.

Ports

The block has the following ports:

+
: Positive electrical voltage.

-
: Negative electrical voltage.

See Also

Pulse Voltage Source

Purpose

Model periodic square pulse voltage source

Library

SPICE-Compatible 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:

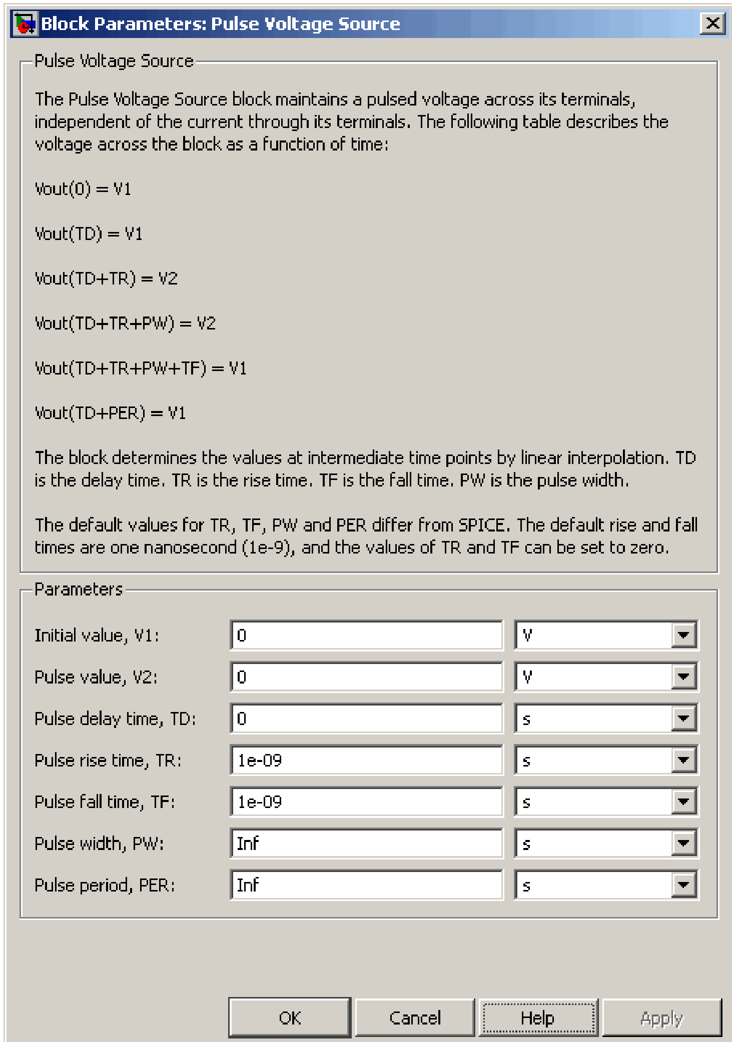
- *V1* is the **Initial value, V1** parameter value.
- *V2* is the **Pulse value, V2** parameter value.
- *TD* is the **Pulse delay time, TD** parameter value.
- *TR* is the **Pulse rise time, TR** parameter value.
- *TF* is the **Pulse fall time, TF** parameter value.
- *PW* is the **Pulse width, PW** 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



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

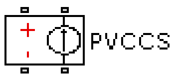
Purpose

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:

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

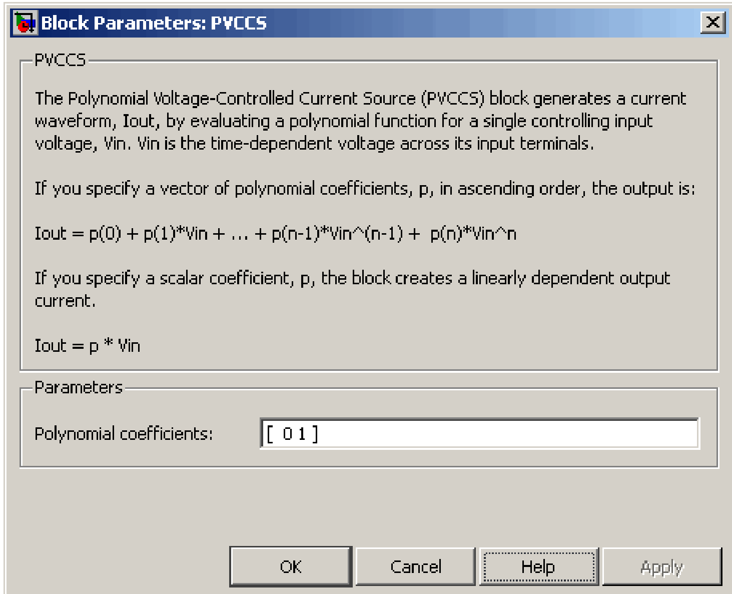
- If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$I_{out} = p * V_{in}$$

where:

- V_{in} is the voltage across the input ports.
- p is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters



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 ]`.

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 PCCCS, PCCVS, and PVCVS

PVCVS

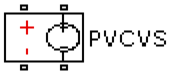
Purpose

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:

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

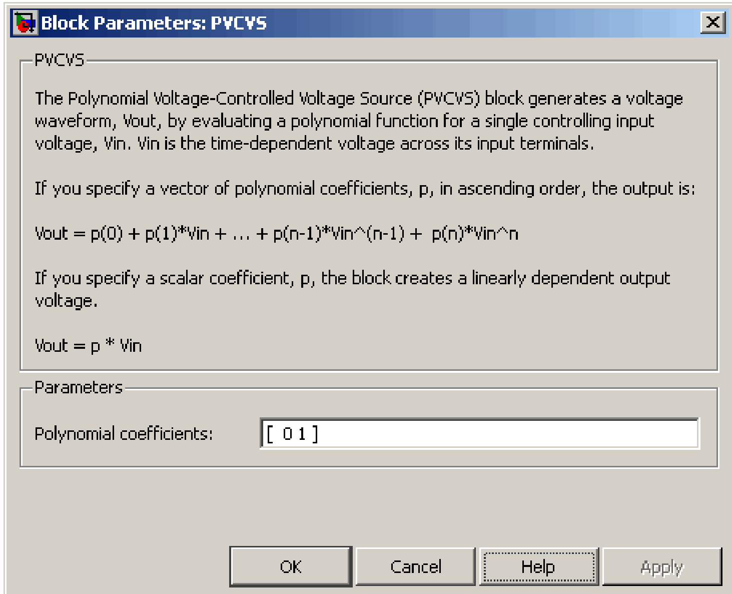
- If you specify a scalar coefficient for the **Polynomial coefficients** parameter:

$$V_{out} = p * V_{in}$$

where:

- V_{in} is the voltage across the input ports.
- p is the **Polynomial coefficients** parameter value.

Dialog Box and Parameters



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 ]`.

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 PCCCS, PCCVS, and PVCCS

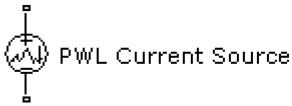
Purpose

Model lookup table current source

Library

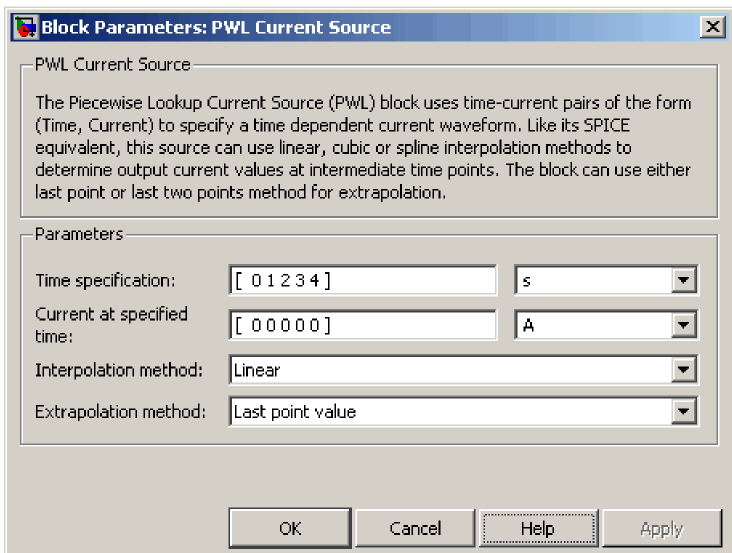
SPICE-Compatible Sources

Description



The PWL Current Source block represents a current source that you specify in lookup table form using a vector of time values and a vector of the corresponding current values. You must specify at least four time-current value pairs. The block generates a time-dependent current based on these time-current values using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods. The output current is independent of the voltage across the terminals of the source.

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 `[ 0 1 2 3 4 ]` 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

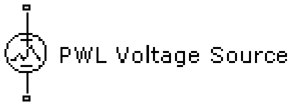
Purpose

Model lookup table voltage source

Library

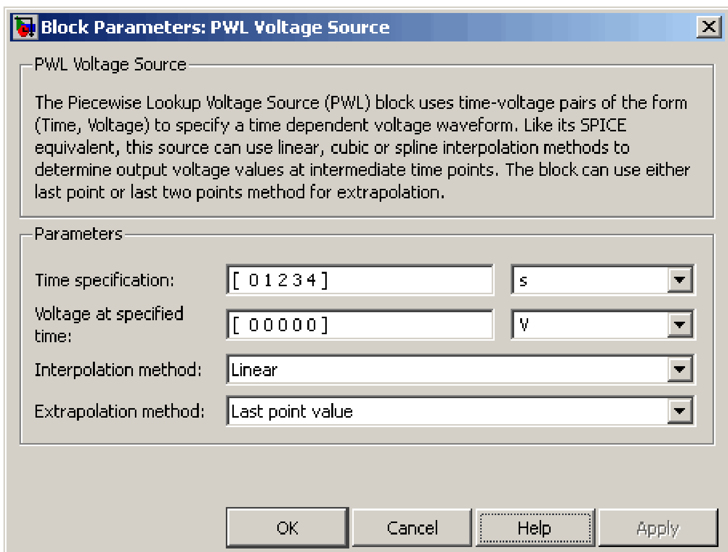
SPICE-Compatible Sources

Description



The PWL Voltage Source block represents a voltage source that you specify in lookup table form using a vector of time values and a vector of the corresponding voltage values. You must specify at least four time-current value pairs. The block generates a time-dependent voltage based on these time-voltage values using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods. The output voltage is independent of the current through the source.

