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SimElectronics[™] Reference

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Block Reference

Actuators & Drivers (p. 1-2)	Mechanical control and motor devices
Integrated Circuits (p. 1-2)	Electronic circuits
Logic (p. 1-3)	Logic gates
Passive Devices (p. 1-3)	Passive electrical devices
Semiconductor Devices (p. 1-3)	Circuit components made from semiconductor material
Sensors (p. 1-4)	Electromechanical sensors
Sources (p. 1-5)	Electrical supplies
SPICE-Compatible Sources (p. 1-5)	SPICE-compatible electrical supplies
SPICE-Compatible Semiconductors (p. 1-6)	SPICE-compatible circuit components made from semiconductor material
Utilities (p. 1-7)	System-level parameter specification

Actuators & Drivers

Controlled PWM Voltage	Model pulse-width modulated voltage source
DC Motor	Model electrical and torque characteristics of DC motor
H-Bridge	Model H-bridge motor driver
Induction Motor	Model induction motor powered by ideal AC supply
Piezo Stack	Model electrical and force characteristics of piezoelectric stacked actuator
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

Logic

CMOS AND	Model CMOS AND gate behaviorally
CMOS Buffer	Model CMOS Buffer gate behaviorally
CMOS NAND	Model CMOS NAND gate behaviorally
CMOS NOR	Model CMOS NOR gate behaviorally
CMOS NOT	Model CMOS NOT gate behaviorally
CMOS OR	Model CMOS OR gate behaviorally
CMOS XOR	Model CMOS XOR gate behaviorally

Passive Devices

Fuse	Model fuse that protects against excessive current
Relay	Model switching and associated delay of relay
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

N-Channel IGBT

Model piecewise linear, piecewise linear zener, or exponential diode 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
Proximity Sensor	Model simple distance sensor
PS Sensor	Model generic linear sensor
Strain Gauge	Model deformation sensor

Thermistor	Model NTC thermistor using B-parameter equation
Thermocouple	Model sensor that converts thermal potential difference into electrical potential difference

Sources

Generic Battery	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
DC Voltage Source	Model constant voltage source
Exponential Current Source	Model exponential pulse current source
Exponential Voltage Source	Model exponential pulse voltage source
PCCCS	Model polynomial current-controlled current source
PCCVS	Model polynomial current-controlled voltage source
Pulse Current Source	Model periodic square pulse current source
Pulse Voltage Source	Model periodic square pulse voltage source

PVCCS	Model polynomial voltage-controlled current source
PVCVS	Model polynomial voltage-controlled voltage source
PWL Current Source	Model lookup table current source
PWL Voltage Source	Model lookup table voltage source
SFFM Current Source	Model single-frequency FM current source
SFFM Voltage Source	Model single-frequency FM voltage source
Sinusoidal Current Source	Model damped sinusoidal current source
Sinusoidal Voltage Source	Model damped sinusoidal voltage source

SPICE-Compatible Semiconductors

Diode (SPICE)	Model SPICE-compatible diode
NJFET	Model SPICE-compatible N-Channel JFET
NMOS	Model SPICE-compatible N-Channel MOSFET
NPN	Model Gummel-Poon NPN Transistor
PJFET	Model SPICE-compatible P-Channel JFET
PMOS	Model SPICE-compatible P-Channel MOSFET
PNP	ModelGummel-PoonPNPTransistor

Utilities

SPICE Environment Parameters

Set parameters that apply to all connected SPICE-compatible blocks

Blocks — Alphabetical List

Band-Limited Op-Amp

Purpose Model band-limited operational amplifier

Library

Integrated Circuits

Description

•<u>+</u>f_-•

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

Band-Limited Op-Amp

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

where:

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

The input current is:

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

where R_{in} is the input resistance.

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

Dialog Box and **Parameters**

	m, then the output voltage is given b	y
Vout = A*(Vp-Vm)*1/(s/(2*p	pi*f)+1)-lout*Rout	
Laplace operator, and f is t	s the output resistance, lout is the ou he 3dB bandwidth. The input curren tance. The no-load output voltage is limited to +-Vdot.	t is given by (Vp-V
not take account of any vo	/0, sets the initial op-amp output volt ltage drop across Rout. The initial c rom steady state option in the Solver	ondition is not use
Parameters		
Gain, A:	1000	
Input resistance, Rin:	1e+06	Ohm
Output resistance, Rout:	100	Ohm
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
Maximum slew rate, Vdot:	1000	V/s
Bandwidth, f:	1e+05	Hz
Initial output voltage, V0:	0	V

Gain, A

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

Input resistance, Rin

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

Output resistance, Rout

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

CMOS AND

Purpose	Model CMOS AND	gate behaviorally
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Library Logic

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



CMOS AND

- The block output voltage value equals the **High level output voltage** parameter value if the logic levels of both of the gate inputs are 1.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

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

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Box and Parameters

Dialog

nputs Outputs			
ow level input voltage:	2	V	•
High level input voltage:	3	V	_
Average input capacitance:	5	pF	•

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

🛃 Block Parameters: CMOS AND					×
CMOS AND					
The block implements a simplified mode parameters for the supply voltage use				low and Output l	high
Parameters					
Inputs Outputs					1
Low level output voltage:	0			V	•
High level output voltage:	5			V	-
Output resistance:	450			Ohm	.
Propagation delay:	1.2e-07			s	_
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by

	dividing the high-level output voltage by the maximum low-level output current.
	Propagation delay Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.
Ports	The block has the following ports:
	A Electrical input port. B
	Electrical input port.
	J Electrical output port.

CMOS Buffer

Purpose	Model CMOS Buffer	gate behaviorally
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Logic

Library

Description



CMOS Buffer

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

- The block output voltage value equals the **High level output** voltage parameter value if the logic level of the gate input is 1.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

The block determines the logic level of the gate input as follows:

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate input has infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Dialog Box and Parameters

'arameters				
Inputs Outputs		 		
Low level input voltage:	2		V	•
High level input voltage:	3		V	•
Average input capacitance:	5		pF	•
	,			_

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

🙀 Block Parameters: CM05 Buffer					×
CMOS Buffer					
The block implements a simplified model of parameters for the supply voltage used.				v and Output high	
Parameters					
Inputs Outputs					1
Low level output voltage:	0			٧	•
High level output voltage:	5			۷	-
Output resistance:	450			Ohm	•
Propagation delay:	1.2e-07			s	•
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.

Ports The block has the following ports:

Α

Electrical input port.

J

Electrical output port.

CMOS NAND

Purpose	Model CMOS NAND	gate behaviorally
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Logic

Library

Description



CMOS NAND

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

- The block output voltage value equals the **High level output voltage** parameter value if the logic levels of both of the gate inputs are 0.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

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

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.

• The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Dialog Box and Parameters

Inputs Tab

arameters				
Inputs Outputs		 		
Low level input voltage:	2		۷	•
High level input voltage:	3		V	•
Average input capacitance:	5		pF	•

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

e block implements a simplified mod rameters for the supply voltage us			put low and out	purnign
rameters				
Inputs Outputs				
Low level output voltage:	0		V	•
High level output voltage:	5		V	•
Output resistance:	450		Ohm	•
Propagation delay:	1.2e-07		s	•

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.

The block has the following ports:

А

Ports

Electrical input port.

В

Electrical input port.

J

Electrical output port.

CMOS NOR

Purpose	Model	CMOS	NOR	gate	behaviora	llv
1 01 0000	mouci	01100	11010	Sauc	Denaviora	шy

Library Logic

Description



CMOS NOR

- The CMOS NOR block represents a CMOS NOR logic gate behaviorally:
- The block output voltage value equals the **Low level output voltage** parameter value if the logic levels of any of the gate inputs are 1.
- The block output voltage value equals the **High level output voltage** parameter value otherwise.

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

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Dialog Box and Parameters

The block implements a simplified mod parameters for the supply voltage us			put low and Outp	ut high
Parameters Inputs Outputs				
Low level input voltage:	2		V	•
High level input voltage: Average input capacitance:	3		PF	
	,			

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

Block Parameters: CMOS NOR					×
CMOS NOR-					
The block implements a simplified mode parameters for the supply voltage use				t low and Output l	high
Parameters					
Inputs Outputs					1
Low level output voltage:	0			V	-
High level output voltage:	5			V	•
Output resistance:	450			Ohm	•
Propagation delay:	1.2e-07			s	_
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by

	dividing the high-level output voltage by the maximum low-level output current.
	Propagation delay Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.
Ports	The block has the following ports:
	A Electrical input port.
	B Electrical input port.
	J Electrical output port.

CMOS NOT

Purpose	Model CMOS NOT	gate behaviorally
	1100001 011100 1101	gave somariorany

Library Logic

Description The CMOS NOT block represents a CMOS NOT logic gate behaviorally:



CMOS NOT

- The block output voltage value equals the **High level output voltage** parameter value if the logic level of the gate input is 0.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

The block determines the logic level of the gate input as follows:

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate input has infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Dialog Box and Parameters

Block Parameters: CMOS NOT					×
CMOS NOT-					
The block implements a simplified mode parameters for the supply voltage use				ut low and Outpu	ut high
Parameters					
Inputs Outputs					1
Low level input voltage:	2			V	•
High level input voltage:	3			V	_
Average input capacitance:	5			pF	•
1					
		ОК	Cancel	Help	Apply

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

Block Parameters: CMOS NOT					×
CMOS NOT					
The block implements a simplified mode parameters for the supply voltage use				t low and Output	t high
Parameters					
Inputs Outputs					1
Low level output voltage:	0			V	•
High level output voltage:	5			V	•
Output resistance:	450			Ohm	-
Propagation delay:	1.2e-07			s	•
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by dividing the high-level output voltage by the maximum low-level output current.

Propagation delay

Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.

Ports The block has the following ports:

Α

Electrical input port.

J

Electrical output port.

CMOS OR

Purpose	Model CMOS OR gate behaviorally
---------	---------------------------------

Library Logic

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



CMOS OR

- The block output voltage value equals the **High level output voltage** parameter value if the logic levels of any of the gate inputs are 1.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

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

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Dialog Box and Parameters

arameters for the supply voltage us		 		
Inputs Outputs		 		
Low level input voltage:	2		V	•
High level input voltage:	3	 	V	•
Average input capacitance:	5	 	pF	•
Average input capacitance:	13		1 pr	

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

당 Block Parameters: CMOS OR					×
CMOS OR					
The block implements a simplified model of parameters for the supply voltage used				ow and Output hig	h
Parameters					
Inputs Outputs					1
Low level output voltage:	0			V	•
High level output voltage:	5			V	-
Output resistance:	450			Ohm	_
Propagation delay:	1.2e-07			s	-
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by

	dividing the high-level output voltage by the maximum low-level output current.
	Propagation delay Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.
Ports	The block has the following ports:
	A Electrical input port.
	B Electrical input port.
	J Electrical output port.

CMOS XOR

FULPOSE Model CMUS XUR gate behaviorall	Purpose	Model CMOS XOR gate behaviorally
--	---------	----------------------------------

Library Logic

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



CMOS XOR

- The block output voltage value equals the **High level output** voltage parameter value if the logic level of exactly one of the gate inputs is 1.
- The block output voltage value equals the **Low level output voltage** parameter value otherwise.

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

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

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

Note The block does not model the internal individual MOSFET devices that make up the gate.

The block models the gate as follows:

- The gate inputs have infinite resistance and finite or zero capacitance.
- The gate output (voltage source) drives a series resistor and capacitor connected to ground.
- The block sets the value of the gate output capacitor such that the resistor-capacitor time constant equals the **Propagation delay** parameter value.

Basic Assumptions and Limitations

The block does not model the internal individual MOSFET devices that make up the gate. This limitation has the following implications:

- The block does not accurately model the gate's response to input noise and inputs that are around the logic threshold voltage.
- The block does not accurately model dynamic response.
- The block's linear drop in output voltage as a function of output current is an approximation to the MOSFET output behavior.

To model a logic gate at the device level, use the netlist2s1 function to import the netlist of the logic gate.

Inputs Tab

Dialog Box and Parameters

parameters for the supply voltage us	ed. Default values are f	for a supply voltage o	of 5 volts.		
Inputs Outputs					
Low level input voltage:	2			V	•
High level input voltage:	3			V	•
Average input capacitance:	5			pF	•

Low level input voltage

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

High level input voltage

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

Average input capacitance

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

Outputs Tab

Block Parameters: CMOS XOR					×
CMOS XOR					
The block implements a simplified model parameters for the supply voltage used				t low and Output l	high
Parameters					
Inputs Outputs					1
Low level output voltage:	0			V	.
High level output voltage:	5			V	-
Output resistance:	450			Ohm	_
Propagation delay:	1.2e-07			s	•
		ОК	Cancel	Help	Apply

Low level output voltage

Voltage value at the output when the output logic level is LOW. The default value is 0 V.

High level output voltage

Voltage value at the output when the output logic level is HIGH. The default value is 5 V.

Output resistance

Value of the series output resistor that is used to model the drop in output voltage resulting from the output current. The default value is 450 Ω . You can derive this value from a datasheet by

	dividing the high-level output voltage by the maximum low-level output current.
	Propagation delay Time it takes for the output to swing from LOW to HIGH or HIGH to LOW after the input logic levels change. The default value is 1.2e-07 s.
Ports	The block has the following ports:
	A Electrical input port.
	B Electrical input port.
	J Electrical output port.

Controlled PWM Voltage

Purpose Model pulse-width modulated voltage source

Library Actuators & Drivers

Description

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

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

where:

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

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

At time zero, the pulse is initialized as high, unless the duty cycle is set to zero.

The model is based on the following assumptions:

- The REF output of this block is floating, i.e. it is not tied to the Electrical Reference. One consequence of this is that if you connect the PWM and REF electrical ports directly to the H-Bridge PWM and REF electrical ports, you must attach an Electrical Reference block to the REF connection line.
- Do not use the Controlled PWM block to drive a motor block directly. A PWM motor driver goes open circuit in between pulses. Use the H-Bridge block to drive a motor block.
- Set the **Simulation mode** parameter to Averaged to speed up simulations when driving a motor via the H-Bridge block. You must also set the **Simulation mode** parameter of the H-Bridge block to Averaged mode. This applies the average of the demanded

Basic Assumptions and Limitations PWM voltage to the motor. The Averaged mode assumes that the impedance of the motor inductive term is small at the **PWM frequency**. To verify this assumption, run the simulation using the PWM mode and compare the results to those obtained from using the Averaged mode.

Dialog Box and Parameters

and Vmax are the minin	ends on the reference voltage Vref percent is given by 100*(Vref-Vmir num and maximum values for Vref. 1 Output voltage amplitude.	n)/(Vmax-Vmin) where Vmin
At time zero, the pulse	is initialized as high (unless the duty	· cycle is set to zero).
	n be set to PWM or Averaged. In P ed mode, the output is constant wit	· · · ·
PWM frequency:	1000	Hz
Input value Vmin for 0% duty cycle:	0	V
Input value Vmax for 100% duty cycle:	5	V
Output voltage amplitude:	5	V
Simulation mode:	PWM	▼

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 M	odel constant current source
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Library SPICE-Compatible Sources

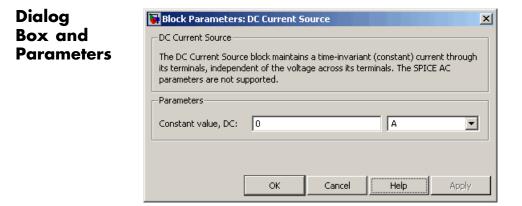
Description

DC Current Source

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

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

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



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

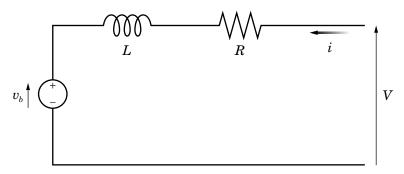
Purpose Model electrical and torque characteristics of DC motor

Library Actuators & Drivers

Description

DC Motor

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



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

$$v_b = k_v \omega$$

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

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

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

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

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

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

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

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

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

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

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_i .

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

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

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

DC Motor

Dialog Box and Parameters

Electrical	Torque	Tab
------------	--------	-----

DC Motor	C Motor		
This block represents the	e electrical and torque characteristic	s of a DC motor.	
torque constants have t either be specified direct	no electromagnetic energy is lost, a he same numerical value when in SI ily, or derived from no-load speed a inductance, this parameter can be s	units. Motor parameter and stall torque. If no in	rs can formation
	flows from the electrical + to - port Motor torque direction can be char tants.		
Parameters			
Electrical Torque	Mechanical		
Model parameterization:	By equivalent circuit parameters		•
Armature resistance:	3.9	Ohm	•
Armature resistance: Armature inductance:	1	Ohm H	•
	1		•
Armature inductance: Define back-emf or	1.2e-05		•
Armature inductance: Define back-emf or torque constant:	1.2e-05 Specify back-emf constant	Н	• •
Armature inductance: Define back-emf or torque constant:	1.2e-05 Specify back-emf constant	Н	•

Model parameterization

Select one of the following methods for block parameterization:

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

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

Armature resistance

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

Armature inductance

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

Define back-emf or torque constant

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

Back-emf constant

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

Torque constant

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

Stall torque

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

No-load speed

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

Rated speed (at rated load)

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

Rated load (mechanical power)

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

Rated DC supply voltage

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

Mechanical Tab

Block Parameters: DC Motor				
DC Motor				
This block represents the electrical and torque characteristics of a DC motor.				
The block assumes that no electromagnetic energy is lost, and hence the back-emf and torque constants have the same numerical value when in SI units. Motor parameters can either be specified directly, or derived from no-load speed and stall torque. If no information is available on armature inductance, this parameter can be set to some small non-zero value. When a positive current flows from the electrical + to - ports, a positive torque acts from the mechanical C to R ports. Motor torque direction can be changed by altering the sign of the back-emf or torque constants.				
Parameters				
	chanical	1		
Rotor inertia:	0.01	g*cm^2 ▼		
Rotor damping:	1e-08	N*m/(rad/s)		
Initial rotor speed:	0	rpm 💌		
	OK Cancel	Help Apply		

Rotor inertia

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

Rotor damping

Energy dissipated by the rotor. The default value is 1e-08 N*m/(rad/s). The value can be zero.

	Initial rotor speed Speed of the rotor at the start of the simulation. The default value is 0 rpm.
Ports	The block has the following ports:
	+ Positive electrical input.
	- Negative electrical input.
	C Mechanical rotational conserving port.
	R Mechanical rotational conserving port.
Examples	See the following demos:
	Linear Electrical Actuator (Motor Model)
	• Linear Electrical Actuator (System-Level Model)
	Linear Electrical Actuator (Implementation Model)
References	[1] Bolton, W. Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 3rd edition Pearson Education, 2004.
See Also	Induction Motor, Servomotor, Shunt Motor, and Universal Motor.

Purpose	Model constant voltage source
---------	-------------------------------

Library SPICE-Compatible Sources

Description

DC Voltage Source

The DC Voltage Source block represents a constant voltage source whose output voltage value is independent of the current through the source.

Dialog Box and Parameters

DC Voltage Source The DC Voltage Source its output terminals, in parameters are not su	e block maintair ndependent of t	ns a time-invari		
Parameters Constant value, DC:	0		V	T
	ОК	Cancel	Help	Apply

Constant value, DC

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

Ports The block has the following ports:

+

Positive electrical voltage.

Negative electrical voltage.

DC Voltage Source

See Also DC Current Source

Model piecewise linear, piecewise linear zener, or exponential diode
Semiconductor Devices
The Diode block represents one of the following types of diodes:
 "Piecewise Linear" on page 2-49 "Piecewise Linear Zener" on page 2-49

• "Exponential" on page 2-50

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:

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

where:

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

When $\frac{qV}{NkT} > 40$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} - 39\right)e^{40}$, which matches the gradient of the diode current at qV/(NkT) = 40 and extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

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

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

where:

- $V_t = kT / q$.
- V₁ and V₂ are the values in the Voltages [V1 V2] vector.
- I_1 and I_2 are the values in the **Currents** [I1 I2] vector.

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

- When you select Include fixed or zero junction capacitance for the **Junction capacitance** parameter, the capacitance is fixed.
- When you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter, the block uses the coefficients CJO, VJ, M, and FC to calculate a junction capacitance that depends on the junction voltage.
- When you select Use C-V curve data points for the Junction capacitance parameter, the block uses three capacitance values on the C-V capacitance curve to estimate CJO, VJ, and M and uses these values with the specified value of FC to calculate a junction capacitance that depends on the junction voltage. The block calculates CJO, VJ, and M as follows:

-
$$CJ0 = C_1((V_{R2} - V_{R1})/(V_{R2} - V_{R1}(C_2/C_1)^{-1/M}))^M$$

•
$$VJ = -(-V_{R2}(C_1/C_2)^{-1/M} + V_{R1})/(1 - (C_1/C_2)^{-1/M})$$

- $M = \log(C_3 / C_2) / \log(V_{R2} / V_{R3})$ where:
- V_{R1}, V_{R2}, and V_{R3} are the values in the Reverse bias voltages [VR1 VR2 VR3] vector.
- C₁, C₂, and C₃ are the values in the Corresponding capacitances
 [C1 C2 C3] vector.

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

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

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

• For $V < FC \times VJ$:

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

• For $V \ge FC \times VJ$:

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

where:

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

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

The Exponential diode model has the following limitations:

Basic Assumptions and Limitations

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

Diode

Dialog Box and Parameters

Main Tab

🙀 Block Parameters: I	Diode			×
Diode				
This block represents a following model types:	diode. Use th	e Diode model	parameter to sele	ct one of the
[1] Piecewise Linear Dio Foundation Library.	 Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library. 			
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage V2. For voltages below V2 the diode breaks down with a low corresponding Zener Resistance R2.				
[3] Exponential Diode, I Is*(exp(V/(N*Vt))-1) w N is the emission coeffic constant, T is the absol charge on an electron. Parameters	here Is is the tient (>=1). V	Saturation curr 't is given by Vt	ent, Vt is the ther = k*T/e where k	rmal voltage, and is Boltzmann's
Main Reverse Bre	eakdown 📔 i	Ohmic Resistar	ce Junction C	Capacitance
Diode model:	Piecewise L	inear (Foundat	ion Library)	_
Forward voltage:	0.6		٧	
On resistance:	0.3 Ohm 💌			
Off conductance:	1e-08		5	
	ОК	Cance	el Help	Apply

Diode model

Select one of the following diode models:

• Piecewise Linear (Foundation Library) — Use a piecewise linear model for the diode, as described in "Piecewise Linear" on page 2-49. 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 2-49.
- Exponential Use a standard exponential model for the diode, as described in "Exponential" on page 2-50.

Forward voltage

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

On resistance

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

Off conductance

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

Parameterization

Select one of the following methods for model parameterization:

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

Currents [I1 I2]

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

Parameterization parameter. The default value is [0.07 1.5] A.

Voltages [V1 V2]

A vector of the voltage values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Exponential for the **Diode model** parameter and Use I-V curve data points for the **Parameterization** parameter. The default value is [0.7 0.8] V.

Saturation current IS

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

Measurement temperature

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

Emission coefficient N

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

Reverse Breakdown Tab

🙀 Block Parameters: Diode 🛛 🗙			
Diode			
This block represents a diode. Use the Diode model parameter to select one of the following model types:			
 Piecewise Linear Diode. This option invokes the diode model from the Simscape Foundation Library. 			
[2] Piecewise Linear Zener Diode (i.e. piecewise linear diode with reverse breakdown characteristics). This model is identical to the Piecewise Linear Diode for reverse voltages above the Reverse Breakdown Voltage Vz. For voltages below Vz the diode breaks down with a low corresponding Zener Resistance Rz.			
[3] Exponential Diode. Uses the standard exponential diode equation I = Is*(exp(V/(N*Vt))-1) where Is is the Saturation current, Vt is the thermal voltage, and N is the emission coefficient (>=1). Vt is given by Vt = $k*T/e$ where k is Boltzmann's constant, T is the absolute Temperature of the p-n junction, and e is the magnitude of charge on an electron.			
Parameters			
Main Reverse Breakdown Ohmic Resistance Junction Capacitance			
Zener resistance Rz: 0.3 Ohm			
voltage V2:			
OK Cancel Help Apply			

Zener resistance Rz

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

Reverse breakdown voltage Vz

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

Reverse breakdown voltage BV

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

Ohmic Resistance Tab

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

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 0.01Ω .

Junction Capacitance Tab

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

Junction capacitance

- When you select Piecewise Linear (Foundation Library) or Piecewise Linear Zener for the **Diode model** parameter, the **Junction capacitance** parameter is the fixed junction capacitance value. The default value is 5 pF.
- When you select Exponential for the **Diode model** parameter, the **Junction capacitance** parameter lets you select one of the following options for modeling the junction capacitance:
 - Include fixed or zero junction capacitance Model the junction capacitance as a fixed value.
 - Use C-V curve data points Specify measured data at three points on the diode C-V curve.
 - Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

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

Reverse bias voltages [VR1 VR2 VR3]

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

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate 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. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.		
	[2] G. Massobrio and P. Antognetti. Semiconductor Device Modeling		

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

Diode

See Also Simscape Diode, Diode (SPICE)

Purpose	Model SPICE-compatible diode
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Library SPICE-Compatible Semiconductors

Description 1

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Diode

The Diode block represents a SPICE-compatible diode.

The Diode block model includes the following components:

- "Current-Voltage Model" on page 2-63
- "Junction Charge Model" on page 2-65
- "Temperature Dependence" on page 2-66

Current-Voltage Model

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

Applicable Range of V _d Values	Corresponding I _d Equation
$V_d > 80 * V_t$	$I_d = IS\left(\left(\frac{V_d}{V_t} - 79\right)e^{80} - 1\right) + V_d * G \min$
$80 * V_t \ge V_d \ge -3 * V_t$	$I_d = IS * (e^{V_d/V_t} - 1) + V_d * G \min$

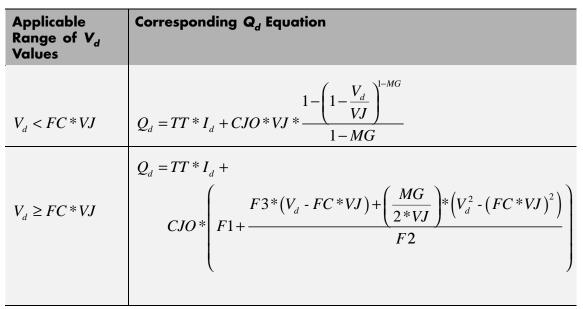
Applicable Range of V _d Values	Corresponding I _d Equation
$-3*V_t > V_d \ge -BV$	$I_{d} = -IS\left(1 + \frac{27}{(V_{d} / V_{t})^{3} e^{3}}\right) + V_{d} * G \min$
$V_d < -BV$	
	$I_{d} = -IBV * (e^{(-(BV+V_{d})/V_{t}} - 1) - IS * \left(1 - \left(\frac{3}{e^{*}BV}\right) - \frac{3}{V_{t}}\right)$
Where:	

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

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

Junction Charge Model

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



Where:

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

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

Temperature Dependence

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

• When you select Device temperature for the Model temperature dependence using parameter, the diode temperature is

$$T = T_C + T_O$$

where:

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

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

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

where:

- IS is the Transport saturation current, IS parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.
- *XTI* is the **Saturation current temperature exponent**, **XTI** parameter value.
- ND is the Emission coefficient, ND parameter value.
- *EG* is the **Activation energy**, **EG** parameter value.
- $V_t = kT/q$.

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

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

where:

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

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

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

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

Diode (SPICE)

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

Diode (SPICE)

Dialog Box and Parameters

 	Tab
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as instance parameters on parameters KF and AF are i	SPICE diode. You specify both model o this mask. The instance parameter OF not supported. Additional instance par	F and the noise model	
TOFFSET.			
	allel diode instances for this device. So directly. This differs from the AREA pa and IBV, and divides RS.		
	erature to a fixed temperature or to t	he circuit temperature (i	fron
the Custom Electrical Enviro	onment block) plus TOFFSET.		
The block lets you include o	r exclude capacitance modeling, initial	conditions and reverse	
	apacitance modeling uses the publishe		
	an SPICE for capacitance. The initial ic	condition VO is the volta	ge -
		ation conscitones is pro-	
across the internal diode ju	nction, so it is only effective when jun is not adjusted as a function of the br		
across the internal diode ju The breakdown voltage BV	nction, so it is only effective when jun		
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across the internal diode ju The breakdown voltage BV Parameters Main Junction Capac Device area, AREA: Number of parallel devices, SCALE: Saturation current, IS: Ohmic resistance, RS:	nction, so it is only effective when jun is not adjusted as a function of the br itance Reverse Breakdown Te 1 1 1e-14 0	mperature m^2	
across the internal diode ju The breakdown voltage BV Parameters Main Junction Capac Device area, AREA: Number of parallel devices, SCALE: Saturation current, IS:	nction, so it is only effective when jun is not adjusted as a function of the br itance Reverse Breakdown Te 1 1 1e-14 0	mperature m^2	
across the internal diode ju The breakdown voltage BV Parameters Main Junction Capac Device area, AREA: Number of parallel devices, SCALE: Saturation current, IS: Ohmic resistance, RS:	nction, so it is only effective when jun is not adjusted as a function of the br itance Reverse Breakdown Te 1 1 1e-14 0	mperature m^2	

Device area, AREA

The diode area. This value multiplies the **Saturation current**, **IS**, **Zero-bias junction capacitance CJ0**, and **Reverse breakdown current**, **IBV** parameter values. It divides the

Ohmic resistance, RS parameter value. The default value is $1 m^2$. The value must be greater than 0.

Number of parallel devices, SCALE

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

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Ohmic resistance, RS

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

Emission coefficient, ND

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

Junction Capacitance Tab

вюск ра	arameters: Diode	
Diode ——		
as instanc	el approximates a SPICE diode. You specify both model card and instance param ce parameters on this mask. The instance parameter OFF and the noise model rrs KF and AF are not supported. Additional instance parameters are SCALE and	
urrent ar	the number of parallel diode instances for this device. SCALE multiplies the outp nd device charge directly. This differs from the AREA parameter, which multiple rrameters IS, CJO and IBV, and divides RS.	
	et the diode temperature to a fixed temperature or to the circuit temperature (om Electrical Environment block) plus TOFFSET.	(from
oreakdow a slightly (lets you include or exclude capacitance modeling, initial conditions and reverse in modeling. The capacitance modeling uses the published equations, which may different value than SPICE for capacitance. The initial condition VO is the volta e internal diode junction, so it is only effective when junction capacitance is pre	y yield age
The break	kdown voltage BV is not adjusted as a function of the breakdown current IBV.	
The break Parameter	kdown voltage BV is not adjusted as a function of the breakdown current IBV.	
	kdown voltage BV is not adjusted as a function of the breakdown current IBV.	
Parameter Main	kdown voltage BV is not adjusted as a function of the breakdown current IBV.	
Parameter Main	kdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature	
Parameter Main	kdown voltage BV is not adjusted as a function of the breakdown current IBV. rs Junction Capacitance Reverse Breakdown Temperature junction capacitance?: No	

Model junction capacitance

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

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient MG

The grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

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

Transit time, TT

The transit time of the minority carriers that cause diffusion capacitance. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 s. The value must be greater than or equal to 0.

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

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

Initial voltage V0

Diode voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Note The block applies the initial condition across the diode junction, so the initial condition is only effective when charge storage is included, i.e. when one or both of the **Zero-bias junction capacitance CJ0** and **Transit time, TT** parameters are greater than zero.

Reverse Breakdown Tab

🙀 Block Parameters: Diode	x
_ Diode	
This model approximates a SPICE diode. You specify both model card and instance paramet as instance parameters on this mask. The instance parameter OFF and the noise model parameters KF and AF are not supported. Additional instance parameters are SCALE and TOFFSET.	ers
SCALE is the number of parallel diode instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples t device parameters IS, CJO and IBV, and divides RS.	
You can set the diode temperature to a fixed temperature or to the circuit temperature (fro the Custom Electrical Environment block) plus TOFFSET.	m
The block lets you include or exclude capacitance modeling, initial conditions and reverse breakdown modeling. The capacitance modeling uses the published equations, which may y a slightly different value than SPICE for capacitance. The initial condition VO is the voltage across the internal diode junction, so it is only effective when junction capacitance is present The breakdown voltage BV is not adjusted as a function of the breakdown current IBV.	
-Parameters	
Main Junction Capacitance Reverse Breakdown Temperature	
Model reverse breakdown?: No]

Model reverse breakdown

Select one of the following options for modeling the diode reverse breakdown:

- No Don't model reverse breakdown. This is the default option.
- Yes Introduce a second exponential term to the diode I-V relationship, thereby modeling a rapid increase in conductance as the breakdown voltage is exceeded.

Reverse breakdown current, IBV

The diode current that corresponds to the **Reverse breakdown** voltage, BV value. This parameter is only visible when you select Yes for the **Model reverse breakdown** parameter. The default value is 0.001 A/m_{2} . The value must be greater than 0.

Note The Diode model does not use this parameter at this time.

Reverse breakdown voltage, BV

The voltage below which to model the rapid increase in conductance that occurs at diode breakdown. This parameter is only visible when you select Yes for the **Model reverse breakdown** parameter. The default value is Inf V. The value must be greater than or equal to 0.

Temperature Tab

France of the second se	sk. The instance parame ported. Additional insta	model card and instance pa eter OFF and the noise mo nce parameters are SCALE	del
France of the second se	sk. The instance parame ported. Additional insta	eter OFF and the noise mo	del
	de instances for this de		
meters IS, CJO and IB	. This differs from the A	vice. SCALE multiplies the REA parameter, which mul	
		or to the circuit temperati	ure (from
modeling. The capacita ferent value than SPIC nternal diode junction,	nce modeling uses the p E for capacitance. The so it is only effective wh	bublished equations, which initial condition VO is the v hen junction capacitance is	i may yield voltage s present.
	Reverse Breakdown	Temperature	
mperature dependence	Device temperatu	re	•
	3		
n energy, EG:	1.11	eV	•
	0	K	•
er extraction temperati	ure, 300.15	К	•
	Electrical Environment ets you include or exclue modeling. The capacita fferent value than SPIC internal diode junction, lown voltage BV is not a gunction Capacitance emperature dependence on current temperature at, XTI: on energy, EG: bcal circuit temperature, T:	Electrical Environment block) plus TOFFSET. At you include or exclude capacitance modeling frerent value than SPICE for capacitance. The internal diode junction, so it is only effective w lown voltage BV is not adjusted as a function of junction Capacitance Reverse Breakdown emperature dependence t, XTI: an energy, EG: 1.11 an energy, EG: an energy, EG: breakdown an energy and an energy are extraction temperature breakdown an energy are structure temperature breakdown an energy are structure temperature breakdown break	ats you include or exclude capacitance modeling, initial conditions and reverence modeling. The capacitance modeling uses the published equations, which fferent value than SPICE for capacitance. The initial condition VO is the value than SPICE for capacitance. The initial condition VO is the value published equations, so it is only effective when junction capacitance is lown voltage BV is not adjusted as a function of the breakdown current IE Junction Capacitance Reverse Breakdown Temperature generature dependence Device temperature on current temperature 3 it, XTI: 1.11 eV ocal circuit temperature, 0 K

Model temperature dependence using

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

- Device temperature Use the device temperature, which is the **Circuit temperature** parameter value (from the SPICE Environment Parameters block, if one exists in the circuit, or the default value for this block otherwise) plus the **Offset local circuit temperature**, **TOFFSET** parameter value.
- Fixed temperature Use a temperature that is independent of the circuit temperature to model temperature dependence.

Saturation current temperature exponent, XTI

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than 0.

Activation energy, EG

The diode activation energy. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Offset local circuit temperature, TOFFSET

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

Parameter extraction temperature, TMEAS

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

Fixed circuit temperature, TFIXED

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

Ports The block has the following ports:

Positive electrical voltage.

Negative electrical voltage.



