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Bipolar P-N-P Transistor Level 500

1.1 Introduction

The Lateral bipolar transistor model, level 500, provides an extensive description of a lateral integrated circuit junction-isolated PNP transistor. It is meant to be used for DC, transient and AC analyses at all current levels, i.e. including high and low injection.

For **Pstar**, **Spectre** and **ADS** users it is available as built-in model.

1.2 Physics

1.2.1 Survey of modeled effects

- Temperature effects
- Charge storage effects
- Excess phase shift for current and storage charges
- Substrate effects and parasitic pnp (for the TPS device only)
- High-injection effects
- Built-in electric field in base region
- Bias-dependent Early effect
- Low-level non-ideal base currents
- Hard and quasi-saturation
- Weak avalanche
- Current crowding (DC, AC and transient) and conductivity modulation for base resistance
- Hot carrier effects in the collector epilayer
- Explicit modeling of inactive regions
- Split base-collector depletion capacitance

1.3 Symbols, parameters and constants

The parameters for TPL-level-500 are listed in the table below.

Parameter name	Units	Description
<i>LEVEL</i>	-	Model level, must be set to 500
<i>PARAMCHK</i>	-	Level of clip warning info *)
<i>IS</i>	A	Collector-emitter saturation current
<i>BF</i>		Ideal forward common-emitter current gain
<i>IBF</i>	A	Saturation current of non-ideal forward base current
<i>VLF</i>	V	Cross-over voltage of non-ideal forward base current
<i>IK</i>	A	High injection knee current
<i>XIFV</i>	-	Vertical fraction of forward current
<i>EAFV</i>	V	Early voltage of the lateral forward current component at zero collector-base bias
<i>EARV</i>	V	Early voltage of the vertical forward current component at zero collector-base bias
<i>BR</i>	-	Ideal reverse common-emitter current gain
<i>IBR</i>	A	Saturation current of non-ideal reverse base current
<i>VLR</i>	V	Cross-over voltage of non-ideal reverse base current
<i>XIRV</i>	-	Vertical fraction of reverse current
<i>EARL</i>	V	Early voltage of the lateral reverse current component at zero emitter-base bias
<i>EARV</i>	V	Early voltage of the vertical reverse current component at zero emitter-base bias
<i>XES</i>	-	Ratio between saturation current of e-b-s transistor and e-b-c transistor
<i>XHES</i>	-	Fraction of substrate current of e-b-s transistor subject to high injection
<i>XCS</i>	-	Ratio between the saturation current of c-b-s transistor and c-b-e transistor
<i>XHCS</i>	-	Fraction of substrate current of c-b-s transistor subject to high injection
<i>ISS</i>	A	Saturation current of substrate-base diode

Parameter name	Units	Description
<i>RCEX</i>	Ω	External part of the collector resistance
<i>RCIN</i>	Ω	Internal part of the collector resistance
<i>RBCC</i>	Ω	Constant part of the base resistance RBC
<i>RBCV</i>	Ω	Variable part of the base resistance RBC
<i>RBEC</i>	Ω	Constant part of the base resistance RBE
<i>RBEV</i>	Ω	Variable part of the base resistance RBE
<i>REEX</i>	Ω	External part of the emitter resistance
<i>REIN</i>	Ω	Internal part of the emitter resistance
<i>RSB</i>	Ω	Substrate-base leakage resistance
<i>TLAT</i>	s	Low injection (forward and reverse) transit time of charge stored in the epilayer between emitter and collector
<i>TFVR</i>	s	Low injection forward transit time due to charge stored in the epilayer under the emitter
<i>TFN</i>	s	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter
<i>CJE</i>	F	Zero-bias emitter-base depletion capacitance
<i>VDE</i>	V	Emitter-base diffusion voltage
<i>PE</i>	-	Emitter-base grading coefficient
<i>TRVR</i>	s	Low injection reverse transit time due to charge stored in the epilayer under the collector
<i>TRN</i>	s	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector
<i>CJC</i>	F	Zero-bias collector-base depletion capacitance
<i>VDC</i>	V	Collector-base diffusion voltage
<i>PC</i>	-	Collector-base grading coefficient
<i>CJS</i>	F	Zero-bias substrate-base depletion capacitance
<i>VDS</i>	V	Substrate-base diffusion voltage
<i>PS</i>	-	Substrate-base grading coefficient
<i>TREF</i>	$^{\circ}\text{C}$	Reference temperature of the parameter set
<i>DTA</i>	$^{\circ}\text{C}$	Difference between the device temperature and the ambient analysis temperature
<i>VGEB</i>	V	Bandgap voltage of the emitter-base depletion region
<i>VGCB</i>	V	Bandgap voltage of the collector-base depletion region

Parameter name	Units	Description
<i>VGSB</i>	V	Bandgap voltage of the substrate-base depletion region
<i>VGB</i>	V	Bandgap voltage of the base between emitter and collector
<i>VGE</i>	V	Bandgap voltage of the emitter
<i>VGJE</i>	V	Bandgap voltage recombination emitter-base junction
<i>AE</i>	-	Temperature coefficient of BF
<i>SPB</i>	-	Temperature coefficient of the epitaxial base hole mobility
<i>SNB</i>	-	Temperature coefficient of the epitaxial base electron mobility
<i>SNBN</i>	-	Temperature coefficient of buried layer electron mobility
<i>SPE</i>	-	Temperature coefficient of emitter hole mobility
<i>SPC</i>	-	Temperature coefficient of collector hole mobility
<i>SX</i>	-	Temperature coefficient of combined minority carrier mobilities in emitter and buried layer
<i>KF</i>	-	Flickernoise coefficient
<i>AF</i>	-	Flickernoise exponent
<i>EXPHI</i>	rad	Excess phase shift

The additional parameters for the thermal model TPLT-level-500 are:

Parameter name	Units	Description
<i>RTH</i>	$^{\circ}\text{C}/\text{W}$	Thermal resistance
<i>CTH</i>	$\text{J}/^{\circ}\text{C}$	Thermal capacitance
<i>ATH</i>	-	Temperature coefficient of the thermal resistance

The additional parameter MULT for all level-500 models is listed in the table below.

Parameter name	Units	Description
<i>MULT</i>	-	Multiplication factor
<i>PRINT-SCALED</i>		Flag to add scaled parameters to the OP output

*) See Appendix B for the definition of PARAMCHK.

Parameter *MULT*

This parameter may be used to put several transistors in parallel. To scale the geometry of a transistor use of the process-block is preferable over using this feature.

The following parameters are multiplied by *MULT*:

IS, IBF, IK, IBR, ISS, CJE, CJC, CJS, CTH

Divided by *MULT* are:

RCEX, RCIN, RBCC, RBCV, RBEC, RBEV, REEX, REIN, RSB, RTH

Default and clipping values

The default values and clipping values for the TPL-level-500 are listed below.