Dialog Box and Parameters



Time 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 `[ 0 1 2 3 4 ]` 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

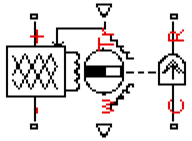
Purpose

Model brushless motor with closed-loop torque control

Library

Actuators & Drivers

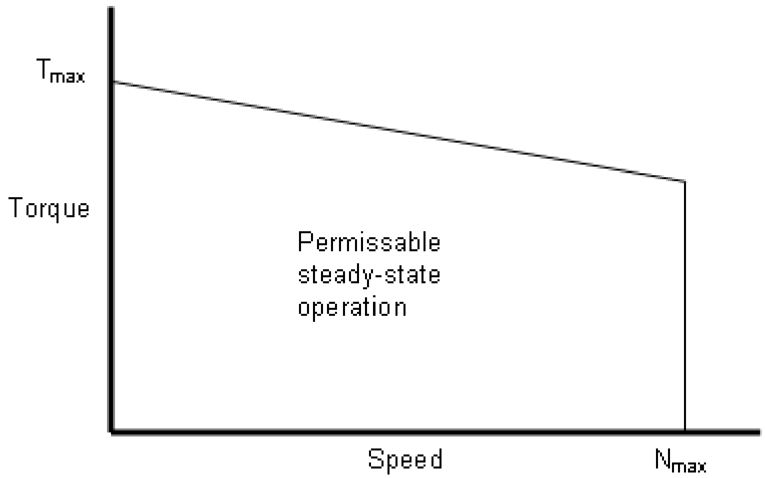
Description



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}.

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:

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

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

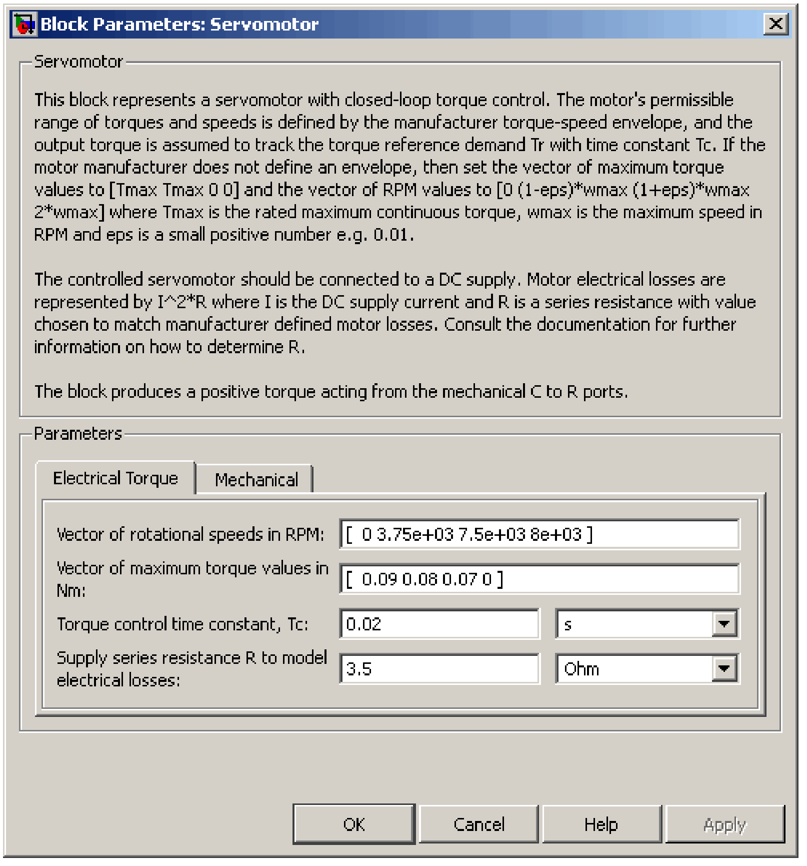
Basic Assumptions and Limitations

The model is based on the following assumptions:

- The 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.

Dialog Box and Parameters

Electrical Torque Tab



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

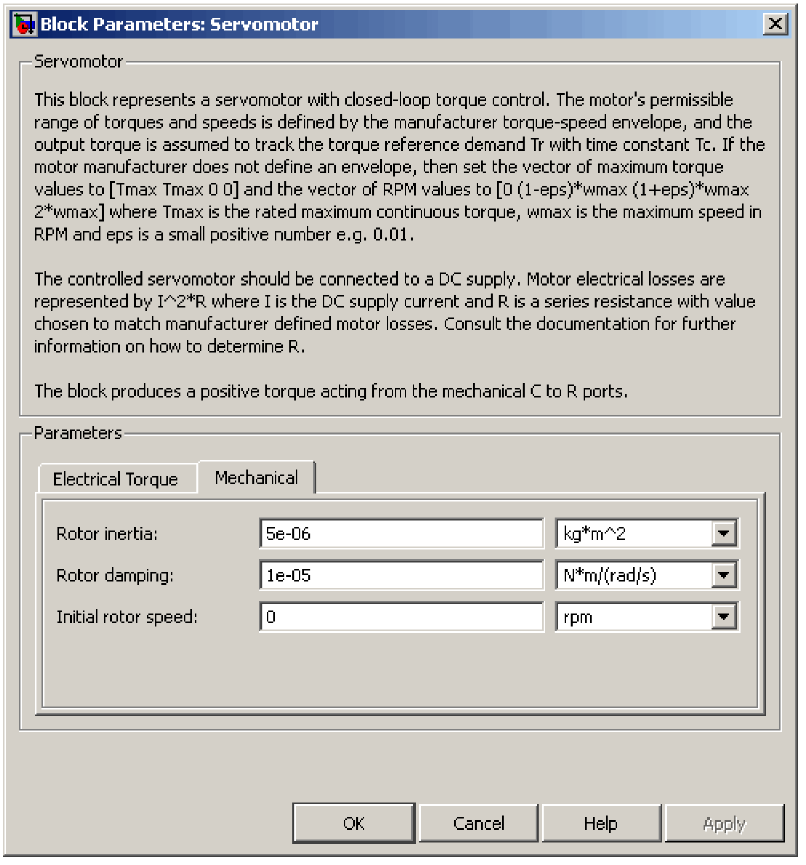
Maximum torque values for permissible steady-state operation. These values correspond to the speeds in the **Vector of rotational**

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` Ω

Mechanical Tab



Rotor inertia

Rotor inertia. The default value is `5e-06` kg*m^2. The value can be zero.

Rotor damping

Rotor damping. The default value is `1e-05` N*m/(rad/s). The value can be zero.

Initial rotor speed
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

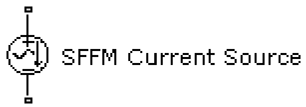
Purpose

Model single-frequency FM current source

Library

SPICE-Compatible Sources

Description



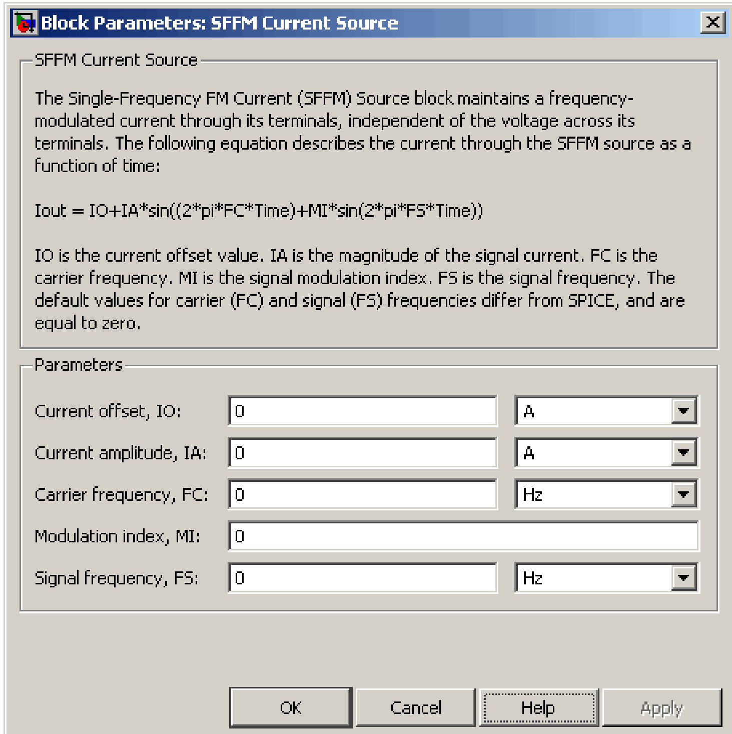
The SFFM Current Source block represents a single-frequency current source whose frequency-modulated output current value is independent of the voltage across its terminals. The following equation describes the current through the source as a function of time:

$$I_{out} = IO + IA * \sin\left(\left(2\pi * FC * Time\right) + MI * \sin\left(2\pi * FS * Time\right)\right)$$

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



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

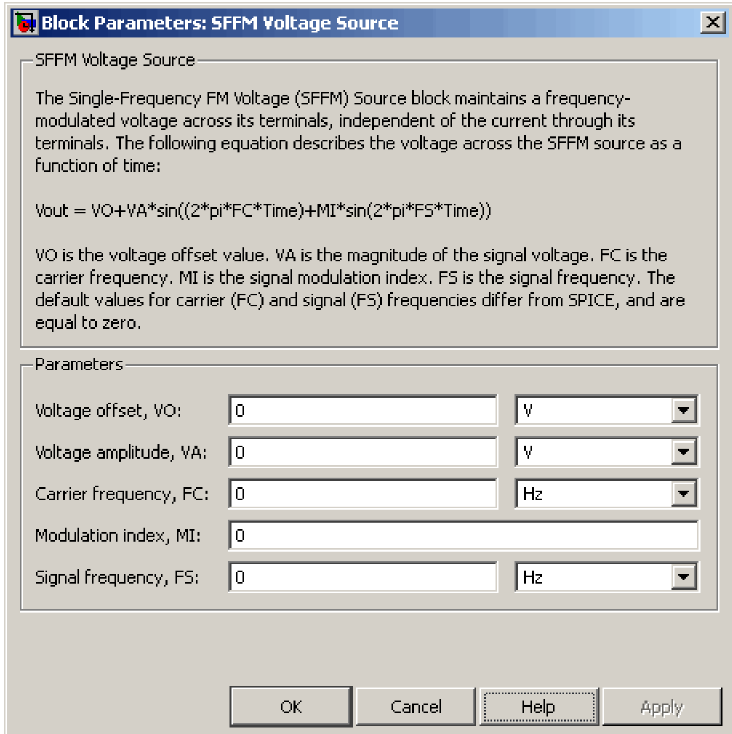
The SFFM Voltage Source block represents a single-frequency voltage source whose frequency-modulated output voltage value is independent of the current through the source. The following equation describes the output voltage as a function of time:

$$V_{out} = VO + VA * \sin\left(\left(2\pi * FC * Time\right) + MI * \sin\left(2\pi * FS * Time\right)\right)$$

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.

