Compact Models
for
Bipolar Transistors

by

Jörg Berkner
Infineon Technologies
Munich

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1 Introduction

This paper deals with a short comparison of the most important equations for the compact models SGP, VBIC, HICUM and MEXTRAM. It is based on the model equations, as described in the book “Kompaktmodelle für Bipolartransistoren (Compact Models for Bipolar Transistors)” [2]. It includes four model chapters describing both the model equations and the equivalent circuits and, additional, three sections considering measurement technique’s, model parameter extraction methods and model parameter extraction strategies.

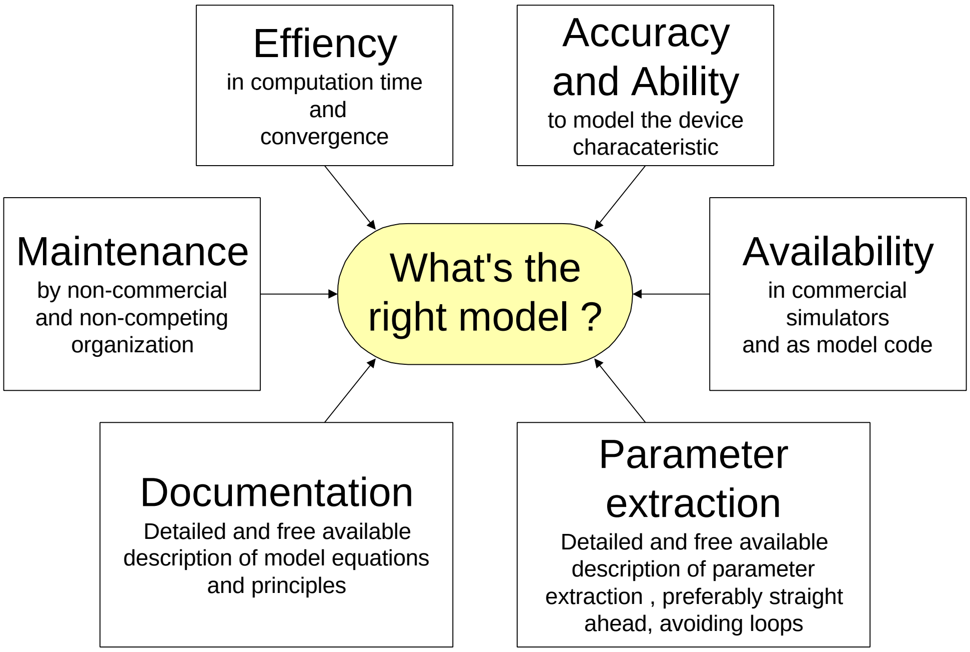


Fig. 1: Six important topics for compact model evaluation [8]

As it is shown in Fig. 1, there are six important topics for compact model evaluation. We will focus here on the topic "Ability to model device characteristics", which is mainly determined by the model equations the model consist of. That is why we will compare some main model equations in the next sections. In detail, we will consider the following important points:

- equivalent circuit,
- transfer current calculation,
- base charge calculation,
- base current calculation,
- base resistance calculation and
- transit time calculation.

This comparison is based on the following model versions:

- SGP, version Spice3G2 as described in [1][2],
- VBIC, version 1.2 [3],
- HICUM, version 2.1 [4] and
- MEXTRAM, version 504 [5] .

