# Bipolar Junction Transistor **bjtnpn**

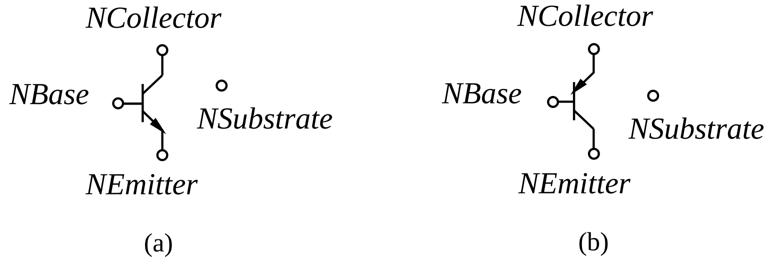


Figure 1: Q — Bipolar Polar Junction Transistor: (a) NPN transistor; (b) PNP transistor.

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fREEDA™ *Form:* `bjtnpn`:⟨`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:*
bjtnpn:Q20 10 50 0
bjtnpn:QFAST IC=0.65,15.0
bjtnpn: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**

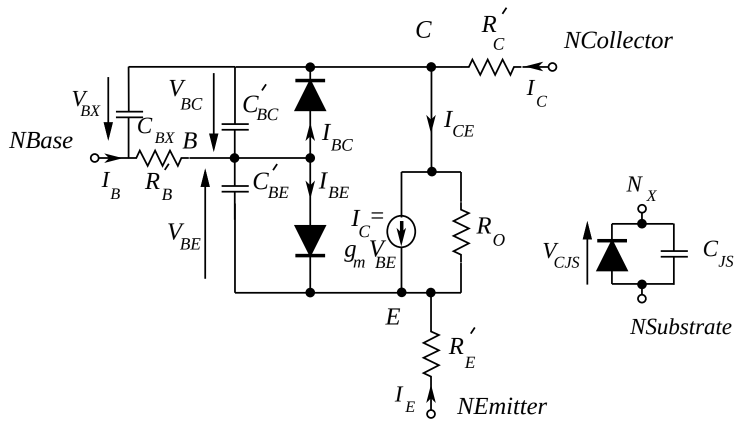


Figure 2: Schematic of the BJT Model

## 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,

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

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 $\tau_F$

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

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

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

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*Bugs:*

Parameters: OFF and IC are not functional.

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*Version:*
2002.09.01

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*Credits:*

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

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*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.