Dialog Box and Parameters



Voltage offset, VO

The magnitude of the time-independent part of the output voltage. The default value is 0 V.

Voltage amplitude, VA

The magnitude of the sinusoidal part of the output voltage. The default value is 0 V.

Carrier frequency, FC

Frequency of the carrier wave. The default value is 0 Hz. The value must be greater than or equal to 0.

Modulation index, MI

The amount by which the modulated signal varies around its unmodulated level. The default value is `0`. The value must be greater than or equal to `0`.

Signal frequency, FS

Frequency of the modulated signal. The default value is `0` Hz. The value must be greater than or equal to `0`.

Ports

The block has the following ports:

+

Positive electrical voltage.

-

Negative electrical voltage.

See Also

SFFM Current Source

Shunt Motor

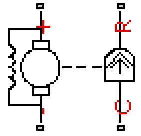
Purpose

Model electrical and torque characteristics of shunt motor

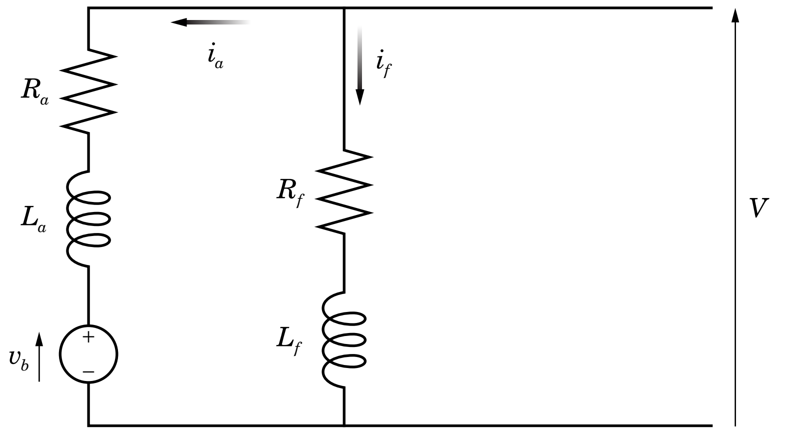
Library

Actuators & Drivers

Description



The Shunt Motor block represents the electrical and torque characteristics of a shunt motor using the following equivalent circuit model.



When you set the **Model parameterization** parameter to `By equivalent circuit parameters`, you specify the equivalent circuit parameters for this model:

- R_a — **Armature resistance**
- L_a — **Armature inductance**
- R_f — **Field winding resistance**

- L_f — **Field winding inductance**

The Shunt Motor block computes the motor torque as follows:

1. The magnetic field in the motor induces the following back 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:

$$i_f = \frac{V}{R_f}$$

$$i_a = \frac{V}{R_a}\left(1 - \frac{L_{af} w}{R_f}\right)$$

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.

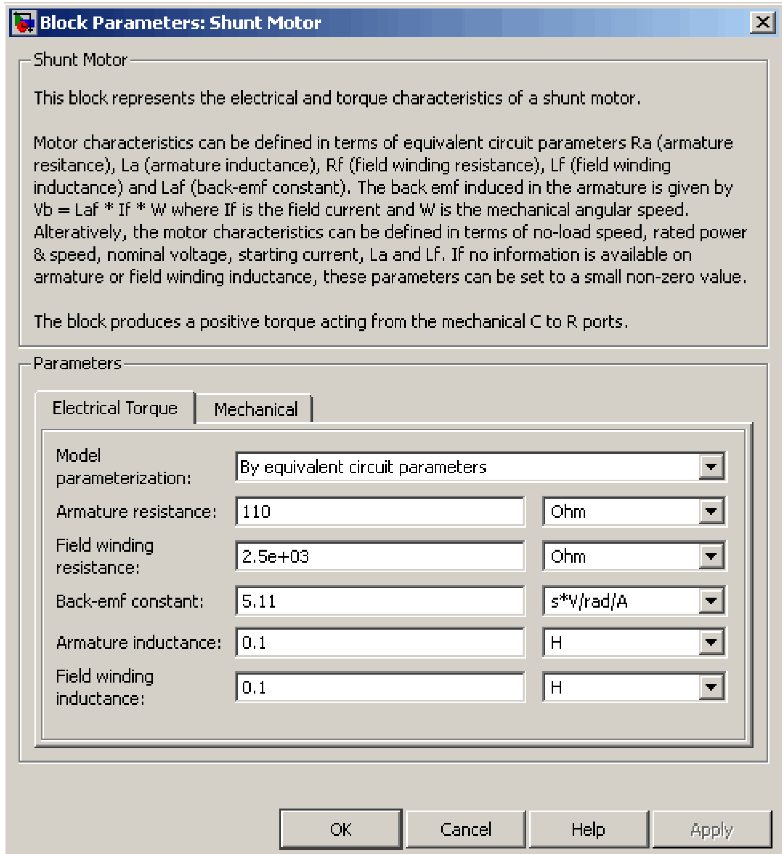
The block models motor inertia J and damping B for all values of the **Model parameterization** parameter. The output torque is:

$$T_{load} = \frac{L_{af}}{R_a R_f}\left(1 - \frac{L_{af}\omega}{R_f}\right)V^2 - J\dot{\omega} - B\omega$$

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

Dialog Box and Parameters

Electrical Torque Tab



Model parameterization

Select one of the following methods for block parameterization:

- `By equivalent circuit parameters` — Provide electrical parameters for an equivalent circuit model of the motor. This is the default method.

- `By rated power, rated speed & no-load speed` — Provide power and speed parameters that the block converts to an equivalent circuit model of the motor.

Armature resistance
Resistance of the armature. This parameter is only visible when you select `By equivalent circuit parameters` for the **Model parameterization** parameter. The default value is `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`

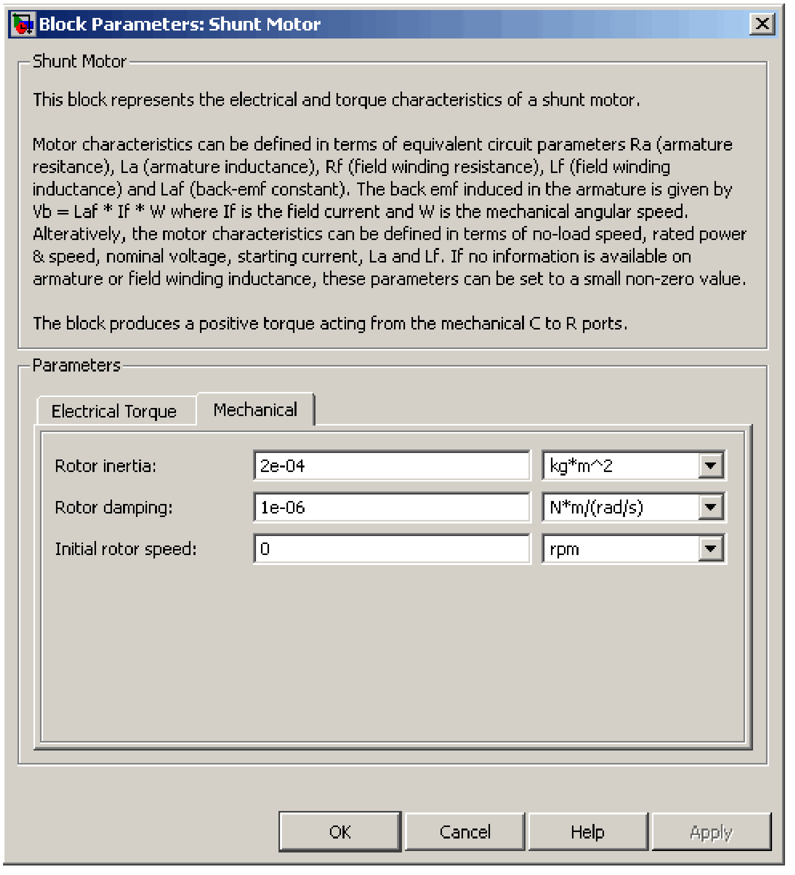
speed for the **Model parameterization** parameter. The default value is 4e+03 rpm.

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



Rotor inertia

Rotor inertia. The default value is `2e-04` kg*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 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

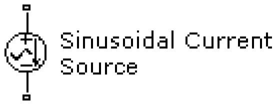
DC Motor, Induction Motor, Servomotor, and Universal Motor.

Sinusoidal Current Source

Purpose Model damped sinusoidal current source

Library SPICE-Compatible Sources

Description



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:

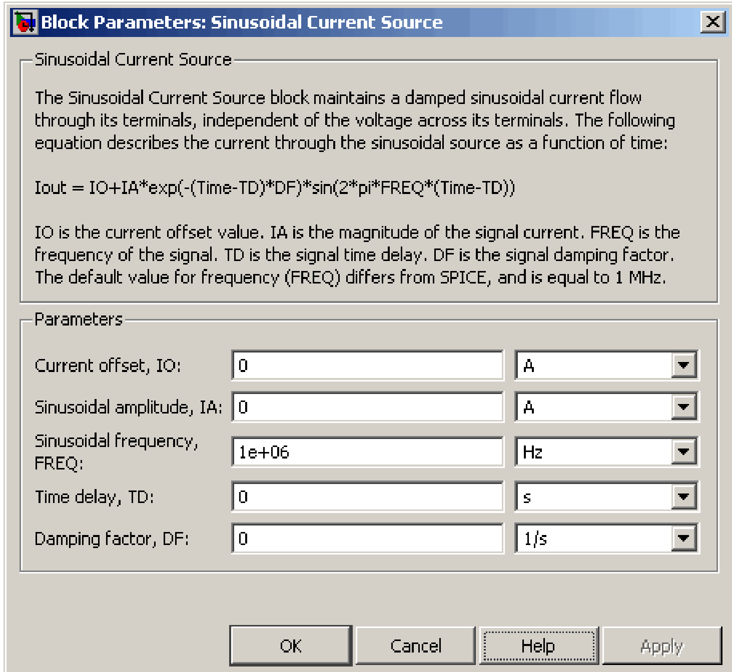
$$I_{out}\left(Time < TD\right) = IO$$

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

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



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 output current. The default value is 0 1/s. The value must be greater than or equal to 0.