Parameter name	Units	Default	Clip low	Clip high
<i>LEVEL</i>	-	500	-	-
<i>PARAMCHK</i>	-	0	-	-
<i>IS</i>	A	1.80×10^{-16}	0.0	-
<i>BF</i>		131.00	1.0×10^{-4}	-
<i>IBF</i>	A	2.60×10^{-14}	0.0	-
<i>VLF</i>	V	0.54	-	-
<i>IK</i>	A	1.10×10^{-4}	0.0	-
<i>XIFV</i>	-	0.43	0.0	1.0
<i>EAFV</i>	V	20.50	0.01	-
<i>EAFV</i>	V	75.00	0.01	-
<i>BR</i>	-	25.00	1.0×10^{-4}	-
<i>IBR</i>	A	1.20×10^{-13}	0.0	-
<i>VLR</i>	V	0.48	-	-
<i>XIRV</i>	-	0.43	0.0	1.0
<i>EARL</i>	V	13.10	0.01	-
<i>EARV</i>	V	104.00	0.01	-
<i>XES</i>	-	2.70×10^{-3}	0.0	-
<i>XHES</i>	-	0.70	0.0	1.0
<i>XCS</i>	-	3.00	0.0	-
<i>XHCS</i>	-	1.00	0.0	1.0
<i>ISS</i>	A	4.00×10^{-13}	0.0	-
<i>RCEX</i>	Ω	5.00	1.0×10^{-6}	-
<i>RCIN</i>	Ω	47.00	1.0×10^{-6}	-
<i>RBCC</i>	Ω	10.00	1.0×10^{-6}	-
<i>RBCV</i>	Ω	10.00	0.0	-

Parameter name	Units	Default	Clip low	Clip high
<i>RBEC</i>	Ω	10.00	1.0×10^{-6}	-
<i>RBEV</i>	Ω	50.00	0.0	-
<i>REEX</i>	Ω	27.00	1.0×10^{-6}	-
<i>REIN</i>	Ω	66.00	1.0×10^{-6}	-
<i>RSB</i>	Ω	1.00×10^{15}	1.0×10^{-6}	-
<i>TLAT</i>	s	2.40×10^{-9}	0.0	-
<i>TFVR</i>	s	3.00×10^{-8}	0.0	-
<i>TFN</i>	s	2.00×10^{-10}	0.0	-
<i>CJE</i>	F	6.10×10^{-14}	0.0	-
<i>VDE</i>	V	0.52	0.05	-
<i>PE</i>	-	0.30	0.01	0.99
<i>TRVR</i>	s	1.00×10^{-9}	0.0	-
<i>TRN</i>	s	3.00×10^{-9}	0.0	-
<i>CJC</i>	F	3.90×10^{-13}	0.0	-
<i>VDC</i>	V	0.57	0.05	-
<i>PC</i>	-	0.36	0.01	0.99
<i>CJS</i>	F	1.30×10^{-12}	0.0	-
<i>VDS</i>	V	0.52	0.05	-
<i>PS</i>	-	0.35	0.01	0.99
<i>TREF</i>	$^{\circ}\text{C}$	25.00	-273.15	-
<i>DTA</i>	$^{\circ}\text{C}$	0.00	-	-
<i>VGEB</i>	V	1.206	0.1	-
<i>VGCB</i>	V	1.206	0.1	-
<i>VGSB</i>	V	1.206	0.1	-
<i>VGB</i>	V	1.206	0.1	-
<i>VGE</i>	V	1.206	0.1	-
<i>VGJE</i>	V	1.123	0.1	-

Parameter name	Units	Default	Clip low	Clip high
<i>AE</i>	-	4.48	-	-
<i>SPB</i>	-	2.853	-	-
<i>SNB</i>	-	2.60	-	-
<i>SNBN</i>	-	0.30	-	-
<i>SPE</i>	-	0.73	-	-
<i>SPC</i>	-	0.73	-	-
<i>SX</i>	-	1.00	-	-
<i>KF</i>	-	0.00	0.0	-
<i>AF</i>	-	1.00	0.01	-
<i>EXPHI</i>	rad	0.00	0.0	-

The default values and clipping values for the TPLT-level-500 are:

Parameter name	Units	Default	Clip low	Clip high
<i>RTH</i>	°C/W	300.00	0.00	-
<i>CTH</i>	J/°C	3.00×10^{-9}	0.00	-
<i>ATH</i>	-	0.00	-	-

The additional parameter MULT for all level-500 models is listed in the table below.

Parameter name	Units	Default	Clip low	Clip high
<i>MULT</i>	-	1.00	0.00	-
<i>PRINT-SCALED</i>	-	0	-	-

1.4 Equivalent circuit and model equations

This section contains a full description of the TPL-level-500 PNP transistor. The equivalent circuits are shown in Figures 1 and 2.

