3 Parameters

This chapter contains a reference list of model parameters with a brief description. The provided default values should be used for model implementation in a circuit simulator; with these values, all but the absolutely necessary functions, that define a bipolar transistor, are turned off. This way, the user only needs to specify the parameters for those effects that are desired to be taken into account. Next to that column specifies the possible range of the parameter values, where according to the standard mathematical notation, brackets [ ] indicate that the range includes the endpoints, but parentheses ( ) signifies the exclusion of the endpoints. Few of the parameters (e.g. some flags) take only one of the two or three possible values and the corresponding values are given as *x/y* or *x/y/z*, where the parameter takes either of the values given. Empty 'range' column signifies that the particular parameter can take any value. In addition to these, a second set of parameter values is provided for exercising the model with most of the physical effects being turned on. This set can be used for, e.g. model testing.

Finally, in the most right column, a multiplication factor is given, which represents the scaling of the respective parameter in case of M identical devices connected in parallel. Note though, that this scaling becomes inaccurate at high frequencies due to the missing interconnect elements that need to be accounted for separately for such device structures.

3.1 Parameter list for HICUM/Level2

The following list of model parameters is supposed to be available in all (commercial) implementations of the model. The list is divided into groups of parameters according to the elements in the HICUM equivalent circuit shown in Fig. 2.1.1/1 as well as those for additional physical effects such as noise and temperature dependence. Although the total number of model parameters appears to be large, less time and effort needs to be spent for model parameter extraction - assuming the same physical effects are considered as in the SGPM - due to (a) the physical nature and modularity of the model formulation and (b) the reliable and clearly defined extraction procedure. Note, that not every parameter always needs to be specified for a particular process or application in order to achieve the required accuracy. For example, certain parameters are related to HBTs only and, therefore, can be left at their default values for homojunction transistors.

Many HICUM parameters have been chosen as simple factors, that are related to physically meaningful basic parameters like a capacitance, charge or transit time. This choice significantly re-

duces changes (and the probability of errors) in the parameter list if the basic parameters are changed for, e.g., statistical simulation, because the factors often assume very similar values even for different process technologies.

Input for the factor M in the last column is interpreted as follows: multiplication of the parameter value is indicated by M while division is indicated by 1/M and no action by leaving the entry blank. Caution is required if the factor is applied to r_{su}, C_{su}, R_{th} and C_{th}, in which no interaction between parallel devices is assumed.

For production-type parameter library releases, it is recommended to have self-heating and non-quasi-static effects turned off by their respective flags, since the effects may not be required for many design tasks, especially not for first phase design and feasibility studies. Including these effects will unneccessarily increase the simulation time for *all* users during the entire design phase. These effects can become important in the last phase for tuning the performance of certain types of circuits or for design verification before tape-out. It is suggested to make these flags available in the design system as options for circuit designers.

As reference temperature, 27^{o}C has been chosen to remain compatible with other simulators and models. The value for "∞" may be dependent on the simulator system. **Therefore, the user is referred to the manual of the respective simulator.**

3.1.1 Transfer current

no	name	description	default	range	test	unit	factor
1	**is (c10)**	Saturation current (GICCR constant) (C10=IS*QP0)	1E-16 (2E-30)	[0:1] ([0:1])	1.35E-18 (3.76e-32)	A (AC)	M (M^2)
2	**qp0**	Zero-bias hole charge	2E-14	(0:1]	2.78e-14	C	M
3	**ich**	High-current correction for 2D and 3D effects	∞	[0:inf)	2.09e-02	A	M
4	**hfe**	Emitter minority charge weighting factor in HBTs	1	[0:inf]	1.0	-	
5	**hfc**	Collector minority charge weighting factor in HBTs	1	[0:inf]	1.0	-	
6	**hjei**	B-E depletion charge weighting factor in HBTs	1	[0:100]	1.0	-	

no	name	description	default	range	test	unit	factor
7	**hjci**	B-C depletion charge weighting factor in HBTs	1	[0:100]	1.0	-	
8	**mcf**	non-ideality factor (for III-V HBTs)	1	(0:10]	1.0	-	