Ports

The block has the following ports:

+

Positive electrical voltage.

-

Negative electrical voltage.

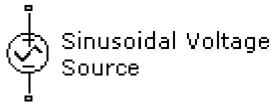
See Also

Sinusoidal Voltage Source

Purpose Model damped sinusoidal voltage source

Library SPICE-Compatible Sources

Description



The Sinusoidal Voltage Source block represents a damped sinusoidal voltage source whose output voltage is independent of the current through the source. The following equations describe the output as a function of time:

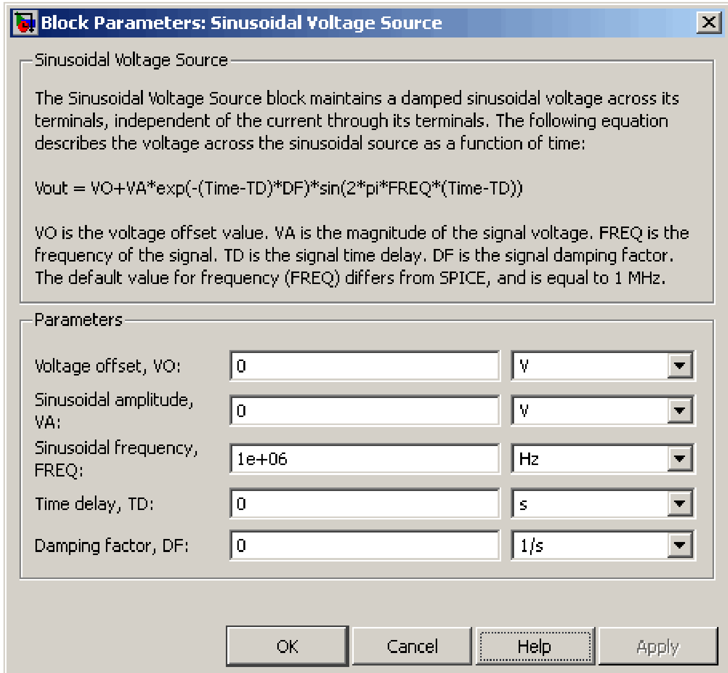
$$V_{out}\left(Time < TD\right) = VO$$

$$V_{out}\left(Time \geq TD\right) = VO + VA * e^{-(Time-TD)*DF} * \sin\left(2\pi * FREQ * \left(Time - TD\right)\right)$$

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



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` s. The value can be less than `0`.

Damping factor, DF

The amount by which to amplify or reduce the exponential damping term that multiples the sine wave to produce the output voltage. The default value is `0` 1/s. The value must be greater than or equal to `0`.

Ports

The block has the following ports:

+

Positive electrical voltage.

-

Negative electrical voltage.

See Also

Sinusoidal Current Source

Solar Cell

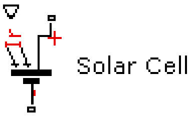
Purpose

Model single solar cell

Library

Sources

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:

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

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/m^2 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.

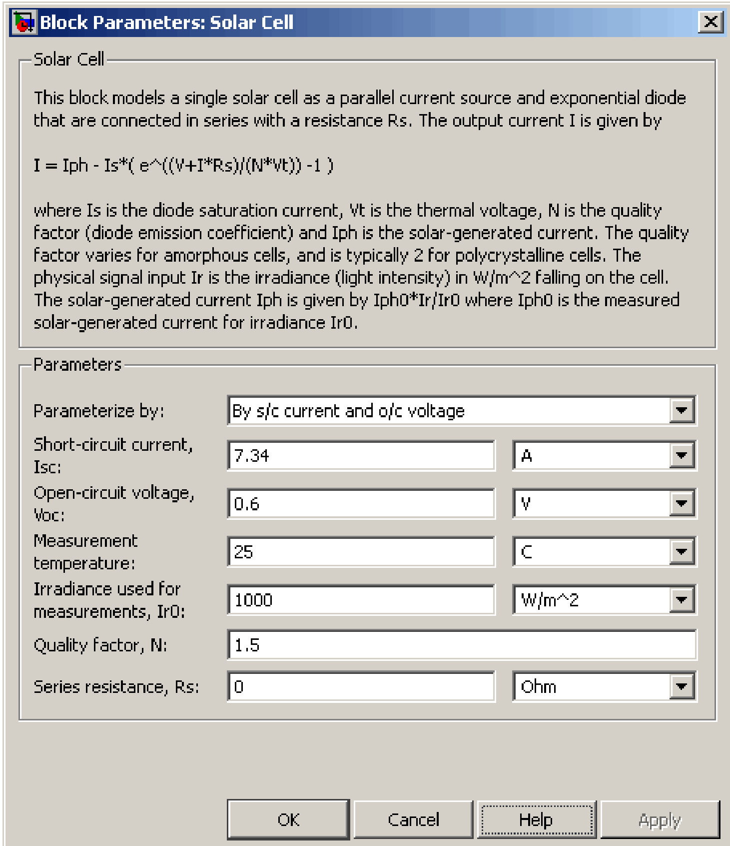
You can parameterize this block in terms of the preceding equivalent circuit model parameters or in terms of the short-circuit current and open-circuit voltage the block uses to derive these parameters.

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.

Dialog Box and Parameters



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/m^2.

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:

`Ir`
: Incident irradiance.

`+`
: Positive electrical voltage.

`-`
: Negative electrical voltage.

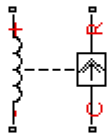
Purpose

Model electrical characteristics and generated force of solenoid

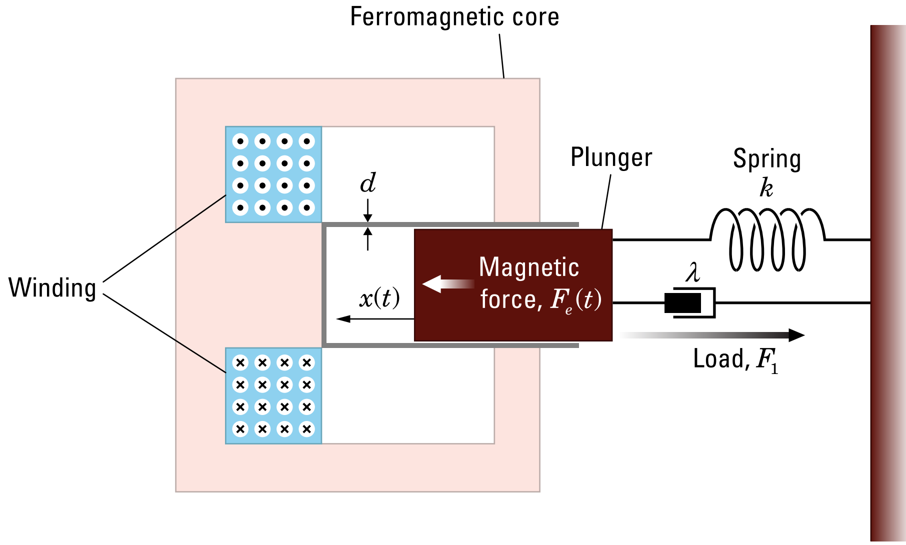
Library

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:

$$F_l + m\ddot{x} + \lambda\dot{x} + kx = F_e$$

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:

$$\frac{\partial L(x)}{\partial x} = \frac{-\beta}{(\alpha + \beta x)^2}$$

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:

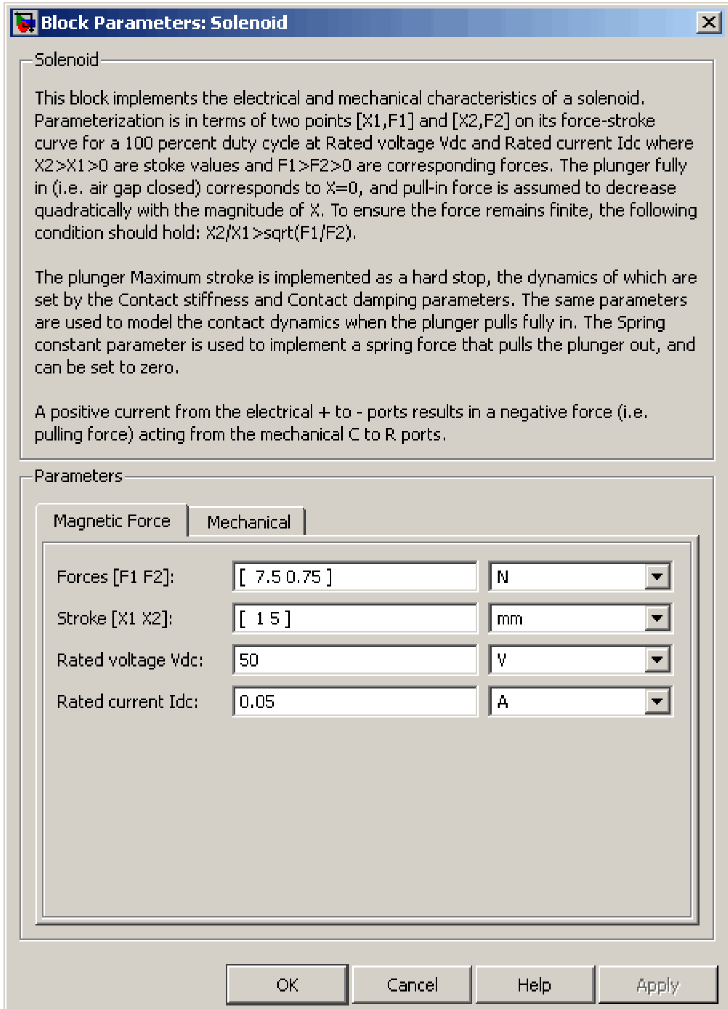
$$F = \frac{1}{2} i_0^{\,2} \frac{-\beta}{(\alpha + \beta x)^2}$$

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



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.