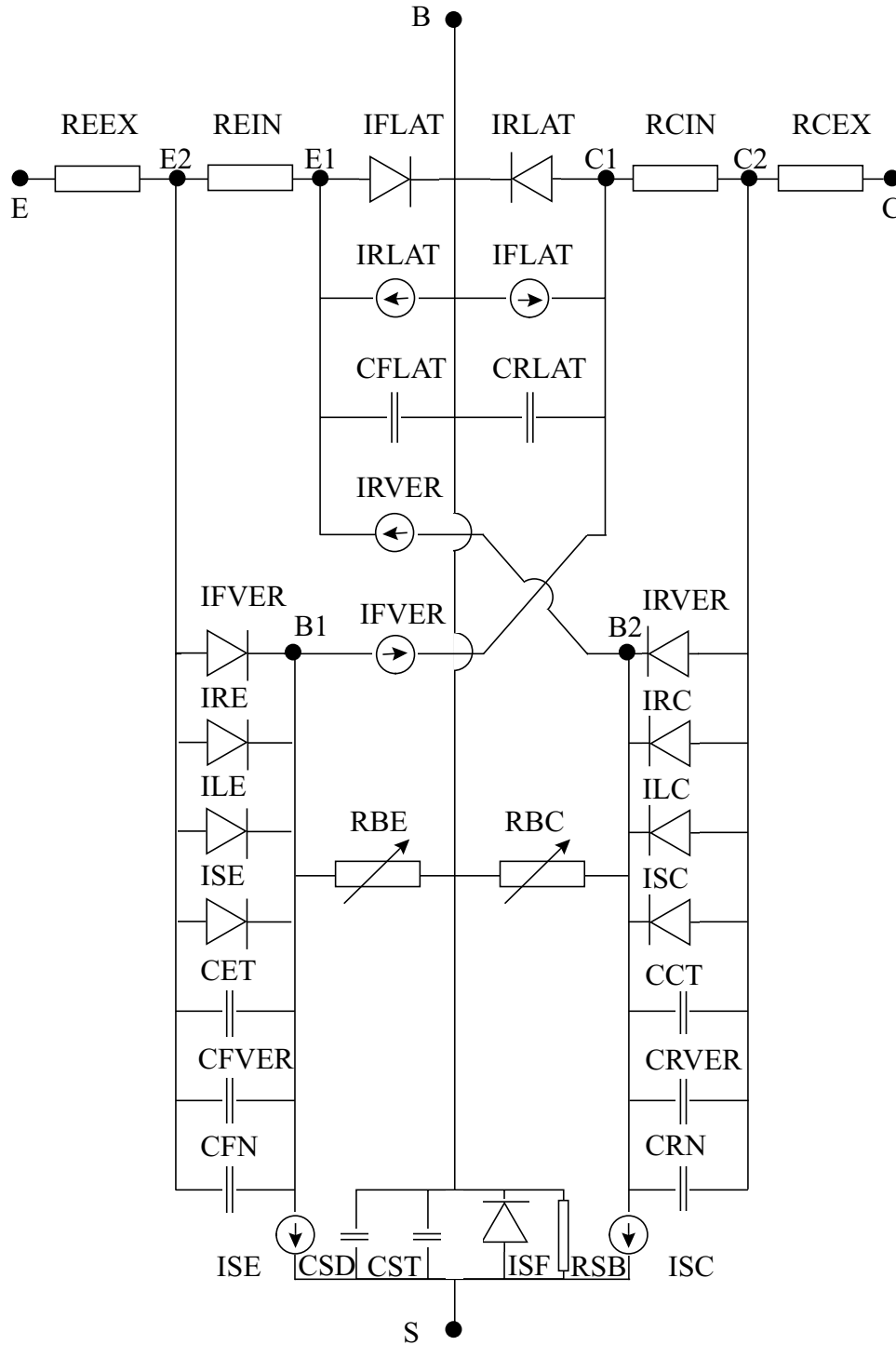


Figure 1: Large signal equivalent circuit

Model constants

$$TEMP = 273.15 + TNOM + DTA$$

$$k = 1.3806226 \cdot 10^{-23} \text{JK}^{-1}$$

$$q = 1.6021918 \cdot 10^{-19} \text{C}$$

$$k/q = 0.86171 \cdot 10^{-4} \text{J/K}$$

$$\delta = 0.01$$

$$T_{sd} = 1.0 \cdot 10^{-6} \text{s (fixed transit time for } Q_{sd})$$

$$VD = 0.7 \cdot V \text{ (the base diffusion voltage)}$$

The default reference temperature $TREF$ for parameter determination is 25°C.

Temperature dependence of the parameters

$$T_K = TREF + 273.15 \quad (1.1)$$

$$T_N = \frac{TEMP}{TREF + 273.15} \quad (1.2)$$

$$T_I = \frac{1}{TREF + 273.15} - \frac{1}{TEMP} \quad (1.3)$$

Series resistances:

$$RCIN_T = RCIN \cdot T_N^{SPC} \quad (1.4)$$

$$RBCC_T = RBCC \cdot T_N^{SNBN} \quad (1.5)$$

$$RBCV_T = RBCV \cdot T_N^{SNB} \quad (1.6)$$

$$RBEC_T = RBEC \cdot T_N^{SNBN} \quad (1.7)$$

$$RBEV_T = RBEV \cdot T_N^{SNB} \quad (1.8)$$

$$REIN_T = REIN \cdot T_N^{SPE} \quad (1.9)$$

$REEX$, $RCEX$ and RSB are assumed temperature independent.

- Depletion capacitances:

$$VDx_T = -3k \frac{TEMP}{q} \cdot \ln(T_N) + VDx \cdot T_N + (1 - T_N) \cdot V_{gap} \quad (1.10)$$

$$CJx_T = CJx \cdot \left(\frac{VDx}{VDx_T} \right)^{Px} \quad (1.11)$$

for the emitter-base junction: $\begin{cases} V_{gap} = VGEB \\ x = E \end{cases}$

with:for the collector-base junction: $\begin{cases} V_{gap} = VGCB \\ x = C \end{cases}$

for the substrate-base junction: $\begin{cases} V_{gap} = VGSB \\ x = S \end{cases}$

The internal diffusion voltage VD :

$$VD_T = -3k \frac{TEMP}{q} \cdot \ln(T_N) + VD \cdot T_N + (1 - T_N) \cdot VGB \quad (1.12)$$

- The Early voltages:

$$EAFI_T = EAFI \cdot \sqrt{VD_T / (VD)} \quad (1.13)$$

The parameters $EARL$, $EAFV$ and $EARV$ are subject to the same scaling rule.

$$IS_T = IS \cdot T_N^{(4.0 - SPB)} \cdot \exp(q \cdot VGB \cdot T_I / k) \quad (1.14)$$

$$BF_T = BF \cdot T_N^{(AE - SPB)} \cdot \exp\{q \cdot (VGB - VGE) \cdot T_I / k\} \quad (1.15)$$

$$IBF_T = IBF \cdot (T_N)^2 \cdot \exp\{q \cdot (VGJE/2) \cdot T_I/k\} \quad (1.16)$$

$$IK_T = IK \cdot (T_N)^{(1-SPB)} \quad (1.17)$$

$$BR_T = BR \cdot \frac{BF_T}{BF} \quad (1.18)$$

$$IBR_T = IBR \cdot \frac{IBF_T}{IBF} \quad (1.19)$$

$$ISS_T = ISS \cdot (T_N)^2 \cdot \exp(q \cdot VGSB \cdot T_I/k) \quad (1.20)$$

The transit times:

$$TLAT_T = TLAT \cdot T_N^{(SPB-1.0)} \quad (1.21)$$

$$TFVR_T = TFVR \cdot \frac{TLAT_T}{TLAT} \quad (1.22)$$

$$TFN_T = TFN \cdot T_N^{(SX-1.0)} \quad (1.23)$$

$$TRVR_T = TRVR \cdot \frac{TLAT_T}{TLAT} \quad (1.24)$$

$$TRN_T = TRN \cdot \frac{TFN_T}{TFN} \quad (1.25)$$

All other model parameters are assumed to be temperature independent.

Temperature parameters: *VGEB*, *VGCB*, *VGSB*, *VGB*, *VGE*, *VGJE*, *AE*, *SPB*, *SNB*, *SNBN*, *SPE*, *SPC*, *SX*.

Early factors

The Early factors for the components of the main current I_p are derived from the variation of the depletion widths in the base relative to the base width itself.

- Early factor of the lateral current components

$$F_{LAT} = hyp_1 \left\{ 1 - \left(\frac{\sqrt[4]{\left(1 - \frac{V_{E1B}}{VD_T}\right)^2 + \delta}}{1 + \frac{EARL}{2VD_T}} + \frac{\sqrt[4]{\left(1 - \frac{V_{C1B}}{VD_T}\right)^2 + \delta}}{1 + \frac{EAFV}{2VD_T}} \right), \delta_E \right\} \quad (1.26)$$

- Early factor of the forward vertical current component

$$F_{FVER} = hyp_1 \left\{ 1 - \left(\frac{\sqrt[4]{\left(1 - \frac{V_{E2B1}}{VD_T}\right)^2 + \delta}}{1 + \frac{EARV}{2VD_T}} + \frac{\sqrt[4]{\left(1 - \frac{V_{C1B}}{VD_T}\right)^2 + \delta}}{1 + \frac{EAFV}{2VD_T}} \right), \delta_E \right\} \quad (1.27)$$

- Early factor of the reverse vertical current component

$$F_{RVER} = hyp_1 \left\{ 1 - \left(\frac{\sqrt[4]{\left(1 - \frac{V_{E1B}}{VD_T}\right)^2 + \delta}}{1 + \frac{EARV}{2VD_T}} + \frac{\sqrt[4]{\left(1 - \frac{V_{C2B2}}{VD_T}\right)^2 + \delta}}{1 + \frac{EAFV}{2VD_T}} \right), \delta_E \right\} \quad (1.28)$$

$\delta_E = 10^{-3}$; for the definition of the hyp_1 function, see *Appendix A Hyp functions*.