2 Large Signal Equivalent Circuits

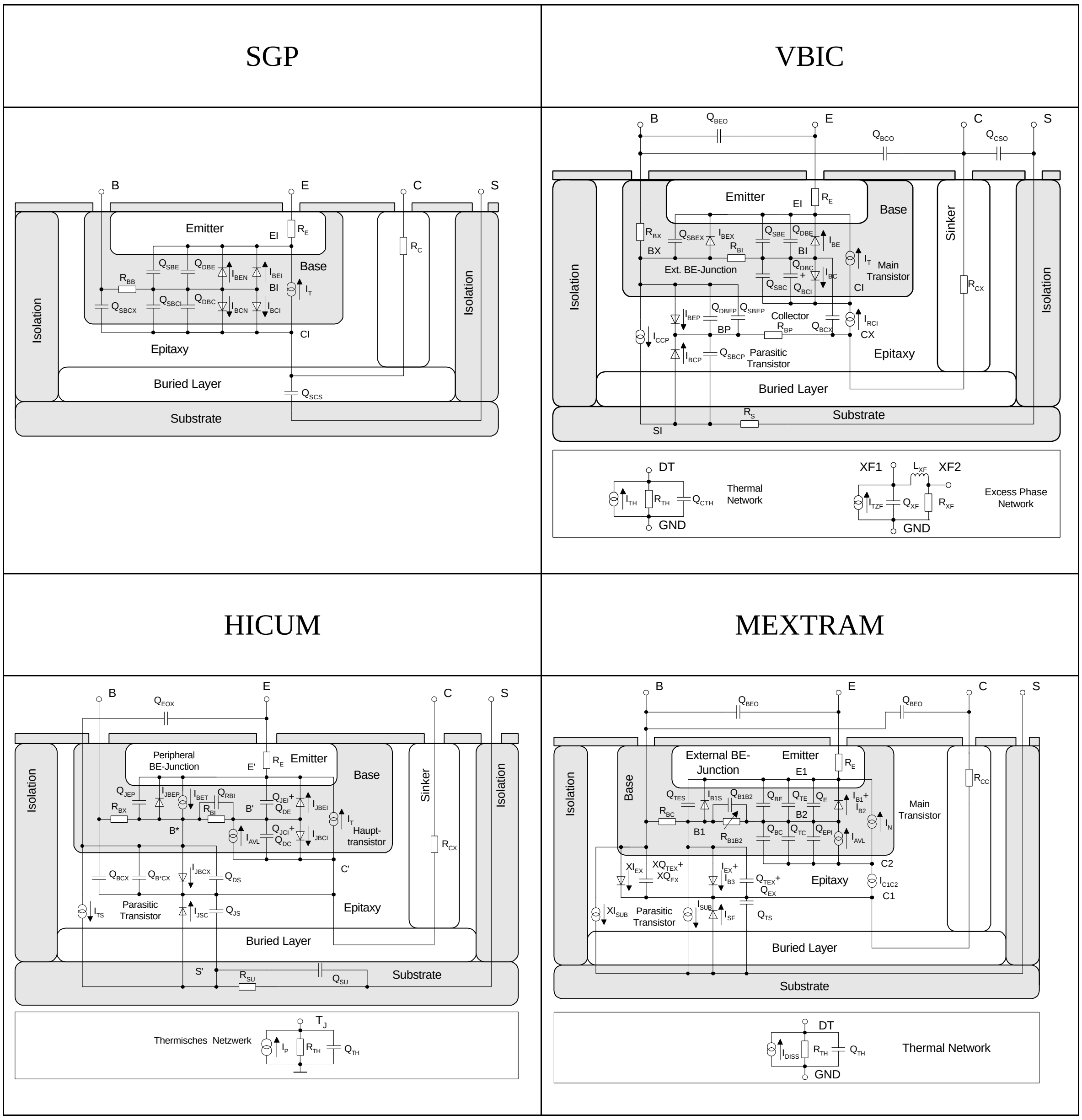
The large signal equivalent circuit for all the models is in a certain amount based on the transport model. It includes e.g. a transfer current source, diodes for ideal and non-ideal base current components as well as series resistances. The large signal equivalent circuits are shown in Fig. 2. Compared to the SGP, all new models use a

- split BE junction,
- split base resistance,
- split BC junction,
- BC avalanche current model and
- a self heating network.

Differences however appear for

- the BE tunnel current (only taken into account in VBIC and HICUM),
- the collector model (modified KULL-model using a collector current source for VBIC and MEXTRAM, whereas HICUM uses a different charge based approach),
- the parasitic pnp transistor model (most detailed for the VBIC- and the MEXTRAM model),
- the substrate model (most detailed for the HICUM model) and the
- the additional phase modeling (additional network for VBIC).