+

_

Purpose Model exponential pulse current source

Library SPICE-Compatible Sources

Description

Exponential Current Source

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

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

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

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

where:

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

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

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

Dialog Box and Parameters

BIOCK Parameters: I	Exponential Current Source	
Exponential Current Sou	urce	
terminals, independent	t Source block maintains an exponer of the voltage across its terminals. T rough the exponential source as a fu	The following equations
Iout(0<=Time<=TDR)	= I1	
Iout(TDR <time<=tdf)< td=""><td>= I1+(I2-I1)*(1-exp(-(Time-TDR))</td><td>(TR))</td></time<=tdf)<>	= I1+(I2-I1)*(1-exp(-(Time-TDR))	(TR))
Iout(TDF <time) =="" i1+<br="">TDF)/TF))</time)>	-(I2-I1)*(1-exp(-(Time-TDR)/TR))+()	I1-I2)*(1-exp(-(Time-
delay. The default valu fall times are one nanos	: the fall time. TDR is the rise time de les for TR, TF and TDF differ from SF econd (1e-9), and the values of TR value for the fall delay time is zero. I s not used.	PICE. The default rise and and TF must be greater
Initial value, I1:	0	A
Pulse value, I2:	0	A
Rise delay time, TDR: 0		
Rise time, TR:	1e-09	
Rise time, TR: Fall delay time, TDF:	1e-09 0	
ŕ		5
Fall delay time, TDF:	0	s v

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

Exponential Voltage Source

Purpose Model exponential pulse voltage source

Library SPICE-Compatible Sources

Description

Exponential Voltage Source

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

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

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

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

where:

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

×

Dialog	Block Parameters	: Exponential Voltage Source	
Box and	Exponential Voltage S		
Parameters	The Exponential Volta terminals, independer	ge Source block maintains an exponen at of the current through its terminals, across the exponential source as a fun	The following equations
	Vout(0<=Time<=TDR	l) = V1	
	Vout(TDR <time<=td< th=""><th>F) = V1+(V2-V1)*(1-exp(-(Time-TDR</th><th>)/TR))</th></time<=td<>	F) = V1+(V2-V1)*(1-exp(-(Time-TDR)/TR))
	Vout(TDF <time) =="" v<br="">TDF)/TF))</time)>	1+(V2-V1)*(1-exp(-(Time-TDR)/TR))+	(V1-V2)*(1-exp(-(Time-
	delay. The default va fall times are one nan	is the fall time. TDR is the rise time de alues for TR, TF and TDF differ from Sf osecond (1e-9), and the values of TR It value for the fall delay time is zero. I e is not used.	PICE. The default rise and and TF must be greater
	Parameters		
	Initial value, V1:	0	V
	Pulse value, V2:	0	V
	Rise delay time, TDR:	0	s 💌
	Rise time, TR:	1e-09	5
	Fall delay time, TDF:	0	s 💌
	Fall time, TF:	1e-09	s 💌
		OK Cancel	Help Apply

Initial value, V1

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

Pulse value, V2

The asymptotic value of the output voltage when the output is high. The default value is $0\ \mathrm{V}.$

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

Purpose Model gain-limited operational amplifier

Library

Integrated Circuits

Description



Finite Gain Op-Amp

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

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

where:

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

The input current is:

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

where R_{in} is the input resistance.

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

Dialog Box and Parameters

are denoted Vp and Vm, the where A is the gain, Rout is I input current is given by (Vp-	e Gain Op-Amp ted op-amp. If the voltages at the positive an n the output voltage is given by Vout = A*{V the output resistance and lout is the output of Vm}/Rin where Rin is the input resistance. T num and maximum values Vmin and Vmax.	p-Vm)-lout*Rout current. The
Parameters		
Gain, A:	1000	
Input resistance, Rin:	1e+06	Ohm 💌
Output resistance, Rout:	100	Ohm 💌
Minimum output, Vmin:	-15	V
Maximum output, Vmax:	15	V
	OK Cancel Help	

Gain, A

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

Input resistance, Rin

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

Output resistance, Rout

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

	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

Fuse

Purpose	Model fuse tha	t protects against	excessive current
---------	----------------	--------------------	-------------------

Library Passive Devices

Description

• - - - • Fuse

Dialog Box and Parameters

The block represents a fuse. The fu where T is the Time to fuse parame		nt through it excee	ds the Rated cur	rrent for more t	than T seconds,
The Fuse resistance R and Open-ci	rcuit conductance G r	nust be greater tha	in zero.		
Parameters					
Rated current:	1			A	•
Time to fuse:	0			S	•
Fuse resistance R:	0.01			0	hm 💌
Open-circuit conductance G:	1e-08			1/	Ohm 💌

The Fuse block breaks the circuit in which it is connected. It does so when the current through the device exceeds the rated current at which

the fuse is designed to blow and continues to exceed it for a specified

Rated current

amount of time.

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

Time to fuse

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

Fuse resistance R

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

Open-circuit conductance G

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

Ports The block has the following ports:

+

-

Positive electrical port.

Negative electrical port.

Generic Battery

Purpose Model simple battery

Library Sources

Description

Generic Battery

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

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

where:

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

Dialog Box and Parameters

🙀 Block Parameters: Gene	ric Batte	ary 👘				×
Generic Battery						
This block models a generic I parameter, the block models source. If you select Finite for the battery as a series resisto	the battery r the Batte	, v as a series re: ry charge capa	sistor and a	a constar neter, the	nt voltage block mo	odels
V = V_nominal*(1 - alpha*(1-x	:)/(1-beta*((1-x)))				
where x = (Ampere-Hours ren are calculated to satisfy a use charge.						
Parameters						
Nominal voltage, V_nominal:	12				V	•
Internal resistance, R1:	2				Ohm	•
Battery charge capacity:	Infinite					•
	OK	Cancel		Help]A	oply

Nominal voltage, V_nominal

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

Internal resistance, R1

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

Battery charge capacity

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

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

Ampere-Hour rating, AH

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

Initial charge

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

Voltage V1 < V_nominal when charge is AH1

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

Charge AH1 when no-load volts are V1

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

Self-discharge resistance, R2

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

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

$\mathbf{R2}$

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

Ports The block has the following ports:

	+ Positive electrical voltage.
	- Negative electrical voltage.
See Also	Simscape DC Voltage Source, Simscape Controlled Voltage Source

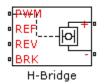
H-Bridge

Purpose Model H-bridge motor driver
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Library

Actuators & Drivers

Description



The H-Bridge block represents an H-bridge motor driver. The block has the following two **Simulation mode** options:

- PWM The H-Bridge output is a controlled voltage that depends on the input signal at the PWM port. If the input signal has a value greater than the **Enable threshold voltage** parameter value, the H-Bridge output is on and has a value equal to the value of the **Output voltage amplitude** parameter. If it has a value less than the **Enable threshold voltage** parameter value, the block maintains the load circuit using a freewheeling diode and one of the bridge switching devices. 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

$$\frac{V_O V_{PWM}}{A_{PWM}} - I_{OUT} R_{ON}$$

where:

- V₀ is the value of the **Output voltage amplitude** parameter.
- V_{PWM} is the value of the voltage at the PWM port.
- *A_{PWM}* is the value of the **PWM signal amplitude** parameter.
- I_{OUT} is the value of the output current.
- R_{ON} is the **Bridge on resistance** parameter.

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.

H-Bridge

Dialog Box and Parameters

·	n H-bridge motor driver.	
PWM mode, the motor threshold voltage. In A	s powered if the PWM port veraged mode, the output v	PWM or Averaged mode. In voltage V is above the Enable voltage magnitude is proportional hen V is equal to the parameter
output voltage polarity		e threshold voltage, then the : voltage is greater than the Is are short circuited.
Voltages at ports PWM,	REV and BRK are defined re	elative to the REF port.
Parameters		
Enable threshold voltage:	2.5	V 💌
PWM signal amplitude:	5	V 💌
Reverse threshold voltage:	2.5	V .
Braking threshold voltage:	2.5	V 💌
Output voltage amplitude:	12	V .
Simulation mode:	PWM	▼
Bridge on resistance:	0.1	Ohm 💌
Freewheeling diode on resistance:	0.1	Ohm

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 H-Bridge block assumes synchronous bridge operation where the load is connected via one of the freewheeling diodes and one of the bridge switching devices. To use a second bridge switching device instead of the freewheeling diodes, set the **Freewheeling diode on resistance** value on resistance to half of the **Bridge on resistance** value. The default value is 0.1Ω .

Freewheeling diode on resistance

The total resistance in the freewheeling diodes that dissipate the current that flows through the motor when the voltage at the PWM port is less than the **Enable threshold voltage**. The default value is 0.1Ω .

H-Bridge

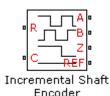
Ports	The block has the following ports:
	+ref Positive electrical output voltage.
	- ref Negative electrical output voltage.
	PWM Pulse-width modulated signal. The voltage is defined relative to the REF port.
	REF Floating zero volt reference.
	REV Voltage that controls when to reverse the polarity 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.

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

Library

Sensors

Description



The Incremental Shaft Encoder block represents a device that converts information about the angular position of a shaft into electrical pulses. The block produces N pulses on ports A and B per shaft revolution, where N is the value you specify for the **Pulses per revolution** parameter. Pulses A and B are 90 degrees out of phase. If the shaft rotates in a positive direction, then A leads B. The block produces a single index pulse on port Z once per revolution. The Z pulse positive transition always coincides with an A pulse positive transition. The voltages at output ports A, B, and Z are defined relative to the REF reference port voltage.

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

The Incremental Shaft Encoder block has the following limitations:

• 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.

Basic Assumptions and Limitations

Dialog Box and Parameters

🙀 Block Parameters: Increme	ntal Shaft Enco	oder		×
Incremental Shaft Encoder This block represents an incremer per shaft revolution, where N is t Pulses A and B are 90 degrees ou leads B. The block produces a sin positive transition always coincide	he value you spe ut of phase. If th gle index pulse o	ecify for the Pul e shaft rotates n output Z once	ses per revolution in a positive direct per revolution.	n parameter. ttion, then A The Z pulse
and Z are defined relative to the				
Pulses per revolution:	2			
Output voltage amplitude:	5		V	_
Index pulse offset relative to sha angle:	aft initial 0		deg	•
			(
	ОК	Cancel	Help	Apply

Pulses per revolution

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

Output voltage amplitude

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

Index pulse offset relative to shaft initial angle

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

Ports The block has the following ports:

R

Mechanical rotational conserving port associated with the sensor positive probe.

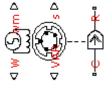
	С	Mechanical rotational conserving port associated with the sensor negative (reference) probe.
	A	Encoded electrical output.
	B Z	Encoded electrical output.
	2 REF	Index, or synchronization, electrical output.
		Floating zero volt reference.
See Also	Sims	cape Ideal Rotational Motion Sensor

Induction Motor

 Purpose
 Model induction motor powered by ideal AC supply

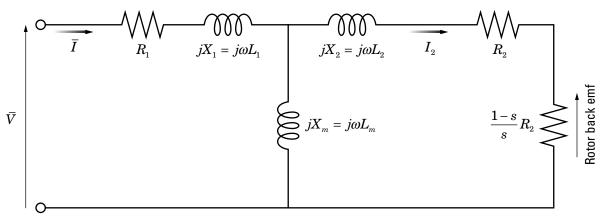
Library Actuators & Drivers

Description



Induction Motor

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



In the figure:

- R₁ is the stator resistance.
- R₂ is the rotor resistance with respect to the stator.
- L₁ is the stator inductance.
- L₂ is the rotor inductance with respect to the stator.

- L_m is magnetizing inductance.
- s is the rotor slip.
- \overline{V} and \overline{I} are the sinusoidal supply voltage and current phasors.

Rotor slip s is defined in terms of the mechanical rotational speed ω_m , the number of pole pairs p, and the electrical supply frequency ω by

$$s = 1 - \frac{p\omega_m}{\omega}$$

This means that the slip is one when starting, and zero when running synchronously with the supply frequency.

For an n-phase induction motor the torque-speed relationship is given by:

$$T = \frac{npR_2}{s\omega} \frac{V_{rms}^2}{\left(R_1 + R_2 + \frac{1 - s}{s}R_2\right)^2 + \left(X_1 + X_2\right)^2}$$

where:

- V_{rms} is the line-neutral supply voltage for a star-configuration induction motor, and the line-to-line voltage for a delta-configuration induction motor.
- *n* is the number of phases.

You can parameterize this block in terms of the preceding equivalent circuit model parameters or in terms of the motor ratings the block uses to derive these parameters.

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

Induction Motor

Basic	The model is based on the following assumptions:
Assumptions and Limitations	• The block does not model the starting mechanism for a single-phase induction motor.
	• When you parameterize the block by motor ratings, the block derives the equivalent circuit model parameters by assuming that the magnetizing inductance L_m is very large compared to L_1 and L_2 .

Induction Motor

Dialog Box and Parameters

Electrical Torque Tab

× 🙀 Block Parameters: Induction Motor Induction Motor This block represents the electrical and torque characteristics of an induction motor powered by an ideal AC supply. The block may be parameterized via motor ratings or equivalent circuit parameters expressed with respect to the stator. Physical signal outputs are provided for slip (s), real power (W), imaginary power (VAR) and mechanical speed (wm). If used to model a singlephase induction motor, then the effect of the starting mechanism (e.g. shaded-pole) is not modeled. The block produces a positive torque acting from the mechanical C to R ports. -Parameters Electrical Torque Power Supply Mechanical By motor ratings • Model parameterization: 0.5 • Magnetizing inductance Lm: н 825 W • Rated mechanical power: • Rated speed: 3.5e+03 rpm Rated RMS line-to-line voltage: 200 ۷ • 60 ٠ Rated supply frequency: Hz Rated RMS line current: 2.7 A • Ŧ L1+L2 parameterization: From starting current RMS starting (or locked rotor) line 7.5 A • current: -From motor efficiency R1 parameterization: 95 Motor efficiency (percent): 1 Number of pole pairs: Number of phases: 3 Star configuration Ŧ Stator connections: ОK Cancel Help Apply

Model parameterization

Select one of the following methods for block parameterization:

- By motor ratings Provide electrical torque parameters that the block converts to an equivalent circuit model of the motor assuming that the magnetizing inductance is very large compared to L_1 and L_2 . This is the default method.
- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor.

Stator resistance R1

Resistance of the stator winding. The default value is 1 Ω . This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Rotor resistance R2

Resistance of the rotor, specified with respect to the stator. The default value is 1 Ω . This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Stator inductance L1

Inductance of the stator winding. The default value is 0.02 H. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Rotor inductance L2

Inductance of the rotor, specified with respect to the stator. The default value is 0.02 H. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter.

Magnetizing inductance Lm

Magnetizing inductance of the stator. Its value is hard to estimate from motor parameters, but the effect is usually small. If you do not know its value, use a typical value of 25 times the **Stator inductance L1** value. The default value is 0.5 H.

Rated mechanical power

Mechanical power the motor delivers when running at the rated speed. The default value is 825 W. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated speed

Speed at which the motor delivers the specified **Rated mechanical power** value. The default value is 3.5e+03 rpm. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated RMS line-to-line voltage

Line-to-line voltage at which the motor ratings are specified. The default value is 200 V. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated supply frequency

Frequency of the AC supply voltage at which the motor ratings are specified. The default value is 60 hertz. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Rated RMS line current

Line current at which the motor delivers the specified **Rated mechanical power** value. The default value is 2.7 A. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

L1+L2 parameterization

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

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

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

RMS starting (or locked rotor) line current

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

Maximum torque

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

R1 parameterization

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

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

• Use measured stator resistance R1 — Measure R_1 directly. This parameter is only visible when you select By motor ratings for the **Model parameterization** parameter.

Motor efficiency (percent)

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

Motor power factor

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

Measured stator resistance R1

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

Number of pole pairs

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

Number of phases

Number of supply phases. The default value is 3.

Stator connections

Select one of the following motor configurations:

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

Power Supply Tab

Block Parameters	: Induction	Motor				
Induction Motor						
This block represents i an ideal AC supply. Th parameters expressed real power (W), imagin phase induction motor modeled. The block produces a	ne block may d with respect nary power (r, then the e	be paramete t to the state (VAR) and me ffect of the s	rized via m or. Physica chanical sp tarting me	notor rating I signal out; beed (wm). chanism (e.	s or equivaler puts are prov If used to mo g. shaded-po	nt circuit ided for slip (s), odel a single-
Parameters						
Electrical Torque	Power Sup	ply Mech	anical			
Supply RMS line-to- voltage:	-line 20	0			V	•
Supply frequency:	60				Hz	-

Supply RMS line-to-line voltage

The line-to-line voltage that supplies the motor. The default value is $200\ \mathrm{V}.$

Supply frequency

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

Mechanical Tab

Block Parameters: Induc	tion Motor	
Induction Motor		
an ideal AC supply. The block parameters expressed with m real power (W), imaginary po phase induction motor, then I modeled. The block produces a positive	ctrical and torque characteristics of may be parameterized via motor r espect to the stator. Physical signa wer (VAR) and mechanical speed (the effect of the starting mechanical e torque acting from the mechanical	atings or equivalent circuit I outputs are provided for slip (s), wm). If used to model a single- m (e.g. shaded-pole) is not
Parameters		
Electrical Torque Powe	r Supply Mechanical	
Rotor inertia:	0.001	kg*m^2 ▼
Rotor damping:	1e-04	N*m/(rad/s)
Initial rotor speed:	0	rpm 💌

	 Rotor inertia Rotor inertia. The default value is 0.1 kg*m². 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.

Light-Emitting Diode

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

Library

Sensors

Description

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

Light-Emitting Diode p

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

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

where:

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

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

extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

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

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

where:

- $V_t = kT/q$
- V₁ and V₂ are the values in the Voltages [V1 V2] vector.
- I_1 and I_2 are the values in the **Currents** [I1 I2] vector.

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

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

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

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

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

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

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

• For $V < FC \times VJ$:

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

• For $V \ge FC \times VJ$:

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

where:

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

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

The Light-Emitting Diode block has the following limitations:

Basic Assumptions and Limitations

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

Dialog Box and Parameters

Main Tab

당 Block Parameters: I	ight-Emitting Diode	×
Light-Emitting Diode		
diode in series with a cu	light-emitting diode. Structurally rrent sensor. The optical power j ct of the current flowing through parameter.	presented at the signal port
Parameters Main Ohmic Resis	tance Junction Capacitance	
Optical power per unit current:	0.005	W/A
Parameterization:	Use I-V curve data points	
Currents [I1 I2]:	[0.0017 0.003]	A
Voltages [V1 V2]:	[0.9 1.05]	V
Measurement temperature:	25	C 💌
	OK Cancel	Help Apply

Optical power per unit current

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

Parameterization

Select one of the following methods for model parameterization:

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

 \bullet Use parameters IS and N- Specify saturation current and emission coefficient.

Currents [I1 I2]

A vector of the current values at the two points on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use I-V curve data points for the **Parameterization** parameter. The default value is [0.0017 0.003] A.

Voltages [V1 V2]

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

Saturation current IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. This parameter is only visible when you select Use parameters IS and N for the **Parameterization** parameter. The default value is 5e-05 A.

Measurement temperature

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

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Use parameters IS and N for the **Parameterization** parameter. The default value is 10.

Ohmic Resistance Tab

Block Parameters: Light-Emitting Diode	×
Light-Emitting Diode	
This block represents a light-emitting diode. Structurally it consists of an exponent diode in series with a current sensor. The optical power presented at the signal po W is equal to the product of the current flowing through the diode and the Optica power per unit current parameter.	ort
Parameters	
Main Ohmic Resistance Junction Capacitance	
Ohmic resistance RS: 0.1	
OK Cancel Help Appl	y

Ohmic resistance RS

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

Junction Capacitance Tab

🙀 Block Parameters: Light-Emitting Diode 🛛 🛛 🔀
Light-Emitting Diode
This block represents a light-emitting diode. Structurally it consists of an exponential diode in series with a current sensor. The optical power presented at the signal port W is equal to the product of the current flowing through the diode and the Optical power per unit current parameter.
Parameters
Main Ohmic Resistance Junction Capacitance
Junction capacitance: Fixed or zero junction capacitance Zero-bias junction capacitance CJ0: 20
OK Cancel Help Apply

Junction capacitance

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

- Fixed or zero junction capacitance Model the junction capacitance as a fixed value.
- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 20 pF.

Reverse bias voltages [VR1 VR2 VR3]

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

Corresponding capacitances [C1 C2 C3]

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

Junction potential VJ

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

Grading coefficient M

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

Capacitance coefficient FC

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

Ports The block has the following ports:

	W Optical output power.
	+ Electrical conserving port associated with the diode positive terminal.
	- Electrical conserving port associated with the diode negative terminal.
References	[1] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.
	[2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993.
See Also	Diode, Optocoupler, Photodiode

N-Channel IGBT

Model N-Channel IGBT

Library

Purpose

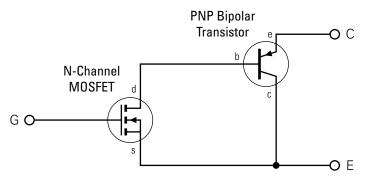
Semiconductor Devices

Description

The N-Channel IGBT block models a PNP Bipolar transistor driven by an N-Channel MOSFET, as shown in the following figure:



N-Channel IGBT



The MOSFET source is connected to the bipolar transistor collector, and the MOSFET drain is connected to the bipolar transistor base. The MOSFET uses the equations shown in the N-Channel MOSFET block reference page. The bipolar transistor uses the equations shown in the PNP Bipolar Transistor block reference page, but with the addition of an emission coefficient parameter N that scales kT/q.

The N-Channel IGBT block uses the on and off characteristics you specify in the block dialog box to estimate the parameter values for the underlying N-Channel MOSFET and PNP bipolar transistor.

- The block uses the off characteristics to calculate the base-emitter voltage, $V_{\rm be}$, and the saturation current, I_S
 - **1** When the transistor is off, the gate-emitter voltage is zero and the IGBT base-collector voltage is large, so the PNP base and collector current equations simplify to:

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

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

2 The block sets β_R and β_F to typical values of 1 and 50, so these two equations can be used to solve for V_{be} and I_S :

$$V_{be} = \frac{-NkT}{q} \log\left(1 + \frac{\beta_F}{\beta_R}\right)$$
$$I_s = \frac{I_c}{e^{-qV_{be}/(NkT)} + \frac{1}{\beta_R}}$$

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

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

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

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

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

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

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

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

3 When saturated, the MOSFET equation is:

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

where V_{th} is the **Gate-emitter threshold voltage Vge(th)** parameter value and $V_{GE(sat)}$ is the **Gate-emitter voltage for** {Vce(sat),Ice(sat)} parameter value.

 V_{ds} is related to the transistor voltages as $V_{ds} = V_{CE} - V_{be}$. The block substitutes this relationship for V_{ds} , sets the base-emitter voltage and base current to their saturated values, and rearranges the MOSFET equation to give

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

where $V_{CE(sat)}$ is the Collector-emitter saturation voltage Vce(sat) parameter value.

These calculations ensure the zero gate voltage collector current and collector-emitter saturation voltage are exactly met at these two specified conditions. However, the current-voltage plots are very sensitive to the emission coefficient N and the precise value of V_{th} . If the manufacturer datasheet gives current-voltage plots for different V_{GE} values, then the N and V_{th} can be tuned by hand to improve the match.

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

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

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

N-Channel IGBT

Dialog Box and Parameters

Main Tab

N-Channel IGBT This block represents an N-channel IC bipolar transistor plus an N-channel M			
datasheet parameters. It is assumed the bipolar forward Early voltage are infinit breakdown is not modeled.	hat both the MOSFET g	ate resistance and the	
Parameters			
Main Junction Capacitance			
Zero gate voltage collector current Ices:	2	mA 💌	
Gate-emitter threshold voltage Vge(th):	6	V	
Collector-emitter saturation voltage Vce(sat):	2.8	V	
Collector-emitter saturation current Ice(sat):	400	A	
Gate-emitter voltage for {Vce(sat),Ice(sat)}:	15	V	
Emission coefficient N:	1		
Measurement temperature:	25	C	

Zero gate voltage collector current Ices

The collector current that flows when the gate-emitter voltage is set to zero, and a large collector-emitter voltage is applied i.e. the device is in the off-state. The default value is 2 mA.

Gate-emitter threshold voltage Vge(th)

The threshold voltage used in the MOSFET equations. The default value is 6 V.

Collector-emitter saturation voltage Vce(sat)

The collector-emitter voltage for a typical on-state as specified by the manufacturer. The default value is 2.8 V.

Collector-emitter saturation current Ice(sat)

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

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

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

Emission coefficient N

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

Measurement temperature

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

Junction Capacitance Tab

Block Parameters: N-Channel IGBT					
N-Channel IGBT This block represents a bipolar transistor plus ar	N-channel MOSFET	whose paramet	ers are derived fr	om the IGBT	
datasheet parameters. I bipolar forward Early vo breakdown is not mode Parameters	ltage are infinite. Ther				
Main Junction Ca	apacitance	asheet			
Input capacitance Cies: Beverse transfer	26.4		nF		
capacitance Cres:	2.7		nF	_	
	ОК	Cancel	Help	Apply	

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:

С

Electrical conserving port associated with the PNP emitter terminal.

G

Electrical conserving port associated with the MOSFET gate terminal.

Е

Electrical conserving port associated with the PNP collector terminal.

N-Channel JFET

Model N-Channel JFET

Library

Purpose

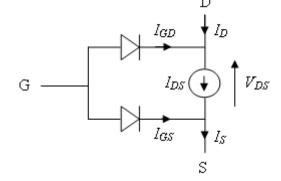
Semiconductor Devices

Description

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

N-Channel JFET



G is the transistor gate, D is the transistor drain and S is the transistor source. The drain-source current, I_{ds} , depends on the region of operation and whether the transistor is operating in normal or inverse mode.

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

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

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

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

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

In the preceding equations:

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

- V_{to} is the threshold voltage. If you select Specify using equation parameters directly for the **Parameterization** parameter, V_{to} is the **Threshold voltage** parameter value. Otherwise, the block calculates V_{to} from the datasheet parameters you specify.
- β is the transconductance parameter. If you select Specify using equation parameters directly for the **Parameterization** parameter, β is the **Transconductance parameter** parameter value. Otherwise, the block calculates β from the datasheet parameters you specify.
- λ is the channel-length modulation parameter. If you select Specify using equation parameters directly for the Parameterization parameter, λ is the Channel-length modulation parameter value. Otherwise, the block calculates λ from the datasheet parameters you specify.

The currents in each of the diodes satisfy the exponential diode equation

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

Where:

- I_S is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, I_S is the **Saturation current** parameter value. Otherwise, the block calculates I_S from the datasheet parameters you specify.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature. The value comes from the **Measurement** temperature parameter.

The block models gate junction capacitance as a fixed gate-drain capacitance C_{GD} and a fixed gate-source capacitance C_{GS} . If you select Specify using equation parameters directly for the **Parameterization** parameter, you specify these values directly using the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

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

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

N-Channel JFET

Dialog Box and Parameters

Main Tab

This block represents an N-Channel JFET. The drain current Id for positive Vds (normal operation) by:) is given
Id = 0 if ∀gs-∀t0 < 0 (off)	
Ids = B*Vds*(2*(Vgs - Vt0) - Vds)*(1+L*Vds) if 0 < Vds < Vgs - Vt0) (linear region)	
lds = B*(Vgs - Vt0)^2*(1+L*Vds) if 0 < Vgs - Vt0 < Vds (saturated region)	
where B is the Transconductance parameter, Vt0 is the Threshold voltage, L is the Channel-lengt modulation, Vgs is the gate-source voltage and Vds is the drain-source voltage.	h
Parameters	
Main Ohmic Resistance Junction Capacitance	1
Parameterization: Specify from a datasheet	•
Gate reverse current I_gss: 1 nA	•
Saturated drain current I_dss: 3 mA	-
I_dss measurement point [V_gs V_ds]: [0 15]	-
Small-signal parameters [g_fs g_os]: [3e+03 10] uS	-
Small-signal measurement point [V_gs [0 15] [V	
Measurement temperature: 25 C	-
OK Cancel Help	Apply

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to equations that describe the transistor. This is the default method.

• Specify using equation parameters directly — Provide equation parameters 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 $1e-04 \text{ A/V}^2$.

Saturation current

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

Measurement temperature

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

Threshold voltage

The gate-source voltage above which the transistor produces a nonzero drain current. For an enhancement device, Vt0 should be positive. For a depletion mode device, Vt0 should be negative. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is -2 V.

Channel-length modulation

The channel-length modulation. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 0 1/V.

Ohmic Resistance Tab

Block P	arameters: N-Chani	nel JFET				
N-Channe	el JFET					
This block	represents an N-Char	nnel JFET. The d	rain current Id f	or positive Vds (n	ormal operation	n) is given
Id = 0 if ۱	/gs-Vt0 < 0 (off)					
Ids = B*\	/ds*[2*(Vgs - Vt0) - Vd	s]*(1+ *Vds) if	0 < Vds < Vas -	Vt0] (linear regio	נחו	
		- · · ·				
	Vgs - Vt0)^2*(1+L*Vd					
	s the Transconductanc n, Vgs is the gate-sour				e Channel-lengt	:h
Paramete	rs	-		-		
Main	Ohmic Resistance	Junction Capa	citance			
		Jancaon Cape				
Source	ohmic resistance:	0.1			Ohm	-
Drain	ohmic resistance:	0.1			Ohm	-

Source ohmic resistance

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

Drain ohmic resistance

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

Junction Capacitance Tab

당 Block	Parameters: N-Chan	nel JFET					×
-N-Cha	nnel JFET						
This bl	ock represents an N-Char	nnel JFET. Ti	he drain current Id fo	r positive Vds (normal	operation) is giver	n by:	
Id = 0	if Vgs-Vt0 < 0 (off)						
Ids = f	3*Vds*[2*(Vqs - Vt0) - Vd	s]*(1+L*Vd	s) if 0 < Vds < Vqs - V	/t0] (linear region)			
Ids = F	3*(Vgs - Vt0)^2*(1+L*Vd	s) if 0 < Vas	- Vt0 < Vds (saturat	ed region)			
where	B is the Transconductanc	e parameter	, Vt0 is the Threshold		nnel-length modula	ation, Vgs is the	gate-source
voltag	e and Vds is the drain-sou	rce voltage.					
Param	eters						
Mair	Ohmic Resistance	Junction (Capacitance				1
Para	ameterization:		Specify from a data	sheet			-
Inn	ut capacitance Ciss:		4.5			pF	
Rev	erse transfer capacitance	2 Crss:	1.5			pF	•
				ОК	Cancel	Help	Apply

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to junction capacitance values. This is the default method.

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

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 4.5 pF.

Reverse transfer capacitance Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 1.5 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the Model junction capacitance parameter. The default value is 3 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction** capacitance parameter. The default value is 1.5 pF.

The block has the following ports:

G

Ports

Electrical conserving port associated with the transistor gate terminal.

D

Electrical conserving port associated with the transistor drain terminal.

S

Electrical conserving port associated with the transistor source terminal.

References	[1] H. Shichman and D. A. Hodges, <i>Modeling and simulation of insulated-gate field-effect transistor switching circuits</i> . IEEE J. Solid State Circuits, SC-3, 1968.			
	[2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2.			
See Also	P-Channel JFET			

Purpose Model N-Channel MOSFET using Shichman-Hodges equation

Semiconductor Devices

Description

Library



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:

N-Channel MOSFET

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

$$I_{DS} = 0$$

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

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

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

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

In the preceding equations:

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

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

Parameterization parameter in the **Junction Capacitance** tab, you specify these values directly using the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

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

Dialog Box and Parameters

Main Tab

🛃 Block Parameters: N	-Chan	nel MOSFET			
-N-Channel MOSFET					
This block represents an positive Vds is given by:	N-char	nnel MOSFET ((or IGFET). The a	drain-source curr	ent Ids for
Ids = 0 if Vgs < Vth (off)					
Ids = K*[(Vgs - Vth)*Vds	- Vds⁄	`2/2] if 0 < Vo	ds < Vgs - Vth] (li	inear region)	
$Ids = (K/2)^*(Vgs - Vth)^{\wedge}$	2 if 0 <	< Vgs - Vth < V	/ds (saturated re	egion)	
where K is a constant, VI Vds is the drain-source v			oltage, Vgs is the	e gate-source vo	ltage and
Parameters					
Main Ohmic Resist	ance	Junction C	apacitance		
Parameterization:	Spec	ify from a dat	asheet		_
Drain-source on resistance, R_DS(on):	0.02	5		Ohm	•
Drain current, Ids, for R_DS(on):	6			A	•
Gate-source voltage, Vgs, for R_DS(on):	10			٧	•
Gate-source threshold voltage Vth:	1.7			۷	•
		ОК	Cancel	Help	Apply

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide the drain-source on resistance and the corresponding drain current and gate-source voltage. The block calculates the transistor gain for the

Shichman and Hodges equations from this information. This is the default method.

• Specify using equation parameters directly — Provide the transistor gain.

Drain-source on resistance, R_DS(on)

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage. $R_{DS}(on)$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.025 Ω .

Drain current, Ids, for R_DS(on)

The drain current the block uses to calculate the value of the drain-source resistance. I_{DS} should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 6 A.

Gate-source voltage, Vgs, for R_DS(on)

The gate-source voltage the block uses to calculate the value of the drain-source resistance. V_{GS} should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 10 V.

Gain K

Positive constant gain coefficient for the Shichman and Hodges equations. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 5 A/V^2 .

Gate-source threshold voltage Vth

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

Ohmic Resistance Tab

5	Block Parameters: N-C	hannel MOSFET		×
	I-Channel MOSFET			
	his block represents an N- ositive Vds is given by:	channel MOSFET (or IGFET). The di	rain-source current Ids for	
I	ds = 0 if Vgs < Vth (off)			
I	ds = K*[(Vgs - Vth)*Vds - '	/ds^2/2] if 0 < Vds < Vgs - Vth] (lin	near region)	
I	ds = (K/2)*(Vgs - Vth)^2 ii	⁻ 0 < Vgs - Vth < Vds (saturated re	gion)	
	where K is a constant, Vth i 'ds is the drain-source volt	s the Threshold voltage, Vgs is the age.	gate-source voltage and	
P	arameters			51
	Main Ohmic Resistan	ce Junction Capacitance		
	Source ohmic resistance:	0.001	Ohm 💌	
	Drain ohmic resistance:	0.001	Ohm 💌	
		OK Cancel	Help Apply	

Source ohmic resistance

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

Drain ohmic resistance

The transistor drain resistance. The default value is $0.001~\Omega.$ The value must be greater than or equal to 0.

Junction Capacitance Tab

당 Block Parameters: N-Channel MOSFE	T	×
N-Channel MOSFET		
This block represents an N-channel MOSFET	(or IGFET). The drain-source current Ids for positive Vds is given by:	
Ids = 0 if Vgs < Vth (off)		
Ids = K*[(Vgs - Vth)*Vds - Vds^2/2] if 0 < V	/ds < Vgs - Vth] (linear region)	
Ids = (K/2)*(Vgs - Vth)^2 if 0 < Vgs - Vth <	Vds (saturated region)	
where K is a constant, Vth is the Threshold	voltage, Vgs is the gate-source voltage and Vds is the drain-source voltage.	
Parameters		
Main Ohmic Resistance Junction	Capacitance	
Parameterization:	Specify from a datasheet	_
Input capacitance Ciss:	350 pF	-
Reverse transfer capacitance Crss:	80 pF	
	OK Cancel Help	Apply

Parameterization

Select one of the following methods for capacitance parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a

	datasheet for the Parameterization parameter. The default value is 350 pF.
	Reverse transfer capacitance Crss The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the Parameterization parameter. The default value is 80 pF.
	Gate-source junction capacitance The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the Parameterization parameter. The default value is 270 pF.
	Gate-drain junction capacitance The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the Parameterization parameter. The default value is 80 pF.
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.

N-Channel MOSFET

See Also P-Channel MOSFET

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	🙀 Block Parameters: Negative Supply Rail	x
Box and Parameters	Negative Supply Rail This block represents an ideal negative supply rail. It can be used in place of the Foundation Library DC Voltage Source. The output voltage is defined relative to the Electrical Reference block. Use the Constant voltage parameter to specify the output voltage value which must be negative. Do not attach more than one Negative Supply Rail block to any connected line. Parameters	
	Constant voltage: -1 V 💌	1
	OK Cancel Help Apply	

	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

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 2-153
- "Gate-Drain Current-Voltage Model" on page 2-154
- "Drain-Source Current-Voltage Model" on page 2-155
- "Junction Charge Model" on page 2-156
- "Temperature Dependence" on page 2-158

Gate-Source Current-Voltage Model

The block provides the following relationship between the gate-source current $I_{\rm gs}$ and the gate-source voltage $V_{\rm gs}$ after adjusting the applicable model parameters for temperature.

Applicable Range of V _{gs} Values	Corresponding I _{gs} Equation
$V_{gs} > 80 * V_t$	$I_{gs} = IS * \left(\left(\frac{V_{gs}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{gs} * G \min$
$80 * V_t \ge V_{gs}$	$I_{gs} = IS * (e^{V_{gs}/V_{t}} - 1) + V_{gs} * G \min$

Where:

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

- *q* is the elementary charge on an electron.
- *k* is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Gate-Drain Current-Voltage Model

The block provides the following relationship between the gate-drain current I_{gd} and the gate-drain voltage V_{gd} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{gd} Values	Corresponding I _{gd} Equation
$V_{gd} > 80 * V_t$	$I_{gd} = IS * \left(\left(\frac{V_{gd}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{gd} * G \min$
$80 * V_t \ge V_{gd}$	$I_{gd} = IS * (e^{V_{gd}/V_t} - 1) + V_{gd} * G \min$

Drain-Source Current-Voltage Model

The block provides the following relationship between the drain-source

current I_{ds} and the drain-source voltage V_{ds} in normal mode ($V_{ds} \ge 0$) after adjusting the applicable model parameters for temperature.