Model parameters : $EAFV$, $EAFV$, $EARL$, $EARV$.

Ideal diodes

$$V_T = \frac{k \cdot TEMP}{q} \quad (1.29)$$

The ideal diode equations are as follows

$$I_{F1} = IS_T \cdot [\exp(V_{E1B}/V_T) - 1] \quad (1.30)$$

$$I_{F2} = IS_T \cdot [\exp(V_{E2B1}/V_T) - 1] \quad (1.31)$$

$$I_{R1} = IS_T \cdot [\exp(V_{C1B}/V_T) - 1] \quad (1.32)$$

$$I_{R2} = IS_T \cdot [\exp(V_{C2B2}/V_T) - 1] \quad (1.33)$$

Model parameter : IS .

The main current I_P

$$I_P = I_{FLAT} + I_{FVER} - I_{RLAT} - I_{RVER} \quad (1.34)$$

- Forward currents I_{FLAT} and I_{FVER}

The main forward current is separated into lateral and vertical components originating from the emitter-base junction sidewall and bottom respectively. These formulations include Early and high injection effects and because the two currents depend on different internal emitter-base junction voltages, emitter current crowding is also modelled. The lateral forward current component I_{FLAT} :

$$I_{FLAT} = \left\{ \frac{4 \cdot (1 - XIFV) \cdot I_{F1}}{3 + \sqrt{1 + 16 \cdot \frac{I_{F1}}{IK}}} \right\} / F_{LAT} \quad (1.35)$$

The vertical forward current component I_{FVER}

$$I_{FVER} = \left\{ \frac{4 \cdot XIFV \cdot I_{F2}}{3 + \sqrt{1 + 16 \cdot \frac{I_{F2}}{IK}}} \right\} / F_{FVER} \quad (1.36)$$

Model parameters : $XIFV$, IK .

- Reverse currents I_{RLAT} and I_{RVER}

The main reverse current is separated into lateral and vertical components originating from the collector-base junction sidewall and bottom respectively. These formulations include Early and high injection effects and because the two currents depend on different internal collector-base junction voltages, collector current crowding is also modelled.

The lateral reverse current component I_{RLAT}

$$I_{RLAT} = \left\{ \frac{4 \cdot (1 - XIRV) \cdot I_{R1}}{3 + \sqrt{1 + 16 \cdot \frac{I_{R1}}{IK}}} \right\} / F_{LAT} \quad (1.37)$$

The vertical reverse current component I_{RVER}

$$I_{RVER} = \left\{ \frac{4 \cdot XIRV \cdot I_{R2}}{3 + \sqrt{1 + 16 \cdot \frac{I_{R2}}{IK}}} \right\} / F_{RVER} \quad (1.38)$$

Model parameters : $XIRV$.

The Base current

- Forward components

The total forward base current is composed of an ideal and a non-ideal component. Both components depend on the bottom part of the emitter-base junction.

Ideal component :

$$I_{RE} = \frac{I_{F2}}{BF_T} \quad (1.39)$$

Non-ideal component:

$$I_{LE} = \frac{IBF_T \cdot \{ \exp(V_{E2B1}/V_T) - 1 \}}{\exp(V_{E2B1}/2 \cdot V_T) + \exp(VLF/2 \cdot V_T)} \quad (1.40)$$

Model parameters : BF , IBF , VLF .

- Reverse components

The total reverse base current is composed of an ideal and a non-ideal component. Both components depend on the bottom part of the collector-base junction.

Ideal component:

$$I_{RC} = \frac{I_{R2}}{BR_T} \quad (1.41)$$

Non-ideal component:

$$I_{LC} = \frac{IBR_T \cdot \{ \exp(V_{C2B2}/V_T) - 1 \}}{\exp(V_{C2B2}/2 \cdot V_T) + \exp(VLR/2 \cdot V_T)} \quad (1.42)$$

Model parameters : BR , IBR , VLR .

The substrate current

- Forward component

The forward substrate component depends on the bottom part of the emitter-base junction and consists of an ideal component and a component subject to high injection effects. The parameter $XHES$ determines the fraction subject to high injection.

$$I_{SE} = (1 - XHES) \cdot XES \cdot I_{F2} + \frac{4 \cdot XHES \cdot XES \cdot I_{F2}}{3 + \sqrt{1 + 16 \cdot \frac{I_{F2}}{IK}}} \quad (1.43)$$

Model parameters : XES , $XHES$.

Reverse component

The reverse substrate component depends on the bottom part of the collector-base junction and consists of an ideal component and a component subject to high injection effects. The parameter $XHCS$ determines the fraction subject to high injection.

$$I_{SC} = (1 - XHCS) \cdot XCS \cdot I_{R2} + \frac{4 \cdot XHCS \cdot XCS \cdot I_{R2}}{3 + \sqrt{1 + 16 \cdot \frac{I_{R2}}{IK}}} \quad (1.44)$$

Model parameters : XCS , $XHCS$.

Additional substrate and base current

An ideal diode models the substrate-base junction. The reverse leakage current of this junction can be used to model the zero-crossover phenomena sometimes observed in the base current at low bias conditions and high temperatures.

$$I_{SF} = ISS_T \cdot [\exp(V_{SB}/V_T) - 1] \quad (1.45)$$

Model parameters : ISS .

Depletion charges

The Poon-Gummel formulation is used in the modelling of the depletion charges.

- Emitter-base depletion charge

$$Q_{TE} = \frac{-CJE_T}{1-PE} \cdot \left\{ \frac{VDE_T - V_{E2B1}}{\left(\left(1 - \frac{V_{E2B1}}{VDE_T} \right)^2 + \delta \right)^{\frac{PE}{2}}} \right\} \quad (1.46)$$

Model parameters : CJE , VDE , PE .

- Collector-base depletion charge

$$Q_{TC} = \frac{-CJC_T}{1-PC} \cdot \left\{ \frac{VDC_T - V_{C2B2}}{\left(\left(1 - \frac{V_{C2B2}}{VDC_T} \right)^2 + \delta \right)^{\frac{PC}{2}}} \right\} \quad (1.47)$$

Model parameters : CJC , VDC , PC .

- Substrate-base depletion charge

$$Q_{TS} = \frac{-CJS_T}{1-PS} \cdot \left\{ \frac{VDS_T - V_{SB}}{\left(\left(1 - \frac{V_{SB}}{VDS_T} \right)^2 + \delta \right)^{\frac{PS}{2}}} \right\} \quad (1.48)$$

Model parameters : CJS , VDS , PS .

Charges

- Forward stored charges

The storage of charge in the forward active case is divided into three main components. The first component represents charge storage in the epilayer between emitter and collector. Charge storage in the epilayer under the emitter is another component and the storage of charge in the neutral regions forms the third component. The neutral charge formulation is obtained simply from the charge control principle. The epilayer charge storage formulations, however, are obtained by relating the charge storage to the injected minority concentration, p' , in the epilayer. In the epilayer between emitter and collector p' is assumed to have a linear profile for all injection levels.