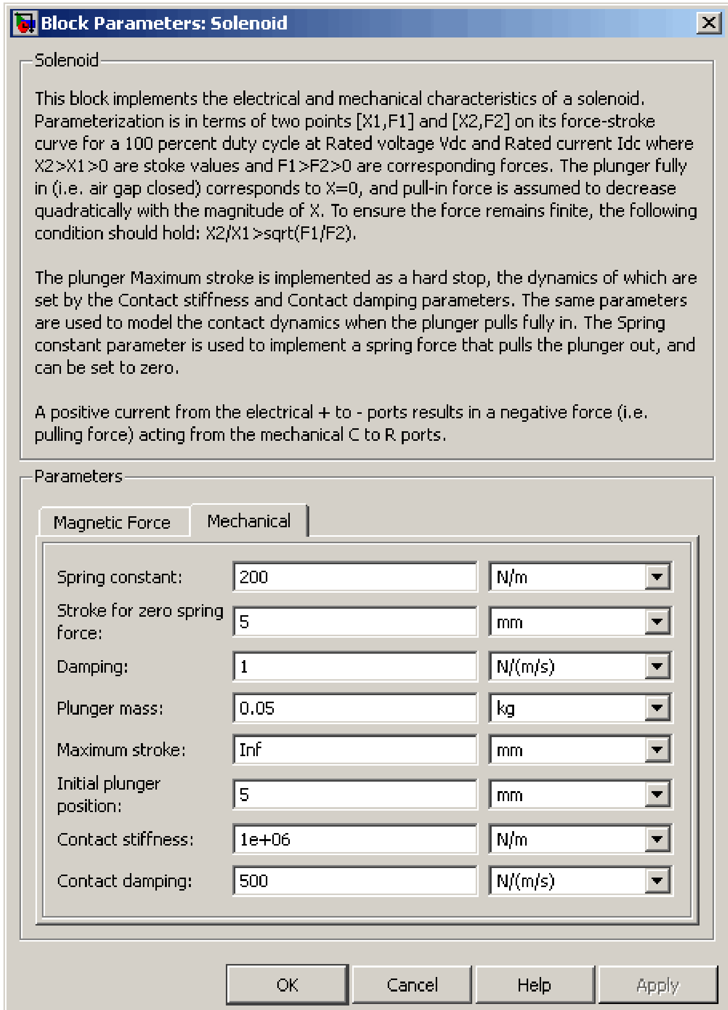
Rated voltage Vdc

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



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).

Ports

The block has the following ports:

`+`
: Positive electrical input.

`-`
: Negative electrical input.

`C`
: Mechanical translational conserving port.

`R`
: Mechanical translational conserving port.

References

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

SPICE Environment Parameters

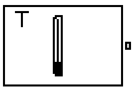
Purpose

Set parameters that apply to all connected SPICE-compatible blocks

Library

Utilities

Description



SPICE Environment Parameters

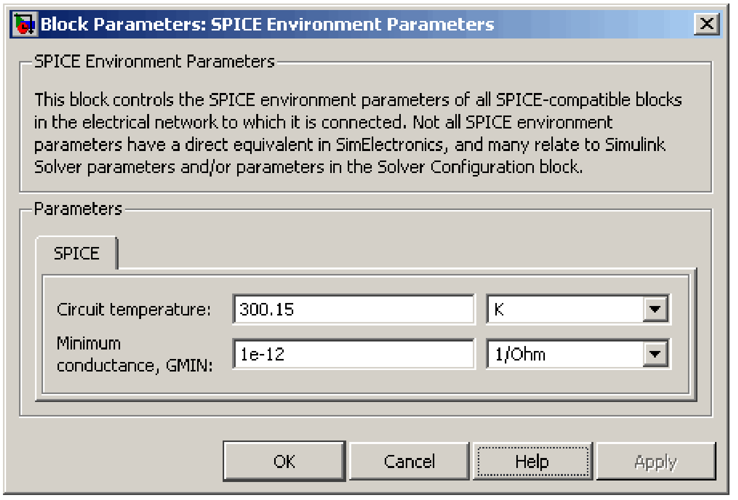
The SPICE Environment Parameters block lets you set parameters that apply to all SPICE-compatible blocks in an electrical network:

- Circuit temperature
- Minimum conductance

If your Simulink® model does not contain a SPICE Environment Parameters block, all blocks use the default values of these parameters. You must connect every network in the system to a SPICE Environment Parameters block to override the default values.

Note The simple semiconductor models in the Semiconductors sublibrary are not temperature dependent, so the SPICE Environment Parameters block only changes the minimum conductance parameter used by the exponential diode and bipolar transistor models.

Dialog Box and Parameters



Circuit temperature

The temperature of the connected SPICE-compatible blocks. The default value is `300.15` K.

Minimum conductance GMIN

The minimum conductance used by some blocks. The default value is `1e-12` 1/Ω

Ports

The block has the following ports:

`OUT`

Electrical output.

Stepper Motor

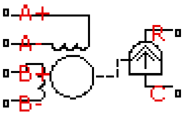
Purpose

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.

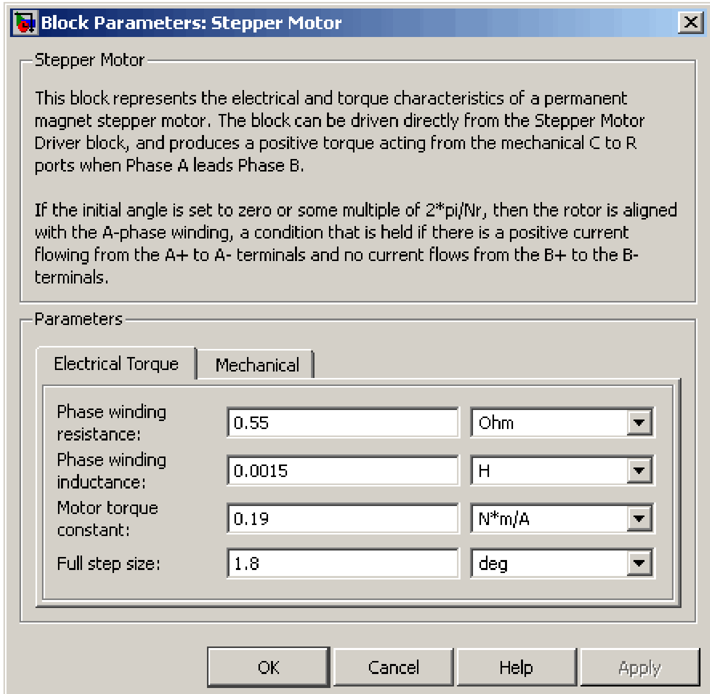
Basic Assumptions and Limitations

The model is based on the following assumptions:

- This model neglects magnetic saturation effects, detent torque, and any magnetic coupling between phases.
- When you select the **Start simulation from steady state** check box in the Simscape™ Solver Configuration block, this block will not initialize an **Initial rotor angle** value between $-\pi$ and π.

Dialog Box and Parameters

Electrical Torque Tab



Phase winding resistance

Resistance of the A and B phase windings. The default value is `0.55` Ω

Phase winding inductance

Inductance of the A and B phase windings. The default value is `0.0015` H.

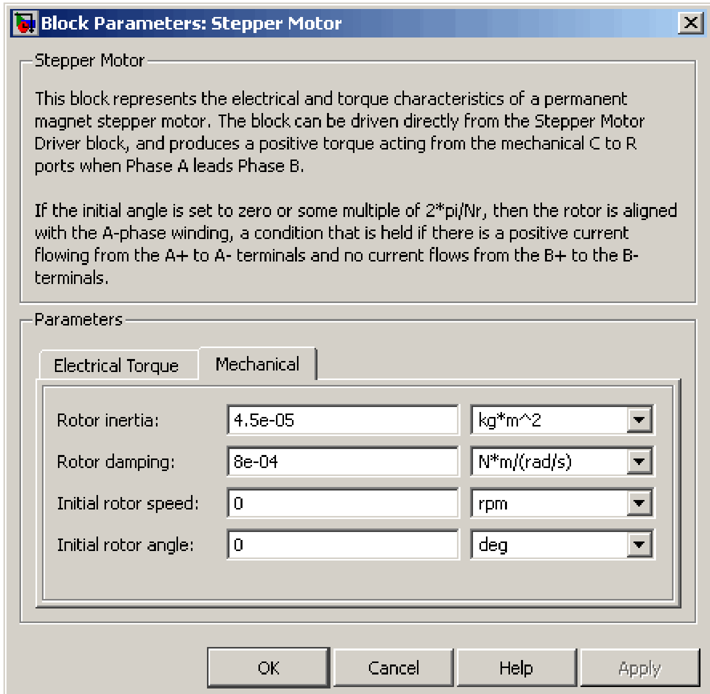
Motor torque constant

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

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



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.

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. *Stepping Motors: A Guide to Modern Theory and Practice*. 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

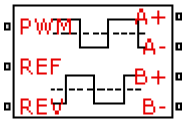
Purpose

Model stepper motor driver

Library

Actuators & Drivers

Description



Stepper Motor Driver

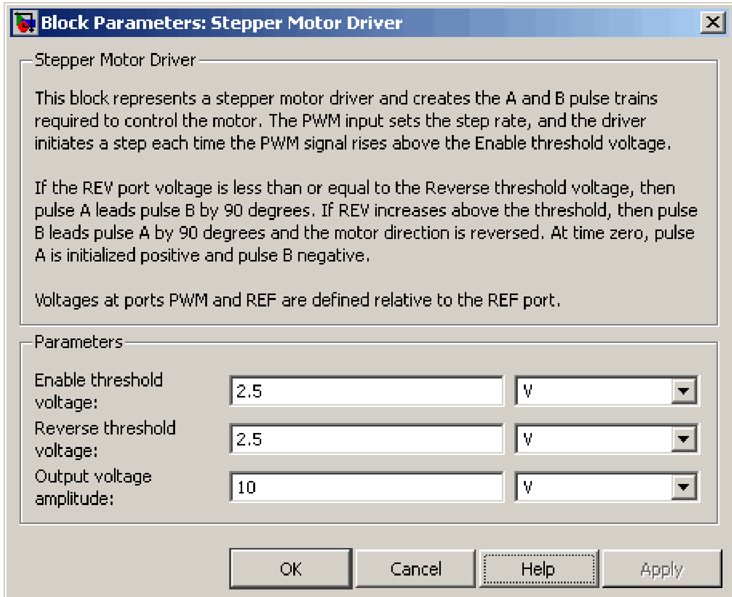
The Stepper Motor Driver block represents a stepper motor driver. It creates the pulse trains, A and B, required to control the motor. This block initiates a step each time the voltage at the PWM port rises above the **Enable threshold voltage**.