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

Where:

- V_{to} is the **Threshold voltage**, **VTO** parameter value.
- β is the **Transconductance**, **BETA** parameter value.
- λ is the **Channel modulation**, **LAMBDA** parameter value.

The block provides the following relationship between the drain-source

current I_{ds} and the drain-source voltage V_{ds} in inverse mode ($V_{ds} < 0$) after adjusting the applicable model parameters for temperature.

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

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

Junction Charge Model

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

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

Where:

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

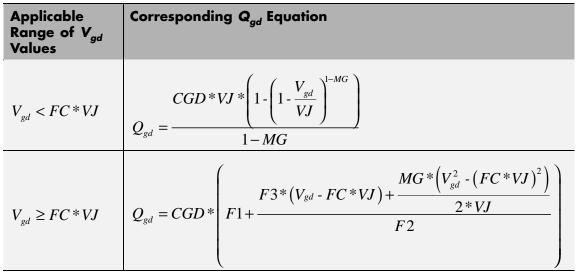
- CGS is the Zero-bias GS capacitance, CGS parameter value.
- *MG* is the **Grading coefficient**, **MG** parameter value.

•
$$F1 = \frac{VJ * (1 - (1 - FC)^{1-MG})}{1 - MG}$$

• $F2 = (1 - FC)^{1+MG}$

•
$$F3 = 1 - FC * (1 + MG)$$

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



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

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

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

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.

The model is based on the following assumptions:

Basic Assumptions and Limitations

- 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

parameters as instance para	PICE N-channel JFET. You specify meters on this mask. The instance ot supported. Additional instance EG.	e parameter OFF and noise r
current and device charge di	Illel JFET instances for this device irectly. This differs from the ARE/ CGS, CGD, and divides RS and F	A parameter, which multiples
•	ature to a fixed temperature or t ment block) plus TOFFSET. The p parameters.	
capacitance modeling uses the different value than SPICE for voltages across the internal voltages across the internal sectors across the inte	exclude capacitance modeling an he published temperature equatio or capacitance. The initial conditio junctions, and are only effective	ons, which may yield a slightly ons ICVDS and ICVGS are the
capacitances are present.		
Parameters		
Main Junction Capacit	ance Temperature	
Device area, AREA:	1	m^2
Number of parallel devices, SCALE:	1	
	-2	V
devices, SCALE: Threshold voltage, VTO: Transconductance,	1- -	
devices, SCALE: Threshold voltage, VTO:	-2	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation,	-2 1e-04	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA:	-2 1e-04 0	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS:	-2 1e-04 0 1e-14	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND:	-2 1e-04 0 1e-14	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS:	-2 1e-04 0 1e-14 1	A/m^2/V^2
devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS:	-2 1e-04 0 1e-14 1	A/m^2/V^2

Device area, AREA

The transistor area. This value multiplies the **Transconductance, BETA**, **Zero-bias GS capacitance, CGS**, **Zero-bias GD capacitance, CGD**, and **Saturation current, IS** parameter values. It divides the **Source resistance, RS** and **Drain resistance, RD** parameter values. The default value is 1 m². The value must be greater than 0.

Number of parallel devices, SCALE

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

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is -2 V.

Transconductance, **BETA**

The derivative of drain current with respect to gate voltage. The default value is $1e - 04 \text{ A/m}^2/\text{V}^2$. The value must be greater than or equal to 0.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Emission coefficient, ND

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

Source resistance, RS

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

Drain resistance, RD

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

Junction Capacitance Tab

NJFET	
This model approximates a SPICE N-channel JFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise mo parameters KF and AF are not supported. Additional instance parameters are SCALE, TOFFSET, ND, MG, XTI and EG.	de
SCALE is the number of parallel JFET instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples th device parameters BETA, IS, CGS, CGD, and divides RS and RD.	e
You can set the JFET temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters ND, MG, XTI and EC adjust temperature sensitive parameters.	
The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVDS and ICVGS are the voltages across the internal junctions, and are only effective when the corresponding juncti capacitances are present.	n
Parameters	
Main Junction Capacitance Temperature	
Model junction capacitance?: No	

Model junction capacitance

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

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias GS capacitance, CGS

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Zero-bias GD capacitance, CGD

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient, MG

The transistor grading coefficient. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

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

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

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

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Temperature Tab

Block Parameters: NJFET		
NJFET This model approximates a SPICE N-cha parameters as instance parameters on parameters KF and AF are not supports TOFFSET, ND, MG, XTI and EG.	this mask. The instance (parameter OFF and noise mod
SCALE is the number of parallel JFET in: current and device charge directly. This device parameters BETA, IS, CGS, CGD	s differs from the AREA p	arameter, which multiples the
You can set the JFET temperature to a the Custom Electrical Environment block adjust temperature sensitive paramete	k) plus TOFFSET. The par	
The block lets you include or exclude ca capacitance modeling uses the publishe different value than SPICE for capacita voltages across the internal junctions, capacitances are present.	ed temperature equations ance. The initial conditions	;, which may yield a slightly s ICVDS and ICVGS are the
Parameters		
	[emperature	
Model temperature dependence using: Saturation current temperature	Device temperature	
exponent, XTI: Activation energy, EG:	1.11	eV 🔻
Offset local circuit temperature, TOFFSET:	0	K V
Parameter extraction temperature, TMEAS:	300.15	К

Model temperature dependence using

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

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

Saturation current temperature exponent, XTI

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

Activation energy, EG

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

Offset local circuit temperature, TOFFSET

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

Fixed circuit temperature, TFIXED

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

Parameter extraction temperature, TMEAS

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

Ports	The block has the following ports:			
	G Electrical conserving port associated with the transistor gate terminal.			
	D Electrical conserving port associated with the transistor drain terminal.			
	S Electrical conserving port associated with the transistor source terminal.			
References	[1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 3.			
See Also	N-Channel JFET, PJFET			

NMOS

Purpose	Model SPICE-compatible N-Channel MOSFET
Library	SPICE-Compatible Semiconductors
Description ای ^۲	The NMOS block represents a SPICE-compatible N-channel MOSFET. The NMOS block model includes the following components:
יין <mark>לב"</mark> NMOS	 "Resistance Calculations" on page 2-170 "Bulk-Source Diode Model" on page 2-171
	• "Bulk-Drain Diode Model" on page 2-172

- "Drain Current Model" on page 2-173
- "Junction Charge Model" on page 2-176
- "Temperature Dependence" on page 2-181

Resistance Calculations

The following table shows how the NMOS block calculates the transistor drain resistance. The abbreviations in the table represent the values of the following block parameters:

- Drain resistance, RD
- Sheet resistance, RSH
- Number of drain squares, NRD

Drain resistance, RD Parameter	Sheet resistance, RSH Parameter	Drain Resistance
NaN	NaN	0
RD	NaN or RSH	RD
NaN	RSH	RSH*NRD

The following table shows how the NMOS block calculates the transistor source resistance. The abbreviations in the table represent the values of the following block parameters:

- Source resistance, RS
- Sheet resistance, RSH
- Number of source squares, NRS

Source resistance, RS Parameter	Sheet resistance, RSH Parameter	Source Resistance
NaN	NaN	0
RS	NaN or RSH	RS
NaN	RSH	RSH*NRS

Bulk-Source Diode Model

The block provides the following relationship between the bulk-source current I_{bs} and the bulk-source voltage V_{bs} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{bs} Values	Corresponding I _{gs} Equation
$V_{bs} > 80 * V_{tn}$	$I_{bs} = IS_{bs} * \left(\left(\frac{V_{bs}}{V_{tn}} - 79 \right) e^{80} - 1 \right) + V_{bs} * G \min$
$80V_{tn} \ge V_{bs}$	$I_{bs} = IS_{bs} * (e^{V_{bs}/V_{tn}} - 1) + V_{bs} * G \min$

Where:

- IS_{bs} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of source**, **AS** parameter value if both these

parameter values and the Area of drain, AD parameter value are nonzero.

- The Bulk saturation current, IS parameter value, otherwise.
- $V_{tn} = NkT/q$
- q is the elementary charge on an electron, 1.6021918e-19 C.
- *N* is the **Emission coefficient**, **ND** parameter value.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Bulk-Drain Diode Model

The block provides the following relationship between the bulk-drain current I_{bd} and the bulk-drain voltage V_{bd} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{bs} Values	Corresponding I _{gs} Equation
$V_{bd} > 80 * V_{tn}$	$I_{bd} = IS_{bd} * \left(\left(\frac{V_{bd}}{V_{m}} - 79 \right) e^{80} - 1 \right) + V_{bd} * G \min$
$80V_{tn} \ge V_{bd}$	$I_{bd} = IS_{bd} * (e^{V_{bd}/V_{tn}} - 1) + V_{bd} * G \min$

- IS_{bd} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of drain**, **AD** parameter value if both these parameter values and the **Area of source**, **AS** parameter value are nonzero.
 - The Bulk saturation current, IS parameter value, otherwise.

Drain Current Model

The block provides the following relationship between the drain current

 I_d and the drain-source voltage V_{ds} in normal mode ($V_{ds} \geq 0$) after adjusting the applicable model parameters for temperature.

Normal Mode

Applicable Range of V _{gs} and V _{ds} Values	Corresponding I _d Equation
V_{gs} - $V_{on} \leq 0$	$I_d = 0$

Normal Mode (Continued)

Applicable Range of V _{gs} and V _{ds} Values	Corresponding I _d Equation
$0 < V_{gs} - V_{on} \leq V_{ds}$	$I_{d} = BETA * \left(V_{gs} - V_{on}\right)^{2} \frac{\left(1 + LAMBDA * V_{ds}\right)}{2}$
$0 < V_{ds} < V_{gs} - V_{on}$	$I_{d} = BETA * V_{ds} \left(\left(V_{gs} - V_{on} \right) - \frac{V_{ds}}{2} \right) \left(1 + LAMBDA * V_{ds} \right)$

Where:

- *V*_{on} is:
 - $MTYPE * VBI + GAMMA \sqrt{PHI V_{bs}}$ if $V_{bs} \le 0$.

-
$$MTYPE * VBI + GAMMA \left(\sqrt{PHI} - \frac{V_{bs}}{2\sqrt{PHI}} \right)$$
 if $0 < V_{bs} \le 2 * PHI$.

- MTYPE*VBI if $V_{bs} > 2*PHI$.
- *MTYPE* is 1.
- *BETA* is *KP*WIDTH/(LENGTH-2*LD)*
- *KP* is:
 - The **Transconductance**, **KP** parameter value, if this parameter has a numerical value.
 - $U0*3.9*\varepsilon_0/TOX$, if **Transconductance**, **KP** is NaN and you specify values for both the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters.
- *WIDTH* is the **Width of channel, WIDTH** parameter value.

- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.
- *VBI* is an built-in voltage value the block uses in calculations. The value is a function of temperature. For a detailed definition, see "Temperature Dependence" on page 2-181.
- *PHI* is:
 - The **Surface potential**, **PHI** parameter value, if this parameter has a numerical value.
 - $2 * kT_{meas} / q * \log(NSUB / n_i)$, if Surface potential, PHI is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- *LAMBDA* is the **Channel modulation**, **LAMBDA** parameter value.
- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- ε_0 is the permittivity of free space, 8.854214871e-12 F/m.
- n_i is the carrier concentration of intrinsic silicon, 1.45e10 cm⁻³.

The block provides the following relationship between the drain current

 I_d and the drain-source voltage V_{ds} in inverse mode ($V_{ds} < 0$) after adjusting the applicable model parameters for temperature.

Inverse Mode

Applicable Range of V _{gd} and V _{ds} Values	Corresponding I _d Equation
V_{gd} - $V_{on} \leq 0$	$I_d = 0$
$0 < V_{gd} - V_{on} \leq -V_{ds}$	$I_{d} = -BETA \left(V_{gd} - V_{on} \right)^{2} \left(1 - LAMBDA * V_{ds} \right) / 2$
$0 < V_{ds} < V_{gd} - V_{on}$	$I_{d} = BETA * V_{ds} \left(\left(V_{gd} - V_{on} \right) + V_{ds} / 2 \right) \left(1 - LAMBDA * V_{ds} \right)$

Where:

- V_{on} is:
 - $MTYPE * VBI + GAMMA \sqrt{PHI V_{bd}}$ if $V_{bd} \le 0$.

-
$$MTYPE * VBI + GAMMA \left(\sqrt{PHI} - \frac{V_{bd}}{2\sqrt{PHI}} \right)$$
 if $0 < V_{bd} \le 2 * PHI$.

• MTYPE*VBI if $V_{bd} > 2*PHI$.

Junction Charge Model

The block models the following junction charges:

- Junction Overlap Charges
- Bulk Junction Charges

Junction Overlap Charges

The block calculates the following junction overlap charges:

• $Q_{GS} = CGSO*WIDTH*V_{gs}$

- Q_{GS} is the gate-source overlap charge.
- CGSO is the G-S overlap capacitance, CGSO parameter value.
- *WIDTH* is the **Width of channel, WIDTH** parameter value.
- $Q_{GD} = CGDO^*WIDTH^*V_{gd}$

Where:

- Q_{GD} is the gate-drain overlap charge.
- *CGDO* is the **G-D overlap capacitance**, **CGDO** parameter value.
- Q_{GB} =CGBO*(LENGTH-2*LD)* V_{gb}

Where:

- Q_{GB} is the gate-bulk overlap charge.
- CGBO is the G-B overlap capacitance, CGBO parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.

Bulk Junction Charges

The block provides the following relationship between the bulk-drain bottom junction charge Q_{bottom} and the junction voltage V_{bd} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{bd} Values	Corresponding Q _{bottom} Equation
$V_{bd} < FC * PB$	$Q_{bottom} = \frac{CBD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1-MJ}\right)}{1 - MJ} \text{ if } CBD > 0.$
	$Q_{bottom} = \frac{CJ * AD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1 - MJ}\right)}{1 - MJ} \text{ otherwise.}$
$V_{bd} \ge FC * PB$	$Q_{bottom} = CBD * \left(F1 + \frac{F3 * (V_{bd} - FC * PB) + \frac{MJ * (V_{bd}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right)$ if $CBD > 0$.
	$Q_{bottom} = CJ * AD *$ $\left(F1 + \frac{F3 * (V_{bd} - FC * PB) + \frac{MJ * (V_{bd}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right)$ otherwise.

- *PB* is the **Bulk junction potential**, **PB** parameter value.
- *FC* is the **Capacitance coefficient FC** parameter value.
- CBD is the Zero-bias BD capacitance, CBD parameter value.
- CJ is the Bottom junction cap per area, CJ parameter value.
- *AD* is the **Area of drain**, **AD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1-MJ})}{1 - MJ}$$

•
$$F2 = (1 - FC)^{1+MJ}$$

•
$$F3 = 1 - FC * (1 + MJ)$$

The block uses the equations in the preceding table to calculate the bulk-source bottom junction charge, with the following substitutions:

- V_{bs} replaces V_{bd}.
- AS (the Area of source, AS parameter value) replaces AD.
- *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) replaces *CBD*.

The block provides the following relationship between the bulk-drain sidewall junction charge $Q_{sidewall}$ and the junction voltage V_{bd} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{bd} Values	Corresponding Q _{sidewall} Equation
$V_{bd} < FC * PB$	$Q_{sidewall} = \frac{CJSW * PD * PB * \left(1 - \left(1 - \frac{V_{bd}}{PB}\right)^{1-MGSW}\right)}{1 - MGSW}$
$V_{bd} \ge FC * PB$	$Q_{sidewall} = CJSW * PD * \left(F1 + \frac{F3 * (V_{bd} - FC * PB) + \frac{MGSW * (V_{bd}^2 - (FC * PB)^2)}{2 * PB}}{F2} \right)$

- *CJSW* is the **Side jct cap/area of jct perimeter**, **CJSW** parameter value.
- *PD* is the **Perimeter of drain, AD** parameter value.
- *MGSW* is the **Side grading coefficient**, **MJSW** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1 - MJSW})}{1 - MJSW}$$

• $F2 = (1 - FC)^{1 + MJSW}$

• F3 = 1 - FC * (1 + MJSW)

The block uses the equations in the preceding table to calculate the bulk-source sidewall junction charge and the sidewall junction voltage, with the following substitutions:

- V_{bs} replaces V_{bd}.
- *PS* (the **Perimeter of source, PS** parameter value) replaces *PD*.

Temperature Dependence

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

• When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

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

The block provides the following relationship between the transconductance KP and the transistor temperature T:

$$KP(T) = \frac{KP}{\left(\frac{T}{T_{meas}}\right)^{3/2}}$$

where:

- *KP* is the **Transconductance**, **KP** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.

The block provides the following relationship between the surface potential *PHI* and the transistor temperature *T*:

$$\begin{split} PHI(T) &= \frac{T}{T_{meas}} \Bigg(PHI + \frac{kT_{meas}}{q} \Bigg(\log \Bigg(\frac{T_{meas}}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T_{meas}} \Bigg) \Bigg) \Bigg) \\ &- \frac{kT}{q} \Bigg(\log \Bigg(\frac{T}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_T}{T} \Bigg) \Bigg) \end{split}$$

where:

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

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

The block provides the following relationship between the built-in voltage VBI and the transistor temperature T:

$$VBI(T) = VTO + MTYPE * \left(\frac{PHI(T) - PHI}{2} - GAMMA\sqrt{PHI}\right) + \frac{EG_{T_{meas}} - EG_T}{2}$$

where:

- *VTO* is:
 - The **Threshold voltage**, **VTO** parameter value, if this parameter has a numerical value.

• $\Phi - 3.25 + EG_{T_{max}}/2 + MTYPE * PHI/2 - NSS * q * TOX / (3.9 * \varepsilon_0)$

+ $MTYPE * (GAMMA * \sqrt{PHI} + PHI)$, if Threshold voltage, VTO is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

- Φ is:
 - **3.2**, if *TPG* (the **Gate type?**, **TPG** parameter value) is **0**.

-
$$3.25 + EG_{T_{max}}/2 - MTYPE * TPG * EG_{T_{max}}/2$$
, otherwise.

- GAMMA is:
 - The Bulk threshold, GAMMA parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

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

$$IS(T) = IS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

- *ND* is the **Emission coefficient**, **ND** parameter value.
- IS is the **Bulk saturation current**, **IS** parameter value.

The block provides the following relationship between the bulk junction saturation current density JS and the transistor temperature T:

$$JS(T) = JS * e^{\frac{-qEG_T}{ND^*kT} + \frac{qEG_{T_{meas}}}{ND^*kT_{meas}}}$$

where:

• JS is the Bulk jct sat current density, JS parameter value.

The block provides the following relationship between the bulk junction potential PB and the transistor temperature T:

$$PB(T) = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas} / T} - \frac{kT}{q} \left(\log \left(\frac{T}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_T}{T} \right) \right)$$

where:

• *PB* is the **Bulk junction potential**, **PB** parameter value.

The block provides the following relationship between the bulk-drain junction capacitance CBD and the transistor temperature T:

$$CBD(T) = CBD \frac{pbo + MJ * (4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo))}{MJ * (4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo))}$$

where:

- *CBD* is the **Zero-bias BD capacitance**, **CBD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$pbo = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas}}$$

The block uses the CBD(T) equation to calculate:

- The bulk-source junction capacitance by substituting *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) for *CBD*.
- The bottom junction capacitance by substituting *CJ* (the **Bottom junction cap per area**, *CJ* parameter value) for *CBD*.

The block provides the following relationship between the sidewall junction capacitance CJSW and the transistor temperature T:

$$CJSW(T) = CJSW \frac{pbo + MJSW * \left(4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo)\right)}{pbo + MJSW * \left(4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo)\right)}$$

where:

• *MJSW* is the **Side grading coefficient**, **MJSW** parameter value.

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

Dialog Box and Parameters

Model Selection Tab

Block Parameters: N	105						
VMOS-							
This model approximates this mask. The instance (MOS instances for this d which multiples the devic and RSH.	arameter OFF and no vice. SCALE multiplies	vise model parameters s the output current	ers KF and AF t and device d	are not supp harge directly	orted. SCAL y. This diffe	.E is the numbe rs from the AR	er of parall EA parame
You can set the MOS ten olus TOFFSET. The block ICVBS are the voltages a present. If physical para parameters TOX and NSI	lets you include or ex cross the internal junc meters VTO, KP, PHI,	clude capacitance r ctions, and are only or GAMMA are assi	modeling and ir / effective whe igned a NaN va	nitial conditio en the corres alue, they wi	ns. The initia ponding jun I be calculat	al conditions IC oction capacitar ted from specifi	VDS, ICVG
Parameters							
Model Selection D	mensions Resistor	rs DC currents	C-V Pr	ocess Te	mperature	1	
MOS model:		Level 1 MOS					
Gate type?, TPG:		Opposite of substr	rate				
			OK		Cancel	Help	

MOS model

Select one of the following MOSFET model options:

• Level 1 MOS — This is the default (and only) option.

Gate type?,TPG

Select one of the following MOSFET gate materials (as compared to the substrate):

- Opposite of substrate The gate material is the opposite of the substrate. This means that TPG = 1 in the device equations. This is the default option.
- Same as substrate The gate material is the same as the substrate. This means that TPG = -1 in the device equations.
- Aluminum The gate material is aluminum. This means that TPG = 0 in the device equations.

Dimensions Tab

MOS		
nis mask. The instance parameter OFF IOS instances for this device. SCALE m	. nMOSFET. You specify both model card and instance and noise model parameters KF and AF are not suppo ultiplies the output current and device charge directly P, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJ	rted. SCALE is the number of paralle . This differs from the AREA parame
us TOFFSET. The block lets you include CVBS are the voltages across the interr resent. If physical parameters VTO, KP	ixed temperature or to the circuit temperature (from 1 e or exclude capacitance modeling and initial condition hal junctions, and are only effective when the corresp , PHI, or GAMMA are assigned a NaN value, they will RD, RS or RSH are not used in block calculations when	s. The initial conditions ICVDS, ICVG onding junction capacitances are be calculated from specified process
arameters		
Model Selection Dimensions R	esistors DC currents C-V Process Ten	nperature
Device area factor, AREA:	1	
Number parallel devices, SCALE:	1	
Length of channel, LENGTH:	1e-04	m
Width of channel, WIDTH:	1e-04	m
Area of drain, AD:	0	m^2
Area of source, AS:	0	m^2
	0	m
Perimeter of drain, PD:	Ju	
Perimeter of drain, PD: Perimeter of source, PS:	0	m
,		

Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transconductance, KP
- Bulk saturation current, IS
- Bulk jct sat current density, JS

- Zero-bias BD capacitance, CBD
- Zero-bias BS capacitance, CBS
- G-S overlap capacitance, CGSO
- G-D overlap capacitance, CGDO
- G-B overlap capacitance, CGBO
- Bottom junction cap per area CJ
- Side jct cap/area of jct perimeter CJSW

It divides the following parameter values:

- Drain resistance, RD
- Source resistance, RS
- Sheet resistance, RSH

The default value is 1. The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel MOS instances for this device. This parameter multiplies the output current and device charge. The default value is 1. The value must be greater than 0.

Length of channel, LENGTH

Length of the channel between the source and drain. The default value is 1e-04 m.

Width of channel, WIDTH

Width of the channel between the source and drain. The default value is 1e-04 m.

Area of drain, AD

Area of the transistor drain diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Area of source, AS

Area of the transistor source diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Perimeter of drain, PD

Perimeter of the transistor drain diffusion. The default value is 0 m. $\,$

Perimeter of source, PS

Perimeter of the transistor source diffusion. The default value is 0 m.

Resistors Tab

Block Parameters: NMO5 × NMOS This model approximates a SPICE level 1 nMOSFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. You can set the MOS temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters block) plus TOFFSET. The block lets you include or exclude capacitance modeling and initial conditions. The initial conditions ICVDS, ICVGS and ICVBS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NaN. Parameters Model Selection Dimensions Resistors DC currents C-V Process Temperature NaN Ohm -Drain resistance, RD: Source resistance, RS: NaN Ohm -NaN Ohm Sheet resistance, RSH: • Number of drain squares, NRD: 1 1 Number of source squares, NRS: OK Cancel Help Apply

Drain resistance, RD

The transistor drain ohmic resistance. The default value is Nan Ω . This value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 2-170. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Source resistance, RS

The transistor source ohmic resistance. The default value is Nan Ω . This value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 2-170. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Sheet resistance, RSH

Resistance per square of the transistor source and drain. The default value is Nan Ω . This value means the parameter is unspecified. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-170. The value must be greater than or equal to 0.

Number of drain squares, NRD

Number of squares of resistance that make up the transistor drain diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-170.

Number of source squares, NRD

Number of squares of resistance that make up the transistor source diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-170.

DC Currents Tab

🙀 Block Parameters: NMOS		×
-NMOS		
this mask. The instance parameter OFF and MOS instances for this device. SCALE multip	IOSFET. You specify both model card and instance paran I noise model parameters KF and AF are not supported. S Nies the output current and device charge directly. This of S, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW an	SCALE is the number of parallel differs from the AREA parameter,
plus TOFFSET. The block lets you include or ICVBS are the voltages across the internal present. If physical parameters VTO, KP, P	d temperature or to the circuit temperature (from the SP exclude capacitance modeling and initial conditions. The junctions, and are only effective when the correspondin HI, or GAMMA are assigned a NaN value, they will be cal , RS or RSH are not used in block calculations when their	initial conditions ICVDS, ICVGS and g junction capacitances are culated from specified process
Parameters		
Model Selection Dimensions Resi	stors DC currents C-V Process Temperat	ture
Threshold voltage, VTO:	0	V
Transconductance, KP:	2e-05	A/V^2
Bulk threshold, GAMMA:	0	V^0.50000 -
Surface potential, PHI:	0.6	V
Channel modulation, LAMBDA:	0	1/V
Bulk saturation current, IS:	1e-14	A 🔽
Bulk jct sat current density, JS:	0	A/m^2 ▼
Emission coefficient, ND:	1	
	OK Cancel	Help Apply

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is 0 V. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate**

doping, NSUB parameters. For more information about this calculation, see "Temperature Dependence" on page 2-181.

Transconductance, KP

The derivative of drain current with respect to gate voltage. The default value is $2e \cdot 05 \text{ A/V}^2$. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Bulk threshold, GAMMA

Body effect parameter, which relates the threshold voltage, VTH, to the body bias, VBS, as described in "Drain Current Model" on

page 2-173. The default value is 0 \sqrt{V} . The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Surface potential, PHI

Twice the voltage at which the surface electron concentration becomes equal to the intrinsic concentration and the device transitions between depletion and inversion conditions. The default value is 0.6 V. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Bulk saturation current, IS

The magnitude of the current that the junction approaches asymptotically for very large reverse bias levels. The default value is 1e-14 A. The value must be greater than or equal to 0.

Bulk jct sat current density, JS

The magnitude of the current per unit area that the junction approaches asymptotically for very large reverse bias levels. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

Emission coefficient, ND

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

C-V Tab

Block Paramete	rs: NMO5						
NMOS							
this mask. The inst MOS instances for	ance parameter OF this device. SCALE	l 1 nMOSFET. You spe F and noise model pa multiplies the output of KP, IS, JS, CBD, CBS	ameters KF and current and devic	AF are not sup e charge direc	ported. SCALE tly. This differs	is the number from the AR	er of parallel EA parameter
plus TOFFSET. The ICVBS are the volta present. If physica	block lets you inclu ages across the inte l parameters VTO, l	a fixed temperature o ide or exclude capacit rmal junctions, and a KP, PHI, or GAMMA a rs RD, RS or RSH are	ance modeling an re only effective re assigned a Nañ	nd initial conditi when the corre V value, they v	ons. The initial esponding junc vill be calculate	conditions IC tion capacitated d from specif	CVDS, ICVGS a nces are
Parameters							
Model Selection	Dimensions	Resistors DC cur	rents C-V	Process 1	[emperature]		
Model junction o	poddarce:	No					

Model junction capacitance

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

• No — Do not include junction capacitance in the model. This is the default option.

• Yes — Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion and capacitance coefficient.

G-S overlap capacitance, CGSO

Gate-source capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-D overlap capacitance, CGDO

Gate-drain capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-B overlap capacitance, CGBO

Gate-base capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BD capacitance, CBD

The value of the capacitance placed between the base and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BS capacitance, CBS

The value of the capacitance placed between the base and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0

F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom junction cap per area CJ

Zero-bias bulk junction bottom capacitance per junction area. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom grading coefficient, MJ

The transistor bottom grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Side jct cap/area of jct perimeter CJSW

Zero-bias bulk junction sidewall capacitance per junction perimeter. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Side grading coefficient, MJSW

The transistor sidewall grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Bulk junction potential, PB

The potential across the bulk junction. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.8 V. The value must be equal to 0 or greater than or equal to VJmin. VJmin is a built-in model constant whose value is 0.01.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than or equal to FCmax. FCmax is a built-in model constant whose value is 0.95.

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

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

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Initial condition voltage ICVBS

Bulk-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Process Tab

	nMOSFET. You specify both model card and instance para	
MOS instances for this device. SCALE m	and noise model parameters KF and AF are not supported. ultiplies the output current and device charge directly. This P, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW ar	differs from the AREA parame
plus TOFFSET. The block lets you include ICVBS are the voltages across the interr present. If physical parameters VTO, KF	ixed temperature or to the circuit temperature (from the SR e or exclude capacitance modeling and initial conditions. The nal junctions, and are only effective when the correspondin , PHI, or GAMMA are assigned a NaN value, they will be ca RD, RS or RSH are not used in block calculations when thei	e initial conditions ICVDS, ICVG g junction capacitances are lculated from specified proces
Parameters		
Model Selection Dimensions R	esistors DC currents C-V Process Tempera	ture
Oxide thickness, TOX:	NaN	m
Lateral diffusion, LD:	0	m
Substrate doping, NSUB:	NaN	1/cm^3
Surface state density, NSS:	0	1/cm^2
Surface mobility, U0:	600	cm^2/s/V
Sarrace mobility your		
Surface mobility, our		

Oxide thickness, TOX

Thickness of the gate oxide. The default value is NaN m. The value must be greater than or equal to 0.

Lateral diffusion, LD

Length of lateral diffusion. The default value is $0\ \text{m}.$

Substrate doping, NSUB

Substrate doping. The default value is NaN $1/cm^3$. The value must be greater than or equal to 1.45e10 (the carrier concentration of intrinsic silicon).

Surface state density, NSS

Substrate doping. The default value is $0 \ 1/cm^2$.

Surface mobility, U0

Zero-bias surface mobility coefficient. The default value is $600\ \mbox{cm}^2/\mbox{V/s}.$

Temperature Tab

MOS				
his model approximates a SPICE level 1 nl nis mask. The instance parameter OFF an IOS instances for this device. SCALE multi hich multiples the device parameters KP, nd RSH.	nd noise model paramete tiplies the output curren	ers KF and AF are not t and device charge d	supported. SCALE irectly. This differe	E is the number of para s from the AREA para
ou can set the MOS temperature to a fixe lus TOFFSET. The block lets you include o CVBS are the voltages across the internal resent. If physical parameters VTO, KP, F arameters TOX and NSUB. Parameters R	or exclude capacitance r l junctions, and are only PHI, or GAMMA are assi	modeling and initial co effective when the c igned a NaN value, th	nditions. The initial corresponding junc ey will be calculate	l conditions ICVDS, IC tion capacitances are d from specified proce
arameters				
Model Selection Dimensions Res	sistors DC currents	C-V Process	Temperature	
Model temperature dependence using:	Device temperature			
Offset local circuit temperature, TOFFSET:	0			К
Parameter extraction temperature, TMEAS:	300.15			К

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

NMOS

	one exists in the circuit. Otherwise, it comes from the default value for this block.
	• Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.
	Offset local circuit temperature, TOFFSET The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the Model temperature dependence using parameter. The default value is 0 K.
	Fixed circuit temperature, TFIXED The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the Model temperature dependence using parameter. The default value is 300.15 K. The value must be greater than 0.
	Parameter extraction temperature, TMEAS The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.
Ports	The block has the following ports:
	G Electrical conserving port associated with the transistor gate terminal.
	D Electrical conserving port associated with the transistor drain terminal.
	S Electrical conserving port associated with the transistor source terminal.
	B Electrical conserving port associated with the transistor bulk terminal.

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

Purpose	Model Gummel-Poon NPN Transistor
Library	SPICE-Compatible Semiconductors
Description	The NPN block represents a SPICE-compatible four-terminal Gummel-Poon NPN transistor. The substrate port is connected to the transistor body using a capacitor, so these devices are equivalent to a three-terminal transistor when you connect the substrate port to any other port and use the default value of zero for the C-S junction capacitance, CJS parameter.
	The NPN block model includes the following components:

- "Current-Voltage and Base Charge Model" on page 2-204
- "Base Resistance Model" on page 2-207
- "Transit Charge Modulation Model" on page 2-208
- "Junction Charge Model" on page 2-209
- "Temperature Dependence" on page 2-211

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 204
- Terminal Currents on page 206
- Base Charge Model on page 207

Base-Emitter and Base-Collector Junction Currents

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

• When $V_{BE} > 80 * V_{TF}$:

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

• When $V_{BE} \leq 80 * V_{TF}$

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

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

• When $V_{BC} > 80 * V_{TR}$:

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

• When $V_{BC} \leq 80 * V_{TR}$

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

In the preceding equations:

• V_{BE} is the base-emitter voltage and V_{BC} is the base-collector voltage.

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

- $V_{TR} = NR * k * T / q.$
- *ISC* and *ISE* are the **B-C leakage current**, **ISC** and **B-E leakage current**, **ISE** parameter values, respectively.
- *NE*, *NC*, *NF*, and *NR* are the **B-E emission coefficient**, **NE**, **B-C emission coefficient**, **NC**, **Forward emission coefficient**, **NF** and **Reverse emission coefficient**, **NR** parameter values, respectively.
- *q* is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the transistor temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, T is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- G_{min} is the minimum conductance. By default, G_{min} matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change G_{min} , add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Terminal Currents

The terminal currents, I_B and I_C are the base and collector currents, defined as positive into the device. They are calculated as:

$$I_{B} = -\left(\frac{I_{ebf}}{BF} + I_{ebe} + \frac{I_{cbr}}{BR} + I_{cbc}\right)$$
$$I_{C} = -\left(\frac{I_{ebf} - I_{cbr}}{q_{b}} - \frac{I_{cbr}}{BR} - I_{cbc}\right)$$

where *BF* and *BR* are the **Forward beta**, **BF** and **Reverse beta**, **BR** parameter values, respectively.

Base Charge Model

The base charge, q_b , is calculated using the following equations:

$$\begin{split} q_{b} &= \frac{q_{1}}{2} \bigg(1 + \sqrt{0.5 * \big(\sqrt{(1 + 4 * q_{2} - eps)^{2}} + eps^{2}} + 1 + 4 * q_{2} - eps \big) + eps \bigg) \\ q_{1} &= \bigg(1 - \frac{V_{BC}}{VAF} - \frac{V_{BE}}{VAR} \bigg)^{-1} \\ q_{2} &= \frac{I_{bef}}{IKF} + \frac{I_{bcr}}{IKR} \end{split}$$

where

- *VAF* and *VAR* are the Forward Early voltage, VAF and Reverse Early voltage, VAR parameters, respectively.
- *IKF* and *IKR* are the **Forward knee current**, **IKF** and **Reverse knee current**, **IKR** parameter values, respectively.
- *eps* is 1e-4.

Base Resistance Model

The block models base resistance in one of two ways:

 If you use the default value of infinity for the Half base resistance cur, IRB parameter, the NPN block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + \frac{RB - RBM}{q_b}$$

where:

- *RBM* is the **Minimum base resistance**, **RBM** parameter value.
- *RB* is the **Zero-bias base resistance**, **RB** parameter value.
- If you specify a finite value for the **Half base resistance cur, IRB** parameter, the NPN block calculates the base resistance r_{bb} as

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

where

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

Transit Charge Modulation Model

If you specify nonzero values for the **Coefficient of TF, XTF** parameter, the block models transit charge modulation by scaling the **Forward transit time, TF** parameter value as follows:

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

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:

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

• For the internal base-collector junctions:

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

• For the external base-collector junctions:

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

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

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

Where:

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

- The **B-C depletion capacitance, CJC** parameter value for the base-collector junction.
- $F1 = VJ * (1 (1 FC)^{(1-MJ)}) / (1 MJ)$
- $F2 = (1 FC)^{(1+MJ)}$
- F3 = 1 FC * (1 + MJ)

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

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

where:

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

Temperature Dependence

Several transistor parameters depend on temperature. There are two ways to specify the transistor temperature: • When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

 $T = T_C + T_O$

where:

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

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

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

where:

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

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

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

where:

• *VJE* is the **B-E built-in potential**, **VJE** parameter value.

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

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

The block uses the VJE(T) equation to calculate the base-collector junction potential by substituting VJC (the **B-C built-in potential**, **VJC** parameter value) for VJE.