Charge stored in epitaxial base region between emitter and collector:

$$Q_{FLAT} = TLAT_T \cdot IK \cdot \left(\sqrt{1 + 16 \cdot \frac{I_{F1}}{IK}} - 1 \right) \cdot \frac{F_{LAT}}{8} \quad (1.49)$$

Charge stored in epitaxial base region under emitter:

$$Q_{FVER} = TFVR_T \cdot IK \cdot \left(\sqrt{1 + 16 \cdot \frac{I_{F2}}{IK}} - 1 \right) / 8 \quad (1.50)$$

Charge stored in emitter and buried layer under emitter:

$$Q_{FN} = TFN_T \cdot I_{F2} \quad (1.51)$$

Model parameters : $TLAT$, $TFVR$, TFN .

- Reverse stored charges

The storage of charge in the reverse active case is divided into three main components. The first component represents charge storage in the epilayer between emitter and collector. Charge storage in the epilayer under the collector is another component and the storage of charge in the neutral regions forms the third component. Charge formulations are obtained in a similar manner to the forward case.

Charge stored in epitaxial base region between emitter and collector:

$$Q_{RLAT} = TLAT_T \cdot IK \cdot \left(\sqrt{1 + 16 \cdot \frac{I_{R1}}{IK}} - 1 \right) \cdot \frac{FLAT}{8} \quad (1.52)$$

Charge stored in epitaxial base region under collector:

$$Q_{RVER} = TRVR_T \cdot IK \cdot \left(\sqrt{1 + 16 \cdot \frac{I_{R2}}{IK}} - 1 \right) / 8 \quad (1.53)$$

Charge stored in collector and buried layer under collector:

$$Q_{RN} = TRN_T \cdot I_{R2} \quad (1.54)$$

Model parameters : $TRVR$, TRN .

- Substrate-base stored charge

Charge stored in substrate and base due to the substrate-base junction. This charge storage *only* occurs when the substrate-base junction is forward biased (note that TSD is a constant):

$$Q_{SD} = TSD \cdot I_{SF} \quad (1.55)$$

Series resistances

emitter	$REEX$	=	constant
	$REIN_T$	=	constant
collector:	$RCEX$	=	constant
	$RCIN_T$	=	constant

The conductivity modulation of the base resistances is derived from the fact that the voltage drop across the epitaxial layer is inversely proportional to the electron concentration under the emitter and collector.

Base resistance under the emitter:

$$RBE_T = RBEC_T + \frac{2 \cdot RBEV_T}{1 + \sqrt{1 + 16 \cdot \frac{I_{F2}}{IK}}} \quad (1.56)$$

Base resistance under the collector:

$$RBC_T = RBCC_T + \frac{2 \cdot RBCV_T}{1 + \sqrt{1 + 16 \cdot \frac{I_{R2}}{IK}}} \quad (1.57)$$

The resistance RSB models ohmic leakage across the substrate-base junction.

Model parameters : $REEX$, $REIN$, $RCEX$, $RCIN$, $RBEC$, $RBEV$, $RBCC$, $RBCV$, RSB .

Excess phase shift

Excess phase shift is implemented in the following way.

In case the parameter *EXPHI* does not equal zero, calculations are done with a current I_{XLAT} instead of I_{FLAT} and I_{XVER} instead of I_{FVER} . The two currents are connected by means of the differential equation:

$$3\omega_0^2 \cdot I_{FLAT} = \left(\frac{d^2 I_{XFLAT}}{dt^2} \right) + 3\omega_0 \cdot \left(\frac{dI_{XFLAT}}{dt} \right) + 3\omega_0^2 \cdot I_{XFLAT} \quad (1.58)$$

$$3\omega_0^2 \cdot I_{FVER} = \left(\frac{d^2 I_{XVER}}{dt^2} \right) + 3\omega_0 \cdot \left(\frac{dI_{XVER}}{dt} \right) + 3\omega_0^2 \cdot I_{XVER} \quad (1.59)$$

Where

$$\omega_0 = \frac{1}{EXPHI \cdot T_{LAT_T}} \quad (1.60)$$

Noise model

For noise analysis current sources are added to the small signal equivalent circuit. In these equations f represents the operation frequency of the transistor and Δf is the bandwidth. When Δf is taken as 1 Hz, a noise density is obtained.

Thermal noise:

- Emitter Resistor

$$\overline{iN_{REEX}^2} = \frac{4 \cdot k \cdot T_K}{REEX} \cdot \Delta f \quad (1.61)$$

$$\overline{iN_{REIN}^2} = \frac{4 \cdot k \cdot T_K}{REIN_T} \cdot \Delta f \quad (1.62)$$

- Collector Resistor

$$\overline{iN_{RCIN}^2} = \frac{4 \cdot k \cdot T_K}{RCIN_T} \cdot \Delta f \quad (1.63)$$

$$\overline{iN_{RCEX}^2} = \frac{4 \cdot k \cdot T_K}{RCEX} \cdot \Delta f \quad (1.64)$$

Collector Resistor Noise:

$$\overline{iN_{RC}^2} = \overline{iN_{RCIN}^2} + \overline{iN_{RCEX}^2} \quad (1.65)$$

- Base Resistor

$$\overline{iN_{RBE}^2} = \frac{4 \cdot k \cdot T_K}{RBE_T} \cdot \Delta f \quad (1.66)$$

$$\overline{iN_{RBC}^2} = \frac{4 \cdot k \cdot T_K}{RBC_T} \cdot \Delta f \quad (1.67)$$

$$\overline{iN_{RSB}^2} = \frac{4 \cdot k \cdot T_K}{RSB} \cdot \Delta f \quad (1.68)$$

Base Resistor Noise:

$$\overline{iN_{RB}^2} = \overline{iN_{RBE}^2} + \overline{iN_{RBC}^2} + \overline{iN_{RSB}^2} \quad (1.69)$$

Lateral collector current shot noise:

$$\overline{iN_{CLAT}^2} = 2 \cdot q \cdot |I_{FLAT} - I_{RLAT}| \cdot \Delta f \quad (1.70)$$

Vertical collector current shot noise:

$$\overline{iN_{CVER}^2} = 2 \cdot q \cdot |I_{FVER} - I_{RVER}| \cdot \Delta f \quad (1.71)$$

Forward base current shot noise and 1/f noise:

$$\overline{iN_B^2} = 2 \cdot q \cdot |I_{RE} + I_{LE}| \cdot \Delta f + \frac{KF \cdot MULT^{1-AF} \cdot |I_{RE} + I_{LE}|^{AF}}{f} \cdot \Delta f \quad (1.72)$$

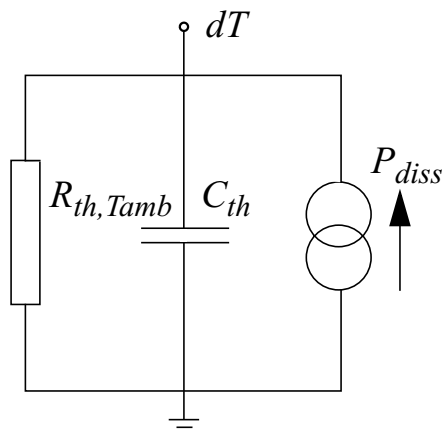
1.4.1 Numerical Adaptation

To implement the model in a circuit simulator, care must be taken of the numerical stability of the simulation program. A small non-physical conductance, G_{min} , is connected between the nodes SB , $BC1$ and $BE1$. The value of the conductance is 10^{-12} [1/Ω].