3.1.2 Base-emitter current components

no	name	description	default	range	test	unit	factor
1	**ibeis**	Internal B-E saturation current	1E-18	[0:1]	1.16e-20	A	M
2	**mbei**	Internal B-E current ideality factor	1	(0:10]	1.0150	-	
3	**ireis**	Internal B-E recombination saturation current	0	[0:1]	1.16e-16	A	M
4	**mrei**	Internal B-E recombination current ideality factor	2	(0:10]	2.0	-	
5	**ibeps**	Peripheral B-E saturation current	0	[0:1]	3.72e-21	A	M
6	**mbep**	Peripheral B-E current ideality factor	1	(0:10]	1.0150	-	
7	**ireps**	Peripheral B-E recombination saturation current	0	[0:1]	1.0e-30	A	M
8	**mrep**	Peripheral B-E recombination current ideality factor	2	(0:10]	2.0	-	
9	**tbhrec**	base current recombination time constant at the BC barrier for high forward injection (default is v2.1 compatible)	0 ($\equiv \infty$)	[0:inf)	250	ps	

3.1.3 Base-collector current components

no	name	description	default	range	test	unit	factor
1	**ibcis**	Internal B-C saturation current	1E-16	[0:1]	1.16e-20	A	M
2	**mbci**	Internal B-C current ideality factor	1	(0:10]	1.0150	-	
3	**ibcxs**	External B-C saturation current	0	[0:1]	4.39e-20	A	M
4	**mbcx**	External B-C current ideality factor	1	(0:10]	1.03	-	

3.1.4 Base-emitter tunnelling current

no	name	description	default	range	test	unit	factor
1	**ibets**	B-E tunnelling saturation current	0	[0:1]	0.0	A	M
2	**abet**	Exponent factor for tunnelling current	40	[0:inf)	40	-	
3	**tunode**	specifies the base node connection of the tunneling current source (default is v2.1 compatible)	1	[0/1]	0	-	

3.1.5 Base-collector avalanche current

no	name	description	default	range	test	unit	factor
1	**favl**	Avalanche current factor	0	[0:inf)	1.186	1/V	
2	**qavl**	Exponent factor for avalanche current	0	[0:inf)	11.1e-15	C	M

3.1.6 Series resistances

no	name	description	default	range	test	unit	factor
1	**rbi0**	Zero-bias internal base resistance	0	[0:inf)	71.76	Ω	1/M
2	**rbx**	External base series resistance	0	[0:inf)	8.83	Ω	1/M
3	**fgeo**	Factor for geometry dependence of emitter current crowding (r_{Bi})	0.6557	[0:1]	0.73	-	
4	**fdqr0**	Correction factor for modulation by B-E and B-C Space charge layer	0	[0:1]	0.2	-	
5	**fcrbi**	Ratio of HF shunt to total internal capacitance (lateral NQS effect)	0	[0:1]	0.0	-	
6	**fqi**	Ratio of internal to total minority charge	1.0	[0:1]	0.9055	-	
7	**re**	Emitter series resistance	0	[0:inf)	12.534	Ω	1/M
8	**rcx**	External collector series resistance	0	[0:inf)	9.165	Ω	1/M

3.1.7 Substrate transistor

no	name	description	default	range	test	unit	factor
1	**itss**	Saturation current of substrate transistor transfer current	0	[0:1]	1.0e-16	A	M
2	**msf**	Forward ideality factor of substrate transfer current (note: set $m_{sr} = m_{sf}$ in (2.1.12-1))	1	(0:10]	1.05	-	
3	**iscs**	Saturation current of C-S diode	0	[0:1]	1e-17	A	M
4	**msc**	Ideality factor of C-S diode	1	(0:10]	1.0	-	
5	**tsf**	Transit time (forward operation)	0	[0:inf)	1.05	s	

3.1.8 Intra-device substrate coupling

Note: using the M factor is dangerous in this case, unless the transistor cell is exactly replicated and no coupling exists between cells.

no	name	description	default	range	test	unit	factor
1	**rsu**	Substrate series resistance	0	[0:inf)	0	Ω	1/M
2	**csu**	Shunt capacitance (caused by substrate permittivity)	0	[0:inf)	0	F	M

3.1.9 Depletion charge and capacitance components

To avoid any confusion with TCs, version 2.1 parameters *ALJEI* and *ALJEP* have been changed to *AJEI* and *AJEP*.