The block provides the following relationship between the base-emitter junction capacitance CJE and the transistor temperature T:

$$CJE(T) = CJE * \left[1 + MJE * \left(400e - 6 * \left(T - T_{meas} \right) - \frac{VJE(T) - VJE}{VJE} \right) \right]$$

where:

- *CJE* is the **B-E depletion capacitance**, **CJE** parameter value.
- *MJE* is the **B-E exponential factor**, **MJE** parameter value.

The block uses the CJE(T) equation to calculate the base-collector junction capacitance by substituting CJC (the **B-C depletion** capacitance, CJC parameter value) for CJE and MJC (the **B-C** exponential factor, MJC parameter value) for MJE.

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

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

where:

- β is the Forward beta, BF or Reverse beta, BR parameter value.
- *XTB* is the **Beta temperature exponent**, **XTB** parameter value.

The block provides the following relationship between the base-emitter leakage current ISE and the transistor temperature T:

$$ISE(T) = ISE * \left(\frac{T}{T_{meas}}\right)^{\text{XTB}} * \left(\frac{\text{IS}(T)}{\text{IS}}\right)^{1/NE}$$

where:

- *ISE* is the **B-E leakage current**, **ISE** parameter value.
- *NE* is the **B-E emission coefficient**, **NE** parameter value.

The block uses this equation to calculate the base-collector leakage current by substituting *ISC* (the **B-C leakage current, ISC** parameter value) for *ISE* and *NC* (the **B-C emission coefficient, NC** parameter value) for *NE*.

The model is based on the following assumptions:

• The NPN block does not support noise analysis.

Basic Assumptions and Limitations

• The NPN block applies initial conditions across junction capacitors and not across the block ports.

Dialog Box and Parameters

	•	Table
M	ain	Tab

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curri devi	ent an ce par	id device cha	irge dire IKF, ISE	ctly. This differ , IKR, ISC, IRE	s from the AREA	SCALE multiplies A parameter, whi and CJS, and di	ich multiples th
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141	ain	Forward G	ain F	Reverse Gain	Resistors	Capacitance	Temperature
D	evice	area, AREA:	i	L		m^2	•
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Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transport saturation current, IS
- Forward knee current, IKF
- B-E leakage current, ISE
- Reverse knee current, IKR
- B-C leakage current, ISC
- Half base resistance cur, IRB
- B-E depletion capacitance, CJE
- Coefficient of TF, ITF
- B-C depletion capacitance, CJC
- C-S junction capacitance, CJS

It divides the following parameter values:

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

The default value is $1 m^2$. The value must be greater than 0.

Number of parallel devices, SCALE

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

Forward Gain Tab

oise model parameters KF	ameters on this mask and AF are not suppo		parameters en an	
CALE is the number of par urrent and device charge evice parameters IS, IKF, arameters RB, RBM, RE ar	directly. This differs fr ISE, IKR, ISC, IRB, C	rom the AREA	parameter, which m	ultiples t
ou can set the BJT temper ustom Electrical Environme emperature sensitive para	ent block) plus TOFFS			
ifferent value than SPICE oltages across the interna apacitances are present.				
arameters)	×		
arameters Main Forward Gain	Reverse Gain	Resistors (Capacitance Ter	nperatur
	Reverse Gain I	Resistors (Capacitance Ter	nperatur •
Main Forward Gain		Resistors 📔 🤇		nperatur
Main Forward Gain Transport saturation current, IS: Forward beta, BF: Forward emission	1e-16	Resistors (nperatur _
Main Forward Gain Transport saturation current, IS: Forward beta, BF:	1e-16 100 1	Resistors (
Main Forward Gain Transport saturation current, IS: Forward beta, BF: Forward beta, BF: Forward emission coefficient, NF: B-E leakage current, ISE B-E emission coefficient, SE	1e-16 100 1 0	Resistors (A/m^2	
Main Forward Gain Transport saturation current, IS: Forward beta, BF: Forward emission coefficient, NF: B-E leakage current, ISE	1e-16 100 1 0	Resistors (A/m^2	nperatur
Transport saturation current, IS: Forward beta, BF: Forward emission coefficient, NF: B-E leakage current, ISE B-E emission coefficient, NE: Forward knee current,	1e-16 100 1 0 1.5	Resistors (A/m^2	

Transport saturation current, IS

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

Forward beta, BF

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

Forward emission coefficient, NF

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

B-E leakage current, ISE

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

B-E emission coefficient, NE

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

Forward knee current, IKF

The current value at which forward-beta high-current roll-off occurs. The default value is $Inf A/m^2$. The value must be greater than or equal to 0.

Forward Early voltage, VAF

The forward Early voltage. The default value is Inf V. The value must be greater than or equal to 0.

Reverse Gain Tab

	noise model parameters KF (ameters on this mask. The instance and AF are not supported.	e parameters PTF and OFF and
	urrent and device charge d	allel BJT instances for this device. : lirectly. This differs from the AREA ISE, IKR, ISC, IRB, CJE, ITF, CJC d RC.	parameter, which multiples the
		ature to a fixed temperature or to nt block) plus TOFFSET. The parar neters.	
	apacitance modeling uses t different value than SPICE f	exclude capacitance modeling and he published temperature equatio for capacitance. The initial conditio junctions, and are only effective of	ns, which may yield a slightly ns ICVBE and ICVCE are the
F	Parameters		
	Main Forward Gain	Reverse Gain Resistors	Capacitance Temperature
	Reverse beta, BR:	1	
	Reverse emission	1	
	coefficient, NR: B-C leakage current, ISC:	0	A/m^2
	B-C emission coefficient,	2	
	NC: Reverse knee current,	Inf	A/m^2
	NC:	Inf	A/m^2
	NC: Reverse knee current, IKR: Reverse Early voltage,	-	

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

ise model parameters KF -	ameters on this ma	ask. The instar	y both model card and nee parameters PTF a	
IALE is the number of para irrent and device charge o wice parameters IS, IKF, 1	directly. This differ	s from the ARI	EA parameter, which i	multiples t
arameters RB, RBM, RE an	nd RC.			
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ustom Electrical Environme mperature sensitive parar	· · ·	FSET. The par	rameters XTB, XTI and	l EG adjus
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rameters				
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Main Forward Gain	Reverse Gain	Resistors	Capacitance Te	emperatur
Emitter resistance, RE:	0		m^2*Ohm	-
Collector resistance, RC:				
Zero-bias base				
resistance, RB:	0		m^2*Ohm	•
	0		m^2*Ohm	
Minimum base resistance,			mr *2**Onm	-
Minimum base resistance RBM: Half base resistance cur,	Inf		A/m^2	•

Emitter resistance, RE

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

Collector resistance, RC

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

Zero-bias base resistance, RB

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

Minimum base resistance, RBM

The resistance of the collector. The default value is $0 \text{ m}^{2*}\Omega$. The value must be less than or equal to the **Zero-bias base** resistance, **RB** parameter value.

Half base resistance cur, IRB

The base current at which the base resistance has dropped to half of its zero-bias value. The default value is $Inf A/m^2$. The value must be greater than or equal to 0. Use the default value of Inf if you do not want to model the change in base resistance as a function of base current.

Capacitance Tab

	k Param	eters: NPN				
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param	ieters as i	instance par	5PICE NPN transist ameters on this ma and AF are not sup	isk. The instar		
curren device	nt and dev e paramet	vice charge o	allel BJT instances I directly. This differ: ISE, IKR, ISC, IRB Id RC.	s from the AR	EA parameter, w	hich multiples the
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capaci differe voltag capaci	itance mo ent value jes across itances ar	deling uses t than SPICE	r exclude capacitar the published temp for capacitance. Th junctions, and are	erature equal ne initial condi	tions, which may tions ICVBE and I	yield a slightly ICVCE are the
Param	ieters —					
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Mair		ward Gain	Reverse Gain	Resistors	Capacitance	Temperature
		ward Gain		Resistors	Capacitance	
				Resistors	Capacitance	
				Resistors	Capacitance	

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 ${\bf Specify\ initial\ condition\ }$ parameter. The default value is 0 V.

C-S junction capacitance, CJS

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

Substrate built-in potential, VJS

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

Substrate exponential factor, MJS

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

Temperature Tab

•	IN transistor. You specify both model card and i on this mask. The instance parameters PTF and	
noise model parameters KF and AF ar	re not supported.	
current and device charge directly. T	instances for this device. SCALE multiplies the o This differs from the AREA parameter, which mu , ISC, IRB, CJE, ITF, CJC and CJS, and divides	ultiples the
	a fixed temperature or to the circuit temperatu) plus TOFFSET. The parameters XTB, XTI and f	
apacitance modeling uses the publis different value than SPICE for capac voltages across the internal junctions	 capacitance modeling and initial conditions. Th shed temperature equations, which may yield a sitance. The initial conditions ICVBE and ICVCE. <i>is</i>, and are only effective when the correspond 	i slightly are the
capacitances are present.		
Parameters		
Main Forward Gain Revers	se Gain Resistors Capacitance Tem	nperature
Model temperature dependence using:	Device temperature	•
		•
using:		•
using: Beta temperature exponent, XTB:	: 0 1.11 eV	•
using: Beta temperature exponent, XTB: Energy gap, EG:	: 0 1.11 eV	• •
using: Beta temperature exponent, XTB: Energy gap, EG: Temperature exponent for IS, XTI Offset local circuit temperature	: 0 1.11 eV I: 3 0 K	• •
using: Beta temperature exponent, XTB: Energy gap, EG: Temperature exponent for IS, XTI Offset local circuit temperature TOFFSET: Parameter extraction temperature	: 0 1.11 eV I: 3 0 K	Y Y Y
using: Beta temperature exponent, XTB: Energy gap, EG: Temperature exponent for IS, XTI Offset local circuit temperature TOFFSET: Parameter extraction temperature	: 0 1.11 eV I: 3 0 K	V V

Model temperature dependence using

Select one of the following options for modeling the transistor temperature dependence:

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

Beta temperature exponent, XTB

The forward and reverse beta temperature exponent that models base current temperature dependence. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0. The value must be greater than or equal to 0.

Energy gap, EG

The energy gap that affects the increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Temperature exponent for IS, XTI

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than or equal to 0.

Offset local circuit temperature, TOFFSET

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

	Parameter extraction temperature, TMEAS The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.
	Fixed circuit temperature, TFIXED The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the Model temperature dependence using parameter. The default value is 300.15 K. The value must be greater than 0.
Ports	The block has the following ports:
	B Electrical conserving port associated with the transistor base terminal.
	C Electrical conserving port associated with the transistor collector terminal.
	E Electrical conserving port associated with the transistor emitter terminal.
	S Electrical conserving port associated with the transistor substrate terminal.
Examples	See the Creating a SPICE-Compatible Circuit with the Extended Electrical Library demo.
References	[1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2.
See Also	NPN Bipolar Transistor

NPN Bipolar Transistor

Purpose

Model NPN bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



The NPN Bipolar Transistor block uses a variant of the Ebers-Moll equations to represent an NPN bipolar transistor. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. The NPN Bipolar Transistor block provides the following enhancements to that model:

- Early voltage effect
- Optional base, collector, and emitter resistances.
- Optional fixed base-emitter and base-collector capacitances.

The collector and base currents are:

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

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- V_{be} is the base-emitter voltage and V_{bc} is the base-collector voltage.
- β_F is the ideal maximum current gain BF
- β_R is the ideal maximum current gain BR
- V_A is the forward Early voltage VAF
- q is the elementary charge on an electron (1.602176e–19 Coulombs).
- k is the Boltzmann constant (1.3806503e–23 J/K).

NPN Bipolar Transistor • *T* is the transistor temperature, as defined by the **Measurement** temperature parameter value.

You can specify the transistor behavior using datasheet parameters that the block uses to calculate the parameters for these equations, or you can specify the equation parameters directly.

If $qV_{\scriptscriptstyle RC}/(kT) > 40$ or $qV_{\scriptscriptstyle RE}/(kT) > 40$, the corresponding exponential

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

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

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

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

Optionally, you can specify parasitic fixed capacitances across the base-emitter and base-collector junctions. You also have the option to specify base, collector, and emitter connection resistances.

The NPN Bipolar Transistor model has the following limitations:

Basic Assumptions and Limitations

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

NPN Bipolar Transistor

Dialog Box and Parameters

Main Tab

arameti		cified directly, or are der			
Main	Ohmic Resistance Junction	Capacitance			
Param	neterization:	Specify from a datashe	et		1
Forwa	ard current transfer ratio h_fe:	100			
Outpu	ut admittance h_oe:	5e-05		1/Ohm	
	tor current at which h-parameters afined:	1		mA	
Voltag	je Vbe:	0.55		٧	
Curre	nt Ib for voltage Vbe:	0.5		mA	
Rever	se current transfer ratio BR:	1			
Measu	urement temperature:	25		C	

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to equations that describe the transistor. 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 $1/\Omega$.

Collector current at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 1 mA.

Voltage Vbe

Base-emitter voltage when the collector current is zero and the base current is Ib. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.55 V.

Current Ib for voltage Vbe

Base current when the base-emitter voltage is *Vbe* and the collector current is zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.5 mA.

Forward current transfer ratio BF

Ideal maximum forward current gain. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 100.

Saturation current IS

Transistor saturation current. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 1e-14 A.

Forward Early voltage VAF

In the standard Ebers-Moll equations, the gradient of the *Ic* versus *Vce* curve is zero in the normal active region. The additional forward Early voltage term increases this gradient. The intercept on the *Vce*-axis is equal to -VAF when the linear region is extrapolated. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 200 V.

Reverse current transfer ratio BR

Ideal maximum reverse current gain. This value is often not quoted in manufacturer datasheets, because it is not significant when the transistor is biased to operate in the normal active region. When the value is not known and the transistor is not to be operated on the inverse region, use the default value of 1.

Measurement temperature

Temperature at which *Vbe* and *Ib* or *IS* are measured. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is $25 \, ^{\circ}$ C.

Ohmic Resistance Tab

Paramete		,, -	ndard datasheet paramet
Main	Ohmic Resistance	Junction Capacitance	
Collec	tor resistance RC:	0.1	Ohm
Emitte	r resistance RE:	0.1	 Ohm
Zero b	oias base resistance RB:	0.1	Ohm

Collector resistance RC

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

Emitter resistance RE

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

Zero bias base resistance RB

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

Junction Capacitance Tab

Block Parameters: NPN Bipo	lar Transistor		
equations are based on two exp block adds the Early voltage effe ixed base-emitter and base-coll	nsistor modeled using a variant onential diodes plus two current act, and gives the option to inclu ector capacitances. For full deta ther be specified directly, or are	-controlled current sources. 1 de base, emitter and emitter ils of the equations, consult t	in addition, this resistances plus the documentatio
Parameters	ner be specified directly, or are	derived from standard datas	neet parameters
Main Ohmic Resistance	Junction Capacitance		
Base-collector capacitance:	5	pF	•
Base-emitter capacitance:	5	pF	•

Base-collector capacitance

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

Base-emitter capacitance

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

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. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993.	
	[2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.	
See Also	Diode, PNP Bipolar Transistor	

Optocoupler

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:
Ţ‡Ķ Optocouple	• 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 Optessurlar block to interface two electrical singuits without

Use the Optocoupler block to interface two electrical circuits without making a direct electrical connection. A common reason for doing this is that the two circuits work at very different voltage levels.

Note Each electrical circuit must have its own Electrical Reference block.

If the output circuit is a phototransistor, typical values for the **Current transfer ratio** parameter are 0.1 to 0.5. If the output stage consists of a Darlington pair, the parameter value can be much higher than this. The **Current transfer ratio** value also varies with the light-emitting diode current, but this effect is not modeled by the Photodiode block.

Some manufacturers provide a maximum data rate for optocouplers. In practice, the maximum data rate depends on the following factors:

- The capacitance of the photodiode and the type of the driving circuit
- The construction of the phototransistor and its associated capacitance

The Optocoupler block only lets you define the capacitance on the light-emitting diode. You can use the **Junction capacitance** parameter to add your own capacitance across the collector and emitter connections.

The Optocoupler block has the following limitations:

Basic Assumptions and Limitations

- The output side is modeled as a controlled current source. As such, it only correctly approximates a bipolar transistor operating in its normal active region. To create a more detailed model, connect the Optocoupler output directly to the base of an NPN Bipolar Transistor block, and set the parameters to maintain a correct overall value for the current transfer ratio. If you need to connect optocouplers in series, use this approach to avoid the invalid topology of two current sources in series.
- This block does not model temperature-dependent effects. 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 issues, but the simulation may run faster with these values set to zero.

Optocoupler

Dialog Box and Parameters

Main Tab

model consists of an exp side, and a controlled cu	implified implementation of an opt ionential diode in series with a cur rrent source on the output side. T tter junction, and is equal to CTR	rent sensor on the input- The output side current flows
Main Ohmic Resist Current transfer ratio: Diode parameterization:	ance Junction Capacitance	
Currents [I1 I2]: Voltages [V1 V2]: Measurement temperature:	[0.001 0.015] [0.9 1.05] 25	
	OK Cancel	Help Apply

Current transfer ratio

The output current flowing from the transistor collector to emitter junctions is equal to the product of the current transfer ratio and the current flowing the light-emitting diode. The default value is 0.2.

Diode parameterization

Select one of the following methods for model parameterization:

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

Currents [I1 I2]

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

Voltages [V1 V2]

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

Saturation current IS

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

Measurement temperature

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

Emission coefficient N

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

Ohmic Resistance Tab

🙀 Block Pa	rameters: Op	otocoupler			×
Optocoup	er				
model con side, and a from the c	sists of an expo a controlled cur ollector to emit	nential diode in rent source on t	series with a cur he output side. 1 d is equal to CTR	ocoupler. Structu rent sensor on th The output side c *Id where Id is th	ne input- urrent flows
Parameter	·s				
Main	Ohmic Resista	ance Junctio	n Capacitance		
Ohmic r	Main Ohmic Resistance Junction Capacitance Ohmic resistance R5: 0.1 Ohm				
		ОК	Cancel	Help	Apply

Ohmic resistance RS

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

Junction Capacitance Tab

Block Parameters: Optocoupler				
Optocoupler				
This block represents a simplified implementation of an optocoupler. Structurally the model consists of an exponential diode in series with a current sensor on the input- side, and a controlled current source on the output side. The output side current flows from the collector to emitter junction, and is equal to CTR*Id where Id is the diode current and CTR is the Current Transfer Ratio.				
Parameters				
Main Ohmic Resistance Junction Capacitance				
Main Ohmic Resistance Junction Capacitance Junction capacitance: Fixed or zero junction capacitance Image: Capacitance Zero-bias junction capacitance Image: Capacitance Image: Capacitance Capacitance CJ0: Image: Capacitance Image: Capacitance				
OK Cancel Help Apply				

Junction capacitance

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

- Fixed or zero junction capacitance Model the junction capacitance as a fixed value.
- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

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

Junction potential VJ

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

Grading coefficient M

The coefficient that quantifies the grading of the junction. This parameter is only visible when you select Use parameters CJO, VJ, M & FC for the **Junction capacitance** parameter. The default value is 0.5.

Reverse bias voltages [VR1 VR2 VR3]

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

Corresponding capacitances [C1 C2 C3]

A vector of the capacitance values at the three points on the diode C-V curve that the block uses to calculate 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 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.
	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. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993.
	[2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.
See Also	Diode, NPN Bipolar Transistor, Simscape Controlled Current Source

P-Channel JFET

Purpose Model P-Channel JFET

Library

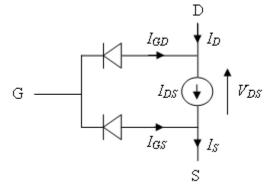
Semiconductor Devices

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 $(-V_{ds} \ge 0)$, the block provides the following relationship between the drain-source current I_{ds} and the drain-source voltage V_{ds} .

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

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

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

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

In the preceding equations:

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

is the **Threshold voltage** parameter value. Otherwise, the block calculates V_{to} from the datasheet parameters you specify.

- β is the transconductance parameter. If you select Specify using equation parameters directly for the **Parameterization** parameter, β is the **Transconductance parameter** parameter value. Otherwise, the block calculates β from the datasheet parameters you specify.
- λ is the channel-length modulation parameter. If you select Specify using equation parameters directly for the Parameterization parameter, λ is the Channel-length modulation parameter value. Otherwise, the block calculates λ from the datasheet parameters you specify.

The currents in each of the diodes satisfy the exponential diode equation

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

Where:

- I_S is the saturation current. If you select Specify using equation parameters directly for the **Parameterization** parameter, I_S is the **Saturation current** parameter value. Otherwise, the block calculates I_S from the datasheet parameters you specify.
- *q* is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature. The value comes from the **Measurement** temperature parameter.

The block models gate junction capacitance as a fixed gate-drain capacitance C_{GD} and a fixed gate-source capacitance C_{GS} . If you select Specify using equation parameters directly for the **Parameterization** parameter, you specify these values directly using the **Gate-drain junction capacitance** and **Gate-source junction capacitance** parameters. Otherwise, the block derives them from the **Input capacitance Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

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

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

- 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 issues, but the simulation may run faster with these values set to zero.

P-Channel JFET

Dialog Box and Parameters

Main Tab

14 – 0 if A	k represents a P-Channel JFET. Vgs-Vt0 < 0 (off)	The drain current Id for negative Vds (r	normal operation) is given by
		ds) if 0 < -Vds < -Vgs - Vt0] (linear regior	ป
lds = -B*(-Vgs - Vt0)^2*(1-L*Vds) if 0 < -Vg	s - Vt0 < -Vds (saturated region)	
modulatio	on, Vgs is the gate-source voltage	eter, Vt0 is the Threshold voltage, L is th a and Vds is the drain-source voltage.	ne Channel-length
Paramete Main	1	on Capacitance	
Param	eterization:	Specify from a datasheet	•
Gate r	everse current l_gss:	5	nA 💌
Satura	ated drain current I_dss:	-3	mA 💌
I_dss	measurement point [V_gs V_ds]:	[0.15]	V
Small-	signal parameters [g_fs g_os]:	[2.5e+03 75]	uS 💌
Small- V_ds]:	signal measurement point [V_gs :	[0.15]	V
- asi	urement temperature:	25	C 💌

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to equations that describe the transistor. This is the default method.

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

Gate reverse current I_gss

The reverse current that flows in the diode when the drain and source are short-circuited and a large positive gate-source voltage is applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 5 nA.

Saturated drain current I_dss

The current that flows when a large negative drain-source voltage is applied for a specified gate-source voltage. For a depletion-mode device, this gate-source voltage may be zero, in which case I_{dss} may be referred to as the zero-gate voltage drain current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -3 mA.

I_dss measurement point [V_gs V_ds]

A vector of the values of V_{gs} and V_{ds} at which I_{dss} is measured. Normally V_{gs} is zero. V_{ds} should be less than zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 -15] V.

Small-signal parameters [g_fs g_os]

A vector of the values of g_{fs} and g_{os} . g_{fs} is the forward transfer conductance, i.e. the conductance for a fixed drain-source voltage. g_{os} is the output conductance, i.e. the conductance for a fixed gate-source voltage. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [2.5e+03 75] uS.

Small-signal measurement point [V_gs V_ds]

A vector of the values of V_{gs} and V_{ds} at which g_{fs} and g_{os} are measured. V_{ds} should be less than zero. For depletion-mode devices, V_{gs} is typically zero. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is [0 -15] V.

Transconductance parameter

The derivative of drain current with respect to gate voltage. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is $1e-04 \text{ A/V}^2$.

Saturation current

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

Measurement temperature

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

Threshold voltage

The gate-source voltage above which the transistor produces a nonzero drain current. For an enhancement device, Vt0 should be negative. For a depletion mode device, Vt0 should be positive. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 2 V.

Channel-length modulation

The channel-length modulation. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 0 1/V.

Ohmic Resistance Tab

Block Parameters: P-Chan	nel JFET			
P-Channel JFET				
This block represents a P-Chann	el JFET. The drain current Id	for negative Vds (no	ormal operation) i	is given
Id = 0 if -Vgs-Vt0 < 0 (off)				
Ids = -B*Vds*[2*(-Vgs - Vt0) +		-Vgs - Vt0] (linear re	gion)	
Ids = -B*(-Vgs - Vt0)^2*(1-L*V	ds) if 0 < -Vas - Vt0 < -Vds (s	aturated region)		
where B is the Transconductanc			a Channel-Iength	
modulation, Vgs is the gate-sour			s channenengun	
Parameters				
Main Ohmic Resistance	Junction Capacitance			
Source ohmic resistance:			Loh-u	_
	0.1		Ohm	
Drain ohmic resistance:	0.1		Ohm	

Source ohmic resistance

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

Drain ohmic resistance

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

Junction Capacitance Tab

🙀 Block Parameters: P-Channel JF	ET
-P-Channel JFET	
This block represents a P-Channel JFE	T. The drain current Id for negative Vds (normal operation) is given by:
Id = 0 if -Vgs-Vt0 < 0 (off)	
Ids = -B*Vds*[2*(-Vgs - Vt0) + Vds]*	(1-L*Vds) if 0 < -Vds < -Vgs - Vt0] (linear region)
Ids = -B*(-Vgs - Vt0)^2*(1-L*Vds) if () < -Vgs - Vt0 < -Vds (saturated region)
where B is the Transconductance para voltage and Vds is the drain-source vo	meter, Vt0 is the Threshold voltage, L is the Channel-length modulation, Vgs is the gate-source ltage.
Parameters	
Main Ohmic Resistance Jun	ction Capacitance
Parameterization:	Specify from a datasheet
Input capacitance Ciss:	5 pF
Reverse transfer capacitance Crss	: 1 pF 💌
	OK Cancel Help Apply

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to junction capacitance values. This is the default method.

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

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 4.5 pF.

Reverse transfer capacitance Crss

The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the **Model junction capacitance** parameter. The default value is 1.5 pF.

Gate-source junction capacitance

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the Model junction capacitance parameter. The default value is 3 pF.

Gate-drain junction capacitance

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the **Model junction** capacitance parameter. The default value is 1.5 pF.

The block has the following ports:

G

Ports

Electrical conserving port associated with the transistor gate terminal.

D

Electrical conserving port associated with the transistor drain terminal.

S

Electrical conserving port associated with the transistor source terminal.

References	[1] H. Shichman and D. A. Hodges, <i>Modeling and simulation of insulated-gate field-effect transistor switching circuits</i> . IEEE J. Solid State Circuits, SC-3, 1968.
	[2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2.
See Also	N-Channel JFET

Purpose Model P-Channel MOSFET using Shichman-Hodges equation

Semiconductor Devices

Description

Library



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:

P-Channel MOSFET

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

$$I_{DS} = 0$$

• In the linear region ($0 < -V_{DS} < -V_{GS} + V_{th}$) 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 Ciss** and **Reverse transfer capacitance Crss** parameter values. The two parameterizations are related as follows:

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

Dialog Box and Parameters

Main Tab

🙀 Block Parameters: P	-Channel MOSFET			×		
P-Channel MOSFET						
	This block represents a P-channel MOSFET (or IGFET). The drain-source current Ids for negative Vds is given by:					
Ids = 0 if $-Vgs < -Vth$ (of	f)					
Ids = -K*[(Vgs - Vth)*Vd	s - Vds^2/2] if 0 < -\	/ds < -Vgs + VtH	n] (linear region)			
Ids = -(K/2)*(Vgs - Vth)/	2 if 0 < -Vgs + Vth -	< -Vds (saturate	d region)			
where K is a constant, Vt Vds is the drain-source v		oltage, Vgs is the	e gate-source vo	ltage and		
-Parameters						
Main Ohmic Resist	ance 📔 Junction Ca	apacitance		(
Parameterization:	Specify from a data	asheet		•		
Drain-source on resistance R_DS(on):	0.167		Ohm	•		
Drain current, Ids, for R_DS(on):	Drain current, Ids,					
Gate-source voltage, Vgs, for R_DS(on):	Gate-source voltage, 4 5					
Gate-source threshold voltage	Gate-source					
Vth:						
	ОК	Cancel	Help	Apply		

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide the drain-source on resistance and the corresponding drain current and gate-source voltage. The block calculates the transistor gain for the

Shichman and Hodges equations from this information. This is the default method.

• Specify using equation parameters directly — Provide the transistor gain.

Drain-source on resistance, R_DS(on)

The ratio of the drain-source voltage to the drain current for specified values of drain current and gate-source voltage. $R_{DS}(on)$ should have a positive value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.167 Ω .

Drain current, Ids, for R_DS(on)

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

Gate-source voltage, Vgs, for R_DS(on)

The gate-source voltage the block uses to calculate the value of the drain-source resistance. V_{GS} should have a negative value. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is -4.5 V.

Gain K

Positive constant gain coefficient for the Shichman and Hodges equations. This parameter is only visible when you select Specify using equation parameters directly for the **Parameterization** parameter. The default value is 2 A/V^2 .

Gate-source threshold voltage Vth

Gate-source threshold voltage V_{th} in the Shichman and Hodges equations. For an enhancement device, V_{th} should be negative. For a depletion mode device, V_{th} should be positive. The default value is -1.4 V.

Ohmic Resistance Tab

Block Parameters: P-Channel MOSFET	×			
P-Channel MOSFET				
This block represents a P-channel MOSFET (or IGFET). The drain-source current Ids for negative Vds is given by:				
Ids = 0 if -Vgs < -Vth (off)				
$Ids = -K^*[(Vgs - Vth)^*Vds - Vds^2/2] \ if \ 0 < -Vds < -Vgs + Vth] \ (linear \ region)$				
$Ids = -(K/2)^*(Vgs - Vth)^2 \ if \ 0 < -Vgs + Vth < -Vds \ (saturated \ region)$				
where K is a constant, \mbox{Vth} is the Threshold voltage, \mbox{Vgs} is the gate-source voltage and \mbox{Vds} is the drain-source voltage.				
Parameters				
Main Ohmic Resistance Junction Capacitance				
Source ohmic 0.001 Ohm 🔽				
Drain ohmic resistance: 0.001 Ohm				
OK Cancel Help Apply				

Source ohmic resistance

The transistor source resistance. The default value is $0.001~\Omega.$ The value must be greater than or equal to 0.

Drain ohmic resistance

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

Junction Capacitance Tab

🙀 Block Parameters: P-Channel MOSFE		×		
P-Channel MOSFET				
This block represents a P-channel MOSFET (or IGFET). The drain-source current Ids for negative Vds is given by:			
Ids = 0 if -Vgs < -Vth (off)				
Ids = -K*[(Vgs - Vth)*Vds - Vds^2/2] if 0 $<$	-Vds < -Vgs + Vth] (linear region)			
Ids = -(K/2)*(Vgs - Vth)^2 if 0 < -Vgs + Vth	< -Vds (saturated region)			
where K is a constant, Vth is the Threshold voltage, Vgs is the gate-source voltage and Vds is the drain-source voltage.				
Parameters				
Main Ohmic Resistance Junction Capacitance				
Parameterization:	Specify from a datasheet			
Input capacitance Ciss:	270 pF	_		
Reverse transfer capacitance Crss:	45 pF	•		
	OK Cancel Help	Apply		

Parameterization

Select one of the following methods for capacitance parameterization:

- Specify from a datasheet Provide parameters that the block converts to junction capacitance values. This is the default method.
- Specify using equation parameters directly Provide junction capacitance parameters directly.

Input capacitance Ciss

The gate-source capacitance with the drain shorted to the source. This parameter is only visible when you select Specify from a

	datasheet for the ${\bf Parameterization}$ parameter. The default value is 270 pF.
	Reverse transfer capacitance Crss The drain-gate capacitance with the source connected to ground. This parameter is only visible when you select Specify from a datasheet for the Parameterization parameter. The default value is 45 pF.
	Gate-source junction capacitance The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Specify using equation parameters directly for the Parameterization parameter. The default value is 225 pF.
	Gate-drain junction capacitance The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Specify using equation parameters directly for the Parameterization parameter. The default value is 45 pF.
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.

P-Channel MOSFET

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:

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

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

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

where:

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

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

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

Dialog Box and Parameters

Block Parameters: PCCC5				
PCCC5				
The Polynomial Current-Controlled Current Source (PCCCS) block generates a current waveform, Iout, by evaluating a polynomial function for a single controlling input current, Iin. Iin is the time-dependent current flowing through the input terminals.				
If you specify a vector of polynomial coefficients, p, in ascending order, the output is:				
$Iout = p(0) + p(1)*Iin + + p(n-1)*Iin^{(n-1)} + p(n)*Iin^{n}$				
If you specify a scalar coefficient, p, the block creates a linearly dependent output current.				
Iout = p * Iin				
Parameters				
Polynomial coefficients: [0 1]				
OK Cancel Help Apply				

Polynomial coefficients

The polynomial coefficients that relate the input current to the output current, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

Positive electrical output voltage.

Ports

N -

Negative electrical output voltage.

See Also PCCVS, PVCCS, and PVCVS

PCCVS

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:

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

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

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

where:

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

Dialog Box and Parameters

🙀 Block Parameters: PCCVS 🛛 🗙 🗙			
-PCCVS			
The Polynomial Current-Controlled Voltage Source (PCCVS) block generates a voltage waveform, Vout, by evaluating a polynomial function for a single controlling input current, Iin. Iin is the time-dependent current flowing through the input terminals.			
If you specify a vector of polynomial coefficients, p, in ascending order, the output is:			
$Vout = p(0) + p(1)*Iin + + p(n-1)*Iin^{(n-1)} + p(n)*Iin^{n}$			
If you specify a scalar coefficient, $p,$ the block creates a linearly dependent output voltage.			
Vout = p * Iin			
Parameters			
Polynomial coefficients: [0 1]			
OK Cancel Help Apply			

Polynomial coefficients

The polynomial coefficients that relate the input current to the output voltage, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Ports

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

-

Positive electrical output voltage.

N -

Negative electrical output voltage.

See Also PCCCS, PVCCS, and PVCVS

Purpose Model photodiode as parallel controlled current source and exponential diode

Library

Sensors

Description



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

Photodiode

$I_{p} = DeviceSensitivity \times RadiantFluxDensity$

where:

- *DeviceSensitivity* is the ratio of the current produced to the incident radiant flux density.
 - If you select Specify measured current for given flux density for the Sensitivity parameterization parameter, the block calculates this variable by converting the Measured current parameter value to units of amps and dividing it by the Flux density parameter values.
 - If you select Specify current per unit flux density for the Sensitivity parameterization parameter, this variable is defined by the Device sensitivity parameter value.
- *RadiantFluxDensity* is the incident radiant flux density.

To model dynamic response time, use the **Junction capacitance** parameter to include the diode junction capacitance in the model.

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

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

where:

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

When $\frac{qV}{NkT} > 40$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} - 39\right)e^{40}$, which matches the gradient of the diode current at qV/(NkT) = 40 and extrapolates linearly. When $\frac{qV}{NkT} < -39$, the block replaces $e^{\frac{qV}{NkT}}$ with $\left(\frac{qV}{NkT} + 40\right)e^{-39}$, which also matches the gradient and extrapolates linearly. Typical electrical circuits do not reach these extreme values. The block provides this linear extrapolation to help convergence when solving for the constraints during simulation.

When you select Use dark current and N for the **Diode parameterization** parameter, you specify the diode in terms of the **Dark current** and **Emission coefficient** N parameters. When you select Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter, you specify the **Dark current** parameter and a voltage and current measurement point on the diode I-V curve. The block calculates N from these values as follows:

$$N = V_F / (V_t \log(I_F / IS + 1))$$

where:

• V_F is the Forward voltage VF parameter value.

- $V_t = kT / q$.
- *I_F* is the **Current IF at forward voltage VF** parameter value.

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

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

It is not possible to estimate FC reliably from tabulated data, so you must specify its value using the **Capacitance coefficient FC** parameter. In the absence of suitable data for this parameter, use a typical value of 0.5. The reverse bias voltages (defined as positive values) should satisfy $V_{R3} > V_{R2} > V_{R1}$. This means that the capacitances should satisfy $C_1 > C_2 > C_3$ as reverse bias widens the depletion region and hence reduces capacitance. Violating these inequalities results in an error. Voltages V_{R2} and V_{R3} should be well away from the Junction potential VJ. Voltage V_{R1} should be less than the Junction potential VJ, with a typical value for V_{R1} being 0.1 V.

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

• For $V < FC \times VJ$:

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

• For $V \ge FC \times VJ$:

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

where:

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

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

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 issues, but the simulation may run faster with these values set to zero.

Photodiode

Dialog Box and Parameters

Main Tab

😽 Block Parameters: Pho	otodiode			×
Photodiode				
	ed in parallel. The controlle Radiant flux density preser adiant flux density	d current sour ited at the phy	ce produces a cu /sical signal port	ırrent Ip D:
Parameters				
Main Ohmic Resistar	nce 📔 Junction Capacitan	ce		
Sensitivity parameterization:	Specify measured current	: for given flux		-
Measured current:	25		Au	
Flux density:	5		W/m^2	•
Diode parameterization:	Use dark current plus a fo	orward bias I-V	/ data point	•
Current IF at forward voltage VF:	0.08		A	- I
Forward voltage VF:	1.3		V	•
Dark current:	5e-09		A	-
Measurement temperature:	25		C	
	ОК	Cancel	Help	Apply

Sensitivity parameterization

Select one of the following methods for sensitivity parameterization:

• Specify measured current for given flux density — Specify the measured current and the corresponding flux density. This is the default method.