1.6 Self-heating

1.6.1 Equivalent circuit

Self-heating is part of the model. It is defined in the usual way by adding a self-heating network (see Figure 3), containing a current source describing the dissipated power, and both a thermal resistance R_{TH} and a thermal capacitance C_{TH} .



Material	A_{th}
Si	1.3
Ge	1.25
GaAs	1.25
AlAs	1.37
InAs	1.1
InP	1.4
GaP	1.4
SiO ₂	0.7

Figure 3: On the left, the self-heating network, where the node voltage V_{dT} is used in the temperature scaling relations. Note that for increased flexibility the node dT is available to the user. On the right are parameters values that can be used for A_{th} .

The resistance and capacitance are both connected between ground and the temperature node dT . The value of the voltage V_{dT} at the temperature node gives the increase in local temperature. For example, if the value of V_{dT} is 0.5V, the increase of the temperature is 0.5 degrees Celsius.

1.6.2 Model equations

The total dissipated power for the electrical model is a sum of the dissipated power of each branch of the equivalent circuit, and is given by:

For devices without substrate node:

$$\begin{aligned}
 P_{diss} = & V_{E2E}^2/REEX + V_{E1E2}^2/REIN + V_{C2C}^2/RCEX + V_{C1C2}^2/RCIN + \\
 & V_{B2B}^2/RBC + V_{B1B}^2/RBE + V_{SB}^2/RSB + (I_{RLAT} - I_{FLAT}) \cdot V_{C1E1} + \\
 & I_{RVER} \cdot V_{C2E1} + I_{FVER} \cdot V_{E2C1} + (I_{RC} + I_{LC}) \cdot V_{C2B2} + (I_{RE} + I_{LE}) \cdot V_{E2B1} + \\
 & I_{SC} \cdot V_{C2S} + I_{SE} \cdot V_{E2S} + I_{SF} \cdot V_{SL}
 \end{aligned} \tag{1.73}$$

Note that the effect of the parameter DTA and dynamic self-heating as discussed here are independent [1]. To use a more complicated self-heating network, one can increase RTH to very large values, make CTH zero, and add the wanted self-heating networking externally to the node dT .

For the value of A_{th} we recommend using values from literature that describes the temperature scaling of the thermal conductivity. For the most important materials, the values are given in Figure 3, which is largely based on Ref. [2], see also [3].

Please note that taking $C_{th} = 0$ in the self-heating model is *incorrect* for AC simulations (and hence also for transient simulations). The reason is that $C_{th} = 0$ means that self-heating is infinitely fast. In reality, however, self heating is much slower than the relevant time scales in most application. Therefore, for simulations, a non-zero thermal capacitance should always be used, even when the thermal capacitance has not been extracted. Since in practice the thermal time delay is of the order of $1\mu s$, a reasonable estimate for the thermal capacitance can be given by $C_{th} = 1\mu s/R_{th}$.

1.6.3 Usage

Below, an example (*Pstar*) is given to illustrate the working of self-heating.

□ Example

Title: example self-heating 500;

```
circuit;
  e_be (0, b) 1;
  e_ce (0, c) 3.3;
  e_se (0, s) 3.3;
  tplt_1 (c, b, 0, s, dt) level=500,Rth=100,cth=1e-9;

end;
dc;
print: vn(dt), pdiss.tplt_1;
end;
run;

result:

DC   Analysis.
VN(DT)                =      1.053E+00
Pdiss.TPLT_1          =      10.533E-03
```

The voltage on node dT is 1.053+00 V, which means that the local temperature is increased by 1.053 °C.

1.7 DC Operating point output

The DC operating point output facility gives information on the state of a device at its operation point. Figure 1 shows the DC large signal equivalent circuit of the TPL500 model. The small signal equivalent circuit is given in Figure 2.

$REEX$, $REIN$, $RCIN$ and $RCEX$ are constant resistors.

$$dILAT = g_{fL} \cdot dV_{E1B} - g_{rL} \cdot dV_{C1B} \quad (1.74)$$

$$dIFVER = g_{11V} \cdot dV_{E2B1} + g_{12V} \cdot dV_{C1B} \quad (1.75)$$

$$dIRVER = g_{21V} \cdot dV_{E1B} + g_{22V} \cdot dV_{C2B2} \quad (1.76)$$

$$dI_{B1B} = G_{IBE} \cdot dV_{E2B1} \quad (1.77)$$

$$dI_{B2B} = G_{IBC} \cdot dV_{C2B2} \quad (1.78)$$

$$dI_{\pi L} = j\omega \cdot C_{I\pi L} \cdot dV_{C1B} \quad (1.79)$$

$$dI_{\mu L} = j\omega \cdot C_{I\mu L} \cdot dV_{E1B} \quad (1.80)$$

$$dISE = G_{ISE} \cdot dV_{E2B1} \quad (1.81)$$

$$dISC = G_{ISC} \cdot dV_{C2B2} \quad (1.82)$$

3 Note

The operating-point output will not be influenced by the value of G_{min} . I_{B1B} and I_{B2B} represent the current through the nonlinear resistors RBE and RBC respectively.

Quantity	Equation	Description
<i>LEVEL</i>	<i>500</i>	Model level
<i>REEX</i>	<i>REEX</i>	External emitter resistance
<i>REIN</i>	<i>REIN</i>	Internal emitter resistance
<i>RCEX</i>	<i>RCEX</i>	External collector resistance
<i>RCIN</i>	<i>RCIN</i>	Internal collector resistance
<i>GFL</i>	g_{fL}	Forward conductance, lateral path.: $\partial I_{FLAT} / \partial V_{E1B1}$
<i>GRL</i>	g_{rL}	Reverse conductance, lateral path.: $\partial I_{RLAT} / \partial V_{C1B}$
<i>G11</i>	g_{11}	Forward conductance, vertical path.: $\partial I_{FVER} / \partial V_{E2B1}$
<i>G12</i>	g_{12}	Collector Early-effect on I_{FVER} : $\partial I_{FVER} / \partial V_{C1B}$
<i>G21</i>	g_{21}	Emitter Early-effect on I_{RVER} : $\partial I_{RVER} / \partial V_{E1B}$
<i>G22</i>	g_{22}	Reverse conductance, vertical path.: $\partial I_{RVER} / \partial V_{C2B2}$
<i>GPIV</i>	$G_{\pi V}$	Conductance e-b junction: $\partial (I_{RE} + I_{LE}) / \partial V_{E2B1}$
<i>GMUV</i>	$G_{\mu V}$	Conductance c-b junction: $\partial (I_{RC} + I_{LC}) / \partial V_{C2B2}$
<i>GBE</i>	G_{BE}	Emitter-side: base conductance B1-B: $\partial I_{B1B} / \partial V_{B1B}$
<i>GIBE</i>	G_{IBE}	Emitter Early-effect on I_{B1B} : $\partial I_{B1B} / \partial V_{E2B1}$
<i>GBC</i>	G_{BC}	Collector-side: base conductance B2-B: $\partial I_{B2B} / \partial V_{B2B}$
<i>GIBC</i>	G_{IBC}	Collector Early-effect on I_{B2B} : $\partial I_{B2B} / \partial V_{C2B2}$
<i>CPIL</i>	$C_{\pi L}$	Forward diffusion cap., lateral path: $\partial Q_{FLAT} / \partial V_{E1B}$
<i>CIPIL</i>	$C_{I\pi L}$	Collector Early-effect on Q_{FLAT} : $\partial Q_{FLAT} / \partial V_{C1B}$
<i>CPIV</i>	$C_{\pi V}$	Forward total capacitance, vertical path: $\partial (Q_{TE} + Q_{FVER} + Q_{FN}) / \partial V_{E2B1}$
<i>CMUL</i>	$C_{\mu L}$	Reverse diffusion capacitance, lateral path: $\partial Q_{RLAT} / \partial V_{C1B}$
<i>CIMUL</i>	$C_{I\mu L}$	Emitter Early-effect on Q_{RLAT} : $\partial Q_{RLAT} / \partial V_{E1B}$

