Avant!

Chapter 17

Using the Bipolar Transistor Model -VBIC

The VBIC (Vertical Bipolar Inter-Company) model is a new bipolar transistor model for Star-Hspice. You can use VBIC by specifying parameter level=4 for bipolar transistor model.

VBIC addresses many problems of the SPICE Gummel-Poon model:

- More accurate modeling of Early effect
- Parasitic substrate transistor
- Modulation of collector resistance
- Avalance multiplication in collector junction, parasitic capacitances neof base-emitter overlap in double poly BJTs, and self heating.

This chapter covers the following topics:

Understanding the History of VBIC

VBIC was developed by engineers at several companies and is described in the following publication, which provides a major reference to equations of the model:

C. McAndrew, J. Seitchik, D. Bowers, M. Dunn, M. Foisy, I. Getreu, M. McSwain, S. Moinian, J. Parker, D. Roulston, M. Schroter, P. van Wijnen, and L. Wagner, "VBIC95: The vertical bipolar intercompany model,'' IEEE Journal of Solid State Circuits, vol.31, p.1476-1483, 1996.

The detailed equations for all elements are given in the above referenced publication. Recent information and source code can be found on the web site: **http://www-sm.rz.fht-esslingen.de/institute/iafgp/neu/VBIC/index.html**

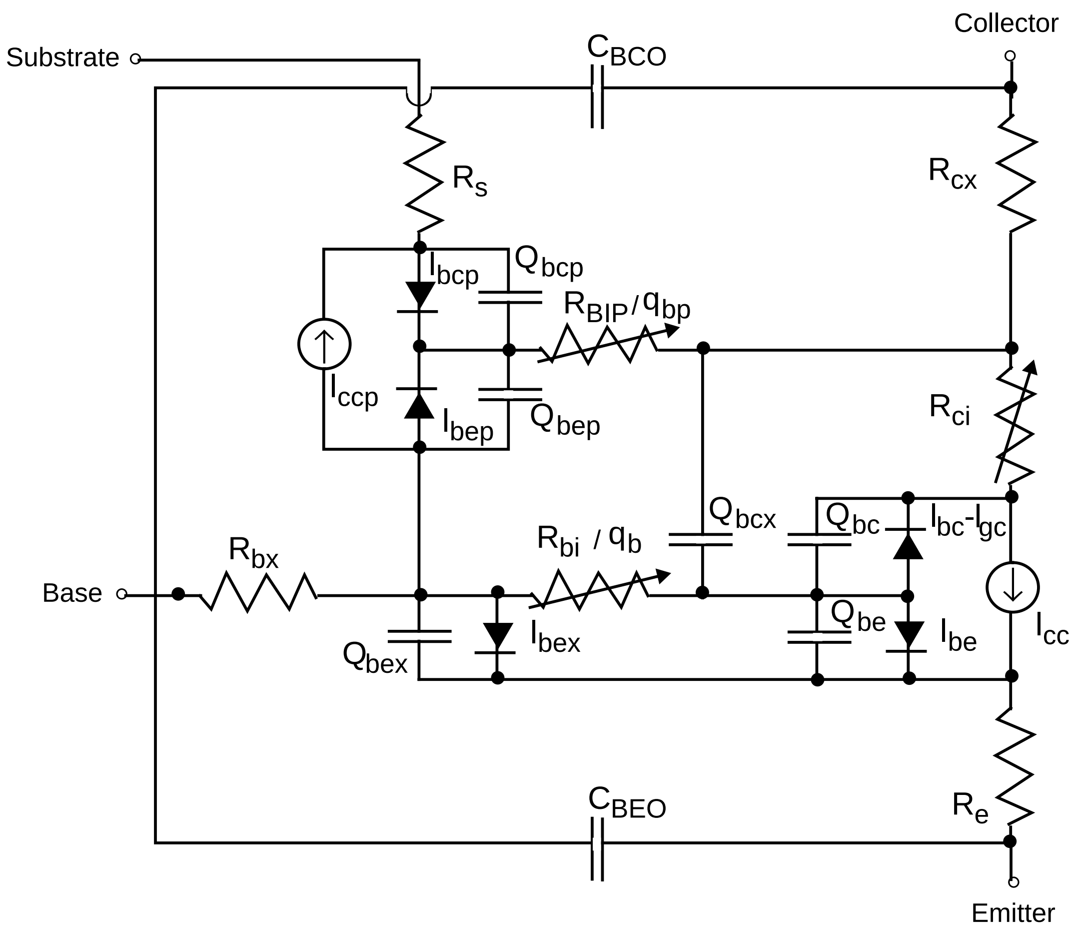
Our implementation is compliant to standard VBIC except that self-heating and excess phases are not implemented or enabled.

The large signal equivalent circuit for VBIC is shown in Figure 17-1. Capacitors CBCO, CBEO and resistors RCX, RBX, RE, and RS are linear elements, all other elements of the equivalent circuit are nonlinear.