• Specify current per unit flux density — Specify the device sensitivity directly.

Measured current

The current the block uses to calculate the device sensitivity. This parameter is only visible when you select Specify measured current for given flux density for the **Sensitivity parameterization** parameter. The default value is 25μ A.

Flux density

The flux density the block uses to calculate the device sensitivity. This parameter is only visible when you select Specify measured current for given flux density for the **Sensitivity parameterization** parameter. The default value is 5 W/m².

Device sensitivity

The current per unit flux density. This parameter is only visible when you select Specify current per unit flux density for the **Sensitivity parameterization** parameter. The default value is $5e-06 \text{ m}^{2*}\text{A/W}$.

Diode parameterization

Select one of the following methods for diode model parameterization:

- Use dark current plus a forward bias I-V data point — Specify the dark current and a point on the diode I-V curve. This is the default method.
- \bullet Use dark current and N Specify dark current and emission coefficient.

Current IF at forward voltage VF

The current at the forward-biased point on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter. The default value is 0.08 A.

Forward voltage VF

The corresponding voltage at the forward-biased point on the diode I-V curve that the block uses to calculate IS and N. This parameter is only visible when you select and Use dark current plus a forward bias I-V data point for the **Diode parameterization** parameter. The default value is 1.3 V.

Dark current

The current through the diode when it is not exposed to light. The default value is 5e-09 A.

Measurement temperature

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

Emission coefficient N

The diode emission coefficient or ideality factor. This parameter is only visible when you select Use dark current and N for the **Diode parameterization** parameter. The default value is 3.

Ohmic Resistance Tab

Block Pa	ameters: Photo	diode			2
Photodiode					
exponentia :hat is prop (p = Device (n order to	l diode connected in ortional to the Rad e sensitivity * Radia	diode. Structurally it n parallel. The contr liant flux density pre ant flux density ponse time, the dioc	olled current sou esented at the p	urce produces a c hysical signal port	urrent Ip : D:
value. Parameters	·				
Main	Ohmic Resistance	Junction Capaci	tance		
	,				
		ок	Cancel	Help	Apply

Ohmic resistance RS

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

Junction Capacitance Tab

Block Parameters: Ph	todiode	>
Photodiode		
exponential diode connect that is proportional to the (p = Device sensitivity * R	otodiode. Structurally it consists of a controlled current s ad in parallel. The controlled current source produces a Radiant flux density presented at the physical signal por adiant flux density response time, the diode junction capacitance can set to	turrent Ip t D:
Parameters		
Main Ohmic Resista	ce Junction Capacitance	1
Junction capacitance: Zero-bias junction capacitance CJ0:	Fixed or zero junction capacitance	•

Junction capacitance

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

• Fixed or zero junction capacitance — Model the junction capacitance as a fixed value.

- Use C-V curve data points Specify measured data at three points on the diode C-V curve.
- Use parameters CJO, VJ, M & FC Specify zero-bias junction capacitance, junction potential, grading coefficient, and forward-bias depletion capacitance coefficient.

Zero-bias junction capacitance CJ0

The value of the capacitance placed in parallel with the exponential diode term. This parameter is only visible when you select Fixed or zero junction capacitance or Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 60 pF. When you select Fixed or zero junction capacitance for the Junction capacitance parameter, a value of zero omits junction capacitance.

Reverse bias voltages [VR1 VR2 VR3]

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

Corresponding capacitances [C1 C2 C3]

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

Junction potential VJ

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

Grading coefficient M

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

	Capacitance coefficient FC Fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Use C-V curve data points or Use parameters CJO, VJ, M & FC for the Junction capacitance parameter. The default value is 0.5.
Ports	The block has the following ports:
	 D Physical port representing incident flux. + Electrical conserving port associated with the diode positive
	terminal.
	Electrical conserving port associated with the diode negative terminal.
References	[1] MH. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.
	[2] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993.
See Also	Diode, Light-Emitting Diode, Optocoupler

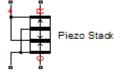
Purpose Model electrical and force characteristics of piezoelectric stacked actuator

Actuators & Drivers

Description

Library

The Piezo Stack block represents the electrical and force characteristics of a piezoelectric stacked actuator using the following equations:



 $S = s^{E}T + d^{T}E$ $D = dT + \varepsilon^{T}E$

where

- *S* is the strain tensor.
- *T* is the stress tensor.
- E is the electric field vector.
- *D* is the electric displacement vector.
- s^E is the elastic compliance matrix when subjected to a constant electric field.
- *d* is the piezoelectric constant matrix.
- ε^T is the permittivity measured at a constant stress.

Note The block models one-dimensional lumped parameter behavior, so *S*, *T*, *E* and *D* are all scalar values.

You can specify the block parameters that determine static force using either datasheet parameters or material properties, as determined by the value of the **Parameterization** parameter on the **Static Force** tab of the block dialog box.

The **Dynamic Forces** tab of the block dialog box lets you include optional effective mass and mechanical damping effects.

	• If you specify a nonzero value for the Effective mass parameter or a finite value for the Resonant frequency at constant field parameter, the block attaches a lumped mass to the mechanical R port. When you specify a finite resonant frequency, the block calculates the effective mass to achieve the correct resonant frequency.
	• If you specify a nonzero value for the Damping parameter or a finite value for the Mechanical quality factor parameter, the block adds a damping term across the R and C mechanical ports. When you specify a mechanical quality factor, Q_m , the block calculates the
	damping from this parameter value as \sqrt{Mk}/Q_m , where k is the short-circuit device stiffness, or equivalently the stiffness at constant field.
	A positive voltage across the electrical + to – ports creates a positive displacement acting from the mechanical C to R ports.
Basic Assumptions and Limitations	The model does not include hysteresis effects.

Piezo Stack

Dialog Box and Parameters

Static Force Tab

Block Parameters: Piezo Stack Piezo Stack This block implements the electrical and fo	rce characteristics of a piezoelectric stacked actuator. Effecti	ve mass and mechanical
damping effects may also be optionally in A positive voltage across the electrical +	duded. to - ports results in a positive displacement acting from the me	echanical C to R ports.
Parameters Static Force Dynamic Forces In	itial Conditions	1
Parameterization:	Specify from a datasheet	_
Stack area:	100	mm^2 💌
Stack length:	36	mm
No-load displacement at V0 volts:	0.038	mm
Blocking force at V0 volts:	3.8e+03	N
Test voltage V0:	120	V
Capacitance:	13	uF 💌
	OK Cancel	Help Apply

Parameterization

Select one of the following methods for static force parameterization:

- Specify from a datasheet Provide datasheet parameters that the block converts to static force values. This is the default method.
- Specify material properties Provide material properties that the block converts to static force values.

Stack area

Cross-sectional area of the stack. The default value is 100 mm^2 .

Stack length

Stack length when no load and no electrical potential are applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 36 mm.

No-load displacement at V0 volts

Unconstrained displacement of the stack when a voltage of V0 volts is applied. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 0.038 mm.

Blocking force at V0 volts

Force the stack produces when a voltage of V0 volts is applied and the stack is physically prevented from expanding. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 3.8e+03 N.

Test voltage V0

Voltage used to determine the no-load displacement and blocking force. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 120 V.

Capacitance

This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 13 uF.

Piezo layer thickness

Thickness of each layer in the piezo stack. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0.3 mm.

Number of layers

Number of layers in the piezo stack. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 50.

Piezoelectric charge constant

Mechanical strain per unit electric field applied. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 5e-10 m/V.

Dielectric constant

Permittivity or dielectric displacement per unit electric field measured at constant stress. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 2.124e-08 F/m.

Elastic compliance

Strain produced in a piezoelectric material per unit of stress applied. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is $1.9e-11 \text{ m}^2/\text{N}$.

Dynamic Forces Tab

zo Stack		
is block implements the electrical and for mping effects may also be optionally inclu	ce characteristics of a piezoelectric stacked actuator. Effective mass and mechanic uded.	al
positive voltage across the electrical + to	\ensuremath{o} - ports results in a positive displacement acting from the mechanical C to R ports.	
rameters		
Static Force Dynamic Forces Init	tial Conditions	
Parameterization:	Specify from a datasheet	•
Resonant frequency at constant field:	Inf	•
Mechanical quality factor:	Inf	

Parameterization

Select one of the following methods for dynamic force parameterization:

- Specify from a datasheet Provide datasheet parameters that the block converts to dynamic force values. This is the default method.
- Specify material properties Provide material properties that the block converts to dynamic force values.

Resonant frequency at constant field

Frequency at which the actuator naturally resonates if mechanically perturbed with the electrical ports shorted. This parameter is only visible when you select Specify from a datasheet for the Parameterization parameter. The default value is Inf kHz.

Mechanical quality factor

Factor that affects the damping across the R and C mechanical ports. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is Inf.

Damping

Translational damping term. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0 N/(m/s).

Effective mass

Mass that approximates the distributed dynamics of the device and causes the stack to resonate at the correct frequency when attached to the mechanical R port. This mass is usually about one third of the actual stack mass. This parameter is only visible when you select Specify material properties for the **Parameterization** parameter. The default value is 0 g.

Initial Conditions Tab

damping effects may also be optionally	d force characteristics of a piezoelectric stacked actuator. Effective mass and mechanical y included. I + to - ports results in a positive displacement acting from the mechanical C to R ports.
Static Force Dynamic Forces Initial stack deflection: Initial voltage:	Initial Conditions
	OK Cancel Help Apply

Initial stack deflection

Stack deflection at time zero. If you have an external Ideal Translational Motion Sensor block attached across the Piezo Stack block, you must use the same initial deflection parameter for both blocks. The default value is 0 mm.

Initial voltage

Stack voltage at time zero. The default value is 0 V.

Ports The block has the following ports:

+

Positive electrical port.

Negative electrical port.

- Mechanical rotational conserving port.
- R

-

С

Mechanical rotational conserving port.

PJFET

Purpose	Model SPICE-compatible P-Channel JFET
Library	SPICE-Compatible Semiconductors
Description	The PJFET block represents a SPICE-compatible P-channel JFET.
°╼┽╗	The PJFET block model includes the following components:
PJFET	• "Source-Gate Current-Voltage Model" on page 2-294
	• "Drain-Gate Current-Voltage Model" on page 2-295
	 "Source-Drain Current-Voltage Model" on page 2-296

- "Junction Charge Model" on page 2-297
- "Temperature Dependence" on page 2-299

Source-Gate Current-Voltage Model

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

Applicable Range of V _{sg} Values	Corresponding I _{sg} Equation
$V_{sg} > 80 * V_t$	$I_{sg} = IS * \left(\left(\frac{V_{sg}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{sg} * G \min$
$80 * V_t \geq V_{sg}$	$I_{sg} = IS * (e^{V_{sg}/V_t} - 1) + V_{sg} * G \min$

Where:

- *IS* is the **Saturation current**, **IS** parameter value.
- $V_t = ND * k * T/q$
- *ND* is the **Emission coefficient**, **ND** parameter value.
- *q* is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Drain-Gate Current-Voltage Model

The block provides the following relationship between the drain-gate current I_{dg} and the drain-gate voltage V_{dg} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{dg} Values	Corresponding I _{dg} Equation
$V_{dg} > 80 * V_t$	$I_{dg} = IS * \left(\left(\frac{V_{dg}}{V_t} - 79 \right) e^{80} - 1 \right) + V_{dg} * G \min$
$80 * V_t \ge V_{dg}$	$I_{dg} = IS * (e^{V_{dg}/V_t} - 1) + V_{dg} * G \min$

Source-Drain Current-Voltage Model

The block provides the following relationship between the source-drain current I_{sd} and the source-drain voltage V_{sd} in normal mode ($V_{sd} \ge 0$) after adjusting the applicable model parameters for temperature.

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

Where:

- V_{to} is the **Threshold voltage**, **VTO** parameter value.
- β is the **Transconductance**, **BETA** parameter value.
- λ is the **Channel modulation**, **LAMBDA** parameter value.

The block provides the following relationship between the source-drain current I_{sd} and the source-drain voltage V_{sd} in inverse mode ($V_{sd} < 0$) after adjusting the applicable model parameters for temperature.

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

Junction Charge Model

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

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

Where:

- *FC* is the **Capacitance coefficient FC** parameter value.
- *VJ* is the **Junction potential VJ** parameter value.
- CGS is the Zero-bias GS capacitance, CGS parameter value.
- *MG* is the **Grading coefficient**, **MG** parameter value.

$$F1 = \frac{VJ * (1 - (1 - FC)^{1-MG})}{1 - MG}$$

•
$$F2 = (1 - FC)^{1+MG}$$

•
$$F3 = 1 - FC * (1 + MG)$$

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

Applicable Range of V _{dg} Values	Corresponding Q _{dg} Equation
$V_{dg} < FC * VJ$	$Q_{dg} = \frac{CGD * VJ * \left(1 - \left(1 - \frac{V_{dg}}{VJ}\right)^{1 - MG}\right)}{1 - MG}$
$V_{dg} \ge FC * VJ$	$Q_{dg} = CGD * \left(F1 + \frac{F3 * (V_{dg} - FC * VJ) + \frac{MG * (V_{dg}^2 - (FC * VJ)^2)}{2 * VJ}}{F2} \right)$

Where:

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

Temperature Dependence

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

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

$$T = T_C + T_O$$

where:

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

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

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

where:

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

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

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

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

where:

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

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

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

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

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

where:

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

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

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

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

where 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

is model approximates a 9	PICE P-channel JFET. You specify	both model card and instance
arameters as instance para	ameters on this mask. The instanc	e parameter OFF and noise n
arameters KF and AF are n DFFSET, ND, MG, XTI and	ot supported. Additional instance EG.	parameters are SCALE,
	allel JFET instances for this device lirectly. This differs from the AREA	
	, CGS, CGD, and divides RS and R	
u can set the JFET temper	rature to a fixed temperature or t	o the circuit temperature (fro
e Custom Electrical Enviror Ijust temperature sensitive	nment block) plus TOFFSET. The p e parameters	parameters ND, MG, XTI and
	 exclude capacitance modeling an he published temperature equation 	
ferent value than SPICE f	or capacitance. The initial condition	ons ICVDS and ICVGS are the
ltages across the internal pacitances are present.	junctions, and are only effective	when the corresponding junc
ameters		
Main Junction Capacit	tance Temperature	
Deutice area, ADEA	1	m^2
	1.	
Device area, AREA:		
Number of parallel devices, SCALE:	1	
Number of parallel	-2	
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance,	-2	
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA:	-2 1e-04	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance,	-2	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation,	-2 1e-04	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA:	-2 1e-04 0	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND:	-2 1e-04 0 1e-14	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS:	-2 1e-04 0 1e-14 1	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND:	-2 1e-04 0 1e-14 1	A/m^2/V^2
Number of parallel devices, SCALE: Threshold voltage, VTO: Transconductance, BETA: Channel modulation, LAMBDA: Saturation current, IS: Emission coefficient, ND: Source resistance, RS:	-2 1e-04 0 1e-14 1	A/m^2/V^2

Device area, AREA

The transistor area. This value multiplies the **Transconductance, BETA**, **Zero-bias GS capacitance, CGS**, **Zero-bias GD capacitance, CGD**, and **Saturation current, IS** parameter values. It divides the **Source resistance, RS** and **Drain resistance, RD** parameter values. The default value is 1 m². The value must be greater than 0.

Number of parallel devices, SCALE

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

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is -2 V.

Transconductance, **BETA**

The derivative of drain current with respect to gate voltage. The default value is $1e - 04 \text{ A/m}^2/\text{V}^2$. The value must be greater than or equal to 0.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Saturation current, IS

The magnitude of the current that the ideal diode equation approaches asymptotically for very large reverse bias levels. The default value is $1e-14 \text{ A/m}^2$. The value must be greater than or equal to 0.

Emission coefficient, ND

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

Source resistance, RS

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

Drain resistance, RD

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

Junction Capacitance Tab

	Parameters: PJFET	
PJFET —		
paramete paramete	el approximates a SPICE P-channel JFET. You specify both model card and instance ers as instance parameters on this mask. The instance parameter OFF and noise mo ers KF and AF are not supported. Additional instance parameters are SCALE, r, ND, MG, XTI and EG.	de
current a	the number of parallel JFET instances for this device. SCALE multiplies the output and device charge directly. This differs from the AREA parameter, which multiples th arameters BETA, IS, CGS, CGD, and divides RS and RD.	e
the Custo	set the JFET temperature to a fixed temperature or to the circuit temperature (from om Electrical Environment block) plus TOFFSET. The parameters ND, MG, XTI and EG imperature sensitive parameters.	
capacitar different voltages	k lets you include or exclude capacitance modeling and initial conditions. The new modeling uses the published temperature equations, which may yield a slightly value than SPICE for capacitance. The initial conditions ICVDS and ICVGS are the across the internal junctions, and are only effective when the corresponding junction news are present.	on
Paramete	ers	_
Main	Junction Capacitance Temperature	
main		
Model	junction capacitance?: No	
	OK Cancel Help Apply	

Model junction capacitance

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

- No Do not include junction capacitance in the model. This is the default option.
- Yes Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion capacitance coefficient, and transit time.

Zero-bias GS capacitance, CGS

The value of the capacitance placed between the gate and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Zero-bias GD capacitance, CGD

The value of the capacitance placed between the gate and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be greater than or equal to 0.

Junction potential VJ

The junction potential. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 1 V. The value must be greater than 0.01 V.

Grading coefficient, MG

The transistor grading coefficient. The default value is 0.5. The value must be greater than 0 and less than 0.9.

Capacitance coefficient FC

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

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

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

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Temperature Tab

Block Parameters: PJFET				
PJFET				
This model approximates a SPICE P-ch parameters as instance parameters or parameters KF and AF are not support TOFFSET, ND, MG, XTI and EG.	n this mask.	The instance pa	rameter OFF and	d noise model
SCALE is the number of parallel JFET ir current and device charge directly. Th device parameters BETA, IS, CGS, CG	is differs fro	om the AREA par		
You can set the JFET temperature to a the Custom Electrical Environment bloo adjust temperature sensitive parameto	:k) plus TOF			
The block lets you include or exclude o capacitance modeling uses the publish different value than SPICE for capacit voltages across the internal junctions, capacitances are present.	ed temperal ance. The ir	ture equations, i nitial conditions I	which may yield (CVDS and ICVGS	a slightly 5 are the
Parameters				
Main Junction Capacitance	Temperatur	•]		
	romporacan	~		1
Model temperature dependence using:	Device te	mperature		_
Saturation current temperature exponent, XTI:	0			
Activation energy, EG:	1.11		eV	-
Offset local circuit temperature, TOFFSET:	0		K	-
Parameter extraction temperature, TMEAS:	300.15		К	-
	ОК	Cancel	Help	Apply

Model temperature dependence using

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

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

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.

PJFET

Ports	The block has the following ports:	
	G Electrical conserving port associated with the transistor gate terminal.	
	D Electrical conserving port associated with the transistor drain terminal.	
	S Electrical conserving port associated with the transistor source terminal.	
References	[1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 3.	
See Also	NJFET, P-Channel JFET	

Purpose Model SPICE-compatible P-Channel MOSFET

Library SPICE-Compatible Semiconductors

Description

HE PMOS The PMOS block represents a SPICE-compatible P-channel MOSFET. The PMOS block model includes the following components:

- "Resistance Calculations" on page 2-311
- "Bulk-Source Diode Model" on page 2-312
- "Bulk-Drain Diode Model" on page 2-313
- "Drain Current Model" on page 2-314
- "Junction Charge Model" on page 2-317
- "Temperature Dependence" on page 2-322

Resistance Calculations

The following table shows how the PMOS block calculates the transistor drain resistance. The abbreviations in the table represent the values of the following block parameters:

- Drain resistance, RD
- Sheet resistance, RSH
- Number of drain squares, NRD

Drain resistance, RD Parameter	Sheet resistance, RSH Parameter	Drain Resistance
NaN	NaN	0
RD	NaN or RSH	RD
NaN	RSH	RSH*NRD

The following table shows how the PMOS block calculates the transistor source resistance. The abbreviations in the table represent the values of the following block parameters:

- Source resistance, RS
- Sheet resistance, RSH
- Number of source squares, NRS

Source resistance, RS Parameter	Sheet resistance, RSH Parameter	Source Resistance
NaN	NaN	0
RS	NaN or RSH	RS
NaN	RSH	RSH*NRS

Bulk-Source Diode Model

The block provides the following relationship between the bulk-source current I_{sb} and the bulk-source voltage V_{sb} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{sb} Values	Corresponding I _{gs} Equation
$V_{sb} > 80 * V_{tn}$	$I_{sb} = IS_{sb} * \left(\left(\frac{V_{sb}}{V_{tn}} - 79 \right) e^{80} - 1 \right) + V_{sb} * G \min$
$80V_{tn} \ge V_{sb}$	$I_{sb} = IS_{sb} * (e^{V_{sb}/V_m} - 1) + V_{sb} * G \min$

Where:

- IS_{sb} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of source**, **AS** parameter value if both these

parameter values and the **Area of drain**, **AD** parameter value are nonzero.

- The Bulk saturation current, IS parameter value, otherwise.
- $V_{tn} = NkT/q$
- q is the elementary charge on an electron, 1.6021918e-19 C.
- *N* is the **Emission coefficient**, **ND** parameter value.
- k is the Boltzmann constant.
- *T* is the diode temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- *GMIN* is the diode minimum conductance. By default, *GMIN* matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change *GMIN*, add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Bulk-Drain Diode Model

The block provides the following relationship between the bulk-drain current I_{db} and the bulk-drain voltage V_{db} after adjusting the applicable model parameters for temperature.

Applicable Range of V _{db} Values	Corresponding I _{gs} Equation
$V_{db} > 80 * V_{tn}$	$I_{db} = IS_{db} * \left(\left(\frac{V_{db}}{V_{in}} - 79 \right) e^{80} - 1 \right) + V_{db} * G \min$
$80V_{tn} \ge V_{db}$	$I_{db} = IS_{db} * (e^{V_{db}/V_{m}} - 1) + V_{db} * G \min$

Where:

- *IS*_{*db*} is
 - The product of the **Bulk jct sat current density**, **JS** parameter value and the **Area of drain**, **AD** parameter value if both these parameter values and the **Area of source**, **AS** parameter value are nonzero.
 - The Bulk saturation current, IS parameter value, otherwise.

Drain Current Model

The block provides the following relationship between the drain current

 I_{sd} and the drain-source voltage V_{sd} in normal mode ($V_{sd} \ge 0$) after adjusting the applicable model parameters for temperature.

Normal Mode

Applicable Range of V _{sg} and V _{sd} Values	Corresponding I _{sd} Equation
V_{sg} - $V_{on} \leq 0$	$I_{sd} = 0$

Normal Mode (Continued)

Applicable Range of V _{sg} and V _{sd} Values	Corresponding I _{sd} Equation
$0 < V_{sg} - V_{on} \leq V_{sd}$	$I_{sd} = BETA * \left(V_{sg} - V_{on}\right)^2 \frac{\left(1 + LAMBDA * V_{sd}\right)}{2}$
$0 < V_{sd} < V_{sg} - V_{on}$	$I_{sd} = BETA * V_{sd} \left(\left(V_{sg} - V_{on} \right) - \frac{V_{sd}}{2} \right) \left(1 + LAMBDA * V_{sd} \right)$

Where:

- V_{on} is:
 - $MTYPE * VBI + GAMMA \sqrt{PHI V_{sb}}$ if $V_{sb} \le 0$.
 - $\begin{array}{ll} \bullet & MTYPE*VBI+GAMMA\left(\sqrt{PHI}-\frac{V_{sb}}{2\sqrt{PHI}}\right) \mbox{if } 0 < V_{sb} \leq 2*PHI \ . \\ \bullet & MTYPE*VBI \mbox{if } V_{sh} > 2*PHI. \end{array}$
- MTYPE is -1.
- *BETA* is *KP*WIDTH/(LENGTH-2*LD)*
- *KP* is:
 - The **Transconductance**, **KP** parameter value, if this parameter has a numerical value.
 - $U0*3.9*\varepsilon_0/TOX$, if **Transconductance**, **KP** is NaN and you specify values for both the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters.
- *WIDTH* is the **Width of channel, WIDTH** parameter value.

- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- LD is the Lateral diffusion, LD parameter value.
- *VBI* is an built-in voltage value the block uses in calculations. The value is a function of temperature. For a detailed definition, see "Temperature Dependence" on page 2-181.
- *PHI* is:
 - The **Surface potential**, **PHI** parameter value, if this parameter has a numerical value.
 - $2 * kT_{meas} / q * \log(NSUB / n_i)$, if Surface potential, PHI is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- LAMBDA is the Channel modulation, LAMBDA parameter value.
- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.
- ε_0 is the permittivity of free space, 8.854214871e-12 F/m.
- n_i is the carrier concentration of intrinsic silicon, 1.45e10 cm⁻³.

The block provides the following relationship between the drain current

 I_{sd} and the drain-source voltage V_{sd} in inverse mode ($V_{sd} < 0$) after adjusting the applicable model parameters for temperature.

Inverse Mode

Applicable Range of V _{dg} and V _{sd} Values	Corresponding I _{sd} Equation
V_{dg} - $V_{on} \leq 0$	$I_{sd} = 0$
$0 < V_{dg} - V_{on} \leq -V_{sd}$	$I_{sd} = -BETA \left(V_{dg} - V_{on} \right)^2 \left(1 - LAMBDA * V_{sd} \right) / 2$
$0 < V_{sd} < V_{dg}$ - V_{on}	$I_{sd} = BETA * V_{sd} \left(\left(V_{dg} - V_{on} \right) + V_{sd} / 2 \right) \left(1 - LAMBDA * V_{sd} \right)$

Where:

• *V*_{on} is:

•

- $MTYPE * VBI + GAMMA \sqrt{PHI - V_{db}}$ if

 $V_{db} \leq 0$

- $MTYPE * VBI + GAMMA\left(\sqrt{PHI} \frac{V_{db}}{2\sqrt{PHI}}\right)$ if $0 < V_{db} \le 2 * PHI$
- MTYPE*VBI if $V_{db} > 2*PHI$.

Junction Charge Model

The block models the following junction charges:

• Junction Overlap Charges

• Bulk Junction Charges

Junction Overlap Charges

The block calculates the following junction overlap charges:

• Q_{SG}=CGSO*WIDTH*V_{so}

Where:

- *Q*_{SG} is the gate-source overlap charge.
- CGSO is the G-S overlap capacitance, CGSO parameter value.
- *WIDTH* is the **Width of channel**, **WIDTH** parameter value.
- $Q_{DG} = CGDO^*WIDTH^*V_{dg}$

Where:

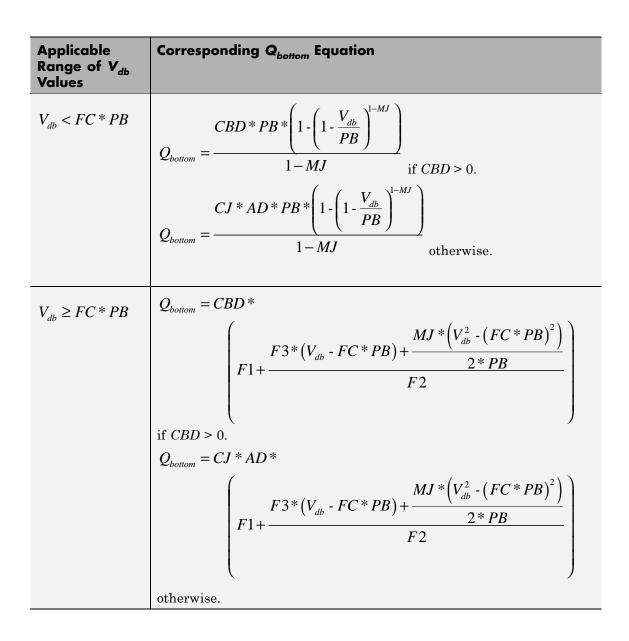
- Q_{DG} is the gate-drain overlap charge.
- *CGDO* is the **G-D overlap capacitance**, **CGDO** parameter value.
- $Q_{BG} = CGBO^*(LENGTH-2^*LD)^*V_{bg}$

Where:

- Q_{BG} is the gate-bulk overlap charge.
- *CGBO* is the **G-B overlap capacitance**, **CGBO** parameter value.
- *LENGTH* is the **Length of channel, LENGTH** parameter value.
- *LD* is the **Lateral diffusion**, **LD** parameter value.

Bulk Junction Charges

The block provides the following relationship between the bulk-drain bottom junction charge Q_{bottom} and the junction voltage V_{db} after adjusting the applicable model parameters for temperature.



Where:

- *PB* is the **Bulk junction potential**, **PB** parameter value.
- FC is the Capacitance coefficient FC parameter value.
- CBD is the Zero-bias BD capacitance, CBD parameter value.
- CJ is the Bottom junction cap per area, CJ parameter value.
- *AD* is the **Area of drain**, **AD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$F1 = \frac{PB * (1 - (1 - FC)^{1 - MJ})}{1 - MJ}$$

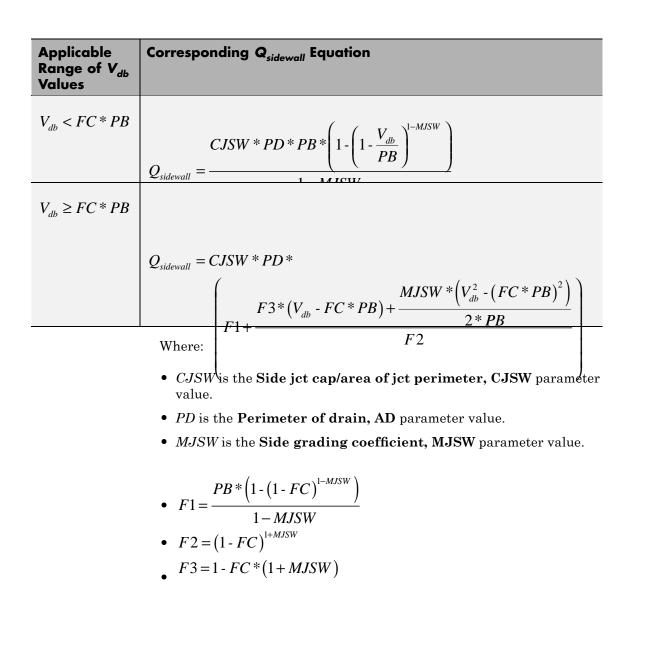
•
$$F2 = (1 - FC)^{I+MJ}$$

•
$$F3 = 1 - FC * (1 + MJ)$$

The block uses the equations in the preceding table to calculate the bulk-source bottom junction charge, with the following substitutions:

- V_{sb} replaces V_{db}.
- *AS* (the **Area of source, AS** parameter value) replaces *AD*.
- *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) replaces *CBD*.

The block provides the following relationship between the bulk-drain sidewall junction charge $Q_{sidewall}$ and the junction voltage V_{db} after adjusting the applicable model parameters for temperature.



The block uses the equations in the preceding table to calculate the bulk-source sidewall junction charge and the sidewall junction voltage, with the following substitutions:

- V_{sb} replaces V_{db} .
- *PS* (the **Perimeter of source, PS** parameter value) replaces *PD*.

Temperature Dependence

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

• When you select Device temperature for the Model temperature dependence using parameter, the transistor temperature is

$$T = T_C + T_O$$

where:

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

The block provides the following relationship between the transconductance KP and the transistor temperature T:

$$KP(T) = \frac{KP}{\left(\frac{T}{T_{meas}}\right)^{3/2}}$$

where:

- *KP* is the **Transconductance**, **KP** parameter value.
- T_{meas} is the **Parameter extraction temperature**, **TMEAS** parameter value.

The block provides the following relationship between the surface potential PHI and the transistor temperature T:

$$\begin{split} PHI(T) &= \frac{T}{T_{meas}} \Bigg(PHI + \frac{kT_{meas}}{q} \Bigg(\log \Bigg(\frac{T_{meas}}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T_{meas}} \Bigg) \Bigg) \Bigg) \\ &- \frac{kT}{q} \Bigg(\log \Bigg(\frac{T}{300.15} \Bigg)^3 + \frac{q}{k} \Bigg(\frac{1.115}{300.15} - \frac{EG_T}{T} \Bigg) \Bigg) \end{split}$$

where:

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

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

The block provides the following relationship between the built-in voltage *VBI* and the transistor temperature *T*:

$$VBI(T) = VTO + MTYPE * \left(\frac{PHI(T) - PHI}{2} - GAMMA\sqrt{PHI}\right) + \frac{EG_{T_{meas}} - EG_T}{2}$$

where:

- VTO is:
 - The **Threshold voltage**, **VTO** parameter value, if this parameter has a numerical value.

• $\Phi - 3.25 + EG_{T_{max}}/2 + MTYPE * PHI/2 - NSS * q * TOX / (3.9 * \varepsilon_0)$

+*MTYPE* *(*GAMMA* * \sqrt{PHI} + *PHI*), if Threshold voltage, VTO is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

- Φ is:
 - **3.2**, if *TPG* (the **Gate type?**, **TPG** parameter value) is **0**.

-
$$3.25 + EG_{T_{meas}}/2 - MTYPE * TPG * EG_{T_{meas}}/2$$
, otherwise.

- GAMMA is:
 - The **Bulk threshold**, **GAMMA** parameter value, if this parameter has a numerical value.
 - $TOX * \sqrt{2*11.7 * \varepsilon_0 * q * NSUB} / (3.9 * \varepsilon_0)$, if Bulk threshold, GAMMA is NaN and you specify values for both the Oxide thickness, TOX and Substrate doping, NSUB parameters.

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

$$IS(T) = IS * e^{\frac{-qEG_T}{ND*kT} + \frac{qEG_{T_{meas}}}{ND*kT_{meas}}}$$

where:

- *ND* is the **Emission coefficient**, **ND** parameter value.
- *IS* is the **Bulk saturation current**, **IS** parameter value.

The block provides the following relationship between the bulk junction saturation current density *JS* and the transistor temperature *T*:

$$JS(T) = JS * e^{\frac{-qEG_T}{ND^*kT} + \frac{qEG_{T_{meas}}}{ND^*kT_{meas}}}$$

where:

• JS is the **Bulk jct sat current density**, JS parameter value.

The block provides the following relationship between the bulk junction potential PB and the transistor temperature T:

$$PB(T) = \frac{PB + \frac{kT_{meas}}{q} \left(\log\left(\frac{T_{meas}}{300.15}\right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T}\right) \right)}{T_{meas}/T} - \frac{kT}{q} \left(\log\left(\frac{T}{300.15}\right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_T}{T}\right) \right)$$

where:

• *PB* is the **Bulk junction potential**, **PB** parameter value.

The block provides the following relationship between the bulk-drain junction capacitance CBD and the transistor temperature T:

$$CBD(T) = CBD \frac{pbo + MJ * (4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo))}{MJ * (4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo))}$$

where:

- *CBD* is the **Zero-bias BD capacitance**, **CBD** parameter value.
- *MJ* is the **Bottom grading coefficient**, **MJ** parameter value.

•
$$pbo = \frac{PB + \frac{kT_{meas}}{q} \left(\log \left(\frac{T_{meas}}{300.15} \right)^3 + \frac{q}{k} \left(\frac{1.115}{300.15} - \frac{EG_{T_{meas}}}{T} \right) \right)}{T_{meas}}$$

The block uses the CBD(T) equation to calculate:

- The bulk-source junction capacitance by substituting *CBS* (the **Zero-bias BS capacitance, CBS** parameter value) for *CBD*.
- The bottom junction capacitance by substituting *CJ* (the **Bottom junction cap per area**, *CJ* parameter value) for *CBD*.

The block provides the following relationship between the sidewall junction capacitance CJSW and the transistor temperature T:

$$CJSW(T) = CJSW \frac{pbo + MJSW * \left(4 * 10^{4} * (T - 300.15) * pbo - (PB(T) - pbo)\right)}{pbo + MJSW * \left(4 * 10^{4} * (T_{meas} - 300.15) * pbo - (PB - pbo)\right)}$$

where:

• *MJSW* is the **Side grading coefficient**, **MJSW** parameter value.