Quantity	Equation	Description
<i>CMUV</i>	$C_{\mu V}$	Reverse total capacitance, vertical path: $\partial(Q_{tc} + Q_{rver} + Q_{rn})/\partial V_{C2B2}$
<i>GISE</i>	G_{ISE}	Transconductance (parasitic PNP) e-b-s- transistor: $\partial I_{SE}/\partial V_{E2B1}$
<i>GISC</i>	G_{ISC}	Transconductance (parasitic PNP) c-b-s- transistor: $\partial I_{SC}/\partial V_{C2B2}$
<i>GSB</i>	G_{SB}	Conductance s-b junction: $\partial I_{SF}/\partial V_{SB} + 1/R_{SB}$
<i>CSB</i>	C_{SB}	Total capacitance s-b junction: $\partial Q_{TS}/\partial V_{SB} + \partial Q_{SD}/\partial V_{SB}$

When the parameter PRINTSCALED is set to 1 the device parameter set after temperature scaling is added to the OP output

Quantity	Description
<i>IS</i>	Collector-emitter saturation current
<i>BF</i>	Ideal forward common-emitter current gain
<i>IBF</i>	Saturation current of non-ideal forward base current
<i>VLF</i>	Cross-over voltage of non-ideal forward base current
<i>IK</i>	High injection knee current
<i>XIFV</i>	Vertical fraction of forward current
<i>EAFV</i>	Early voltage of the lateral forward current component
<i>EAFV</i>	Early voltage of the vertical forward current component
<i>BR</i>	Ideal reverse common-emitter current gain
<i>IBR</i>	Saturation current of non-ideal reverse base current
<i>VLR</i>	Cross-over voltage of non-ideal reverse base current
<i>XIRV</i>	Vertical fraction of reverse current
<i>EARL</i>	Early voltage of the lateral reverse current component
<i>ERARV</i>	Early voltage of the vertical reverse current component

Quantity	Description
<i>XES</i>	Ratio between saturation current of e-b-s transistor and e-b-c transistor
<i>XHES</i>	Fraction of substrate current of e-b-s transistor subject to high injection
<i>XCS</i>	Ratio between saturation current of c-b-s transistor and c-b-e transistor
<i>XHCS</i>	Fraction of substrate current of c-b-s transistor subject to high injection
<i>ISS</i>	Saturation current of substrate-base diode
<i>RCEX</i>	External part of the collector resistance
<i>RCIN</i>	Internal part of the collector resistance
<i>RBCC</i>	Constant part of the base resistance 'rbc'
<i>RBCV</i>	Variable part of the base resistance 'rbc'
<i>RBEC</i>	Constant part of the base resistance 'rbe'
<i>RBEV</i>	Variable part of the base resistance 'rbe'
<i>REEX</i>	External part of the emitter resistance
<i>REIN</i>	Internal part of the emitter resistance
<i>RSB</i>	Substrate-base leakage resistance
<i>TLAT</i>	Low injection
<i>TFVR</i>	Low injection forward transit time due to charge stored in the epilayer under the emitter
<i>TFN</i>	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter
<i>CJE</i>	Zero-bias emitter-base depletion capacitance
<i>VDE</i>	Emitter-base diffusion voltage
<i>PE</i>	Emitter-base grading coefficient
<i>TRVR</i>	Low injection reverse transit time due to charge stored in the epilayer under the collector
<i>TRN</i>	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector
<i>CJC</i>	Zero-bias collector-base depletion capacitance
<i>VDS</i>	Collector-base diffusion voltage

Quantity	Description
<i>PC</i>	Collector-base grading coefficient
<i>CJS</i>	Zero-bias substrate-base depletion capacitance
<i>VDS</i>	Substrate-base diffusion voltage
<i>PS</i>	Substrate-base grading coefficient
<i>VGEB</i>	Bandgap voltage of the emitter-base depletion region
<i>VGCB</i>	Bandgap voltage of the collector-base depletion region
<i>VGSB</i>	Bandgap voltage of the substrate-base depletion region
<i>VGB</i>	Bandgap voltage of the base between emitter and collector
<i>VGE</i>	Bandgap voltage of the emitter
<i>VGJE</i>	Bandgap voltage recombination emitter-base junction
<i>AE</i>	Temperature coefficient of 'bf'
<i>SPB</i>	SC
<i>SNB</i>	Temperature coefficient of the epitaxial base electron mobility
<i>SNBN</i>	Temperature coefficient of buried layer electron mobility
<i>SPE</i>	Temperature coefficient of emitter hole mobility
<i>SPC</i>	Temperature coefficient of collector hole mobility
<i>SX</i>	Temperature coefficient of combined minority carrier mobility in emitter and buried layer
<i>KF</i>	Flickernoise coefficient
<i>AF</i>	Flickernoise cexponent
<i>EXPHI</i>	Not used in model bjt500
<i>RTH</i>	Thermal resistance
<i>CTH</i>	Thermal capacitance

1.8 Simulator specific items

1.8.1 Pstar syntax

p channel substrate model: `tpl_n` (c, b, e, s) level=500, <parameters>
 p channel substrate self-heating model:
 `tplt_n` (c, b, e, s, dt) level=500, <parameters>

`n` : occurrence indicator
 <parameters> : list of model parameters
 c, b, e, s and dt are collector, base, emitter, substrate and self-heating terminals respectively.

Care

When assignment by position is used, the order of the parameters must be equal to the order specified in the model definition. Readability is improved if assignment by name is used.

1.8.2 Spectre syntax

p channel substrate model: `model modelname bjt500 type=pn1 <modpar>`
 `componentname c b e s modelname <inpar>`

p channel substrate self-heating model:
 `model modelname bjt500t type=pn1 <modpar>`
 `componentname c b e s dt modelname <inpar>`

`modelname` : name of model, user defined
`componentname` : occurrence indicator
 <modpar> : list of model parameters²
 <inpar> : list of instance parameters²
 c, b, e, s and dt are collector, base, emitter, substrate and self-heating terminals respectively.

1. Either pnp or pnpl are interpreted as lateral pnp.

2. For more details of these Spectre parameters see also Cadence Spectre Circuit Simulator Reference, version 4.4.6 or 5.0.