If the voltage at the REV port is less than or equal to the **Reverse threshold voltage**, pulse A leads pulse B by 90 degrees. If the voltage at the REV port is greater than the **Reverse threshold voltage**, pulse B leads pulse A by 90 degrees and the motor direction is reversed.

At time zero, pulse A is positive and pulse B is negative.

Use the Controlled PWM Voltage block to create the voltage at the PWM port. This block creates a network engine event every time the PWM signal goes high. The network engine event triggers a simulation time point when the PWM signal goes high, which ensures good simulation accuracy. If you instead use the Controlled Voltage Source block from the Foundation library, 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.

Dialog Box and Parameters



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.

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.

`PWM`
: Triggering input step voltage.

`REF`
: Input floating reference voltage.

`REV`
: Input voltage that controls motor direction.

Examples

See the Controlled Stepper Motor demo.

See Also

Controlled PWM Voltage and Stepper Motor.

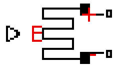
Purpose

Model deformation sensor

Library

Sensors

Description



Strain Gauge

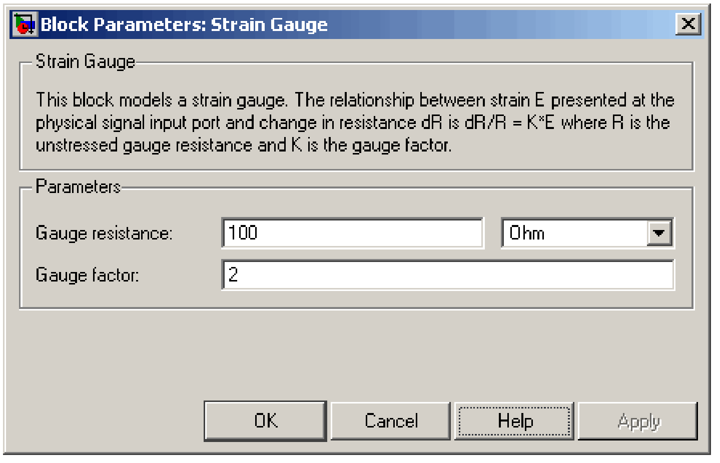
The Strain Gauge block represents a sensor that generates a change in resistance as a function of strain using the following equation:

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

where:

- $\Delta R/R$ is the fractional change in resistance.
- ε is the strain at port B.
- K is the **Gauge factor** parameter value.

Dialog Box and Parameters



Gauge resistance
The unstressed gauge resistance. The default value is 100 Ω.

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:

B

Strain input.

+

Positive electrical port.

-

Negative electrical port.

Purpose

Model resistor with thermal port

Library

Passive Devices

Description

Thermal Resistor

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

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

where:

- R_0 is the nominal resistance at the reference temperature T_0.
- α is the temperature coefficient.

The following equation describes the thermal behavior of the block:

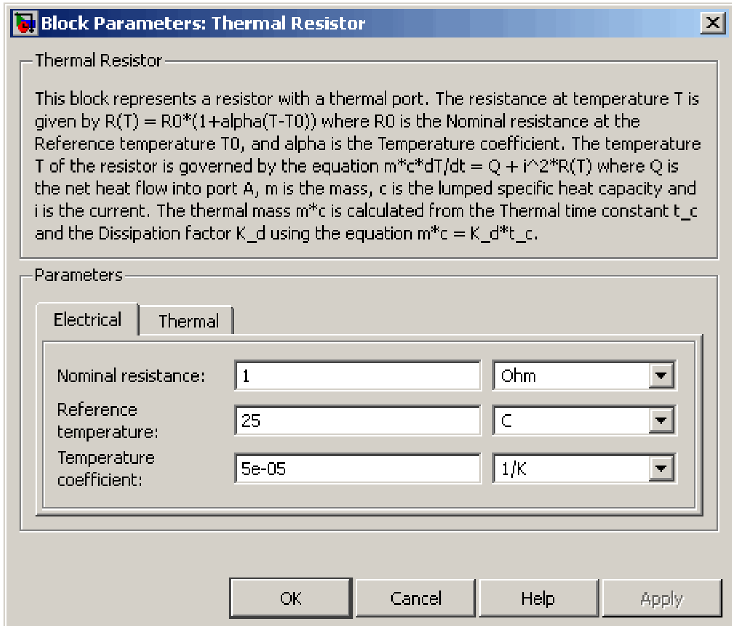
$$Q = K_d t_c \frac{dT}{dt}$$

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.

Dialog Box and Parameters

Electrical Tab



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

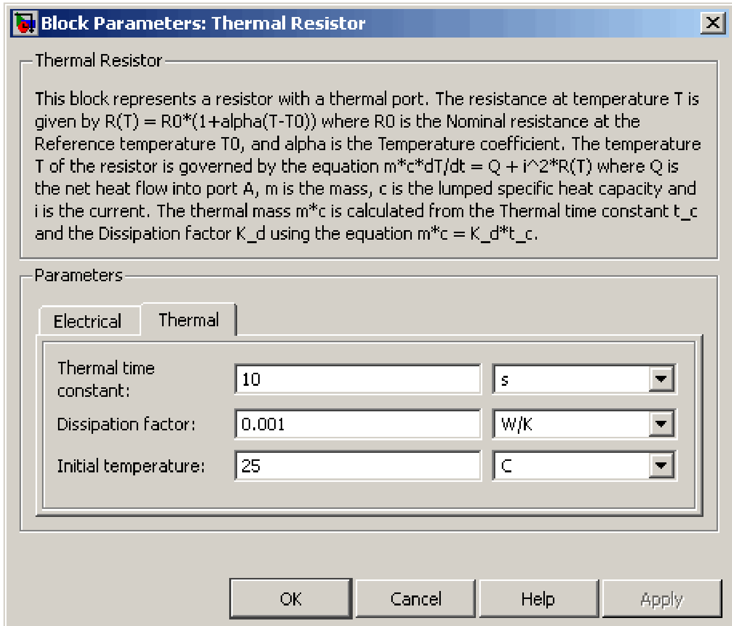
Reference temperature

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



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.

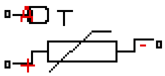
Purpose

Model NTC thermistor using B-parameter equation

Library

Sensors

Description



Thermistor

The Thermistor block represents an NTC thermistor using the B-parameter equation. The resistance at temperature T is

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

where:

- R_0 is the nominal resistance at the reference temperature T_0.
- B is the characteristic temperature constant.

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt}$$

where:

- Q is the net heat flow into port A.
- K_d is the **Dissipation factor 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:

1. Connect the thermistor to the B port of a Simscape™ Convective Heat Transfer block.

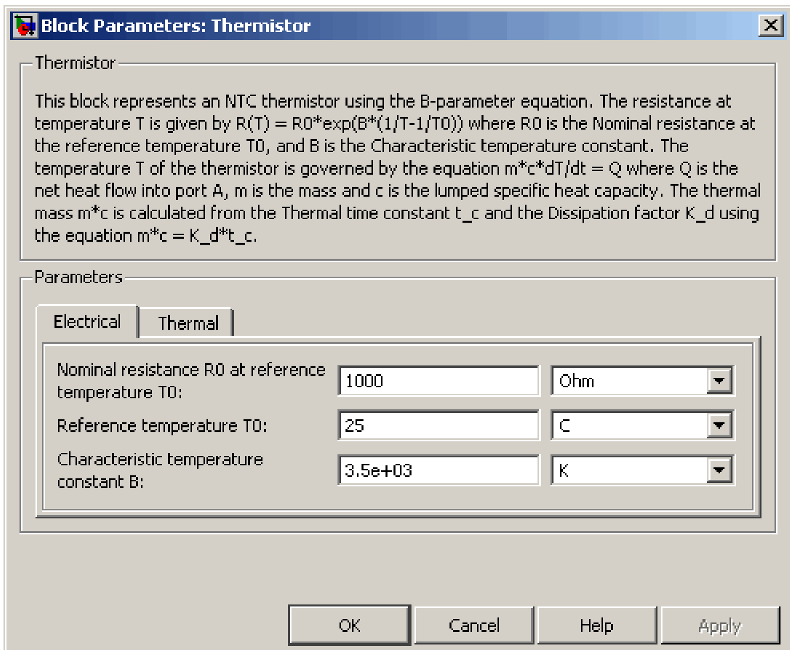
2. Connect the A port of the Convective Heat Transfer block to a Simscape Ideal Temperature Source block whose temperature is set to the ambient temperature.

3 Set the **Area** parameter of the Convective Heat Transfer block to an approximate area A_{nom}.

4 Set the **Heat transfer coefficient** parameter of the Convective Heat Transfer block to K_d/A_{nom}.

Dialog Box and Parameters

Electrical Tab



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.

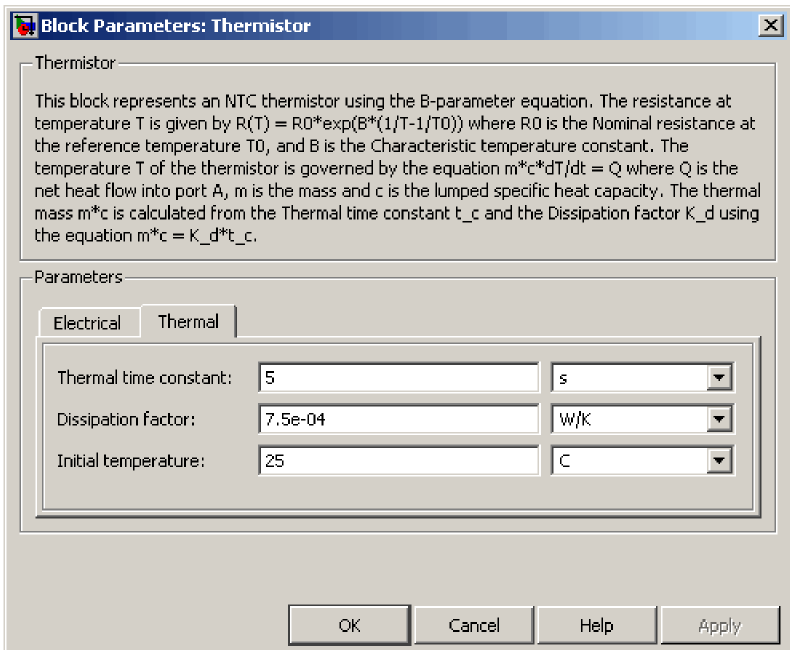
Reference temperature T0

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



Thermal time constant

The time it takes the sensor temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is `5` s.