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

Dialog Box and Parameters

Model Selection Ta

MOS								
This model approxim his mask. The instai MOS instances for the which multiples the o and RSH.	nce parameter C his device. SCAL	OFF and noise E multiplies th	model paramete le output current	ers KF and A t and device	AF are not e charge di	supported. SCA rectly. This diffe	LE is the number ers from the ARE/	of para A parar
You can set the MOS olus TOFFSET. The l CVBS are the voltagoresent. If physical parameters TOX and	block lets you ind ges across the ir parameters VTC	dude or exclu nternal junctio), KP, PHI, or	de capacitance n ns, and are only GAMMA are assig	nodeling an effective v gned a NaN	d initial cor when the c I value, the	ditions. The initi orresponding jur y will be calcula	ial conditions ICV nction capacitanc ted from specifie	DS, IC es are
Parameters								
Model Selection	Dimensions	Resistors	DC currents	C-V	Process	Temperature	1	
MOS model:		Le	vel 1 MOS					
Gate type?, TPG:		Or	oposite of substr	ate				

MOS model

Select one of the following MOSFET model options:

• Level 1 MOS — This is the default (and only) option.

Gate type?,TPG

Select one of the following MOSFET gate materials (as compared to the substrate):

- Opposite of substrate The gate material is the opposite of the substrate. This means that TPG = 1 in the device equations. This is the default option.
- Same as substrate The gate material is the same as the substrate. This means that TPG = -1 in the device equations.
- Aluminum The gate material is aluminum. This means that TPG = 0 in the device equations.

Dimensions Tab

IMOS	1 nMOSFET. You specify both model card and instance pa	rameters as instance parameters
his mask. The instance parameter OF	and noise model parameters KF and AF are not supporte multiplies the output current and device charge directly. Th	d. SCALE is the number of paralle
	KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW	
	fixed temperature or to the circuit temperature (from the de or exclude capacitance modeling and initial conditions. T	
	rnal junctions, and are only effective when the correspon (P. PHI, or GAMMA are assigned a NaN value, they will be	
	s RD, RS or RSH are not used in block calculations when t	
Parameters		
Model Selection Dimensions	Resistors DC currents C-V Process Tempe	rature
Device area factor, AREA:	1	
Number parallel devices, SCALE:	1	
Length of channel, LENGTH:	1e-04	m
Width of channel, WIDTH:	1e-04	m
Area of drain, AD:	0	m^2
i i		
Area of source, AS:	0	m^2
Perimeter of drain, PD:	0	m
Perimeter of source, PS:	0	m

Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transconductance, KP
- Bulk saturation current, IS
- Bulk jct sat current density, JS

- Zero-bias BD capacitance, CBD
- Zero-bias BS capacitance, CBS
- G-S overlap capacitance, CGSO
- G-D overlap capacitance, CGDO
- G-B overlap capacitance, CGBO
- Bottom junction cap per area CJ
- Side jct cap/area of jct perimeter CJSW

It divides the following parameter values:

- Drain resistance, RD
- Source resistance, RS
- Sheet resistance, RSH

The default value is 1. The value must be greater than 0.

Number of parallel devices, SCALE

The number of parallel MOS instances for this device. This parameter multiplies the output current and device charge. The default value is 1. The value must be greater than 0.

Length of channel, LENGTH

Length of the channel between the source and drain. The default value is 1e-04 m.

Width of channel, WIDTH

Width of the channel between the source and drain. The default value is 1e-04 m.

Area of drain, AD

Area of the transistor drain diffusion. The default value is 0 m^2 . The value must be greater than or equal to 0.

Area of source, AS

Area of the transistor source diffusion. The default value is 0 m². The value must be greater than or equal to 0.

Perimeter of drain, PD

Perimeter of the transistor drain diffusion. The default value is 0 m. $\,$

Perimeter of source, PS

Perimeter of the transistor source diffusion. The default value is 0 m.

Resistors Tab

e to a fixed temp	anature or to the				
	le capacitance mo	deling and initial co		conditions ICVE	S, ICVG
/TO, KP, PHI, or (GAMMA are assign	ned a NaN value, th	ey will be calculate	d from specified	
meters RD, RS or	RSH are not used	d in block calculation	s when their value	is NaN.	
		Γ.	,		
s Resistors	DC currents	C-V Process	Temperature		
NaN				Ohm	•
NaN				Ohm	•
NaN				Ohm	•
): 1					
RS: 1					
	VTO, KP, PHI, or (meters RD, RS or is Resistors NaN NaN NaN 0: 1	VTO, KP, PHI, or GAMMA are assign meters RD, RS or RSH are not used is Resistors DC currents NaN NaN D: 1	VTO, KP, PHI, or GAMMA are assigned a NaN value, the meters RD, RS or RSH are not used in block calculation is Resistors DC currents C-V Process NaN NaN D: 1	VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculate meters RD, RS or RSH are not used in block calculations when their value is Resistors DC currents C-V Process Temperature NaN NaN NaN D: 1	NaN Ohm NaN Ohm NaN Ohm 0: 1

Drain resistance, RD

The transistor drain ohmic resistance. The default value is Nan Ω . This value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 2-311. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Source resistance, RS

The transistor source ohmic resistance. The default value is Nan Ω . This value means the parameter is unspecified, so the block calculates the drain resistance as described in "Resistance Calculations" on page 2-311. The value must be equal to 0 or greater than or equal to Rmin. Rmin is a built-in model constant whose value is 1e-12.

Sheet resistance, RSH

Resistance per square of the transistor source and drain. The default value is Nan Ω . This value means the parameter is unspecified. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-311. The value must be greater than or equal to 0.

Number of drain squares, NRD

Number of squares of resistance that make up the transistor drain diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-311.

Number of source squares, NRD

Number of squares of resistance that make up the transistor source diffusion. The default value is 1. The value must be greater than or equal to 0. The block only uses this parameter value if you do not specify one or both of the **Drain resistance**, **RD** and **Source resistance**, **RS** parameter values, as described in "Resistance Calculations" on page 2-311.

DC Currents Tab

10S		
is mask. The instance parameter OFF OS instances for this device. SCALE m	I nMOSFET. You specify both model card and instance par and noise model parameters KF and AF are not supported ultiplies the output current and device charge directly. Thi P, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW a	I. SCALE is the number of parallel s differs from the AREA paramete
us TOFFSET. The block lets you includ WBS are the voltages across the inter esent. If physical parameters VTO, KI	ixed temperature or to the circuit temperature (from the e or exclude capacitance modeling and initial conditions. Ti al junctions, and are only effective when the correspond , PHI, or GAMMA are assigned a NaN value, they will be c RD, RS or RSH are not used in block calculations when the	ne initial conditions ICVDS, ICVGS ing junction capacitances are alculated from specified process
arameters		
Model Selection Dimensions F	esistors DC currents C-V Process Temper	ature
Threshold voltage, VTO:	0	V
Transconductance, KP:	2e-05	A/V^2
Bulk threshold, GAMMA:	0	V^0.50000
Surface potential, PHI:	0.6	V
Channel modulation, LAMBDA:	0	1/V 💌
Bulk saturation current, IS:	1e-14	A
Bulk jct sat current density, JS:	0	A/m^2
Emission coefficient, ND:	1	

Threshold voltage, VTO

The gate-source voltage above which the transistor produces a nonzero drain current. The default value is 0 V. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate**

doping, NSUB parameters. For more information about this calculation, see "Temperature Dependence" on page 2-181.

Transconductance, KP

The derivative of drain current with respect to gate voltage. The default value is $2e \cdot 05 \text{ A/V}^2$. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Bulk threshold, GAMMA

Body effect parameter, which relates the threshold voltage, VTH, to the body bias, VBS, as described in "Drain Current Model" on

page 2-173. The default value is 0 \sqrt{V} . The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness, TOX** and **Substrate doping, NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Surface potential, PHI

Twice the voltage at which the surface electron concentration becomes equal to the intrinsic concentration and the device transitions between depletion and inversion conditions. The default value is 0.6 V. The value must be greater than or equal to 0. If you assign this parameter a value of NaN, the block calculates the value from the specified values of the **Oxide thickness**, **TOX** and **Substrate doping**, **NSUB** parameters. For more information about this calculation, see "Drain Current Model" on page 2-173.

Channel modulation, LAMBDA

The channel-length modulation. The default value is 0 1/V.

Bulk saturation current, IS

The magnitude of the current that the junction approaches asymptotically for very large reverse bias levels. The default value is 1e-14 A. The value must be greater than or equal to 0.

Bulk jct sat current density, JS

The magnitude of the current per unit area that the junction approaches asymptotically for very large reverse bias levels. The default value is 0 A/m^2 . The value must be greater than or equal to 0.

Emission coefficient, ND

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

C-V Tab

NMOS This model approximates a SPICE level 1 nMOSFET. You specify both model card and instance parameters as instance parameters on this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. You can set the MOS temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters bloc plus TOPFSET. The block lets you include or exclude capacitance modeling and initial conditions. The initial conditions ICVDS, ICVDS at CVBS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NAN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NAN. Parameters Model Selection Dimensions Resistors DC currents C-V Process Temperature Model junction capacitancee?: No Image: Top of the selection is not parameter in the internal selection is not parameter in the internal selection is not parameter in the internal selection is not parameters. Image: Top of the selection is not parameter in the internal selection is not parameter in the internal selection is not parameters.	MOS								
this mask. The instance parameter OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel MOS instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters KP, IS, JS, CBD, CBS, CGSO, CGDO, CGBO, CJ and CJSW and divides the parameters RD, RS and RSH. You can set the MOS temperature to a fixed temperature or to the circuit temperature (from the SPICE Environment Parameters bloc plus TOFFSET. The block lets you include or exclude capacitance modeling and initial conditions. The initial conditions ICVDS, ICVDS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters RD, RS or RSH are not used in block calculations when their value is NaN.	NI-105								
Doub TOFFSET. The block lets you include or exclude capacitance modeling and initial conditions. The initial conditions ICVDS, ICVGS are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. If physical parameters VTO, KP, PHI, or GAMMA are assigned a NaN value, they will be calculated from specified process parameters TOX and NSUB. Parameters RD, RS or RSH are not used in block calculations when their value is NaN. Parameters Model Selection Dimensions Resistors DC currents C-V Process Temperature	his mask. The insta MOS instances for t which multiples the o	nce parameter C his device. SCAL	DFF and noise r E multiplies the	nodel parameter output current	rs KF and AF a and device ch	re not suppo arge directly	rted. SCALE i This differs f	s the number from the ARE	of parallel A parameter,
Model Selection Dimensions Resistors DC currents C-V Process Temperature	olus TOFFSET. The ICVBS are the volta present. If physical	block lets you inc ges across the in parameters VTO	dude or exclud nternal junction), KP, PHI, or G	e capacitance m ns, and are only GAMMA are assig	odeling and ini effective wher ned a NaN val	tial condition n the corresp ue, they will	s. The initial c onding junction be calculated	onditions ICV on capacitan from specifie	/DS, ICVGS a ces are
	Parameters								
Model junction capacitance?: No	Model Selection	Dimensions	Resistors	DC currents	C-V Pro	cess Ten	nperature		

Model junction capacitance

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

• No — Do not include junction capacitance in the model. This is the default option.

• Yes — Specify zero-bias junction capacitance, junction potential, grading coefficient, forward-bias depletion and capacitance coefficient.

G-S overlap capacitance, CGSO

Gate-source capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-D overlap capacitance, CGDO

Gate-drain capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

G-B overlap capacitance, CGBO

Gate-base capacitance due to the diffusion that occurs when the device operates in depletion mode. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BD capacitance, CBD

The value of the capacitance placed between the base and the drain. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Zero-bias BS capacitance, CBS

The value of the capacitance placed between the base and the source. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0

F. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom junction cap per area CJ

Zero-bias bulk junction bottom capacitance per junction area. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m^2 . The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Bottom grading coefficient, MJ

The transistor bottom grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Side jct cap/area of jct perimeter CJSW

Zero-bias bulk junction sidewall capacitance per junction perimeter. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0 F/m. The value must be equal to 0 or greater than or equal to Cmin. Cmin is a built-in model constant whose value is 1e-18.

Side grading coefficient, MJSW

The transistor sidewall grading coefficient. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than MGmax. MGmax is a built-in model constant whose value is 0.9.

Bulk junction potential, PB

The potential across the bulk junction. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.8 V. The value must be equal to 0 or greater than or equal to VJmin. VJmin is a built-in model constant whose value is 0.01.

Capacitance coefficient FC

The fitting coefficient that quantifies the decrease of the depletion capacitance with applied voltage. This parameter is only visible when you select Yes for the **Model junction capacitance** parameter. The default value is 0.5. The value must be equal to 0 or less than or equal to FCmax. FCmax is a built-in model constant whose value is 0.95.

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial diode voltage.

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

Initial condition voltage ICVDS

Drain-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model** junction capacitance and Yes for the **Specify initial** condition parameter. The default value is 0 V.

Initial condition voltage ICVGS

Gate-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Initial condition voltage ICVBS

Bulk-source voltage at the start of the simulation. This parameter is only visible when you select Yes for the **Model junction capacitance** and Yes for the **Specify initial condition** parameter. The default value is 0 V.

Process Tab

Block Parameters: NMOS					
MOS					
his model approximates a SPICE level his mask. The instance parameter OFF					
IOS instances for this device. SCALE m					
hich multiples the device parameters P	KP, IS, JS, CBD, CBS, CGS	O, CGDO, CGBO,	CJ and CJSW and divi	ides the parameters	RD, R
nd RSH.					
ou can set the MOS temperature to a					
lus TOFFSET. The block lets you includ CVBS are the voltages across the inter					
resent. If physical parameters VTO, K					
parameters TOX and NSUB. Parameters	s RD, RS or RSH are not u	sed in block calcul	ations when their value	e is NaN.	
Parameters					
arameters					
Model Selection Dimensions F	Resistors DC currents	C-V Proce	ess Temperature		
Oxide thickness, TOX:	NaN			m	-
Lateral diffusion, LD:	0			m	-
i i					- 7
Substrate doping, NSUB:	NaN			1/cm^3	•
Surface state density, NSS:	0			1/cm^2	•
Surface mobility, U0:	600			cm^2/s/V	-

Oxide thickness, TOX

Thickness of the gate oxide. The default value is NaN m. The value must be greater than or equal to 0.

Lateral diffusion, LD

Length of lateral diffusion. The default value is 0 m.

Substrate doping, NSUB

Substrate doping. The default value is NaN $1/cm^3$. The value must be greater than or equal to 1.45e10 (the carrier concentration of intrinsic silicon).

Surface state density, NSS

Substrate doping. The default value is $0 \ 1/cm^2$.

Surface mobility, U0

Zero-bias surface mobility coefficient. The default value is $600\ cm^2/V/s.$

Temperature Tab

Block Parameters: NMOS					
IMOS					
his model approximates a SPICE level 1 nM his mask. The instance parameter OFF and 10S instances for this device. SCALE multip which multiples the device parameters KP, I ind RSH.	noise model parameter	s KF and AF are not and device charge di	supported. SCALE rectly. This differe	E is the number s from the ARE	of parallel A parameter,
ou can set the MOS temperature to a fixed lus TOFFSET. The block lets you include or CVBS are the voltages across the internal present. If physical parameters VTO, KP, Pi parameters TOX and NSUB. Parameters RD	exclude capacitance m unctions, and are only HI, or GAMMA are assig	odeling and initial con effective when the conned a NaN value, the	nditions. The initial orresponding junc ey will be calculate	l conditions ICV tion capacitance d from specifie	, DS, ICVGS and ces are
Parameters					
Model Selection Dimensions Resis	tors DC currents	C-V Process	Temperature		
Model temperature dependence using: Offset local circuit temperature,	Device temperature			K	- -
TOFFSET:	10			I.K.	<u> </u>
Parameter extraction temperature, TMEAS:	300.15			К	•
		ОК			

Model temperature dependence using

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

• Device temperature — Use the device temperature, which is the Circuit temperature value plus the Offset local circuit temperature, TOFFSET value. The Circuit temperature value comes from the SPICE Environment Parameters block, if

	one exists in the circuit. Otherwise, it comes from the default value for this block.
	 Fixed temperature — Use a temperature that is independent of the circuit temperature to model temperature dependence.
	Offset local circuit temperature, TOFFSET The amount by which the transistor temperature differs from the circuit temperature. This parameter is only visible when you select Device temperature for the Model temperature dependence using parameter. The default value is 0 K.
	Fixed circuit temperature, TFIXED The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the Model temperature dependence using parameter. The default value is 300.15 K. The value must be greater than 0.
	Parameter extraction temperature, TMEAS The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.
Ports	The block has the following ports:
	G Electrical conserving port associated with the transistor gate terminal.
	D Electrical conserving port associated with the transistor drain terminal.
	S Electrical conserving port associated with the transistor source terminal.
	B Electrical conserving port associated with the transistor bulk terminal.

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

See Also NMOS

Purpose Model Gummel-Poon PNP Transistor

Library SPICE-Compatible Semiconductors

Description

κ: _{PNP} The PNP block represents a SPICE-compatible four-terminal Gummel-Poon PNP transistor. The substrate port is connected to the transistor body using a capacitor, so these devices are equivalent to a three-terminal transistor when you connect the substrate port to any other port and use the default value of zero for the **C-S junction capacitance**, **CJS** parameter.

The PNP block model includes the following components:

- "Current-Voltage and Base Charge Model" on page 2-345
- "Base Resistance Model" on page 2-348
- "Transit Charge Modulation Model" on page 2-349
- "Junction Charge Model" on page 2-350
- "Temperature Dependence" on page 2-352

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 345
- Terminal Currents on page 347
- Base Charge Model on page 348

Emitter-Base and Collector-Base Junction Currents

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

• When $V_{EB} > 80 * V_{TF}$:

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

• When $V_{EB} \le 80 * V_{TF}$

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

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

• When $V_{CB} > 80 * V_{TR}$:

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

• When $V_{CB} \leq 80 * V_{TR}$

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

In the preceding equations:

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

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

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

- *ISC* and *ISE* are the **B-C leakage current**, **ISC** and **B-E leakage current**, **ISE** parameter values, respectively.
- *NE*, *NC*, *NF*, and *NR* are the **B-E emission coefficient**, **NE**, **B-C emission coefficient**, **NC**, **Forward emission coefficient**, **NF** and **Reverse emission coefficient**, **NR** parameter values, respectively.
- q is the elementary charge on an electron.
- k is the Boltzmann constant.
- *T* is the transistor temperature:
 - If you select Device temperature for the Model temperature dependence using parameter, *T* is the sum of the Circuit temperature value plus the Offset local circuit temperature, TOFFSET parameter value. The Circuit temperature value comes from the SPICE Environment Parameters block, if one exists in the circuit. Otherwise, it comes from the default value for this block.
 - If you select Fixed temperature for the Model temperature dependence using parameter, T is the Fixed circuit temperature, TFIXED parameter value.
- G_{min} is the minimum conductance. By default, G_{min} matches the **Minimum conductance GMIN** parameter of the SPICE Environment Parameters block, whose default value is 1e-12. To change G_{min} , add a SPICE Environment Parameters block to your model and set the **Minimum conductance GMIN** parameter to the desired value.

Terminal Currents

The terminal currents, I_B and I_C are the base and collector currents, defined as positive into the device. They are calculated as:

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

where BF and BR are the **Forward beta**, **BF** and **Reverse beta**, **BR** parameter values, respectively.

Base Charge Model

The base charge, q_b , is calculated using the following equations:

$$\begin{aligned} q_b &= \frac{q_1}{2} \left(1 + \sqrt{0.5 * \left(\sqrt{(1 + 4 * q_2 - eps)^2 + eps^2} + 1 + 4 * q_2 - eps \right) + eps} \right) \\ q_1 &= \left(1 - \frac{V_{CB}}{VAF} - \frac{V_{EB}}{VAR} \right)^{-1} \\ q_2 &= \frac{I_{ebf}}{IKF} + \frac{I_{cbr}}{IKR} \end{aligned}$$

where

- *VAF* and *VAR* are the Forward Early voltage, VAF and Reverse Early voltage, VAR parameters, respectively.
- *IKF* and *IKR* are the **Forward knee current**, **IKF** and **Reverse knee current**, **IKR** parameter values, respectively.
- *eps* is 1e-4.

Base Resistance Model

The block models base resistance in one of two ways:

 If you use the default value of infinity for the Half base resistance cur, IRB parameter, the PNP block calculates the base resistance r_{bb} as

$$r_{bb} = RBM + \frac{RB - RBM}{q_b}$$

where:

- *RBM* is the **Minimum base resistance**, **RBM** parameter value.
- *RB* is the **Zero-bias base resistance**, **RB** parameter value.
- If you specify a finite value for the **Half base resistance cur, IRB** parameter, the PNP block calculates the base resistance r_{bb} as

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

where:

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

Transit Charge Modulation Model

If you specify nonzero values for the **Coefficient of TF, XTF** parameter, the block models transit charge modulation by scaling the **Forward transit time, TF** parameter value as follows:

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

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:

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

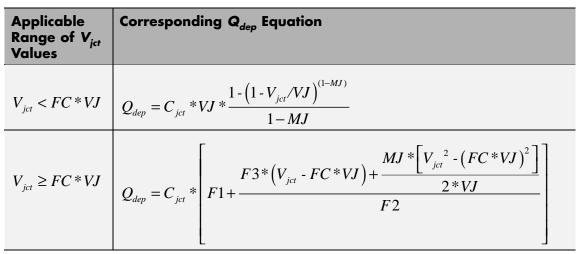
• For the internal base-collector junctions:

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

• For the external base-collector junctions:

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

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



Where:

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

- The **B-C depletion capacitance, CJC** parameter value for the collector-base junction.
- $F1 = VJ * (1 (1 FC)^{(1-MJ)}) / (1 MJ)$
- $F2 = (1 FC)^{(1+MJ)}$
- F3 = 1 FC * (1 + MJ)

The collector-substrate charge Q_{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
$V_{sc} < 0$	$Q_{sc} = CJS * VJS * \left(\frac{1 - \left(1 - V_{sc} / VJS\right)^{(1-MJS)}}{1 - MJS}\right)$
$V_{sc} \ge 0$	$Q_{sc} = CJS * (1 + MJS * V_{sc} / (2 * VJS)) * V_{sc}$
	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.

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

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

The block uses the VJE(T) equation to calculate the base-collector junction potential by substituting VJC (the **B-C built-in potential**, **VJC** parameter value) for VJE.

The block provides the following relationship between the base-emitter junction capacitance CJE and the transistor temperature T:

$$CJE(T) = CJE * \left[1 + MJE * \left(400e - 6 * \left(T - T_{meas} \right) - \frac{VJE(T) - VJE}{VJE} \right) \right]$$

where:

- CJE is the B-E depletion capacitance, CJE parameter value.
- *MJE* is the **B-E exponential factor**, **MJE** parameter value.

The block uses this equation to calculate the base-collector junction capacitance by substituting *CJC* (the **B-C depletion capacitance**, **CJC** parameter value) for *CJE* and *MJC* (the **B-C exponential factor**, **MJC** parameter value) for *MJE*.

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

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

where:

- β is the Forward beta, BF or Reverse beta, BR parameter value.
- *XTB* is the **Beta temperature exponent**, **XTB** parameter value.

The block provides the following relationship between the base-emitter leakage current ISE and the transistor temperature T:

$$ISE(T) = ISE * \left(\frac{T}{T_{meas}}\right)^{\text{XTB}} * \left(\frac{\text{IS}(T)}{\text{IS}}\right)^{1/NE}$$

where:

- *ISE* is the **B-E leakage current**, **ISE** parameter value.
- *NE* is the **B-E emission coefficient**, **NE** parameter value.

The block uses this equation to calculate the base-collector leakage current by substituting *ISC* (the **B-C leakage current, ISC** parameter value) for *ISE* and *NC* (the **B-C emission coefficient, NC** parameter value) for *NE*.

The model is based on the following assumptions:

and not across the block ports.

Basic Assumptions and Limitations

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

Dialog Box and Parameters

Main Tab

	Parameters: PNP				
PNP					
paramete	ers as instance par-		sk. The instanc	both model card and e parameters PTF ar	
current a device pa	and device charge o	lirectly. This differs ISE, IKR, ISC, IRB,	from the ARE	SCALE multiplies the A parameter, which r and CJS, and divide	multiples the
Custom B		nt block) plus TOFF) the circuit temperat meters XTB, XTI and	
capacitar different voltages	nce modeling uses t value than SPICE I	the published tempe for capacitance. Th	erature equations e initial conditions	d initial conditions. T ons, which may yield ons ICVBE and ICVCf when the correspon	a slightly E are the
Paramet	· .				
Main	Forward Gain	Reverse Gain	Resistors	Capacitance Te	mperature
				m^2	
Numb	e area, AREA: er of parallel es: SCALE:	1			
Numb		,			
Numb	er of parallel	,		Jir 2	
Numb	er of parallel	,		Jir 2	
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Numb	er of parallel	,		jir 2	
Numb	er of parallel	,			
Numb	er of parallel	,			
Numb	er of parallel	,	Cancel		Apply

Device area, AREA

The transistor area. This value multiplies the following parameter values:

- Transport saturation current, IS
- Forward knee current, IKF
- B-E leakage current, ISE
- Reverse knee current, IKR
- B-C leakage current, ISC
- Half base resistance cur, IRB
- B-E depletion capacitance, CJE
- Coefficient of TF, ITF
- B-C depletion capacitance, CJC
- C-S junction capacitance, CJS

It divides the following parameter values:

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

The default value is 1 m^2 . The value must be greater than 0.

Number of parallel devices, SCALE

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

Forward Gain Tab

🖥 Block Parameters: PNP X PNP-This model approximates a SPICE PNP transistor. You specify both model card and instance parameters as instance parameters on this mask. The instance parameters PTF and OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel BJT instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides the parameters RB, RBM, RE and RC. You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVBE and ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Forward Gain Reverse Gain Resistors Capacitance Main. Temperature Transport saturation 1e-16 A/m^2 • current, IS: Forward beta, BF: 100 Forward emission 1 coefficient, NF: B-E leakage current, ISE: 0 A/m^2 -B-E emission coefficient, 1.5 NE: Forward knee current, Inf A/m^2 • IKF: Forward Early voltage, Inf ۷ • VAE: OK. Cancel Help Apply

Transport saturation current, IS

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

Forward beta, BF

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

Forward emission coefficient, NF

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

B-E leakage current, ISE

The base-emitter leakage current. The default value is $0~\text{A}/\text{m}^2.$ The value must be greater than or equal to 0.

B-E emission coefficient, NE

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

Forward knee current, IKF

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

Forward Early voltage, VAF

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

Reverse Gain Tab

🙀 Block Parameters: PNP				X	
PNP					
This model approximates a S parameters as instance para noise model parameters KF a	meters on this ma	sk. The instance			
SCALE is the number of parallel BJT instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides the parameters RB, RBM, RE and RC.					
Custom Electrical Environmer	You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters.				
The block lets you include or capacitance modeling uses th different value than SPICE for voltages across the internal capacitances are present.	ne published temp or capacitance. Th	erature equatio he initial conditio	ns, which may yie Ins ICVBE and ICV	eld a slightly /CE are the	
Parameters					
Main Forward Gain	Reverse Gain	Resistors	Capacitance	Temperature	
Reverse beta, BR:	1				
Reverse emission	1				
coefficient, NR: B-C leakage current,	0		A/m^2		
ISC: B-C emission coefficient,	-		Appr 2	`III	
NC:	2				
Reverse knee current, IKR:	Inf		A/m^2	-	
Reverse Early voltage, VAR:	Inf		V	•	
	ОК	Cancel	Help	Apply	

Reverse beta, BR

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

Reverse emission coefficient, NR

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

B-C leakage current, ISC

The base-collector leakage current. The default value is $0~\text{A}/\text{m}^2.$ 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

🖥 Block Parameters: PNP X PNP-This model approximates a SPICE PNP transistor. You specify both model card and instance parameters as instance parameters on this mask. The instance parameters PTF and OFF and noise model parameters KF and AF are not supported. SCALE is the number of parallel BJT instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides the parameters RB, RBM, RE and RC. You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters. The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVBE and ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present. Parameters Reverse Gain Resistors Main Forward Gain Capacitance Temperature Emitter resistance, RE: 0 m^2*Ohm • Collector resistance, RC: 0 • m^2*Ohm Zero-bias base • 0 m^2*Ohm resistance, RB: Minimum base resistance, 0 m^2*Ohm • RBM: Half base resistance cur, Inf A/m^2 Ŧ IRB: OK. Cancel Help Apply

Emitter resistance, RE

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

Collector resistance, RC

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

Zero-bias base resistance, RB

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

Minimum base resistance, RBM

The resistance of the collector. The default value is $0 \text{ m}^{2*}\Omega$. The value must be less than or equal to the **Zero-bias base** resistance, **RB** parameter value.

Half base resistance cur, IRB

The base current at which the base resistance has dropped to half of its zero-bias value. The default value is $Inf A/m^2$. The value must be greater than or equal to 0. Use the default value of Inf if you do not want to model the change in base resistance as a function of base current.

Capacitance Tab

🙀 Block Parameters: PNP	×
PNP	
This model approximates a SPICE PNP transistor. You specify both model card and instance parameters as instance parameters on this mask. The instance parameters PTF and OFF and noise model parameters KF and AF are not supported.	
SCALE is the number of parallel BJT instances for this device. SCALE multiplies the output current and device charge directly. This differs from the AREA parameter, which multiples the device parameters IS, IKF, ISE, IKR, ISC, IRB, CJE, ITF, CJC and CJS, and divides the parameters RB, RBM, RE and RC.	
You can set the BJT temperature to a fixed temperature or to the circuit temperature (from the Custom Electrical Environment block) plus TOFFSET. The parameters XTB, XTI and EG adjust temperature sensitive parameters.	e
The block lets you include or exclude capacitance modeling and initial conditions. The capacitance modeling uses the published temperature equations, which may yield a slightly different value than SPICE for capacitance. The initial conditions ICVBE and ICVCE are the voltages across the internal junctions, and are only effective when the corresponding junction capacitances are present.	
Parameters	
Main Forward Gain Reverse Gain Resistors Capacitance Temperature	
Model junction capacitance?: No	
OK Cancel Help Apply	

Model junction capacitance

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

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

Note To include junction capacitance in the model:

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

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

B-E depletion capacitance, CJE

The depletion capacitance across the base-emitter junction. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 0 F/m². The value must be greater than or equal to 0.

B-E built-in potential, VJE

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

B-E exponential factor, MJE

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

Forward transit time, TF

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

Coefficient of TF, XTF

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

VBC dependence of TF, VTF

The coefficient for the base-emitter bias dependence of the transit time. This parameter is only visible when you select B-E Capacitance for the **Model junction capacitance** parameter. The default value is 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

🙀 Block Parameters: PNP			×
PNP			
This model approximates a SPICE PNP parameters as instance parameters on noise model parameters KF and AF are	this mask. The instar		
SCALE is the number of parallel BJT ins current and device charge directly. Thi device parameters IS, IKF, ISE, IKR, I: parameters RB, RBM, RE and RC.	is differs from the ARI	EA parameter, wh	ich multiples the
You can set the BJT temperature to a f Custom Electrical Environment block) pi temperature sensitive parameters.			
The block lets you include or exclude co capacitance modeling uses the publishe different value than SPICE for capacita voltages across the internal junctions, capacitances are present.	ed temperature equat ance. The initial condil	tions, which may y tions ICVBE and IC	ield a slightly IVCE are the
Parameters			
Main Forward Gain Reverse	Gain Resistors	Capacitance	Temperature
Model temperature dependence using:	Device temperature	•	_
Beta temperature exponent, XTB:	0		
Energy gap, EG:	1.11	eV	-
Temperature exponent for IS, XTI:	3		
Offset local circuit temperature TOFFSET:	0	К	_
Parameter extraction temperature, TMEAS:	300.15	K	_
	OK Canc	el Help	Apply

Model temperature dependence using

Select one of the following options for modeling the transistor temperature dependence:

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

Beta temperature exponent, XTB

The forward and reverse beta temperature exponent that models base current temperature dependence. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 0. The value must be greater than or equal to 0.

Energy gap, EG

The energy gap that affects the increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 1.11 eV. The value must be greater than or equal to 0.1.

Temperature exponent for IS, XTI

The order of the exponential increase in the saturation current as temperature increases. This parameter is only visible when you select Device temperature for the **Model temperature dependence using** parameter. The default value is 3. The value must be greater than or equal to 0.

Offset local circuit temperature, TOFFSET

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

	Parameter extraction temperature, TMEAS The temperature at which the transistor parameters were measured. The default value is 300.15 K. The value must be greater than 0.
	Fixed circuit temperature, TFIXED The temperature at which to simulate the transistor. This parameter is only visible when you select Fixed temperature for the Model temperature dependence using parameter. The default value is 300.15 K. The value must be greater than 0.
Ports	The block has the following ports:
	B Electrical conserving port associated with the transistor base terminal.
	C Electrical conserving port associated with the transistor collector terminal.
	E Electrical conserving port associated with the transistor emitter terminal.
	S Electrical conserving port associated with the transistor substrate terminal.
References	[1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993. Chapter 2.
See Also	PNP Bipolar Transistor

Purpose Model PNP bipolar transistor using enhanced Ebers-Moll equations

Library

Semiconductor Devices

Description



The PNP Bipolar Transistor block uses a variant of the Ebers-Moll equations to represent an PNP bipolar transistor. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. The PNP Bipolar Transistor block provides the following enhancements to that model:

- Early voltage effect
- Optional base, collector, and emitter resistances.
- Optional fixed base-emitter and base-collector capacitances.

The collector and base currents are [1]:

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

Where:

- I_B and I_C are base and collector currents, defined as positive into the device.
- V_{be} is the base-emitter voltage and V_{bc} is the base-collector voltage.
- β_F is the ideal maximum current gain BF
- β_R is the ideal maximum current gain BR
- V_A is the forward Early voltage VAF
- q is the elementary charge on an electron (1.602176e-19 Coulombs).
- k is the Boltzmann constant (1.3806503e-23 J/K).

PNP Bipolar Transistor • *T* is the transistor temperature, as defined by the **Measurement** temperature parameter value.

You can specify the transistor behavior using datasheet parameters that the block uses to calculate the parameters for these equations, or you can specify the equation parameters directly.

If $-qV_{\scriptscriptstyle BC}/(kT)>40$ or $-qV_{\scriptscriptstyle BE}/(kT)>40$, the corresponding exponential terms in the equations are replaced with

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

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

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

Optionally, you can specify parasitic fixed capacitances across the base-emitter and base-collector junctions. You also have the option to specify base, collector, and emitter connection resistances.

The PNP Bipolar Transistor model has the following limitations:

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

Basic Assumptions and Limitations

X

Dialog Box and Parameters

Main Tab

🙀 Block Parameters: PNP Bipolar Transistor

This block represents a PNP transistor modeled using a variant of the Ebers-Moll equations. The Ebers-Moll equations are based on two exponential diodes plus two current-controlled current sources. In addition, this block adds the Early voltage effect, and gives the option to include base, emitter and emitter resistances plus fixed base-emitter and base-collector capacitances. For full details of the equations, consult the documentation. The equation parameters can either be specified directly, or are derived from standard datasheet parameters.

-Parameters

Output admittance h_oe:	, 5e-05	1/Ohm 💌
Collector current at which h-paramete re defined:	1	mA 💌
oltage Vbe:	0.55	V
Current Ib for voltage Vbe:	0.5	mA 💌
leverse current transfer ratio BR:	1	
leasurement temperature:	25	C 💌

Parameterization

Select one of the following methods for block parameterization:

• Specify from a datasheet — Provide parameters that the block converts to equations that describe the transistor. The block calculates the forward Early voltage VAF as Ic/h_oe , where Ic is the **Collector current at which h-parameters are defined** parameter value, and h_oe is the **Output**

admittance h_oe parameter value [2]. The block sets BF to the small-signal Forward current transfer ratio h_fe value. The block calculates the saturation current *IS* from the specified Voltage Vbe value and the corresponding Current Ib for voltage Vbe value when *Ic* is zero. This is the default method.

• Specify using equation parameters directly — Provide equation parameters *IS*, *BF*, and *VAF*.

Forward current transfer ratio h_fe

Small-signal current gain. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 100.

Output admittance h_oe

Derivative of the collector current with respect to the collector-emitter voltage for a fixed base current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 5e-05 $1/\Omega$.

Collector current at which h-parameters are defined

The h-parameters vary with operating point, and are defined for this value of the collector current. This parameter is only visible when you select Specify from a datasheet for the **Parameterization** parameter. The default value is 1 mA.

