Bipolar Junction Transistor **bjtpnp**

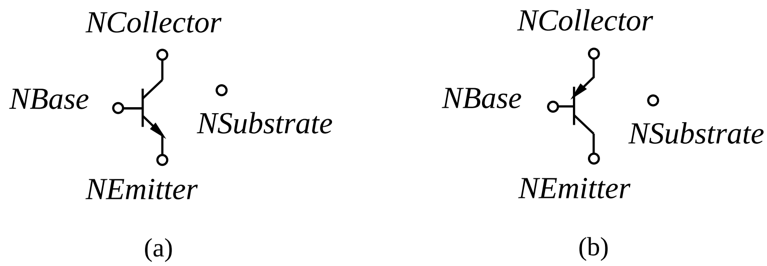

Figure 1: Q — Bipolar Polar Junction Transistor: (a) NPN transistor; (b) PNP transistor.

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*f*REEDA™ *Form:* `bjtpnp`:⟨`instance name`⟩ n_1 n_2 n_3 ⟨`parameter list`⟩

n_1 is the base node

n_2 is the collector node

n_3 is the emitter node

`SPICE` *Form:*
`Q`name NCollector NBase NEmitter [NSubstrate] ModelName [Area] [`OFF`] [`IC=`Vbe,Vce]
where

NCollector is the collector node.

NBase is the base node.

NEmitter is the emitter node.

NSubstrate is the optional substrate node. If not specified, then the ground is used as the substrate node. If *NSubstrate* is a name as allowed in it must be enclosed in square brackets, e.g. `[`*NSubstrate*`]`, to distinguish it from *ModelName*.

ModelName is the model name.

Area is the area factor. If the area factor is omitted, a value of 1.0 is assumed. (Units: none; Optional; Default: 1; Symbol: *Area*)

`OFF` indicates an (optional) initial condition on the device for the dc analysis. If specified the dc operating point is calculated with the terminal voltages set to zero. Once convergence is obtained, the program continues to iterate to obtain the exact value of the terminal voltages. The OFF option is used to enforce the solution to correspond to a desired state if the circuit has more than one stable state.

`IC` is the optional initial condition specification using `IC=`V_{BE}, V_{CE} is intended for use with the `UIC` option on the `.TRAN` line, when a transient analysis is desired starting from other than the quiescent operating point. See the *.IC* line description for a better way to set transient initial conditions.

Example:
bjtpnp:Q20 10 50 0
bjtpnp:QFAST IC=0.65,15.0
bjtpnp:Q5PUSH 10 29 14 200 MODEL1

Model Parameters:

Name	Description	Units	Default
`AREA`	Current multiplier		1.0
`BF`	Ideal maximum forward beta (B_F)		100.0
`BR`	Ideal maximum reverse beta (B_R)		1.0
`C2`	Base-emitter leakage saturation coefficient		I_{SE}/I_S
`C4`	Base-collector leakage saturation coefficient		(I_{SC}/I_S)
`CJC`	Base collector zero bias p-n capacitance (C_{JC})	F	0.0
`CJE`	Base emitter zero bias p-n capacitance (C_{JE})	F	0.0
`EG`	Bandgap voltage (E_G)	eV	1.11
`FC`	Forward bias depletion capacitor coefficient (F_C)		0.5
`IKF`	Corner of forward beta high-current roll-off (I_{KF})	A	10^{-10}
`IKR`	Corner for reverse-beta high current roll off (I_{KR})		10^{-10}
`IS`	Transport saturation current (I_S)	A	10^{-16}
`ISC`	Base collector leakage saturation current (I_{SC})	A	0.0
`ISE`	Base-emitter leakage saturation current (I_{SE})	A	0.0
`IRB`	Current at which `RB` falls to half of R_{BM} (I_{RB})	A	10^{-10}
`ITF`	Transit time dependency on `IC` (I_{TF})	A	0.0
`MJC`	Base collector p-n grading factor (M_{JC})		0.33
`MJE`	Base emitter p-n grading factor (M_{JE})		0.33
`NC`	Base-collector leakage emission coefficient (N_C)		2.0
`NE`	Base-emitter leakage emission coefficient (N_E)		1.5
`NF`	Forward current emission coefficient (N_F)		1.0
`NR`	Reverse current emission coefficient (N_R)		1.0
`RB`	Zero bias base resistance (R_B)	Ω	0.0
`RBM`	Minimum base resistance (R_{BM})	Ω	R_B
`RE`	Emitter ohmic resistance (R_E)	Ω	0.0
`RC`	Collector ohmic resistance (R_C)	Ω	0.0
`T`	Operating Temperature T	K	300
`TF`	Ideal forward transit time (T_S)	secs	0.0
`TNOM`	Nominal temperature (T_{NOM})	K	300
`TR`	Ideal reverse transit time (T_R)	S	0.0
`TRB1`	`RB` temperature coefficient (linear) (T_{RB1})		0.0
`TRB2`	`RB` temperature coefficient (quadratic) (T_{RB2})		0.0
`TRC1`	`RC` temperature coefficient (linear) (T_{RC1})		0.0
`TRC2`	`RC` temperature coefficient (linear) (T_{RC2})		0.0
`TRE1`	`RE` temperature coefficient (linear) (T_{RE1})		0.0
`TRE2`	`RE` temperature coefficient (quadratic) (T_{RE2})		0.0
`TRM1`	`RBM` temperature coefficient (linear) (T_{RM1})		0.0
`TRM2`	`RBM` temperature coefficient (quadratic) (T_{RM2})		0.0