Fig. 2 shows the large signal equivalent circuits and Table 1 compares their components.



SGP

VBIC

HICUM

MEXTRAM

Fig. 2: Large Signal Equivalent Circuits for SGP, VBIC, HICUM and MEXTRAM

Table 1: Comparison of Large Signal Equivalent Circuit Components for SGP, VBIC, HICUM and MEXTRAM

	SGP	VBIC	HICUM	MEXTRAM
External BE base current	-	I_{BEX}	I_{JBEP}	I_{B1S}
BE tunnel current	-	part of I_{BE}	I_{BET}	-
Split base resistance	-	R_{BX} , R_{BI}	R_{BX} , R_{BI}	R_{BC} , R_{B1B2}
Charge parallel to R_{BI} for AC current crowding	-	-	Q_{RBI}	Q_{B1B2}
Collector current source	-	I_{RCI}	-	I_{C1C2}
External BC junction	-	I_{BEP}	I_{JBCX}	I_{EX} , XI_{EX}
BC avalanche current	-	part of I_{BC}	I_{AVL}	I_{AVL}
Base resistance for pnp	-	R_{BP}	-	-
Substrate transfer current for pnp	-	I_{CCP}	I_{TS}	I_{SUB} , X_{ISUB}
Substrate-collector diode	Q_{SCS}	I_{BCP} , Q_{SBCP}	I_{JSC} , Q_{JS}	I_{SF} , Q_{TS}
Substrate model		R_S	R_{SU} , Q_{SU}	-
Thermal components	-	I_{TH}, R_{TH} , Q_{CTH}	I_P , R_{TH} , Q_{TH}	I_{DISS}, R_{TH}, Q_{TH}
Additional phase network	-	I_{TZF}, Q_{XF}, L_{XF}, R_{XF}	-	-

3 Model Equations

In the following section some selected model equations will be treated, starting with the transfer current calculation.

3.1 Transfer Current

For all the models a forward and a reverse transfer current is calculated. Either the sum of both components or each component separately is then modified by a base charge. For SGP, VBIC and MEXTRAM a normalized charge q_B is used, whereas the HICUM model is the only one, applying an absolute base charge Q_{PT} (cf. Table 2).

Table 2: Transfer current for SGP-, VBIC, HICUM- and MEXTRAM-Model

Model	Equation for Fwd Transfer Current	Equation for Reverse Transfer Current	Equation for Transfer Current
SGP	$I_F = IS\left[\exp\frac{U_{BEI}}{NF\cdot U_T}-1\right]$	$I_R = IS\left[\exp\frac{U_{BCI}}{NR\cdot U_T}-1\right]$	$I_T = \frac{I_F - I_R}{q_B}$
VBIC	$I_{TF} = IS\cdot\left(\exp\frac{U_{BEI}}{NF\cdot U_T}-1\right)$	$I_{TR} = IS\cdot ISRR\left(\exp\frac{U_{BCI}}{NR\cdot U_T}-1\right)$	$I_T = \frac{I_{TF} - I_{TR}}{q_B}$
HICUM	$I_{TF} = \frac{c1}{Q_{PT}}\exp\left(\frac{U_{B'E'}}{U_T}\right)$	$I_{TR} = \frac{C10}{Q_{PT}}\exp\left(\frac{U_{B'C'}}{U_T}\right)$	$I_T = I_{TF} + I_{TR}$
MEX-TRAM	$I_F = IS\cdot\exp\left(\frac{U_{B2E1}}{U_T}\right)$	$I_R = IS\cdot\exp\left(\frac{U_{B2C2*}}{U_T}\right)$	$I_N = \frac{I_F - I_R}{q_B}$

3.2 Base Charge

The equations for base charge calculation are given in Table 3.

SGP
The normalized base charge q_B consists of q_1 (Early effect) and q_2 (high injection effect, e.g. high current beta roll off). The main disadvantage of the q_1 definition is the constant output resistance. Moreover, quasisaturation is not taken into account.