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

ed bas	s the Early voltage eff e-emitter and base-col tion parameters can ei		s. For full details	s of the equation	s, consult the do	cumental
ramete	·	uner de specifieu u	irecuy, or are u	enveu from stan	uaru uatasheet p	Jaramete
Main	Ohmic Resistance	Junction Capacil	tance			
Collect	or resistance RC:	0.1			Ohm	•
Emitter	r resistance RE:	0.1			Ohm	-
Zero b	ias base resistance RB	0.1			Ohm	•

Collector resistance RC

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

Emitter resistance RE

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

Zero bias base resistance RB

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

Junction Capacitance Tab

PNP Bipolar Transistor This block represents a PNP tran	sistor modeled using a variant of t	the Ebers-Moll equations. The Et	oers-Moll
	onential diodes plus two current-c ect, and gives the option to include		
fixed base-emitter and base-coll	ector capacitances. For full details ther be specified directly, or are de	of the equations, consult the d	locumental
Parameters			paramete
Main Ohmic Resistance	Junction Capacitance		
Base-collector capacitance:	5	pF	•
Base-emitter capacitance:	5	pF	-
) <u>-</u>			

Base-collector capacitance

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

Base-emitter capacitance

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

PNP Bipolar Transistor

Ports	The block has the following ports:
	B Electrical conserving port associated with the transistor base terminal.
	C Electrical conserving port associated with the transistor collector terminal.
	E Electrical conserving port associated with the transistor emitter terminal.
Examples	See the Bipolar Transistor Characteristics demo.
References	[1] G. Massobrio and P. Antognetti. <i>Semiconductor Device Modeling with SPICE</i> . 2nd Edition, McGraw-Hill, 1993.
	[2] H. Ahmed and P.J. Spreadbury. <i>Analogue and digital electronics for engineers</i> . 2nd Edition, Cambridge University Press, 1984.
See Also	Diode, NPN Bipolar Transistor

 Purpose
 Model ideal positive supply rail

Library Sources

Description

∀+ Positive Supply Rail 1

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

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

Dialog 🖥 Block Parameters: Positive Supply Rail X Box and Positive Supply Rail **Parameters** This block represents an ideal positive supply rail. It can be used in place of the Foundation Library DC Voltage Source. The output voltage is defined relative to the Electrical Reference block. Use the Constant voltage parameter to specify the output voltage value which must be positive. Do not attach more than one Positive Supply Rail block to any connected line. Parameters-1 V Constant voltage: -ΟK Cancel Help

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

- Purpose
 Model simple distance sensor
- Library

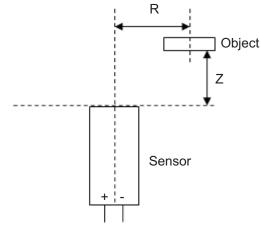
Sensors

Description

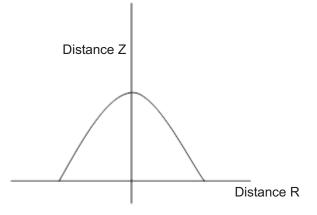


Proximity Sensor

The Proximity Sensor block represents a simple proximity sensor. The sensing distance Z is defined as the distance normal to the sensor surface at which the sensor detects an object for a given radial offset R, as shown in the following figure.



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



The output is modeled by an electrical switch which can either be Normally Open (N.O.) or Normally Closed (N.C.) when no object is detected.

Dialog Box and Parameters

🙀 Block Parameters: Prox	imity Sensor	×
Proximity Sensor		
distance Z is defined as the detected for a given radial of	ble representation of a proximity sensor. The distance normal to the sensor surface at wh fset R. For an explanatory diagram see the electrical switch which can either be Norma en no object is detected.	ich an object is documentation.
Parameters		
Vector of radial offset distances R:	[-25 -20 -15 -10 -5 0 5 10 15 20 25]	mm
Corresponding sensing distances Z:	[00589.5109.58500]	mm 💌
Output when not detected:	Normally Open (N.O.)	•
Closed resistance R_closed:	0.01	Ohm 💌
Open conductance G_open:	1e-08	1/0hm
	OK Cancel Help	Apply

Vector of radial offset distances R

Vector of distances from the sensor to the object resolved into a plane tangential to the sensor head. The default value is [-25 -20 -15 -10 -5 0 5 10 15 20 25] mm.

Corresponding sensing distances Z

Vector of distances from the sensor to the object resolved with respect to a normal vector at the sensor head. The default value is $[0\ 0\ 5\ 8\ 9.5\ 10\ 9.5\ 8\ 5\ 0\ 0\]$ mm.

Output when not detected

Indicates whether the output is Normally Open (N.O.), meaning the output becomes closed only when the object is detected, or Normally Closed (N.C.), meaning the output becomes open

	only when the object is detected. The default value is Normally Open (N.O.).
	Closed resistance R_closed The resistance between the + and - ports when the output contacts are closed. The default value is 0.01 Ω .
	Open conductance G_open The conductance between the + and - ports when the output contacts are open. The default value is $1e-08 \ 1/\Omega$.
Ports	The block has the following ports:
	R Radial distance to the sensor.
	Z Perpendicular distance to the sensor.
	+ Positive electrical voltage.
	- Negative electrical voltage.

Purpose	Model generic linear sensor
---------	-----------------------------

Library

Sensors

Description



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

- PS Sensor
- Output voltage
- Output current
- Output resistance

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

PS Sensor

Dialog Box and Parameters

🙀 Block Parameters: PS 🤅	Sensor X
PS Sensor	
into an electrical output vol	neric linear sensor. The physical signal input U is converted tage Y, output current Y or resistance Y across the + and - ected Output type. Y is related to U with the following
Y = max(min(A×U + B,Ymax)),Ymin)
resistance in ohms, depend	imits on the output voltage in volts, current in amps or ling on the selected Output type. If the Output type is set to e minimum resistance Ymin must be greater than zero.
Parameters	
Output type:	Variable voltage
Sensor gain, A:	1
Sensor offset, B:	0
Maximum output, Ymax:	5
Minimum output, Ymin:	0.01
	OK Cancel Help Apply

Output type

Indicates whether the sensor output is a Variable voltage of Y V, a Variable current of Y A, or Variable resistor with a value of $Y \Omega$. The default value is Variable voltage.

Sensor gain, A

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

Sensor offset, B

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

Maximum output, Ymax

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

Output type	Units
Variable voltage	V
Variable current	А
Variable resistor	Ω

The default value is 5.

Minimum output, Ymin

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

Output type	Units
Variable voltage	V
Variable current	А
Variable resistor	Ω

The default value is 0.01.

If you select Variable resistance for the Output type parameter, the minimum resistance $Y_{\rm min}$ must be greater than zero.

Ports The block has the following ports:

U

Physical input signal.

+

Positive electrical voltage.

Negative electrical voltage.

_

See Also Simscape Controlled Voltage Source, Simscape Controlled Current Source, and Simscape Variable Resistor

 Purpose
 Model periodic square pulse current source

Library SPICE-Compatible Sources

Description

Dulse Current Source

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

$$I_{out}(0) = I1$$

$$I_{out}(TD) = I1$$

$$I_{out}(TD + TR) = I2$$

$$I_{out}(TD + TR + PW) = I2$$

$$I_{out}(TD + TR + PW + TF) = I1$$

$$I_{out}(TD + PER) = I1$$

where:

- *I1* is the **Initial value**, **I1** parameter value.
- *I2* is the **Pulse value**, **I2** parameter value.
- *TD* is the **Pulse delay time, TD** parameter value.
- *TR* is the **Pulse rise time, TR** parameter value.
- *TF* is the **Pulse fall time, TF** parameter value.
- *PW* is the **Pulse width**, **PW** parameter value.

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

The block determines the values at intermediate time points by linear interpolation.

The specified values for PW and PER have the following effect on the block output:

- If both *PW* and *PER* are infinite, the block produces a step response at time *TD*.
- If *PER* is infinite and *PW* is finite, the block produces a single pulse of width *PW* and infinite period.
- If *PW* is infinite and *PER* is finite, the block produces a step response with pulses of width *TR* to a value *I1* every *PER* seconds.
- If *PW* > *PER*, the block produces a step response with pulses of width *TR* to a value *I1* every *PER* seconds.

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

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

Dialog Box and Parameters

🙀 Block Parameters: P	ulse Current Source	×
Pulse Current Source—		
	e block maintains a pulsed current thr age across its terminals. The following k as a function of time:	
Iout(0) = I1		
Iout(TD) = I1		
Iout(TD+TR) = I2		
Iout(TD+TR+PW) = I2		
Iout(TD+TR+PW+TF) =	II	
Iout(TD+PER) = I1		
	e values at intermediate time points b he rise time. TF is the fall time. PW is	
	R, TF, PW and PER differ from SPICE nd (1e-9), and the values of TR and 1	
-Parameters		
Initial value, I1:	0	A
Pulse value, I2:	0	A
Pulse delay time, TD:	0	s 💌
Pulse rise time, TR:	1e-09	s 💌
Pulse fall time, TF:	1e-09	s 💌
Pulse width, PW:	Inf	s 💌
Pulse period, PER:	Inf	s 💌
	OK Cancel	Help Apply

Initial value, I1

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

	Pulse value, I2 The value of the output current when the output is high. The default value is 0 A.
	Pulse delay time, TD The time at which the pulse first starts. The default value is 0 s.
	Pulse rise time, TR The time it takes the output current to rise from the Initial value, I1 value to the Pulse value, I2 value. The default value is 1e-09 s. The value must be greater than or equal to 0.
	 Pulse fall time, TF The time it takes the output current to fall from the Pulse value, I2 value to the Initial value, I1 value. The default value is 1e-09 s. The value must be greater than or equal to 0.
	Pulse width, PW The time width of the output pulse. The default value is Inf s. The value must be greater than 0.
	Pulse period, PER The period of the output pulse. The default value is Inf s. This value means that the block produces a single pulse with an infinite period. The value must be greater than 0 .
Ports	The block has the following ports:
	+ Positive electrical voltage.
	- Negative electrical voltage.
See Also	Pulse Voltage Source

Purpose Model periodic square pulse voltage source

Library SPICE-Compatible 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

당 Block Parameters: I	Pulse Voltage Source	×
Pulse Voltage Source—		
-	e block maintains a pulsed voltage ac rent through its terminals. The followii k as a function of time:	
Vout(0) = V1		
Vout(TD) = V1		
Vout(TD+TR) = V2		
Vout(TD+TR+PW) = V2		
Vout(TD+TR+PW+TF)	= V1	
Vout(TD+PER) = V1		
	e values at intermediate time points t the rise time. TF is the fall time. PW is	
	rR, TF, PW and PER differ from SPICE and (1e-9), and the values of TR and	
Parameters		
Initial value, V1:	0	V
Pulse value, V2:	0	V
Pulse delay time, TD:	0	5 💌
Pulse rise time, TR:	1e-09	5 💌
Pulse fall time, TF:	1e-09	s 💌
Pulse width, PW:	Inf	5 💌
Pulse period, PER:	Inf	5
	OK Cancel	Help Apply

Initial value, V1

The value of the output voltage at time zero. The default value is 0 V. $\,$

	Pulse value, V2 The value of the output voltage when the output is high. The default value is 0 V.
	Pulse delay time, TD The time at which the pulse first starts. The default value is 0 s.
	 Pulse rise time, TR The time it takes the output voltage to rise from the Initial Value, I1 value to the Pulse Value, V2 value. The default value is 1e-09 s. The value must be greater than or equal to 0.
	 Pulse fall time, TF The time it takes the output voltage to fall from the Pulse Value, V2 value to the Initial Value, V1 value. The default value is 1e-09 s. The value must be greater than or equal to 0.
	Pulse width, PW The time width of the output pulse. The default value is Inf s.
	Pulse period, PER The period of the output pulse. The default value is Inf s. This value means that the block produces a single pulse with an infinite period.
Ports	The block has the following ports:
	+ Positive electrical voltage.
	- Negative electrical voltage.
See Also	Pulse Current Source

Purpose Model polynomial voltage-controlled current source

Library SPICE-Compatible Sources

Description



The PVCCS (Polynomial Voltage-Controlled Current Source) block represents a current source whose output current value is a polynomial function of the voltage across the input ports. The following equations describe the current through the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

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

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

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

where:

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

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

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

Dialog Box and Parameters

🙀 Block Parameters: PVCC5
-PVCCS
The Polynomial Voltage-Controlled Current Source (PVCCS) block generates a current waveform, Iout, by evaluating a polynomial function for a single controlling input voltage, Vin. Vin is the time-dependent voltage across its input terminals.
If you specify a vector of polynomial coefficients, p, in ascending order, the output is:
$Iout = p(0) + p(1)*Vin + + p(n-1)*Vin^{(n-1)} + p(n)*Vin^n$
If you specify a scalar coefficient, p, the block creates a linearly dependent output current.
Iout = p * Vin
Parameters-
Polynomial coefficients: [0 1]
OK Cancel Help Apply

Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output current, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

Positive electrical output voltage.

N -

Negative electrical output voltage.

Ports

See Also PCCCS, PCCVS, and PVCVS

PVCVS

Purpose Model polynomial voltage-controlled voltage source

Library SPICE-Compatible Sources

Description



The PVCVS (Polynomial Voltage-Controlled Voltage Source) block represents a voltage source whose output voltage value is a polynomial function of the voltage across the input ports. The following equations describe the voltage across the source as a function of time:

• If you specify an *n*-element vector of polynomial coefficients for the **Polynomial coefficients** parameter:

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

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

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

where:

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

Dialog Box and Parameters

Ports

🙀 Block Parameters: PVCVS 🛛 🔀	
PVCV5	
The Polynomial Voltage-Controlled Voltage Source (PVCVS) block generates a voltage waveform, Vout, by evaluating a polynomial function for a single controlling input voltage, Vin. Vin is the time-dependent voltage across its input terminals.	
If you specify a vector of polynomial coefficients, p, in ascending order, the output is:	
$\label{eq:Vout} {\sf Vout} = {\sf p}(0) + {\sf p}(1)^* {\sf Vin} + \ldots + {\sf p}(n{\text{-}}1)^* {\sf Vin}^{(n{\text{-}}1)} + {\sf p}(n)^* {\sf Vin}^n$	
If you specify a scalar coefficient, p, the block creates a linearly dependent output voltage.	
Vout = p * Vin	
Parameters	
Polynomial coefficients: [0 1]	
OK Cancel Help Apply	

Polynomial coefficients

The polynomial coefficients that relate the input voltage to the output voltage, as described in the preceding section. The default value is $[0\ 1]$.

The block has the following ports:

Positive electrical input voltage.

Negative electrical input voltage.

N+

+

_

Positive electrical output voltage.

N -

Negative electrical output voltage.

See Also PCCCS, PCCVS, and PVCCS

Purpose Model lookup table current source

Library SPICE-Compatible Sources

Description

PWL Current Source

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

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

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

PWL Current Source

Dialog Box and Parameters

🙀 Block Parameters: F	WL Current Source	×
PWL Current Source		
(Time, Current) to speci equivalent, this source o determine output curren	urrent Source (PWL) block uses time y a time dependent current wavefor an use linear, cubic or spline interpo it values at intermediate time points. hts method for extrapolation.	rm. Like its SPICE lation methods to
Parameters		
Time specification:	[01234]	5 💌
Current at specified time:	[00000]	A
Interpolation method:	Linear	-
Extrapolation method:	Last point value	•
	OK Cancel	Help Apply

Time specification

The vector of time values as a tabulated 1-by-n array. The time values vector must be strictly monotonically increasing. The values can be non-uniformly spaced. The default value is [01234] s.

Current at specified time

The vector of current values as a tabulated 1-by-n array. The current values vector must be the same size as the time values vector. The default value is $[0\ 0\ 0\ 0\ 0]$ A.

Interpolation method

Select the method the block uses determine the output current values at intermediate time points that are not specified in the preceding vectors:

• Linear — Use a linear function. This is the default method.

•	Cubic — Use the Piecewise Cubic Hermite Interpolation
	Polinomial (PCHIP). For more information, see [1] and the
	pchip MATLAB [®] function.

• Spline — Use the cubic spline interpolation algorithm described in [2].

Extrapolation method

Select the method the block uses determine the output current values at time points that are outside the time range specified in the preceding vectors:

- Last point value Use the last specified current value at the appropriate end of the range. That is, use the last specified current value for all time values greater than the last specified time argument, and the first specified current value for all time values less than the first specified time argument. This is the default method.
- Last 2 points Extrapolate using the linear method (regardless of the interpolation method specified), based on the last two current values at the appropriate end of the range. That is, use the first and second specified current values if the time value is below the specified range, and the two last specified current values if the time value is above the specified range.

Ports	The block has the following ports:
	+ Positive electrical voltage.
	- Negative electrical voltage.
Defenences	

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

Purpose	Model lookup table voltage source
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Library SPICE-Compatible Sources

Description

PWL Voltage Source

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

Dialog	😽 Block Parameters: I	PWL Voltage Source	×
Box and	PWL Voltage Source-		
Parameters	(Time, Voltage) to speci equivalent, this source determine output voltage	oltage Source (PWL) block uses time- fy a time dependent voltage wavefor can use linear, cubic or spline interpo je values at intermediate time points. ints method for extrapolation.	rm. Like its SPICE lation methods to
	-Parameters		
	Time specification:	[01234]	5
	Voltage at specified time:	[00000]	V
	Interpolation method:	Linear	_
	Extrapolation method:	Last point value	_
		OK Cancel	Help Apply

Time specification

The vector of time values as a tabulated 1-by-n array. The time values vector must be strictly monotonically increasing. The values can be non-uniformly spaced. The default value is $\begin{bmatrix} 0 \\ 1 & 2 & 3 \end{bmatrix}$ s.

Voltage at specified time

The vector of voltage values as a tabulated 1-by-n array. The voltage values vector must be the same size as the time values vector. The default value is $[0\ 0\ 0\ 0\ 0]$ V.

Interpolation method

Select the method the block uses determine the output voltage values at intermediate time points that are not specified in the preceding vectors:

- Linear Use a linear function. This is the default method.
- Cubic Use the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP). For more information, see [1] and the pchip MATLAB function.
- Spline Use the cubic spline interpolation algorithm described in [2].

Extrapolation method

Select the method the block uses determine the output voltage values at time points that are outside the time range specified in the preceding vectors:

- Last point value Use the last specified voltage value at the appropriate end of the range. That is, use the last specified voltage value for all time values greater than the last specified time argument, and the first specified voltage value for all time values less than the first specified time argument. This is the default method.
- Last 2 points Extrapolate using the linear method (regardless of the interpolation method specified), based on the last two voltage values at the appropriate end of the range. That is, use the first and second specified voltage values if

the time value is below the specified range, and the two last specified voltage values if the time value is above the specified range.

Ports The block has the following ports:

Positive electrical voltage.

Negative electrical voltage.

References [1] D. Kahaner, Cleve Moler, and Stephen Nash *Numerical Methods and Software* Prentice Hall, 1988.

[2] W.H. Press, B.P. Flannery, S.A. Teulkolsky, and W.T. Wetterling *Numerical Recipes in C: The Art of Scientific Computing* Cambridge University Press, 1992.

See Also PWL Current Source

+

-

Relay

Purpose

Library	Passive Devices
Description ▷ ≇३(] €₽-	The Relay block models a relay controlled by an external physical signal. In the steady state, the relay behaves as follows:
Relay	• When the external physical signal at port PS is greater than zero, the relay is <i>energized</i> (meaning closed) and the common port C is connected to the normally open port S2.
	• When the external physical signal at port PS is less than or equal to zero, the relay is <i>not energized</i> (meaning open) and the common port C is connected to the normally closed port S1.

During switching, the relay behaves as follows:

Model switching and associated delay of relay

- When the relay closes, the C to S1 connection breaks open after delay **Time-to-break C-S1 connection** and the C to S2 connection closes after delay **Time-to-make C-S2 connection**.
- When the relay opens, the C to S2 connection breaks open after delay **Time-to-break C-S2 connection** and the C to S1 connection closes after delay **Time-to-make C-S1 connection**.

You can specify break delays that are longer than the close delays to implement a make-before-break behavior.

Basic Assumptions and Limitations

If the PS input changes during the switching process, the block behavior may not be representative. The switching delay occurs because of mechanical inertia, and modeling inertia as a delay requires approximation.

Dialog Box and Parameters

Relay Relay The block represents a relay. If the e to terminal S2, otherwise terminal C is	xternal physical signal PS is greater than zero, then the com connected to terminal S1.	mon terminal C gets connected
The Connected resistance R and Oper	n-circuit conductance G must be greater than zero.	
Parameters		
Time-to-break C-S1 connection:	0	s
Time-to-make C-S1 connection:	0	s
Time-to-break C-S2 connection:	0	s 💌
Time-to-make C-S2 connection:	0	s
Connected resistance R:	0.01	Ohm 💌
Open-circuit conductance G:	1e-08	1/Ohm 💌
Initial connection:	C to S1 closed, C to S2 open	•
L	OK Cancel	Help Apply

Time-to-break C-S1 connection

Time it takes the connection between ports C and S1 to break apart when the relay is energized. The default value is 0 s.

Time-to-make C-S1 connection

Time it takes the connection between ports C and S1 to close when the relay is de-energized. The default value is 0 s.

Time-to-break C-S2 connection

Time it takes the connection between ports C and S2 to break apart when the relay is de-energized. The default value is 0 s.

Time-to-make C-S2 connection

Time it takes the connection between ports C and S2 to close when the relay is energized. The default value is 0 s.

Connected resistance R

Resistance across closed relay contacts. The parameter value must be greater than zero. The default value is 0.01 Ω .

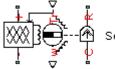
	Open-circuit conductance G Conductance across open relay contacts. The parameter value must be greater than zero. The default value is $1e-08 1/\Omega$.
	Initial connection Select one of the following options for the initial state of the relay:
	• C to S1 closed, C to S2 open — The common port C is connected to the S1 contact. This is the default option.
	• C to S1 open, C to S2 closed — The common port C is connected to the S2 contact.
Ports	The block has the following ports:
	PS Physical signal that energizes and de-energizes the relay.
	C Common electrical port.
	S1 Normally-closed electrical port.
	S2 Normally-open electrical port.
See Also	Simscape Switch

Purpose Model brushless motor with closed-loop torque control

Library

Actuators & Drivers

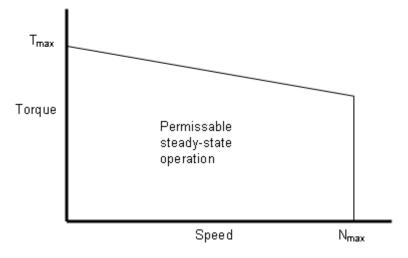
Description



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 $N_{\rm max}$

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:

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

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

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

Servomotor

Dialog Box and Parameters

Electrical Torque Tab

	iervomotor
ra or m V 2	This block represents a servomotor with closed-loop torque control. The motor's permissible ange of torques and speeds is defined by the manufacturer torque-speed envelope, and th butput torque is assumed to track the torque reference demand Tr with time constant Tc. If in notor manufacturer does not define an envelope, then set the vector of maximum torque values to [Tmax Tmax 0 0] and the vector of RPM values to [0 (1-eps)*wmax (1+eps)*wmax **wmax] where Tmax is the rated maximum continuous torque, wmax is the maximum speed RPM and eps is a small positive number e.g. 0.01.
re cl	The controlled servomotor should be connected to a DC supply. Motor electrical losses are epresented by I^2R where I is the DC supply current and R is a series resistance with valuthosen to match manufacturer defined motor losses. Consult the documentation for further information on how to determine R.
T	he block produces a positive torque acting from the mechanical C to R ports.
P	Parameters
	Electrical Torque Mechanical
	Electrical Torque Mechanical Vector of rotational speeds in RPM: [0 3.75e+03 7.5e+03 8e+03] Vector of maximum torque values in Nm: [0.09 0.08 0.07 0]
	Vector of rotational speeds in RPM: [0 3.75e+03 7.5e+03 8e+03] Vector of maximum torque values in [0 0.9 0 0.8 0 07 0]
	Vector of rotational speeds in RPM: [0 3.75e+03 7.5e+03 8e+03] Vector of maximum torque values in Nm: [0.09 0.08 0.07 0]
	Vector of rotational speeds in RPM: [0 3.75e+03 7.5e+03 8e+03] Vector of maximum torque values in Nm: [0.09 0.08 0.07 0] Torque control time constant, Tc: 0.02 s Supply series resistance R to model 3.5 Obm
	Vector of rotational speeds in RPM: [0 3.75e+03 7.5e+03 8e+03] Vector of maximum torque values in Nm: [0.09 0.08 0.07 0] Torque control time constant, Tc: 0.02 s Supply series resistance R to model 3.5 Obm

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 3.5Ω .

Mechanical Tab

		ufacturer torqu	ue-speed envelope, and the r with time constant Tc. If th
values to [Tmax Tmax 0 0		alues to [0 (1-	eps)*wmax (1+eps) [÷] wmax
2*wmax] where Tmax is t RPM and eps is a small po:		ous torque, w	max is the maximum speed i
	r should be connected to a		
	ere I is the DC supply curr turer defined motor losses		I series resistance with value documentation for further
nformation on how to det	ermine R.		
The block produces a posi	tive torque acting from the	e mechanical C	to R ports.
Parameters			
Electrical Torque Me	echanical		
Listing in the			
Rotor inertia:	5e-06		kg*m^2
	5e-06 1e-05		kg*m^2 N*m/(rad/s)
Rotor inertia:			
Rotor inertia: Rotor damping:	1e-05		N*m/(rad/s)
Rotor inertia: Rotor damping:	1e-05		N*m/(rad/s)

Rotor inertia

Rotor inertia. The default value is $5e\,{-}\,06~{\rm kg}^{*}{\rm m}^{2}.$ 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

SFFM Current Source

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

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

where:

- *I0* is the **Current offset**, **IO** parameter value.
- *IA* is the **Current amplitude**, **IA** parameter value.
- FC is the Carrier frequency, FC parameter value.
- MI is the Modulation index, MI parameter value.
- FS is the Signal frequency, FS parameter value.

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

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

Dialog	
Box and	
Parameters	6

modulated current throu	M Current (SFFM) Source block main ugh its terminals, independent of the equation describes the current thro	e voltage across its
Iout = IO+IA*sin((2*pi	*FC*Time)+MI*sin(2*pi*FS*Time))	
carrier frequency. MI is	value. IA is the magnitude of the si the signal modulation index. FS is th r (FC) and signal (FS) frequencies o	ne signal frequency. The
Parameters		
Current offset, IO:	0	A
Current amplitude, IA:	0	A
Conview frequency - EC	0	Hz
Carrier frequency, FC:	0	
Modulation index, MI:	1	
	0	Hz

Current offset, IO

The magnitude of the time-independent part of the output current. The default value is 0 A.

Current amplitude, IA

The magnitude of the sinusoidal part of the output current. The default value is 0 A. $\,$

Carrier frequency, FC

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

	Modulation index, MI The amount by which the modulated signal varies around its unmodulated level. The default value is 0. The value must be greater than or equal to 0.
	Signal frequency, FS Frequency of the modulated signal. The default value is 0 Hz. The value must be greater than or equal to 0.
Ports	The block has the following ports:
	+ Positive electrical voltage.
	- Negative electrical voltage.
See Also	SFFM Voltage Source

Purpose Model single-frequency FM voltage source

Library SPICE-Compatible Sources

Description

SFFM Voltage Source

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

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

where:

- *V0* is the **Voltage offset**, **VO** parameter value.
- VA is the Voltage amplitude, VA parameter value.
- FC is the Carrier frequency, FC parameter value.
- *MI* is the **Modulation index**, **MI** parameter value.
- *FS* is the **Signal frequency**, **FS** parameter value.

SFFM Voltage Source

Dialog Box and Parameters

🙀 Block Parameters: S	FFM Voltage Source	×	
SFFM Voltage Source-			
The Single-Frequency FM Voltage (SFFM) Source block maintains a frequency- modulated voltage across its terminals, independent of the current through its terminals. The following equation describes the voltage across the SFFM source as a function of time:			
Vout = VO+VA*sin((2*pi*FC*Time)+MI*sin(2*pi*FS*Time))			
VO is the voltage offset value. VA is the magnitude of the signal voltage. FC is the carrier frequency. MI is the signal modulation index. FS is the signal frequency. The default values for carrier (FC) and signal (FS) frequencies differ from SPICE, and are equal to zero.			
Parameters		_	
Voltage offset, VO:	0 V 💌	1	
Voltage amplitude, VA:	0	1	
Carrier frequency, FC:	0 Hz]	
Modulation index, MI:	0		
Signal frequency, FS:	0 Hz]	
	OK Cancel Help Apply		

Voltage offset, VO

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

Voltage amplitude, VA

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

Carrier frequency, FC

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

	Modulation index, MI The amount by which the modulated signal varies around its unmodulated level. The default value is 0. The value must be greater than or equal to 0.
	Signal frequency, FS Frequency of the modulated signal. The default value is 0 Hz. The value must be greater than or equal to 0.
Ports	The block has the following ports: + Positive electrical voltage. - Negative electrical voltage.
See Also	SFFM Current Source

Shunt Motor

Purpose Model electrical and torque characteristics of shunt motor

Library

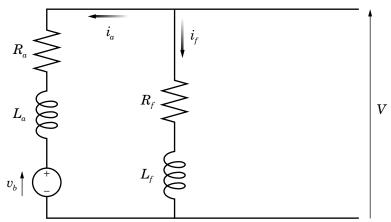
Actuators & Drivers

Description

shu

Shunt Motor

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



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

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

• L_f — Field winding inductance

The Shunt Motor block computes the motor torque as follows:

1 The magnetic field in the motor induces the following back $\operatorname{emf} v_b$ in the armature:

$$v_b = L_{af} i_f \omega$$

where $L_{\rm a\!f}$ is a constant of proportionality and ω is the angular velocity.

2 The mechanical power is equal to the power reacted by the back emf:

$$P = v_b i_a = L_{af} i_f i_a \omega$$

3 The motor torque is:

$$T = P / \omega = L_{af} i_f i_a$$

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

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

$$V = i_a R_a + L_{af} i_f \omega$$
$$V = i_f R_f$$

3 Solve the preceding equations for i_a and i_f :

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

4 Substitute these values of i_a and i_f into the equation for torque:

$$T = \frac{L_{af}}{R_a R_f} \left(1 - \frac{L_{af} \omega}{R_f} \right) V^2$$

The block uses the rated speed and power to calculate the rated torque. The block uses the rated torque and no-load speed values to get one equation that relates R_a and L_{af}/R_{f} . It uses the no-load speed at zero torque to get a second equation that relates these two quantities. Then, it solves for R_a and L_{af}/R_{f} .

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

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

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

Shunt Motor

Dialog Box and Parameters

his block represents the	electrical and torque characteristics o	f a shunt motor.
sitance), La (armature ductance) and Laf (bac o = Laf * If * W where teratively, the motor cl speed, nominal voltage mature or field winding ne block produces a pos	be defined in terms of equivalent circu- inductance), Rf (field winding resistani- k-emf constant). The back emf induced If is the field current and W is the mec- haracteristics can be defined in terms of starting current, La and Lf. If no info- inductance, these parameters can be sitive torque acting from the mechanica	ce), Lf (field winding d in the armature is given l hanical angular speed, of no-load speed, rated po rmation is available on set to a small non-zero va
rameters		
Electrical Torque	1echanical	
Model parameterization:	By equivalent circuit parameters	•
Armature resistance:	110	Ohm 💌
Field winding resistance:	2.5e+03	Ohm
Back-emf constant:	5.11	s*V/rad/A
	0.1	Н
Armature inductance:	,	
Armature inductance: Field winding inductance:	0.1	н

Model parameterization

Select one of the following methods for block parameterization:

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

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

Armature resistance

Resistance of the armature. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is 110Ω .

Field winding resistance

Resistance of the field winding. This parameter is only visible when you select By equivalent circuit parameters for the **Model parameterization** parameter. The default value is $2.5e+03 \Omega$.

Back-emf constant

The ratio of the voltage generated by the motor to the motor speed. The default value is 5.11 s*V/rad/A.

Armature inductance

Inductance of the armature. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. The default value is 0.1 H. The value can be zero.

Field winding inductance

Inductance of the field winding. If you do not have information about this inductance, set the value of this parameter to a small, nonzero number. The default value is 0.1 H. The value can be zero.

No-load speed

Speed of the motor when no load is applied. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 4.6e+03 rpm.

Rated speed (at rated load)

Motor speed at the rated load. This parameter is only visible when you select By rated power, rated speed & no-load speed for the Model parameterization parameter. The default value is 4e+03 rpm.

Rated load (mechanical power)

The mechanical load for which the motor is rated to operate. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 50 W.

Rated DC supply voltage

The voltage at which the motor is rated to operate. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 220 V.

Starting current at rated DC supply voltage

The initial current when starting the motor with the rated DC supply voltage. This parameter is only visible when you select By rated power, rated speed & no-load speed for the **Model parameterization** parameter. The default value is 2.09 A.

Mechanical Tab

🙀 Block Parameters: S	Shunt Motor			×
Shunt Motor				
This block represents th	e electrical and torque d	haracteristics of	a shunt motor.	
resitance), La (armature inductance) and Laf (ba Vb = Laf * If * W where Alteratively, the motor & speed, nominal voltag armature or field windin	n be defined in terms of a inductance), Rf (field w ck-emf constant). The b a If is the field current ar characteristics can be de le, starting current, La a g inductance, these para ositive torque acting from	vinding resistance ack emf induced i ad W is the mecha fined in terms of nd Lf. If no inform ameters can be si), Lf (field winding n the armature is o anical angular spee no-load speed, rai mation is available et to a small non-zo	given by ed. ted power on
Parameters				
	Mechanical			
Electrical Torque				
Rotor inertia:	2e-04		kg*m^2	•
Rotor damping:	1e-06		N*m/(rad/s)	•
Initial rotor speed:	0		rpm	•
	ОК	Cancel	Help	Apply

Rotor inertia

Rotor inertia. The default value is $2e\mathchar`e\mar$

Rotor damping

Rotor damping. The default value is $1e\cdot 06$ N*m/(rad/s). The value can be zero.

	Initial rotor speed Speed of the rotor at the start of the simulation. The default value is 0 rpm.
Ports	The block has the following ports:
	+ Positive electrical input.
	- Negative electrical input.
	C Mechanical rotational conserving port.
	R Mechanical rotational conserving port.
References	[1] Bolton, W. Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 3rd edition Pearson Education, 2004.
See Also	DC Motor, Induction Motor, Servomotor, and Universal Motor.

Sinusoidal Current Source

Purpose Model damped sinusoidal current source

Library SPICE-Compatible Sources

Description

Sinusoidal Current Source

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

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

where:

- *I0* is the **Current offset**, **IO** parameter value.
- IA is the Sinusoidal amplitude, IA parameter value.
- *FREQ* is the **Sinusoidal frequency**, **FREQ** parameter value.
- *TD* is the **Time delay**, **TD** parameter value.
- *DF* is the **Damping factor**, **DF** parameter value.

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

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

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

Dialog Box and Parameters

voltage across its he sinusoidal source *pi*FREQ*(Time-T agnitude of the signime delay. DF is the	ignal current. FREQ is the he signal damping factor.
voltage across its he sinusoidal source *pi*FREQ*(Time-T agnitude of the signime delay. DF is the	s terminals. The following ce as a function of time: TD)) ignal current. FREQ is the he signal damping factor.
agnitude of the sig ime delay. DF is th	ignal current. FREQ is the he signal damping factor.
ime delay. DF is th	he signal damping factor.
	;, and is equal to 1 MHz.
	A .
	A
	Hz
	s
	1/s 💌

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, TDThe 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

Sinusoidal Voltage Source

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

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

where:

- *V0* is the **Voltage offset**, **VO** parameter value.
- VA is the Sinusoidal amplitude, VA parameter value.
- *FREQ* is the **Sinusoidal frequency**, **FREQ** parameter value.
- *TD* is the **Time delay**, **TD** parameter value.
- *DF* is the **Damping factor**, **DF** parameter value.

Dialog Box and Parameters

Block Parameters:	Sinusoidal Voltage Source	x	
Sinusoidal Voltage Source			
The Sinusoidal Voltage Source block maintains a damped sinusoidal voltage across its terminals, independent of the current through its terminals. The following equation describes the voltage across the sinusoidal source as a function of time:			
Vout = VO+VA*exp(-(T	ime-TD)*DF)*sin(2*pi*FREQ*(Tin	ne-TD))	
VO is the voltage offset value. VA is the magnitude of the signal voltage. FREQ is the frequency of the signal. TD is the signal time delay. DF is the signal damping factor. The default value for frequency (FREQ) differs from SPICE, and is equal to 1 MHz.			
Parameters			
Voltage offset, VO:	0	V	
Sinusoidal amplitude, VA:	0	V	
Sinusoidal frequency, FREQ:	1e+06	Hz	
Time delay, TD:	0	s 💌	
Damping factor, DF:	0	1/s 💌	
	OK Cancel	Help Apply	

Voltage offset, V0

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

Sinusoidal amplitude, VA

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

Sinusoidal frequency, FREQ

The frequency of the output sine wave. The default value is 1e+06 Hz. The value can be less than 0.