no	name	description	default	range	test	unit	factor
1	**cjei0**	Internal B-E zero-bias depletion capacitance	0	[0:inf)	8.11e-15	F	M
2	**vdei**	Internal B-E built-in potential	0.9	(0:10]	0.95	V	
3	**zei**	Internal B-E grading coefficient	0.5	(0:1]	0.5	-	
4	**ajei**	Ratio of maximum to zero-bias value of internal B-E capacitance	2.5	[0:inf)	1.8	-	

no	name	description	default	range	test	unit	factor
5	**cjep0**	Peripheral B-E zero-bias depletion capacitance	0	[0:inf)	2.07e-15	F	M
6	**vdep**	Peripheral B-E built-in potential	0.9	(0:10]	1.05	V	
7	**zep**	Peripheral B-E grading coefficient	0.5	(0:1]	0.4	-	
8	**ajep**	Ratio of maximum to zero-bias value of peripheral B-E capacitance	2.5	[0:inf)	2.4	-	
9	**cjci0**	Internal B-C zero-bias depletion capacitance	0	[0:inf)	1.16e-15	F	M
10	**vdci**	Internal B-C built-in potential	0.7	(0:10]	0.8	V	
11	**zci**	Internal B-C grading coefficient	0.4	(0:1]	0.333	-	
12	**vptci**	Internal B-C punch-through voltage	100	(0:100]	100	V	
13	**cjcx0**	External B-C zero-bias depletion capacitance	0	[0:inf)	5.4e-15	F	M
14	**vdcx**	External B-C built-in potential	0.7	(0:10]	0.700	V	
15	**zcx**	External B-C grading coefficient	0.4	(0:1]	0.333	-	
16	**vptcx**	External B-C punch-through voltage	100	(0:100]	100	V	
17	**cjs0**	C-S zero-bias depletion capacitance	0	[0:inf)	3.64e-14	F	M
18	**vds**	C-S built-in potential	0.6	(0:10]	0.6	V	
19	**zs**	C-S grading coefficient	0.5	(0:1]	0.447	-	
20	**vpts**	C-S punch-through voltage	100	(0:100]	100	V	

Note: The punch-through voltages should be limited to values > 0.

3.1.10 Minority charge storage effects

no	name	description	default	range	test	unit	factor
1	**t0**	Low-current forward transit time at VBC=0V	0	[0:inf)	4.75e-12	s	
2	**dt0h**	Time constant for base and B-C space charge layer width modulation	0		2.1e-12	s	
3	**tbvl**	Time constant for modelling carrier jam at low VCE	0	[0:inf)	4.0e-12	s	
4	**tef0**	neutral emitter storage time	0	[0:inf)	1.8e-12	s	
5	**gtfe**	Exponent factor for current dependence of neutral emitter storage time	1	(0:10]	1.4	-	
6	**thcs**	Saturation time constant at high current densities	0	[0:inf)	30e-12	s	
7	**alhc**	Smoothing factor for current dependent of base and collector transit time	0.1	(0:10]	0.75	-	
8	**fthc**	Partitioning factor for base and collector portion	0	[0:1]	0.6	-	
9	**rci0**	Internal collector resistance at low electric field	150	(0:inf)	127.8	Ω	1/M
10	**vlim**	Voltage separating ohmic and saturation velocity regime	0.5	(0:10]	0.70	V	
11	**vces**	Internal C-E saturation voltage	0.1	[0:1]	0.1	V	
12	**vpt**	Collector punch-through voltage	0 (≡ ∞)	[0:inf]	5	V	
13	**tr**	Storage time for inverse operation	0	[0:inf)	0	s	

3.1.11 Parasitic isolation capacitances

The version 2.1 names *CEOX* and *CCOX* will be phased out and replaced by the names below.

no	name	description	default	range	test	unit	factor
1	**cbepar**	total parasitic BE capacitance (spacer and metal component)	0.0	[0:inf)	0.6E-15	F	M
2	**fbepar**	partitioining factor of parasitic BE cap (default is v2.1 compatible)	1.0	[0:1]	0.5	-	
3	**cbcpar**	total parasitic BC capacitance (trench and metal component)	0	[0:inf)	2.97e-15	F	M
4	**fbcpar**	partitioining factor of parasitic BC cap (default is v2.1 compatible)	1.0	[0:1]	0.5	-	

3.1.12 Vertical non-quasi-static effects

no	name	description	default	range	test	unit	factor
1	**alqf**	Factor for additional delay time of minority charge	0	[0:1]	0.225	-	
2	**alit**	Factor for additional delay time of transfer current	0	[0:1]	0.45	-	
3	**flnqs**	flag for turning on (1) or off (0) vertical NQS effects	0	[0/1]	1	-	