VBIC
A modified SGP equation for q_B is used. The additional model parameter NKF enables a better simulation of the current gain roll off. q_1 (Early effect) is calculated using the normalized depletion charges q_{JBE} and q_{JBC} instead of the inner BE and BC branch voltages. The definition of the normalized charge q_2 for high injection modeling is identical to SGP. For quasisaturation, additional equations utilizing a modified Kull-model are used.

HICUM
An absolute charge Q_{PT} instead of an normalized charge is used. Using it's part Q_{FT} resp. the appropriate transit time component T_{FT}, the Early effect as well as high injection effects are taken into account. T_{FT} consists of voltage (T_{F0}) and current dependent parts (ΔT_{FB}, T_{FCT}, ΔT_{FE}). Using T_{F0} (term1) the Early effect is modeled, using T_{F0} (term 2) the effect of drift velocity saturation in the BC space charge region. The current dependent parts ΔT_{FB}, T_{FCT}, ΔT_{FE} are used to model the increase of the hole charge Q_{PT} at high currents.

The onset of high current effects is defined using a critical current I_{CK}. This current I_{CK} is calculated taking into account the effects of velocity saturation in the collector and BC space charge layer reach through. Using I_{CK}, the increase of T_{FT} resp. Q_{PT} with increasing current may be calculated. The effect of quasisaturation is included here.
The hole charge Q_{PT} calculated in this way, determines the value of the transfer current, on which the charge parts are dependent again. That is why a optimization loop is necessary to find a solution for each operating point. The HICUM model is the only one, in which such an optimization loop is realized inside the model code. All the other models use the simulators solver for finding the operating point solution.

Table 3: Base Charge for SGP-, VBIC, HICUM- and MEXTRAM-Model

Model	Equation
SGP	$q_B = \frac{q_1}{2}\left[1+\sqrt{1+4q_2}\right] \qquad q_1 = \frac{1}{1-\frac{U_{BCI}}{VAF}-\frac{U_{BEI}}{VAR}} \qquad q_2 = \frac{I_F}{IKF}+\frac{I_R}{IKR}$
VBIC	$q_B = \frac{q_1}{2}\left[1+\left(1+4q_2\right)^{NKF}\right] \qquad q_1 = 1+\frac{q_{JBE}}{VER}+\frac{q_{JBC}}{VEF} \qquad q_2 = \frac{I_{TF}}{IKF}+\frac{I_{TR}}{IKR}$
HICUM[1]	$Q_{PT} = QP0 + Q_{JEI} + Q_{JCI} + Q_{FT} + Q_{RT}$ $Q_{FT} = Q_{F0} + \Delta Q_{FB} + \Delta Q_{FE} + Q_{FCT}$ $T_{FT} = T_{F0} + \Delta T_{FB} + \Delta T_{FE} + T_{FCT}$ $T_{F0} = T0 + \underbrace{DT0H\ (c-1)}_{Term1} + \underbrace{TBVL\left(\frac{1}{c}-1\right)}_{Term2}$ $\Delta T_{FB} + T_{FCT} + \Delta T_{FE} = THCS \cdot w^2 \left[1+\frac{2}{\frac{I_{TF}}{I_{CK}}\sqrt{i^2+ALHC}}\right] + TEF0\left(\frac{I_{TF}}{I_{CK}}\right)^{GTE}$
MEXTRAM	$q_B = q_1\left(1+\frac{n_0}{2}+\frac{n_B}{2}\right)$ $q_1 \approx q_0 = 1+\frac{q_{TE}}{VER}+\frac{q_{TC}}{VEF}$ $n_0 = \frac{f_1}{1+\sqrt{1+f_1}} \quad f_1 = 4\cdot\frac{I_F}{IK} \qquad n_B = \frac{f_2}{1+\sqrt{1+f_2}} \quad f_2 = \frac{4\cdot I_R}{IK}$

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[1] For all weighting factors here a value of 1 is assumed.