Time delay, TD

The time at which the sine wave first starts. The default value is $0 ext{ s. The value can be less than } 0.$

	Damping factor, DF The amount by which to amplify or reduce the exponential damping term that multiples the sine wave to produce the output voltage. The default value is 0 1/s. The value must be greater than or equal to 0.
Ports	The block has the following ports:
	+ Positive electrical voltage.
	Negative electrical voltage.
See Also	Sinusoidal Current Source

Solar Cell

Purpose	Model single solar cell
---------	-------------------------

Sources

Library

Solar Cell

Description

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

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

where:

• I_{ph} is the solar-induced current:

$$I_{ph} = I_{ph0} \times \frac{I_r}{I_{r0}}$$

where:

- I_r is the irradiance (light intensity) in W/m² falling on the cell.
- I_{ph0} is the measured solar-generated current for the irradiance I_{r0} .
- *Is* is the diode saturation current.
- V_t is the thermal voltage, kT/q, where:
 - k is the Boltzmann constant (1.3806503e-23 J/K).
 - *T* is the **Measurement temperature** parameter value.
 - q is the elementary charge on an electron (1.602176e–19 Coulombs).
- *N* is the quality factor (diode emission coefficient).
- V is the voltage across the solar cell electrical ports.

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

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

Basic Assumptions and Limitations

The Solar Cell model has the following limitations:

• This block does not model temperature-dependent effects. SimElectronics simulates the block at the temperature at which the component behavior was measured, as specified by the **Measurement temperature** parameter value.

Solar Cell

Dialog Box and **Parameters**

Block Parameters: 9	Solar Cell	×	
Solar Cell This block models 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 given by			
I = Iph - Is*(e^((V+I*	Rs)/(N*Vt)) -1)		
where Is is the diode saturation current, Vt is the thermal voltage, N is the quality factor (diode emission coefficient) and Iph is the solar-generated current. The quality factor varies for amorphous cells, and is typically 2 for polycrystalline cells. The physical signal input Ir is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current Iph is given by Iph0*Ir/Ir0 where Iph0 is the measured solar-generated current for irradiance Ir0.			
	1		
Parameterize by:	By s/c current and o/c voltage		
Short-circuit current, Isc:	7.34	A	
Open-circuit voltage, Voc:	0.6	V	
Measurement temperature:	25	c 💌	
Irradiance used for measurements, IrO:	1000	W/m^2	
Quality factor, N:	1.5		
Series resistance, Rs:	0	Ohm 💌	
	OK Cancel	Help Apply	

Parameterize by

Select one of the following methods for block parameterization:

- By s/c current and o/c voltage Provide short-circuit current and open-circuit voltage that the block converts to an equivalent circuit model of the solar cell. This is the default method.
- By equivalent circuit parameters Provide electrical parameters for an equivalent circuit model of the motor.

Short-circuit current, Isc

The current that flows when you short-circuit the solar cell. This parameter is only visible when you select By s/c current and o/c voltage for the **Parameterize by** parameter. The default value is 7.34 A.

Open-circuit voltage, Voc

The voltage across the solar cell when it is not connected. This parameter is only visible when you select By s/c current and o/c voltage for the **Parameterize by** parameter. The default value is 0.6 V.

Diode saturation current, Is

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

Measurement temperature

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

Solar-generated current, Iph0

The solar-induced current when the irradiance is I_{r0} . This parameter is only visible when you select By equivalent circuit parameters for the **Parameterize by** parameter. The default value is 7.34 A.

Irradiance used for measurements, Ir0

The irradiance that produces a current of I_{ph0} in the solar cell. The default value is 1000 W/m².

Quality factor, N

The diode emission coefficient. The default value is 1.5.

Series resistance, Rs

The series terminal resistance. The default value is 0 Ω .

Ports The block has the following ports:

Solar Cell

Ir Incident irradiance.

+

-

Positive electrical voltage.

Negative electrical voltage.

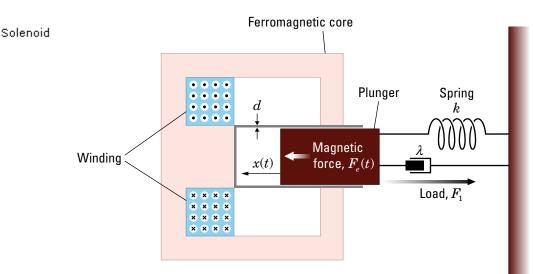
Purpose Model electrical characteristics and generated force of solenoid

Actuators & Drivers

Description

Library

The Solenoid block represents the electrical characteristics and generated force for the solenoid in the following figure:



The return spring is optional. To remove the effects of this spring from the model, set the **Spring constant** parameter to 0.

The equation of motion for the plunger as a function of position, x, is:

 $F_1 + m\ddot{x} + \lambda\dot{x} + kx = F_e$

where F_e is the electromagnetic force, F_l is the load force, λ is the viscous damping term and m is the plunger mass. The electromagnetic force is related to the solenoid current and inductance by:

$$F_e = \frac{1}{2}i^2 \frac{\partial L(x)}{\partial x}$$

The inductance, which is derived in [1], can be written as:

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

where a and β are constants. Plugging the preceding equation into the equation for electromagnetic force gives the force-stroke relationship of the solenoid for a current i_0 :

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

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

A positive current from the electrical + to - ports creates a negative force (i.e., a pulling force) from the mechanical C to R ports.

Dialog Box and Parameters

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

🙀 Block Parameters: S	olenoid			×
Solenoid				
This block implements the electrical and mechanical characteristics of a solenoid. Parameterization is in terms of two points [X1,F1] and [X2,F2] on its force-stroke curve for a 100 percent duty cycle at Rated voltage Vdc and Rated current Idc where X2>X1>0 are stoke values and F1>F2>0 are corresponding forces. The plunger fully in (i.e. air gap closed) corresponds to X=0, and pull-in force is assumed to decrease quadratically with the magnitude of X. To ensure the force remains finite, the following condition should hold: X2/X1>sqrt(F1/F2). The plunger Maximum stroke is implemented as a hard stop, the dynamics of which are set by the Contact stiffness and Contact damping parameters. The same parameters are used to model the contact dynamics when the plunger pulls fully in. The Spring constant parameter is used to implement a spring force that pulls the plunger out, and can be set to zero. A positive current from the electrical + to - ports results in a negative force (i.e.				
pulling force) acting from	n the mechanical C to R	. ports.		
-Parameters				
Magnetic Force M	echanical			
Forces [F1 F2]:	[7.5 0.75]		N	•
Stroke [X1 X2]:	[15]		mm	-
Rated voltage Vdc:	50		۷	•
Rated current Idc:	0.05		A	-
	ок с	ancel	Help	Apply

Forces [F1 F2]

A vector of the force values at the two points on the force-stroke curve. The second measurement point must be at a stroke that is greater than that of the first measurement point. When the manufacturer doesn't provide a force-stroke curve, set F1 to the holding torque (when X1 = 0) and F2 to the pull-in torque when running the solenoid at the **Rated voltage Vdc** and **Rated current Idc** values. The default value is [7.5 0.75] N.

Stroke [X1 X2]

A vector of the stroke (plunger distance from the fully closed position) values at the two points on the force-stroke curve. The second measurement point must be at a stroke that is greater than that of the first measurement point. To ensure a finite force value, the points must meet the condition

$$\frac{X2}{X1} > \sqrt{\frac{F1}{F2}}$$

The default value is [1 5] mm.

Rated voltage Vdc

The voltage at which the solenoid is rated to operate. This voltage value is used to measure the **Forces [F1 F2]** and **Stroke [X1 X2]** values. The default value is 50 V.

Rated current Idc

The current that flows when the solenoid is supplied with the **Rated voltage Vdc** voltage. The default value is 0.05 A.

Mechanical Tab

🙀 Block Parameters: Se	olenoid	×	
Solenoid			
This block implements the electrical and mechanical characteristics of a solenoid. Parameterization is in terms of two points [X1,F1] and [X2,F2] on its force-stroke curve for a 100 percent duty cycle at Rated voltage Vdc and Rated current Idc where X2>X1>0 are stoke values and F1>F2>0 are corresponding forces. The plunger fully in (i.e. air gap closed) corresponds to X=0, and pull-in force is assumed to decrease quadratically with the magnitude of X. To ensure the force remains finite, the following condition should hold: X2/X1>sqrt(F1/F2).			
The plunger Maximum stroke is implemented as a hard stop, the dynamics of which are set by the Contact stiffness and Contact damping parameters. The same parameters are used to model the contact dynamics when the plunger pulls fully in. The Spring constant parameter is used to implement a spring force that pulls the plunger out, and can be set to zero. A positive current from the electrical + to - ports results in a negative force (i.e. pulling force) acting from the mechanical C to R ports. Parameters			
Magnetic Force Me	echanical	1	
Spring constant:	200	N/m 💌	
Stroke for zero spring force:	5	mm	
Damping:	1	N/(m/s)	
Plunger mass:	0.05	kg 💌	
Maximum stroke:	Inf	mm	
Initial plunger position:	5	mm	
Contact stiffness:	1e+06	N/m 💌	
Contact damping:	500	N/(m/s)	
	OK Cancel	Help Apply	

Spring constant

Constant representing the stiffness of the spring that acts to retract the plunger when the solenoid is powered off. The force is zero when the plunger is displaced to the **Stroke for zero spring force** parameter value. The default value is 200 N/m. Set the spring constant to zero if there is no spring.

Stroke for zero spring force

The stroke at which the spring provides no force. The default value is 5 mm.

Damping

The term λ in the equation of motion for the plunger as a function of position that linearly damps the plunger motion. The default value is 1 N/(m/s). The value can be zero.

Plunger mass

The weight of the solenoid plunger. The default value is 0.05 kg. The value can be zero.

Maximum stroke

The maximum amount by which the plunger can be displaced. You can use this parameter to model a hard endstop that limits the stroke. The default value is Inf mm, which means no stroke limit.

Initial plunger position

The amount by which the plunger is displaced at the start of the simulation. The default value is 0 m.

Contact stiffness

Stiffness of the plunger contact that models the hard stop at the minimum (x = 0) and maximum (x = Maximum stroke) plunger positions. The default value is 1e+06 N/m.

Contact damping

Damping of the plunger contact that models the hard stop at the minimum (x = 0) and maximum (x = Maximum stroke) plunger positions. The default value is 150 N/(m/s).

The block has the following ports:

Ports

	+	Positive electrical input.
	-	Negative electrical input.
	С	Mechanical translational conserving port.
	R	Mechanical translational conserving port.
References		.E. Lyshevski. Electromechanical Systems, Electric Machines, and ied MechatronicsCRC, 1999.

SPICE Environment Parameters

Set parameters that apply to all connected SPICE-compatible blocks

Utilities

Description

Purpose

Library



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

Ports

🙀 Block Parameters: S	PICE Environment Paramet	ers 🔀	
SPICE Environment Parameters			
This block controls the SPICE environment parameters of all SPICE-compatible blocks in the electrical network to which it is connected. Not all SPICE environment parameters have a direct equivalent in SimElectronics, and many relate to Simulink Solver parameters and/or parameters in the Solver Configuration block.			
Parameters SPICE			
Circuit temperature:	300.15	К	
Minimum conductance, GMIN:	1e-12	1/Ohm 💌	
	OK Cancel	Help Apply	

Circuit temperature

The temperature of the connected SPICE-compatible blocks. The default value is $300.15\ {\rm K}.$

Minimum conductance GMIN

The minimum conductance used by some blocks. The default value is $1e\mathchar`e\mathch$

The block has the following ports:

0UT

Electrical output.

Stepper Motor

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

Library

Actuators & Drivers

Description

Stepper Motor

The Stepper Motor block represents a stepper motor. It uses the input pulse trains, A and B, to control the mechanical output according to the following equations:

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

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

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

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

where:

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



If the initial rotor is zero or some multiple of $(\pi/2)/N_r$, the rotor is aligned with the phase winding of pulse A. This happens when there is a positive current flowing from the A+ to the A- ports and there is no current flowing from the B+ to the B- ports.

Use the Stepper Motor Driver block to create the pulse trains for the Stepper Motor block.

The Stepper Motor block produces a positive torque acting from the mechanical C to R ports when the phase of pulse A leads the phase of pulse B.

The model is based on the following assumptions:

Basic Assumptions and Limitations

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

Stepper Motor

Dialog Box and Parameters

Electrical Torque Tab

from the Stepper Motor Driver block, Phase B.	nd produces a positive torque acting from	agnet stepper motor. The blo n the mechanical C to R ports	
	e multiple of (pi/2)/Nr where Nr is the num ng. This condition is held if there is a posit		
no current flows from the B+ to the B			
Parameters			
Electrical Torque Mechanical			
Phase winding resistance:	0.55		Dhm
Phase winding inductance:	0.0015	H	1
Motor torque constant:	0.19		I*m/A
Full step size:	1.8	d	eg

Phase winding resistance

Resistance of the A and B phase windings. The default value is $0.55\ \Omega.$

Phase winding inductance

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

Motor torque constant

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

Full step size

Step size when changing the polarity of either the A or B phase current. The default value is 1.8°.

Mechanical Tab

Block Parameters: Stepper Motor

-Stepper Motor-

This block represents the electrical and torque characteristics of a permanent magnet stepper motor. The block can be driven dire from the Stepper Motor Driver block, and produces a positive torque acting from the mechanical C to R ports when Phase A leads Phase B.

If the initial angle is set to zero or some multiple of (pi/2)/N where Nr is the number of teeth on each of the rotor poles, then the rotor is aligned with the A-phase winding. This condition is held if there is a positive current flowing from the A+ to A- terminals ar no current flows from the B+ to the B- terminals.

Rotor inertia:	4.5e-05		kg*m^2	
Rotor damping:	8e-04		N*m/(rad/s)	
Initial rotor speed:	0		rpm	
Initial rotor angle:	0		deg	

Rotor inertia

Resistance of the rotor to change in motor motion. The default value is $4.5e-05 \text{ kg}^{*}\text{m}^{2}$. 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	 M. Bodson, J. N. Chiasson, R. T. Novotnak and R. B. Rekowski. "High-Performance Nonlinear Feedback Control of a Permanent Magnet Stepper Motor." IEEE Transactions on Control Systems Technology, Vol. 1, No. 1, March 1993.
	[2] P. P. Acarnley. <i>Stepping Motors: A Guide to Modern Theory and Practice</i> . New York: Peregrinus, 1982.
	[3] S.E. Lyshevski. <i>Electromechanical Systems, Electric Machines, and Applied Mechatronics</i> . CRC, 1999.
See Also	Stepper Motor Driver

PurposeModel stepper motor driver

Library

Actuators & Drivers

Description



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

REW If the voltage at the REV port is less than or equal to the **Reverse** Stepper Motor Driver **threshold voltage**, pulse A leads pulse B by 90 degrees. If the voltage

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

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

Use the Controlled PWM Voltage block to create the voltage at the PWM port. This block creates a network engine event every time the PWM signal goes high. The network engine event triggers a simulation time point when the PWM signal goes high, which ensures good simulation accuracy. If you instead use the Controlled Voltage Source block from the Foundation library, which is controlled by Simulink, you need to set a suitably small time step for the simulation. For information about specifying the Simulink step size, see "Choosing a Solver" in the Simulink User's Guide.

Dialog Box and Parameters

🙀 Block Parameters	: Stepper Motor Driver
Stepper Motor Driver	
required to control the	a stepper motor driver and creates the A and B pulse trains e motor. The PWM input sets the step rate, and the driver me the PWM signal rises above the Enable threshold voltage.
pulse A leads pulse B B leads pulse A by 90 A is initialized positive	e is less than or equal to the Reverse threshold voltage, then by 90 degrees. If REV increases above the threshold, then pulse degrees and the motor direction is reversed. At time zero, pulse and pulse B negative. 1 and REF are defined relative to the REF port.
Parameters	
Enable threshold voltage:	2.5 V 💌
Reverse threshold voltage:	2.5 V 💌
Output voltage amplitude:	10 V 💌
	OK Cancel Help Apply

Enable threshold voltage

When the voltage at the PWM port rises above this threshold, the Stepper Motor Driver block initiates a step. The default value is 2.5 V.

Reverse threshold voltage

When the voltage at the REV port rises above this threshold, pulse B leads pulse A by 90 degrees and the motor direction is reversed. The default value is 2.5 V.

Output voltage amplitude

Amplitude of the output pulse trains. The default value is 10 V.

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.
	В-	Negative electrical output of pulse B.
	PWM	Triggering input step voltage.
	REF	Input floating reference voltage.
	REV	Input voltage that controls motor direction.
Examples	See t	he Controlled Stepper Motor demo.
See Also	Cont	rolled PWM Voltage and Stepper Motor.

Strain Gauge

Purpose	Model deformation sensor
---------	--------------------------

Sensors

Library

Description



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

This block models a physical signal input unstressed gauge res	port and change i	n resistance dR	is dR/R = K*É who	
Parameters				
Gauge resistance:	100		Ohm	•
Gauge factor:	2			

Gauge resistance

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

Gauge factor

The ratio K of the fractional change in resistance to the fractional change in length. The default value is 2.

Ports The block has the following ports:

В

-

Strain input.

+

Positive electrical port.

Negative electrical port.

Thermal Resistor

Purpose	Model resistor with thermal port
---------	----------------------------------

Library

Passive Devices

Description

▫╇D⊤ ▫₊┎⁴ѴѴѴѵ┚═╹ The Thermal Resistor block represents a temperature-dependent resistor. The resistance when the temperature at the thermal port is T is

Thermal Resistor

 $R = R_0(1 + a(T - T_0))$

where:

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

The following equation describes the thermal behavior of the block:

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

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

Block Parameters: Ti	hermal Resistor	X
given by R(T) = R0*(1+a Reference temperature T T of the resistor is gover the net heat flow into po i is the current. The them	esistor with a thermal port. The r alpha(T-TO)) where R0 is the Nom TO, and alpha is the Temperature ned by the equation m*c*dT/dt = rt A, m is the mass, c is the lump mal mass m*c is calculated from t r K_d using the equation m*c = k	hinal resistance at the coefficient. The temperature = Q + i^2*R(T) where Q is ed specific heat capacity and he Thermal time constant t_c
Parameters Electrical Thermal	1	1
Nominal resistance:	1	Ohm 💌
Reference temperature:	25	C I
Temperature coefficient:	5e-05	1/K 💌
	OK Cancel	Help Apply

Nominal resistance

The nominal resistance of the thermistor at the reference temperature. Many datasheets quote the nominal resistance at 25°C and list it as R25. The default value is 1 Ω .

Reference temperature

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

Temperature coefficient

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

Thermal Tab

당 Block Parameters: Tl	hermal Resistor	×
Thermal Resistor		
given by R(T) = R0*(1+a Reference temperature 1 T of the resistor is gover the net heat flow into po i is the current. The them	esistor with a thermal port. The re alpha(T-T0)) where R0 is the Nom F0, and alpha is the Temperature ned by the equation m*c*dT/dt = rt A, m is the mass, c is the lumpe mal mass m*c is calculated from th r K_d using the equation m*c = K	inal resistance at the coefficient. The temperature $Q + i^2*R(T)$ where Q is ad specific heat capacity and the Thermal time constant t_c
-Parameters		
Electrical Thermal]	1
Thermal time constant:	10	5 💌
Dissipation factor:	0.001	W/K 💌
Initial temperature:	25	C 💽
	OK Cancel	Help Apply

Thermal time constant

The time it takes the resistor temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 10 s.

Dissipation factor

The thermal power required to raise the thermal resistor temperature by one K. The default value is 0.001 W/K.

Initial temperature

The temperature of the thermal resistor at the start of the simulation. The default value is $25 \ ^{\circ}C$.

Ports The block has the following ports:

See Also	The	Negative electrical port. ermistor, Thermocouple.
	-	-
	+	Positive electrical port.
	A	Resistor thermal port.

Thermistor

Purpose Model NTC thermistor using B-parameter equation

Library Sensors

Description

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

Thermistor

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

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

• B is the characteristic temperature constant.

The following equation describes the thermal behavior of the block:

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

where:

where:

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

To model the thermistor in free space:

- **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} .

Electrical Tab

Dialog

Box and Parameters

	d B is the Characteristic t		nt. The
temperature T of the thermistor is net heat flow into port A, m is the	mass and c is the lumped	d specific heat capac	ity. The therm
mass m*c is calculated from the TI the equation m*c = K_d*t_c .	hermal time constant t_c	and the Dissipation I	factor K_d usin
Parameters			
Electrical Thermal			
Nominal resistance R0 at refere temperature T0:	ence 1000	Ohm	•
Reference temperature TO:	25	C	-
Characteristic temperature constant B:	3.5e+03	К	•

Nominal resistance R0 at reference temperature T0

The nominal resistance of the thermistor at the reference temperature. Many datasheets quote the nominal resistance at 25°C and list it as R25. The default value is 1000 Ω .

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

🙀 Block Parameters: The	mistor	×
- Thermistor		
temperature T is given by R the reference temperature temperature T of the thermi net heat flow into port A, m	Thermistor using the B-parameter ex (T) = R0*exp(B*(1/T-1/T0)) where R T0, and B is the Characteristic temper stor is governed by the equation m*c is the mass and c is the lumped speci the Thermal time constant t_c and th 	0 is the Nominal resistance at ature constant. The **dT/dt = Q where Q is the fic heat capacity. The thermal
-Parameters		
Electrical Thermal		1
Thermal time constant:	5	s 💌
Dissipation factor:	7.5e-04	W/K
Initial temperature:	25	C 💌
	OK Cancel	Help Apply

Thermal time constant

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

	 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

Database [1]. The voltage *E* across the device in mV is

Library

Description

он _____ А о

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

where:

Sensors

• *ci* is the *i*th element of the **Coefficients** [**c0 c1 ... cn**] parameter value.

The Thermocouple block represents a thermocouple using the standard polynomial parameterization defined in the NIST ITS-90 Thermocouple

• *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.

Thermocouple

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

To model the thermocouple in free space:

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

The model is based on the following assumptions:

Basic Assumptions and Limitations

- The high-order polynomials this block uses are very sensitive to the number of significant figures used for computation. Use all available significant figures when specifying the **Coefficients [c0 c1 ... cn]** parameter.
- **Coefficients [c0 c1 ... cn]** are defined for use over a specified temperature range.
- This block does not include the additional exponential term that Type K thermocouples use when parameterized for t > 0.

Thermocouple

Dialog Box and Parameters

Electrical Tab

Block Parameters: Thermocoup	e de la constant de l	2
temperature difference in degrees Cel The voltage presented across the out The absolute temperature T of the the	model. The thermocouple voltage is given by $E(mV) = c0 + c1^*t +, cn^*t^n$ where t is the sius between the temperature presented at thermal port A and the Reference temperature, but terminals is in units of volts. The default parameters are for a Type S thermocouple. rmocouple is governed by the equation $m^*c^*dT/dt = Q$ where Q is the net heat flow into poperific heat capacity. The thermal mass m^*c is calculated from the Thermal time constant t_constant t_c.	rt
-Parameters		
Electrical Thermal		
Coefficients [c0 c1 cn]:	3e-05 -2.3248e-08 3.2203e-11 -3.315e-14 2.5574e-17 -1.2507e-20 2.7144e-24]	
	OK Cancel Help Appl	y

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

	Block Parameters: Thermocouple					
	Thermocouple					
	This block implements a thermocouple mode	al. The thermoscourds us	ltaga is siyaa by E	(m)() = c0 + c18t +	aa*t∧a ula	ava tia thu
	temperature difference in degrees Celsius					
	The voltage presented across the output t	erminals is in units of vo	lts. The default pa	rameters are for a	Type S thermoo	ouple.
	The absolute temperature T of the thermo					
	A, m is the mass and c is the lumped specifi and the Dissipation factor K d using the eq		ermal mass m*c is	calculated from the	Thermal time co	onstant t_
L		·				
Γ	Parameters					
	Electrical Thermal					
	Reference temperature:	0			С	•
	Thermal time constant:	1			s	-
	Dissipation factor:	0.001			W/K	-
	Initial temperature:	25			С	
	indu temperature.	125				-
L						
				1		
			OK	Cancel	Help	App

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.

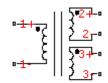
	Thermal time constant The time it takes the thermocouple temperature to reach 63% of the final temperature change when a step change in ambient temperature occurs. The default value is 1 s.
	Dissipation factor The thermal power required to raise the thermocouple temperature by one K. The default value 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.

Purpose Model three coupled inductors

Library

Passive Devices

Description



Three-Winding Mutual Inductor

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

$$V_{1} = L_{1} \frac{dI_{1}}{dt} + M_{12} \frac{dI_{2}}{dt} + M_{13} \frac{dI_{3}}{dt}$$
$$V_{2} = M_{12} \frac{dI_{1}}{dt} + L_{2} \frac{dI_{2}}{dt} + M_{23} \frac{dI_{3}}{dt}$$
$$V_{3} = M_{13} \frac{dI_{1}}{dt} + M_{23} \frac{dI_{2}}{dt} + L_{3} \frac{dI_{3}}{dt}$$

where:

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

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

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

🙀 Block Parameters: T	'hree-Winding	Mutual Inducto)r	X
Three-Winding Mutual Ir	nductor			
This block models three of voltage-current relation: positive node of their re	ships, where cur	rents are positive		
V1 = L1*dI1/dt + M12*	dI2/dt + M13*d	(3/dt		
V2 = M12*dI1/dt + L2*d	dI2/dt + M23*d	(3/dt		
V3 = M13*dI1/dt + M23	*dI2/dt + L3*dI	3/dt		
where parameters L1, L; the mutual inductances. using the equation Mi,j= one and the eignevalues	Mi, j is defined in Ki, j*sqrt(Li*Lj).	terms of the Coe The absolute value	fficient of Coup e of K must b	bling Ki,j e less than
The parameters IC1, IC and 3.	2 and IC3 set th	e initial currents flo	owing through (windings 1, 2
Parameters				
Inductance L1:	0.001		Н	•
Inductance L2:	0.001		Н	•
Inductance L3:	0.001		Н	•
Coefficient of coupling, K12:	0.9			
Coefficient of coupling, K13:	0.9			
Coefficient of coupling, K23:	0.9			
Specify initial condition?:	No			•
	ОК	Cancel	Help	Apply

Inductance L1

The self inductance of the first winding. The default value is $0.001\ \mathrm{H}.$

Inductance L2

The self inductance of the second winding. The default value is 0.001 H.

Inductance L3

The self inductance of the third winding. The default value is $0.001\ {\rm H}.$

Coefficient of coupling, K12

The coefficient that defines the mutual inductance between the first and second windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Coefficient of coupling, K13

The coefficient that defines the mutual inductance between the first and third windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Coefficient of coupling, K23

The coefficient that defines the mutual inductance between the second and third windings. The default value is 0.9. The absolute value must be between 0 and 1, exclusive.

Specify initial condition

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

- No Do not specify an initial condition for the model. This is the default option.
- Yes Specify the initial inductor currents.

Initial current port 1, IC1

The current flowing through the first winding at the start of the simulation. This parameter is only visible when you select Yes for the **Specify initial condition** parameter. The default value is 0 A.

Initial current port 2, IC2

The current flowing through the second winding at the start of the simulation. This parameter is only visible when you select

	 Yes for the Specify initial condition parameter. The default value is 0 A. Initial current port 3, IC3 The current flowing through the third winding at the start of the simulation. This parameter is only visible when you select Yes for the Specify initial condition parameter. The default value is 0 A.
Ports	The block has the following ports:
	1+ Positive electrical voltage of the first mutual inductor.
	1 - Negative electrical voltage of the first mutual inductor.
	2+ Positive electrical voltage of the second mutual inductor.
	2 - Negative electrical voltage of the second mutual inductor.
	3+ Positive electrical voltage of the third mutual inductor.
	3- Negative electrical voltage of the third mutual inductor.

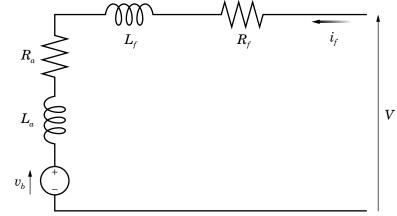
Purpose Model electrical and torque characteristics of a universal (or series) motor

Library Actuators & Drivers

Description



The Universal Motor block represents the electrical and torque characteristics of a universal (or series) motor using the following equivalent circuit model.



Where:

- R_a is the armature resistance.
- L_a is the armature inductance.
- R_f is the field winding resistance.
- L_f is the field winding inductance.

When you set the **Model parameterization** parameter to By equivalent circuit parameters, you specify the equivalent circuit parameters for this model. The Universal Motor block computes the motor torque as follows:

1 The magnetic field in the motor induces the following back $\operatorname{emf} v_b$ in the armature:

$$v_b = L_{af} i_f \omega$$

where $L_{\rm af}$ is a constant of proportionality and ω is the angular velocity.

2 The mechanical power is equal to the power reacted by the back emf:

$$P = v_b i_f = L_{af} i_f^2 \omega$$

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.

Universal Motor

Dialog Box and Parameters

Electrical Torque Tab

This block represents the electrical and torque characteristics of a universal motor (also sometimes called a serie wound motor). Motor characteristics can be defined in terms of equivalent circuit parameters R (total armature and field winding resistance), L (total armature and field winding inductance) and Laf (back-emf constant). The back emf induced the armature is given by Vb = Laf * I * W where I is the motor current and W is the mechanical angular speed. Alternatively, the motor characteristics can be defined in terms of rated mechanical power & speed, stall torque electrical power, nominal DC voltage, and L. If no information is available on armature or field winding inductance can be set to a suitably small non-zero value when driving the motor with DC. The block produces a positive torque acting from the mechanical C to R ports. Parameters Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03 rpm Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding inductance: 0.525 H	wound motor). Motor characteristics can be defined in terms of equivalent circuit parameters R (total armature and field winding inductance) and Laf (back-emf constant). The back emf indit the armature is given by Vb = Laf * I * W where I is the motor current and W is the mechanical angular spe Alternatively, the motor characteristics can be defined in terms of rated mechanical power & speed, stal to electrical power, nominal DC voltage, and L. If no information is available on armature or field winding induct can be set to a suitably small non-zero value when driving the motor with DC. The block produces a positive torque acting from the mechanical C to R ports. Parameters Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03
resistance), L (total armature and field winding inductance) and Laf (back-emf constant). The back emf induced the armature is given by Vb = Laf * I * W where I is the motor current and W is the mechanical angular speed. Alternatively, the motor characteristics can be defined in terms of rated mechanical power & speed, stall torque electrical power, nominal DC voltage, and L. If no information is available on armature or field winding inductance can be set to a suitably small non-zero value when driving the motor with DC. The block produces a positive torque acting from the mechanical C to R ports. Parameters Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated load (mechanical power): 75 Rated load (mechanical power): 75 Rated DC supply voltage: 200 V Electrical power in at rated load: 160 Total armature and field winding 0.525	resistance), L (total armature and field winding inductance) and Laf (back-emf constant). The back emf indu the armature is given by Vb = Laf * I * W where I is the motor current and W is the mechanical angular spe Alternatively, the motor characteristics can be defined in terms of rated mechanical power & speed, stall to electrical power, nominal DC voltage, and L. If no information is available on armature or field winding induc can be set to a suitably small non-zero value when driving the motor with DC. The block produces a positive torque acting from the mechanical C to R ports. Parameters Electrical Torque Mechanical Model parameterization: Rated speed (at rated load): 6.5e+03 [rpm]
Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03 rpm Rated load (mechanical power): 75 W Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding 0.525 H	Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03 rpm
Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03 Rated load (mechanical power): 75 W 1 Rated DC supply voltage: 200 Electrical power in at rated load: 160 Total armature and field winding 0.525	Electrical Torque Mechanical Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03
Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03 rpm Rated load (mechanical power): 75 W Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding 0.525 H	Model parameterization: By DC rated power, rated speed & electrical power Rated speed (at rated load): 6.5e+03
Rated speed (at rated load): 6.5e+03 rpm Rated load (mechanical power): 75 W Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding 0.525 H	Rated speed (at rated load): 6.5e+03
Rated load (mechanical power): 75 W Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding 0.525 H	
Rated DC supply voltage: 200 V Electrical power in at rated load: 160 W Total armature and field winding 0.525 H	Pated load (mechanical power): 75
Electrical power in at rated load: 160 W	Nacca load (incertained power). 73
Total armature and field winding	Rated DC supply voltage: 200 V
	Electrical power in at rated load: 160

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

niversal Motor		
nis block represents the el ound motor).	ectrical and torque characteristics of a u	niversal motor (also sometimes called a serie
sistance), L (total armatu e armature is given by Vb ternatively, the motor ch ectrical power, nominal Do in be set to a suitably sma	re and field winding inductance) and Laf = Laf * I * W where I is the motor curre aracteristics can be defined in terms of ra	
arameters	ve torque acting nom the mechanical c to	r ports.
	harden 1	
Electrical Torque Med	hanical	
Rotor inertia:	2e-04	kg*m^2
Rotor damping:	1e-06	N*m/(rad/s)
Initial rotor speed:	0	rpm

Rotor inertia

Rotor inertia. The default value is $2e\,{-}\,04~{\rm kg^{*}m^{2}}.$ 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: <i>Electronic Control Systems in Mechanical and Electrical Engineering</i> 3rd edition, Pearson Education, 2004.
See Also	DC Motor, Induction Motor, Servomotor, and Shunt Motor.

Variable Capacitor

Purpose Model linear time-varying capacitor

Library

Passive Devices

Description



Variable Capacitor

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

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

where v is the voltage across the capacitor. In the preceding relationship, the capacitance is defined as the ratio of the charge to the voltage. If the capacitance is defined as the local gradient of the

charge-voltage curve, then the $\frac{dC}{dt}$ term is not required.

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 issues 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

This block models a line	ar time-varving canar	titor The rela	tionchin hetwee	en current I
and voltage V is $I=C*d'$	V/dt+dC/dt*V where	C is the valu	e of the physica	l input signal
C. The Minimum capacit The Series resistance p				
resistance, and may be				
the block is connected i	n parallel with anothe	er capacitor.		
Parameters				
Parameters				
Parameters Minimum capacitance	1e-09		F	<u>•</u>
			F	<u>•</u>

Minimum capacitance C>0

The lower limit on the value of the signal at port C. This limit prevents the signal from reaching a value that has no physical meaning. The default value is 1e-09 F.

Series resistance

The value of the resistance placed in series with the variable capacitor. The default value is $1e-06\ \Omega.$

Ports The block has the following ports:

С

+

Capacitance. C must be finite and greater than zero.

Positive electrical port.

Negative electrical port.

See Also Variable Inductor, Simscape Variable Resistor

Variable Inductor

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. In the preceding relationship, the inductance is defined as the ratio of the flux to the current. If the inductance is defined as the local gradient of the

flux-current curve, then the $\frac{dL}{dt}$ term is not required.

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 issues 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

Ports

and current I is V=L*dI The Minimum inductance Parallel conductance pa	ar time-varying inductor. The relation /dt+1*dL/dt where L is the value of t e parameter prevents zero or negati arameter can be used to model insula ulation of some circuit topologies such h another inductor.	he physical input signal L. ve inductance values. The tion conductance, and
Minimum inductance	1e-06	H
Parallel conductance:	1e-09	1/Ohm 💌

Minimum inductance L>0

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

Parallel conductance

The value of the conductance placed in parallel with the variable inductor. The default value is $1e-09 \ 1/\Omega$.

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

Variable Inductor

Functions — Alphabetical List

netlist2sl

Purpose	Convert SPICE netlist to library of Simulink blocks
Syntax	<pre>modelname = netlist2sl(filename, libraryname) modelname = netlist2sl(filename, options)</pre>
Description	<pre>modelname = netlist2s1(filename, libraryname) maps the circuit elements listed in the SPICE netlist file filename to a Simulink library called libraryname that contains one or more blocks.</pre>
	• filename is the full name of the netlist file; it can also include the path name.
	• libraryname is the optional Simulink library name.
	netlist2s1 can import either subcircuit information or model card information into a block:
	• When you import subcircuit data from a SPICE netlist, SimElectronics creates a block that represents the netlist.
	The block dialog box for each imported block contains the following information:
	 Subcircuit name
	 Netlist file name
	 Time the netlist2s1 function created the block You can look at a snapshot of the netlist the function used to create the block by clicking Help in the block dialog box.
	• When you import model card data from a SPICE netlist, SimElectronics uses the data to populate the parameter values of the corresponding SPICE-compatible SimElectronics block.
	<pre>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:</pre>

- LibName A string that specifies the name of the Simulink library where netlist2s1 puts the blocks.
- ModelOnly A boolean value. True tells netlist2s1 to generate a library that contains only blocks representing the model cards that appear in the SPICE file. False (the default value) tells netlist2s1 to generate a library that contains all circuit information that appears in the SPICE file.

The netlist file must define one or more SPICE subcircuits or model cards. To import a netlist that is not a subcircuit into a Simulink library, add a subcircuit wrapper before using the 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, netlist2s1 adds new blocks to this library. If a subcircuit name conflicts with an existing block name in the library, netlist2s1 prompts you to either overwrite the existing block or rename the new block.

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

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

Note You cannot make changes directly to the library blocks that you create with the 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 netlist2s1 function to the modified netlist, as described in the preceding example.

Example 3

See the Creating a Library Block from a Netlist demo.

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