Examining VBIC Equations

Table 17-1 lists the parameters for the model that you can set. Table 1-1 also contains the default values for the parameters. The same names are used for parameters in the table and in the above referenced publication.

Figure 17-1: Transient Analysis



If values of parameters given by the user are beyond their ranges, those parameters will be reset to new values and warnings will be printed unless the option NOWARN is set.

Performing Noise Analysis

The following sources of noise are taken into account:

- The thermal noise of resistors RBX, RCX, RE, RS, RBP, RCI, RBI
- Shot noise of currents IBE, IBEP, ICC, ICCP
- Flicker noise due to currents IBE, IBEP

The noise due to IBEX and IGC is not included in this preliminary version (nor in the standard VBIC), but will be included in the next release.

Examples

Usage:

```
Q1 21 22 22 22 VBIC <parameters>
.MODEL VBIC NPN <parameters>
```

Complete netlist:

```
*VBIC example, DC analysis
.OPTIONS NODE POST NOPAGE
.WIDTH OUT=80
.DC QVcolem 0 5 0.1 SWEEP QVbasem 0.7 0.86 0.05
.TEMP -20.0 +25. +100.
.PRINT DC I1(Q1) I2(Q1) I3(Q1) I4(Q1)
.PRINT DC V(102) V(202)
Vbas 101 0 QVbasem
Vcol 102 0 QVcolem
Vsub 104 0 0.
Vemi 103 0 0.
R1   101 201 10
R2   102 202 10
R4   104 204 10
R3   103 203 10
Q1 202 201 203 204 VBIC_EXAMPLE
.model VBIC_EXAMPLE npn level=4
```

```
  +afn=1 ajc=-0.5 aje=0.5 ajs=0.5
  +avc1=0 avc2=0 bfn=1 cbco=0 cbeo=0 cjc=2e-14
  +cjcp=4e-13 cje=le-13 cjep=le-13 cth=0
  +ea=1.12 eaic=1.12 eaie=1.12 eais=1.12 eanc=1.12
  +eane=1.12 eans=1.12 fc=0.9 gamm=2e-11 hrcf=2
  +ibci=2e-17 ibcip=0 ibcn=5e-15 ibcnp=0
  +ibei=1e-18 ibeip=0 iben=5e-15 ibenp=0
  +ikf=2e-3 ikp=2e-4 ikr=2e-4 is=le-16 isp=le-15
itf=8e-2
  +kfn=0 mc=0.33 me=0.33 ms=0.33
  +nci=1 ncip=1 ncn=2 ncnp=2 nei=1 nen=2
  +nf=1 nfp=1 nr=1 pc=0.75 pe=0.75 ps=0.75 qco=le-12
qtf=0
  +rbi=4 rbp=4 rbx=1 rci=6 rcx=1 re=0.2 rs=2
  +rth=300 tavc=0 td=2e-11 tf=10e-12 tnf=0 tr=100e-12
  +tnom=25 tref=25 vef=10 ver=4 vo=2
  +vtf=0 wbe=1 wsp=1
  +xii=3 xin=3 xis=3 xrb=0 xrc=0 xre=0 xrs=0 xtf=20
xvo=0
  *.END
```

Table 17-1: Default Model Parameters for BJT, Level 4

Name	Units	Default	Comments
AFN		1	Flicker noise exponent for current
AJC		-0.5	Base-collector capacitance switching parameter
AJE		-0.5	Base-emitter capacitance switching parameter
AJS		-0.5	Substrate-collector capacitance switching parameter
AVC1	V^{-1}	0	Base-collector weak avalanche parameter 1
AVC2	V^{-1}	0	Base-collector weak avalanche parameter 2

Name	Units	Default	Comments
BFN		1	Flicker noise exponent for 1/f dependence
CBCO (CBC0)	F	0	Extrinsic base-collector overlap capacitance
CBEO (CBE0)	F	0	Extrinsic base-emitter overlap capacitance
CJC	F	0	Base-collector intrinsic zero bias capacitance
CJCP	F	0	Substrate-collector zero bias capacitance
CJE	F	0	Base-emitter zero bias capacitance
CJEP	F	0	Base-collector extrinsic zero bias capacitance
CTH	J/K	0	Thermal capacitance
EA	eV	1.12	Activation energy for IS
EAIC	eV	1.12	Activation energy for IBCI/IBEIP
EAIE	eV	1.12	Activation energy for IBEI
EAIS	eV	1.12	Activation energy for IBCIP
EANC	eV	1.12	Activation energy for IBCN/IBENP
EANE	eV	1.12	Activation energy for IBEN
EANS	eV	1.12	Activation energy for IBCNP
FC		0.9	Forward bias depletion capacitance limit
GAMM		0	Epi doping parameter
HRCF		1	High current RC factor
IBCI	A	1e-16	Ideal base-collector saturation current
IBCIP	A	0	Ideal parasitic base-collector saturation current
IBCN	A	1e-15	Non-ideal base-collector saturation current