Name	Description	Units	Default
VA	alternative keyword for VAF (V_A)	V	10^{-10}
VAF	Forward early voltage (V_{AF})	V	10^{-10}
VAR	Reverse early voltage (V_{AR})		10^{-10}
VB	alternative keyword for VAR (V_B)		10^{-10}
VJC	Base collector built in potential (V_{JC})	V	0.75
VJE	Base emitter built in potential (V_{JE})	V	0.75
VTF	Transit time dependency on VBC (V_{TF})	V	10^{-10}
XCJC	Fraction of CBC connected internal to RB (X_{CJC})		1.0
XTB	Forward and reverse beta temperature coefficient (X_{TB})		0.0
XTF	Transit time bias dependence coefficient (X_{TF})		0.0
XTI	IS temperature effect exponent (X_{TI})		3.0

ELEMENT Model

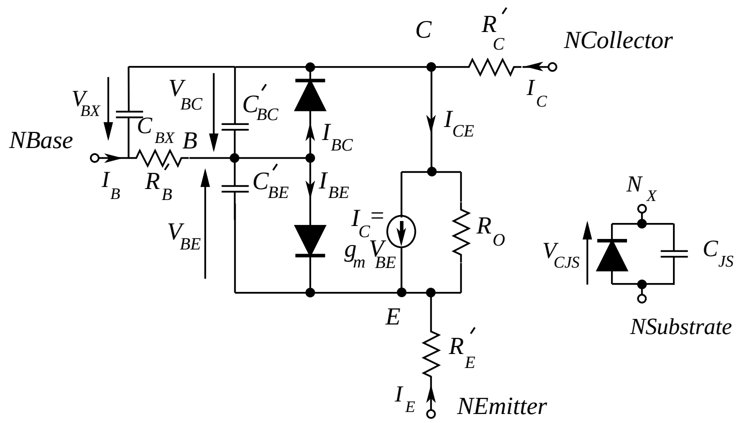

Figure 2: Schematic of the BJT Model

Standard Calculations

The physical constants used in the model evaluation are

k	Boltzman's constant	$1.3806226\, 10^{-23}$ J/K
q	electronic charge	$1.6021918\, 10^{-19}$ C