3.1.13 Noise

no	name	description	default	range	test	unit	factor
1	**kf**	Flicker noise coefficient (no unit only for AF=2)	0	[0:inf)	1.43e-8	-	M^{1-AF}
2	**af**	Flicker noise exponent factor	2	(0:10]	2	-	
3	**cfbe**	flag for determining where to tag the flicker noise source	-1	[-2/-1]	-2		

3.1.14 Lateral geometry scaling (at high current densities)

no	name	description	default	range	test	unit	factor
1	**latb**	Scaling factor for collector minority charge in direction of emitter width b_E	0	[0:inf)	3.765	-	
2	**latl**	Scaling factor for collector minority charge in direction of emitter length l_E	0	[0:inf)	0.342	-	

3.1.15 Temperature dependence

The parameter *ALB* (version 2.1) has been deleted; cf. release notes for version 2.2. Note that *f1vg* and *f2vg* are not HICUM specific, but can be made general parameters in a simulator.

no	name	description	default	range	test	unit	factor
1	**vgb**	Bandgap-voltage extrapolated to 0K	1.17	(0:10]	1.17	V	
2	**f1vg**	coefficient K_1 in T dependent band-gap equation	$1.02377\ 10^{-4}$		$1.02377\ 10^{-4}$	V/K	
3	**f2vg**	coefficient K_2 in T dependent band-gap equation	$4.3215\ 10^{-4}$		$4.3215\ 10^{-4}$	V/K	
4	**zetact**	exponent coefficient in transfer current temperature dependence	3		3.5	-	
5	**vge**	effective emitter bandgap voltage V_{gEeff}	VGB	(0:10]	1.07	V	
6	**zetabet**	exponent coefficient in BE junction current temperature dependence	3.5		4	-	
7	**vgc**	eff. collector bandgap voltage V_{gCeff}	VGB	(0:10]	1.14	V	
8	**vgs**	eff. substrate bandgap voltage V_{gSeff}	VGB	(0:10]	1.17	V	
9	**alt0**	First-order relative temperature coefficient of parameter T0	0		0	1/K	
10	**kt0**	Second-order relative temperature coefficient of parameter T0	0		0	$1/K^2$	

no	name	description	default	range	test	unit	factor
11	**zetaci**	Temperature exponent for RCI0	1.0		1.6	-	
12	**alvs**	Relative temperature coefficient of saturation drift velocity	0		1e-3	1/K	
13	**alces**	Relative temperature coefficient of VCES	0		0.4e-3	1/K	
14	**zetarbi**	Temperature exponent of internal base resistance	0		0.588	-	
15	**zetarbx**	Temperature exponent of external base resistance	0		0.206	-	
16	**zetarcx**	Temperature exponent of external collector resistance	0		0.223	-	
17	**zetare**	Temperature exponent of emitter resistance	0		0	-	
18	**zetacx**	Temperature exponent of the mobility in substrate transistor transit time	1.0		2.2	-	
19	**alfav**	Relative temperature coefficient for FAVL	0		8.25e-5	1/K	
20	**alqav**	Relative temperature coefficient for QAVL	0		1.96e-4	1/K	
21	**alb**	Relative temperature coefficient of forward current gain	0		6e-3		
22	**flcomp**	compatibility flag	0	[0/1]	1		

3.1.16 Self-Heating

no	name	description	default	range	test	unit	factor
1	**rth**	Thermal resistance	0	[0:inf)	0.0	K/W	1/M
2	**cth**	Thermal capacitance	0	[0:inf)	0.0	Ws/K	M
3	**flsh**	flag for turning on (1 = main currents, 2 = all currents) or off (0) self-heating effects	0	[0/1/2]	1	-	M

3.1.17 Circuit simulator specific parameters

The parameters *TNOM* and *DT* are available in most simulators and are also mostly named the same. The “model version identifier” enables version control in simulators with different HICUM generations.

no	name	description	default	unit
1	**tnom**	temperature at which parameters are specified	27	°C
2	**dt**	temperature change w.r.t. chip temperature for particular transistor	0	°C
3	**version**	model version identifier	2.2	-

The Table below contains the syntax for calling HICUM in various circuit simulators (listed in alphabetical order).

simulator name	calling syntax
ADS	HICUM
AnalogOffice	HICUM_L2 (npn) , HICUM_L2_P (pnp)
APLAC	HICUM
ELDO	Level = 9
HSPICE	Level = 8
Silvaco SPICE	Level = 6
SPECTRE	bht