1.8.5 The ON/OFF condition for Spectre

n-channel					
	Default	OFF	Saturation	Reverse	Forward
V_{C1B}	0.01	0.0	0.7	0.7	0.0
V_{C2B2}	0.01	0.0	0.75	0.75	0.0
V_{E1B}	0.7	0.0	0.7	0.0	0.7
V_{E2B1}	0.75	0.0	0.75	0.0	0.75
V_{B2B}	0.01	-0.1	0.0	0.1	-0.1
V_{B1B}	0.01	0.1	0.0	-0.1	0.1
V_{SB}	-1.0	-1.0	-1.0	-1.0	-1.0

n-channel					
	Default	OFF	Saturation	Reverse	Forward
DT	0.0	0.0	0.0	0.0	0.0

For p-channel devices the numbers remain the same but have a negative value, i.e. 0.01 becomes -0.01.

1.8.6 The ON/OFF condition for ADS

n-channel	
	Default
V_{C1B}	0.0
V_{C2B2}	0.0
V_{E1B}	0.0
V_{E2B1}	0.0
V_{B2B}	0.0
V_{B1B}	0.0
V_{SB}	0.0

n-channel for self-heating	
	Default
DT	0.0

For p-channel devices the numbers remain the same but have a negative value, i.e. 0.01 becomes -0.01.

1.9 References

- [1] For the most recent model descriptions, source code, and documentation, see the web-site [http://www.semiconductors.philips.com/Philips Models](http://www.semiconductors.philips.com/Philips_Models).
- [2] S.M. Sze, *Physics of Semiconductor Devices*. Wiley, New York, 2 ed., 1981.
- [3] V. Palankovski, R. Schultheis, and S. Selberherr, *Simulation of power hetero-junction bipolar transistor on gallium arsenide*, *IEEE Trans. Elec. Dev.*, vol 48, pp.1264-1269, 2001. Note: the paper uses $\alpha = 1.65$ for Si, but $\alpha = 1.3$ gives a better fit; also κ_{300} for GaAs is closer to 40 than to the published value of 46 (Palankovski, personal communication).
- [4] **Pstar** User Manual.

A Spectre Specific Information

Imax, Imelt, Jmelt parameters

Introduction

Imax, Imelt and Jmelt are Spectre-specific parameters used to help convergence and to prevent numerical problems. We refer in this text only to the use of Imax model parameter in Spectre with SiMKit devices since the other two parameters, Imelt and Jmelt, are not part of the SiMKit code. For information on Imelt and Jmelt refer to Cadence documentation.

Imax model parameter

Imax is a model parameter present in the following SiMKit models:

- juncap and juncap2
- psp and pspnqs (since they contain juncap models)

In Mextram 504 (bjt504) and Modella (bjt500) SiMKit models, Imax is an internal parameter and its value is set through the adapter via the Spectre-specific parameter Imax.

The default value of the Imax model parameter is 1000A. Imax should be set to a value which is large enough so it does not affect the extraction procedure.

In models that contain junctions, the junction current can be expressed as:

$$I = I_s \exp\left(\frac{V}{N \cdot \phi_{TD}} - 1\right) \quad (1.83)$$

The exponential formula is used until the junction current reaches a maximum (explosion) current Imax.

$$I_{max} = I_s \exp\left(\frac{V_{expl}}{N \cdot \phi_{TD}} - 1\right) \quad (1.84)$$

The corresponding voltage for which this happens is called Vexpl (explosion voltage). The voltage explosion expression can be derived from (1):

$$V_{expl} = N \cdot \phi_{TD} \log\left(\frac{I_{max}}{I_s}\right) + 1 \quad (1.85)$$

For $V > V_{expl}$ the following linear expression is used for the junction current:

$$I = I_{max} + (V - V_{expl}) \frac{I_s}{N \cdot \phi_{TD}} \exp\left(\frac{V_{expl}}{N \cdot \phi_{TD}}\right) \quad (1.86)$$

Region parameter

Region is an Spectre-specific model parameter used as a convergence aid and gives an estimated DC operating region. The possible values of region depend on the model:

- For Bipolar models:
 - subth: Cut-off or sub-threshold mode
 - fwd: Forward
 - rev: Reverse
 - sat: Saturation.
 - off¹
 -
- For MOS models:
 - subth: Cut-off or sub-threshold mode;
 - triode: Triode or linear region;
 - sat: Saturation
 - off¹

For PSP and PSPNQS all regions are allowed, as the PSP(NQS) models both have a MOS part and a juncap (diode). Not all regions are valid for each part, but when e.g. region=forward is set, the initial guesses for the MOS will be set to zero. The same holds for setting a region that is not valid for the JUNCAP.

- For diode models:
 - fwd: Forward
 - rev: Reverse
 - brk: Breakdown
 - off¹

Model parameters for device reference temperature in Spectre

This text describes the use of the tnom, tref and tr model parameters in Spectre with SiMKit devices to set the device reference temperature.

¹.Off is not an electrical region, it just states that the user does not know in what state the device is operating

A Simkit device in Spectre has three model parameter aliases for the model reference temperature, `tnom`, `tref` and `tr`. These three parameters can only be used in a model definition, not as instance parameters.

There is no difference in setting `tnom`, `tref` or `tr`. All three parameters have exactly the same effect. The following three lines are therefore completely equivalent:

```
model nmos11020 mos11020 type=n tnom=30
model nmos11020 mos11020 type=n tref=30
model nmos11020 mos11020 type=n tr=30
```

All three lines set the reference temperature for the `mos11020` device to 30 C.

Specifying combinations of `tnom`, `tref` and `tr` in the model definition has no use, only the value of the last parameter in the model definition will be used. E.g.:

```
model nmos11020 mos11020 type=n tnom=30 tref=34
```

will result in the reference temperature for the `mos11020` device being set to 34 C, `tnom=30` will be overridden by `tref=34` which comes after it.

When there is no reference temperature set in the model definition (so no `tnom`, `tref` or `tr` is set), the reference temperature of the model will be set to the value of `tnom` in the options statement in the Spectre input file. So setting:

```
options1 options tnom=23 gmin=1e-15 reltol=1e-12 \
  vabstol=1e-12 iabstol=1e-16
model nmos11020 mos11020 type=n
```

will set the reference temperature of the `mos11020` device to 23 C.

When no `tnom` is specified in the options statement and no reference temperature is set in the model definition, the default reference temperature is set to 27 C.

So the lines:

```
options1 options gmin=1e-15 reltol=1e-12 vabstol=1e-12 \
  iabstol=1e-16
model nmos11020 mos11020 type=n
```

will set the reference temperature of the `mos11020` device to 27 C.

The default reference temperature set in the SiMKit device itself is in the Spectre simulator never used. It will always be overwritten by either the default "options tnom", an explicitly set option tnom or by a tnom, tref or tr parameter in the model definition.

B Parameter PARAMCHK

Parameter PARAMCHK

Introduction

All models have the parameter PARAMCHK. It is not related to the model behavior, but has been introduced control the clip warning messages. Various situations may call for various levels of warnings. This is made possible by setting this parameter.

PARAMCHK model parameter

This model parameter has been added to control the amount of clip warnings.

PARAMCHK	<	0	No clip warnings
PARAMCHK	≥	0	Clip warnings for instance parameters (default)
PARAMCHK	≥	1	Clip warnings for model parameters
PARAMCHK	≥	2	Clip warnings for electrical parameters at initialisation
PARAMCHK	≥	3	Clip warnings for electrical parameters during evaluation. This highest level is of interest only for selfheating jobs, where electrical parameters may change dependent on temperature.