

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 unnecessarily 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°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(≡ ∞)	[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 fac- tor 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	s	

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	mbei	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:inf)	0.73	-	
4	fdqr0	Correction factor for modulation by B-E and B-C Space charge layer	0	[-0.5:100]	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	1E-20	[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	1E-20	[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	1E-20	[0:inf)	1.16e-15	F	M
10	vdc	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	vpctci	Internal B-C punch-through voltage	100	(0:100]	100	V	
13	cjcx0	External B-C zero-bias depletion capacitance	1E-20	[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	vpctcx	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	ahc	Smoothing factor for current dependent of base and collector transit time	0.1	(0:10]	0.75	-	
8	ftbc	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	vcsc	Internal C-E saturation voltage	0.1	[0:1]	0.1	V	
12	vpt	Collector punch-through voltage	0 ($\equiv \infty$)	[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	partitioning 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	[0:inf)	2.97e-15	F	M
4	fbcpar	partitioning factor of parasitic BC cap (default is v2.1 compatible)	0.0	[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	-1.023 77E-4		-1.023 77E-4	V/K	
3	f2vg	coefficient K_2 in T dependent band-gap equation	4.32 15E-4		4.32 15E-4	V/K	
4	zetact	exponent coefficient in transfer current temperature dependence	3.0		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 RC10	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:inf)	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	call
ADS	HICUM
ELDO	Level = 9
HSPICE	Level = 8
SPECTRE	bht
APLAC	HICUM
AnalogOffice	HICUM_L2 (npn) , HICUM_L2_P (pnp)
Silvaco SPICE	Level = 6
NEXXIM	HICUM
Smart-SPICE	libHICUM
GoldenGate	HICUM