Dissipation factor
The thermal power required to raise the thermistor temperature by one K. The default value is `7.5e-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

Thermocouple

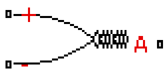
Purpose

Model sensor that converts thermal potential difference into electrical potential difference

Library

Sensors

Description



Thermocouple

The Thermocouple block represents a thermocouple using the standard polynomial parameterization defined in the NIST ITS-90 Thermocouple Database [1]. The voltage E across the device in mV is

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

where:

- ci is the i^{th} element of the **Coefficients [c0 c1 ... cn]** parameter value.
- t is the temperature difference in degrees Celsius between the temperature at the thermal port A and the **Reference temperature** parameter value.

Note The equation for voltage across the device as a function of temperature difference is defined in mV. The units of the voltage across the actual device is V.

The following equation describes the thermal behavior of the block:

$$Q = K_d t_c \frac{dT}{dt}$$

where:

- T is the temperature at port A.
- Q is the net heat flow into port A.
- K_d is the **Dissipation factor** parameter value.

- t_c is the **Thermal time constant** parameter value.
- dT/dt is the rate of change of the temperature.

To model the thermocouple in free space:

1. Connect the thermocouple to the B port of a Simscape™ Convective Heat Transfer block.
2. Connect the A port of the Convective Heat Transfer block to a Simscape Ideal Temperature Source block whose temperature is set to the ambient temperature.
3. Set the **Area** parameter of the Convective Heat Transfer block to an approximate area A_{nom}.
4. Set the **Heat transfer coefficient** parameter of the Convective Heat Transfer block to K_d/A_{nom}.

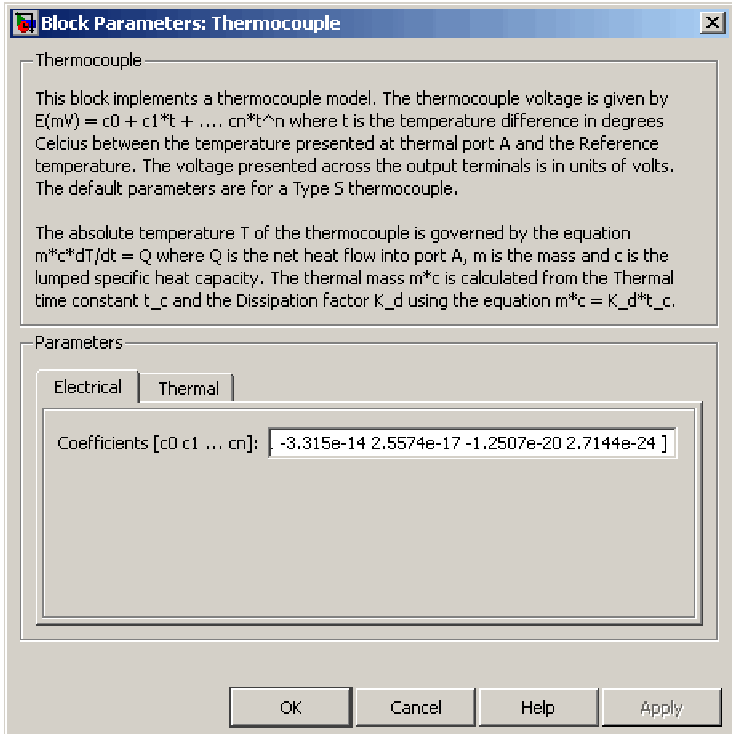
Basic Assumptions and Limitations

The model is based on the following assumptions:

- 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 $t > 0$.

Dialog Box and Parameters

Electrical Tab

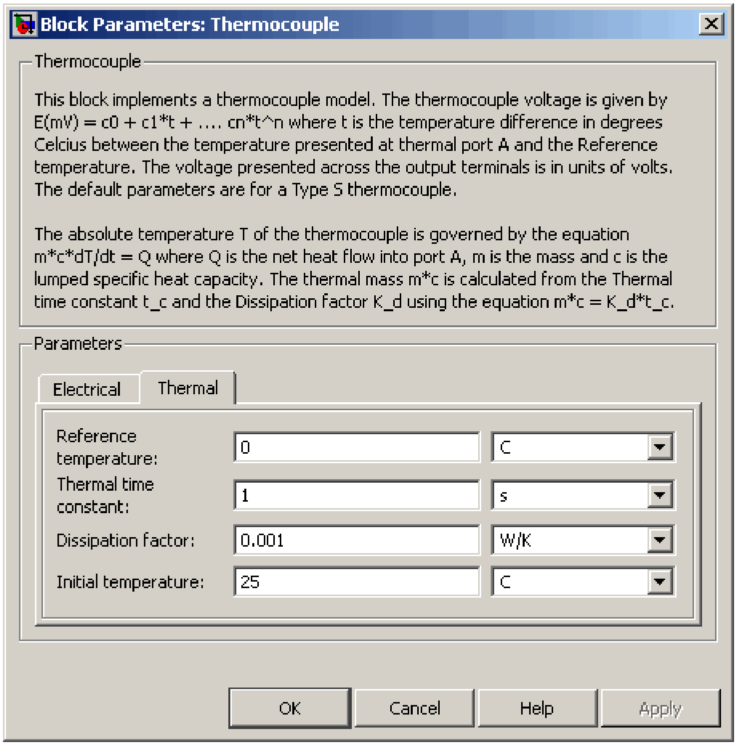


Coefficients [c0 c1 ... cn]

The vector of coefficients *c* in the equation that describes voltage as a function of temperature. The default value is `[ 0 0.0054031 1.2593e-05 -2.3248e-08 3.2203e-11 -3.315e-14 2.5574e-17 -1.2507e-20 2.7144e-24 ]`. This value specifies a Type S thermocouple, which is valid in the range -50 to 1064 degrees C.

Note You can download parameters for other standard thermocouple types from the NIST database [1]. For 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



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

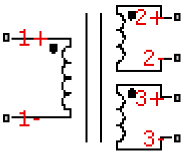
Thermal Resistor.

Three-Winding Mutual Inductor

Purpose Model three coupled inductors

Library Passive Devices

Description The Three-Winding Mutual Inductor block represents a set of three coupled inductors or windings. The voltage across the three windings is



Three-Winding Mutual Inductor

$$V_1 = L_1 \frac{dI_1}{dt} + M_{12} \frac{dI_2}{dt} + M_{13} \frac{dI_3}{dt}$$

$$V_2 = M_{12} \frac{dI_1}{dt} + L_2 \frac{dI_2}{dt} + M_{23} \frac{dI_3}{dt}$$

$$V_3 = M_{13} \frac{dI_1}{dt} + M_{23} \frac{dI_2}{dt} + L_3 \frac{dI_3}{dt}$$

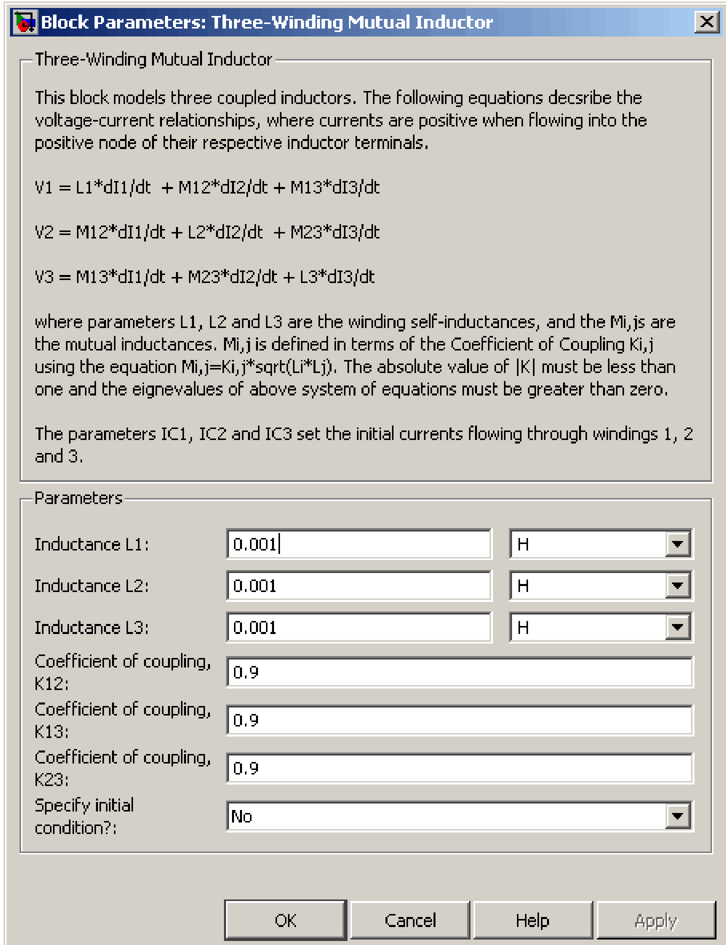
where:

- V_i is voltage across the ith winding.
- I_i is current through the ith winding.
- L_i is self inductance of the ith winding.
- M_{ij} is mutual inductance of the ith and jth windings, $M_{ij} = K_{ij}\sqrt{L_i L_j}$.

In the preceding equations, currents are positive when flowing into the positive node of their respective inductor terminals.

When you run a simulation that includes this block, the software checks the specified parameter values to ensure that the resulting device is passive. If it is not, the software issues an error.

Dialog Box and Parameters



Inductance L1

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

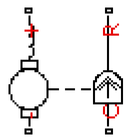
Purpose

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

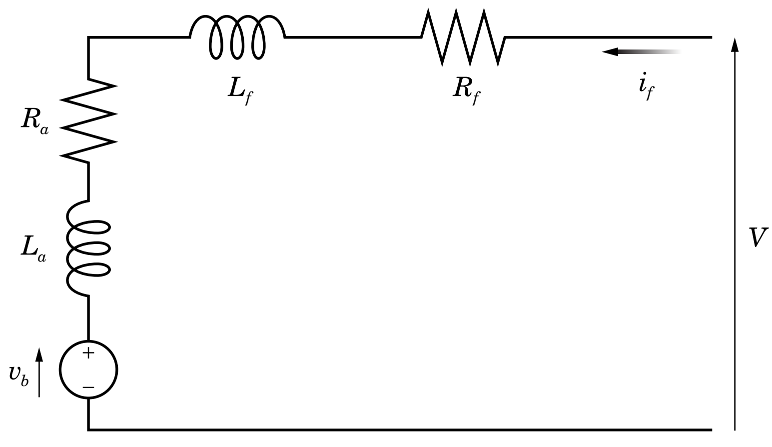
Library

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 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.