Absolute temperatures (in kelvins, K) are used. The thermal voltage

$$V_{TH}(T_{NOM}) = k\, T_{NOM}/q. \tag{1}$$

Current Characteristics

The base-emitter current,

$$I_{BE} = I_{BF}/\beta_F + I_{LE} \tag{2}$$

the base-collector current,

$$I_{BC} = I_{BR}/\beta_R + I_{LC} \tag{3}$$

and the collector-emitter current,

$$I_{CE} = I_{BF} - I_{BR}/K_{QB} \tag{4}$$

where the forward diffusion current,

$$I_{BF} = I_S \left(e^{V_{BE}/(N_F V_{TH})} - 1 \right) \tag{5}$$

the nonideal base-emitter current,

$$I_{LE} = I_{SE} \left(e^{V_{BE}/(N_E V_{TH})} - 1 \right) \tag{6}$$

the reverse diffusion current,

$$I_{BR} = I_S \left(e^{V_{BC}/(N_R V_{TH})} - 1 \right) \tag{7}$$

the non-ideal base-collector current,

$$I_{LC} = I_{SC} \left(e^{V_{BC}/(N_C V_{TH})} - 1 \right) \tag{8}$$

and the base charge factor,

$$K_{QB} = 1/2 \left[1 - V_{BC}/V_{AF} - V_{BE}/V_{AB}\right]^{-1} \left(1 + \sqrt{1 + 4\,(I_{BF}/I_{KF} + I_{BR}/I_{KR})} \right) \tag{9}$$

Thus the conductive current flowing into the base,

$$I_B = I_{BE} + I_{BC} \tag{10}$$

the conductive current flowing into the collector,

$$I_C = I_{CE} - I_{BC} \tag{11}$$

and the conductive current flowing into the emitter,

$$I_C = I_{BE} + I_{CE} \tag{12}$$

Capacitances

$C_{BE} = Area(C_{BE\tau} + C_{BEJ})$ where the base-emitter transit time or diffusion capacitance

$$C_{BE\tau} = \tau_{F,EFF} \partial I_{BF} / \partial V_{BE} \tag{13}$$

the effective base transit time is empirically modified to account for base puchout, space-charge limited current flow, quasi-saturation and lateral spreading which tend to increase τ_F

$$\tau_{F,EFF} = \tau_F \left[1 + X_{TF}(3x^2 - 2x^3)e^{(V_{BC}/(1.44V_{TF})}\right] \tag{14}$$

and $x = I_{BF}/(I_{BF} + AreaI_{TF})$.

The base-emitter junction (depletion) capacitance

$$C_{BEJ} = \begin{cases} C_{JE}\left(1 - V_{BE}/V_{JE}\right)^{-M_{JE}} & V_{BE} \leq F_C V_{JE} \\ C_{JE}\left(1 - F_C\right)^{-(1+M_{JE})}\left(1 - F_C(1 + M_{JE}) + M_{JE}V_{BE}/V_{JE}\right) & V_{BE} > F_C V_{JE} \end{cases} \tag{15}$$

The base-collector capacitance, $C_{BC} = Area(C_{BC\tau} + X_{CJC}C_{BCJ})$ where the base-collector transit time or diffusion capacitance

$$C_{BC\tau} = \tau_R \partial I_{BR}/\partial V_{BC} \tag{16}$$

The base-collector junction (depletion) capacitance

$$C_{BCJ} = \begin{cases} C_{JC}\left(1 - V_{BC}/V_{JC}\right)^{-M_{JC}} & V_{BC} \leq F_C V_{JC} \\ C_{JC}\left(1 - F_C\right)^{-(1+M_{JC})}\left(1 - F_C(1 + M_{JC}) + M_{JC}V_{BC}/V_{JC}\right) & V_{BC} > F_C V_{JC} \end{cases} \tag{17}$$

The capacitance between the extrinsic base and the intrinsic collector

$$C_{BX} = \begin{cases} Area(1 - X_{CJC})C_{JC}\left(1 - V_{BX}/V_{JC}\right)^{-M_{JC}} & V_{BX} \leq F_C V_{JC} \\ \\ (1 - X_{CJC})C_{JC}\left(1 - F_C\right)^{-(1+M_{JC})} & V_{BX} > F_C V_{JC} \\ \quad \times \left(1 - F_C(1 + M_{JC}) + M_{JC}V_{BX}/V_{JC}\right) & \end{cases} \tag{18}$$

Bugs:

Parameters: OFF and IC are not functional.

Version:
2002.09.01

Credits:

Name	Affiliation	Date	
Senthil Velu	North Carolina State University	Sept 2002	NC STATE UNIVERSITY

Publications:

1. C. Christoffersen, S. Velu and M. B. Steer, " A Universal Parameterized Nonlinear Device Model Formulation for Microwave Circuit Simulation," 2002 IEEE Int. Microwave Symp. Digest, June 2002, pp 2189-2192.