Name	Units	Default	Comments
IBCNP	A	0	Non-ideal parasitic base-collector saturation current
IBEI	A	1e-18	Ideal base-emitter saturation current
IBEIP	A	0	Ideal parasitic base-emitter saturation current
IBEN	A	1e-15	Non-ideal base-emitter saturation current
IBENP	A	0	Non-ideal parasitic base-emitter saturation current
IKF	A	2e-3	Forward knee current
IKP	A	2e-4	Parasitic knee current
IKR	A	2e-4	Reverse knee current
IS	A	1e-16	Transport saturation current
ISP	A	1e-16	Parasitic transport saturation current
ITF	A	1e-3	Coefficient of TF dependence in Ic
KFN		0	Base-emitter flicker noise constant
MC		0.33	Base-collector grading coefficient
ME		0.33	Base-emitter grading coefficient
MS		0.33	Substrate-collector grading coefficient
NCI		1	Ideal base-collector emission coefficient
NCIP		1	Ideal parasitic base-collector emission coefficient
NCN		2	Non-ideal base-collector emission coefficient
NCNP		2	Non-ideal parasitic base-collector emission coefficient
NEI		1	Ideal base-emitter emission coefficient
NEN		2	Non-ideal base-emitter emission coefficient
NF		1	Forward emission coefficient
NFP		1	Parasitic forward emission coefficient

Name	Units	Default	Comments
NR		1	Reverse emission coefficient
PC	V	0.75	Base-collector built-in potential
PE	V	0.75	Base-emitter built-in potential
PS	V	0.75	Substrate-collector built-in potential
QCO (QC0)	C	0	Epi charge parameter
QTF		0	Variation of TF with base-width modulation
RBI	Ohm	1e-1	Intrinsic base resistance
RBP	Ohm	1e-1	Parasitic base resistance
RBX	Ohm	1e-1	Extrinsic base resistance
RCI	Ohm	1e-1	Intrinsic collector resistance
RCX	Ohm	1e-1	Extrinsic collector resistance
RE	Ohm	1e-1	Emitter resistance
RS	Ohm	1e-1	Substrate resistance
RTH	K/W	0	Thermal resistance
TAVC	1/K	0	Temperature coefficient of AVC2
TD	s	0	Forward excess-phase delay time
TF	s	1e-11	Forward transit time
TNF	1/K	0	Temperature coefficient of NF
TR	s	1e-11	Reverse transit time
TREF (TNOM)	^{o}C	27	Nominal measurement temperature of parameters (please do not use TNOM alias, though it is allowed)
VEF	V	0	Forward Early voltage
VER	V	0	Reverse Early voltage

Name	Units	Default	Comments
VO (V0)	V	0	Epi drift saturation voltage
VTF	V	0	Coefficient of TF dependence on Vbc
WBE		1	Portion of IBEI from Vbei, 1-WBE from Vbex
WSP		1	Portion of ICCP from Vbep, 1-WSP from Vbci
XII		3	Temperature exponent of IBEI/IBCI/IBEIP/IBCIP
XIN		3	Temperature exponent of IBEN/IBCN/IBENP/IBCNP
XIS		3	Temperature exponent of IS
XRB		1	Temperature exponent of base resistance
XRC		1	Temperature exponent of collector resistance
XRE		1	Temperature exponent of emitter resistance
XRS		1	Temperature exponent of substrate resistance
XTF		0	Coefficient of TF bias dependence
XVO (XV0)		0	Temperature exponent of VO

Using VBIC

The following are tips you can follow when using VBIC.

1. Set Level to 4 to identify the model as a VBIC bipolar junction transistor model.
2. Self-heating has not been enabled for this model, so model parameters RTH and CTH have no influence.
3. The Level 4 model does not scale with any area terms, and does not yet scale with M.
4. The HSPICE option SCALM is ignored for this model.
5. Setting these parameters to zero infers a value of infinity: HRCF, IKF, IKP, IKR, ITF, VEF, VER, VO, VTF.
6. Parameters CBC0, CBE0, QC0, TNOM, V0, and XV0 are aliases for CBCO, CBEO, QCO, TREF, VO, and XVO, respectively. Avant! discourages use of TNOM as a model parameter name as it is used as the name of the default room temperature in HSPICE.
7. The default room temperature is 25 in HSPICE, but is 27 in some other simulators. If the VBIC bipolar junction transistor model parameters are specified at 27 degrees, TREF=27 should be added to the model, so that the model parameters will be interpreted correctly. It is a matter of choice whether or not to set the nominal simulation temperature to 27, by adding .OPTION TNOM=27 to the netlist. This should be done when testing HSPICE versus other simulators that use 27 as the default room temperature.
8. Pole-zero simulation of this model is not supported.
9. Excess phase has not yet been implemented.
10. For this version of implementation, all seven internal resistors should have values greater than or equal to $1.0e^{-3}$. Values smaller than this will be reassigned a value of $1.0e^{-3.}$
11. This implementation is a preliminary version only. It is not to be used for new designs, and has not yet been optimized for speed and memory usage.