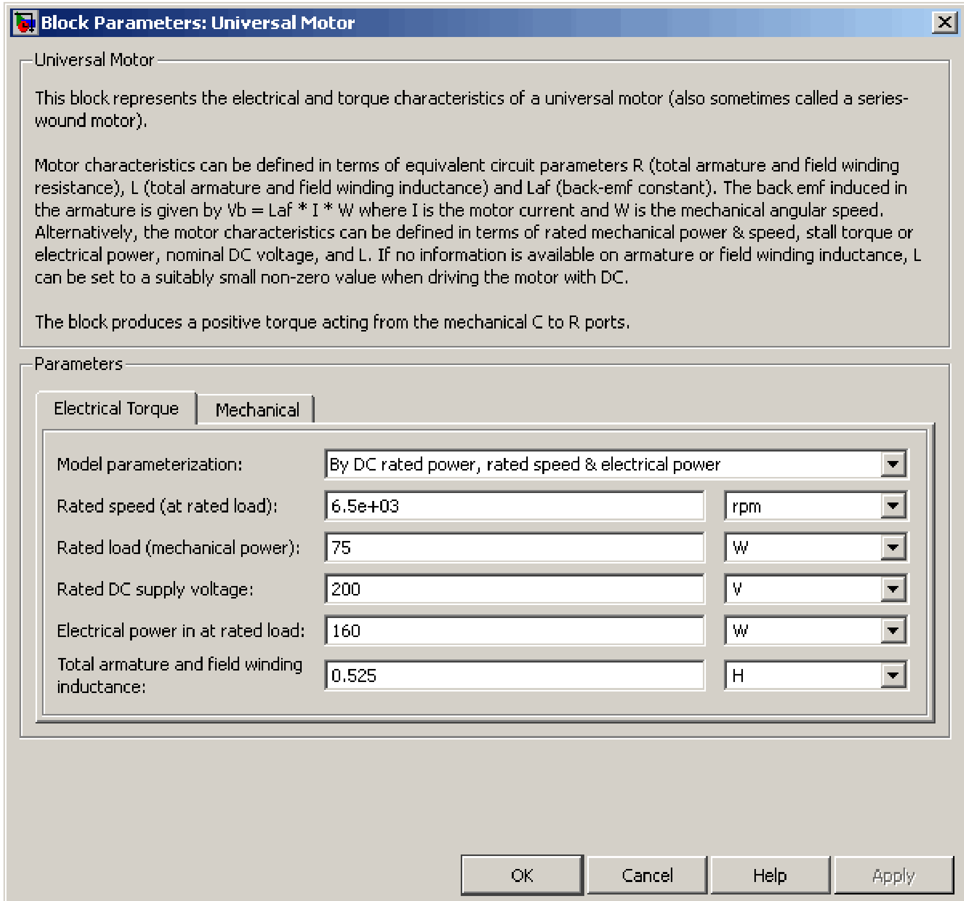
The block models motor inertia J and damping B for all values of the **Model parameterization** parameter. The output torque is:

$$T_{load} = L_{af}\left(\frac{V}{R_f + R_a + L_{af}\omega}\right)^2 - J\dot{\omega} - B\omega$$

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

Dialog Box and Parameters

Electrical Torque Tab



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.

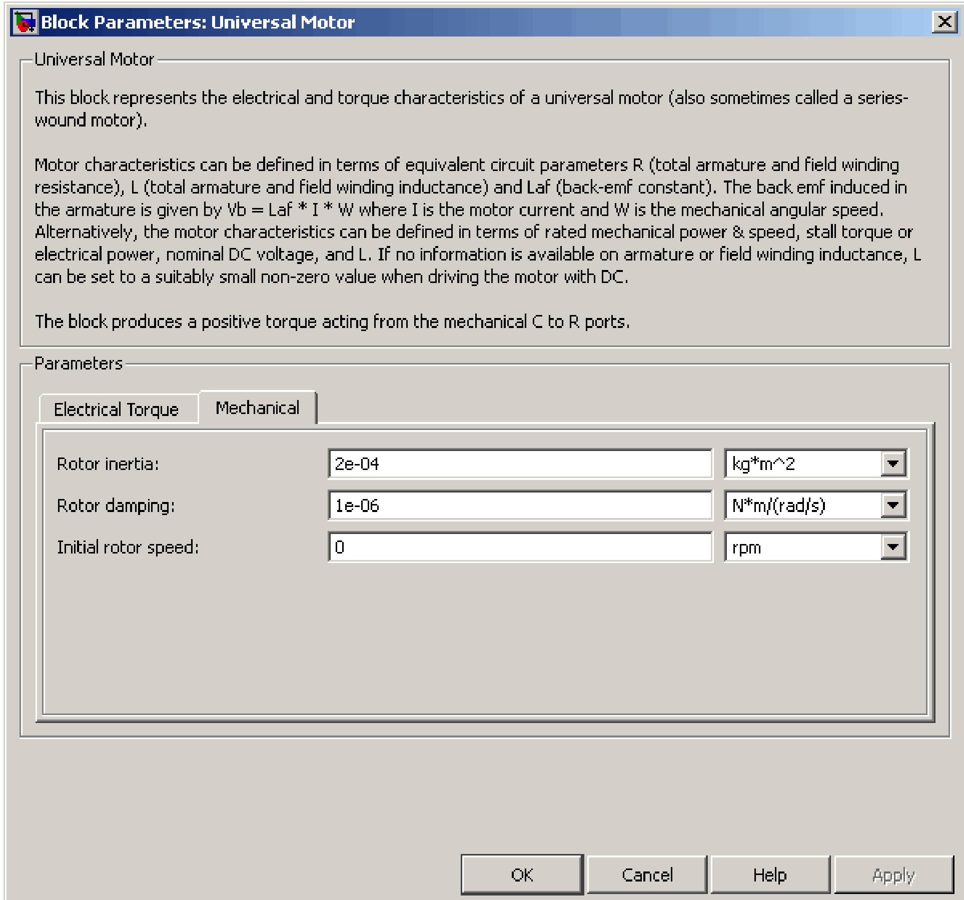
RMS current at rated load

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



Rotor inertia

Rotor inertia. The default value is `2e-04` kg*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: *Electronic Control Systems in Mechanical and Electrical Engineering* 3rd edition, Pearson Education, 2004.

See Also

DC Motor, Induction Motor, Servomotor, and Shunt Motor.

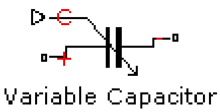
Purpose

Model linear time-varying capacitor

Library

Passive Devices

Description



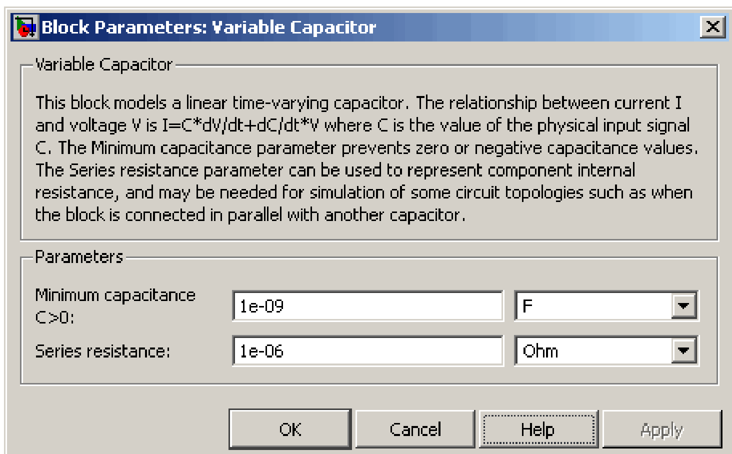
The Variable Capacitor block represents a linear time-varying capacitor. The current *i* through the device when the capacitance at port C is *C* is governed by the following equation:

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

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.

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

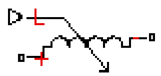
Purpose

Model linear time-varying inductor

Library

Passive Devices

Description



Variable Inductor

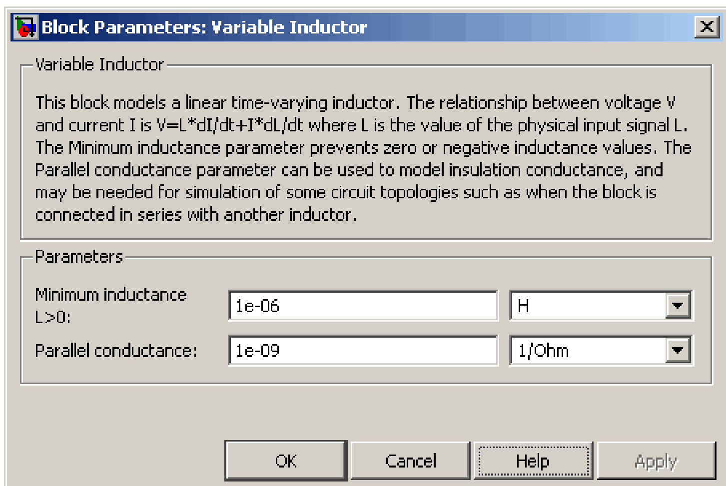
The Variable Inductor block represents a linear time-varying inductor. The voltage v across the device when the inductance at port L is L is governed by the following set of equations:

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

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



Minimum inductance L>0
The lower limit on the value of the signal at port L. This limit prevents the signal from reaching a value that has no physical meaning. The default value is `1e-06` H.

Parallel conductance
The value of the conductance placed in parallel with the variable inductor. The default value is `1e-09` 1/Ω

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

```
modelname = netlist2sl(filename, libraryname)
modelname = netlist2sl(filename, options)
```

Description

`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.

- `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 `netlist2sl` 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 `netlist2sl` puts the blocks.
- `ModelOnly` — A boolean value. True tells `netlist2sl` to generate a library that contains only blocks representing the model cards that appear in the SPICE file. False (the default value) tells `netlist2sl` 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 `netlist2sl` 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, `netlist2sl` adds new blocks to this library. If a subcircuit name conflicts with an existing block name in the library, `netlist2sl` 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 `netlist2sl` function. To update the blocks, you must change the netlist and then re-run the `netlist2sl` 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 `netlist2sl` 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 `netlist2sl` 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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