MEXTRAM
Similarly to SGP and VBIC a normalized base charge q_B is used. As for the VBIC model, q_1 is defined using normalized depletion charges. For the normalized base charge q_2 however, a different definition is used. q_2 is calculated using the electron densities n_0 and n_B , normalized to a knee current IK. There is one knee current parameter only for both forward and reverse direction. The combination of a square root function and an exponential function results in change of the emission factor from 1 to 2, that is, the increase changes from log(e)/V_T in the low current to log(e)/2V_T in the high current range. The quasisaturation is taken into account using additional equations, realizing a modified Kull model.

3.3 BE Base Current Components

As Table 4 emphasizes, there are two different principles for the ideal BE base current modeling: whereas in SGP and MEXTRAM a current gain parameter BF is applied, in VBIC and HICUM the base current description is independent from the transfer current, e.g. using it's own saturation currents and emission coefficients. Additional, contrary to SGP, for all the new models the BE base current is divided into an inner and outer component.

Table 4: BE Base Current for SGP-, VBIC, HICUM- and MEXTRAM-Model

Model	Ideal Component Equation	Non-ideal Component Equation
SGP	$I_{BEI} = \frac{I_F}{BF}$	$I_{BEN} = ISE \cdot \left(\exp \frac{U_{BEI}}{NE \cdot U_T} - 1 \right)$
VBIC	$I_{BEI} = WBE \cdot IBEI \left(\exp \frac{U_{BEI}}{NEI \cdot U_T} - 1 \right)$	$I_{BEN} = WBE \cdot IBEN \left(\exp \frac{U_{BEI}}{NEN \cdot U_T} - 1 \right)$
HICUM	$I_{JBEI} = IBEIS \cdot \left(\exp \frac{U_{B'E'}}{MBEI \cdot U_T} - 1 \right) + IREIS \cdot \left(\exp \frac{U_{B'E'}}{MREI \cdot U_T} - 1 \right)$	
MEX-TRAM	$I_{B1} = (1 - XIBI) \frac{IS \cdot \left(\exp \frac{U_{B2E1}}{U_T} - 1 \right)}{BF}$	$I_{B2} = IBF \exp \left(\frac{U_{B2E1}}{MLF \cdot U_T} - 1 \right)$

VBIC
For the VBIC model both the ideal and non-ideal BE base currents are divided into an inner and outer component, using the model parameter WBE. Additional, a BE tunnel current component is calculated, using a simple exponential equation (cf. Table 5)

HICUM
In HICUM both the inner and the peripheral BE base current component consist of an ideal and an non-ideal component. Table 4 shows only the inner base current equation. Instead of a split parameter, four saturation currents and emission coefficients are used. As Table 5 reveals, for HICUM a BE tunnel current is taken into account too. A more physical based equation is used here, as derived in [6].

MEXTRAM
The appropriate split parameter for MEXTRAM is called XIBI. However, it is applied only to the ideal component I_{B1}. There is no split for the non-ideal part I_{B2}. Different to the earlier MEXTRAM version 503, I_{B2} is calculated now using a saturation current and a non-ideality factor, as usual. A crossover voltage is not longer used here. MEXTRAM does not take into account a BE tunnel current.

Table 5: BE Tunnel Current for SGP-, VBIC, HICUM- and MEXTRAM-Model

Model	Equation
SGP	n/a
VBIC	$I_{BET} = WBE\left[IBBE\left(\exp\frac{-VBBE-U_{BEI}}{NBBE\cdot U_T}\right)\right]$
HICUM	$I_{BET} = IBETS\left(\frac{-U_{B'E'}}{VDEP}\right)\left(\frac{C_{JEI}}{CJEP0}\right)^{1-\frac{1}{ZEP}}\exp\left[-ABET\left(\frac{C_{JEI}}{CJEP0}\right)^{\frac{1}{ZEP}-1}\right]$
MEXTRAM	n/a

3.4 BC Base Current Components

The BC base current calculations are done using the same general principles as for the BE junction, but all the models show some exceptional features.

VBIC
For the VBIC model the inner BC base current part is assigned to the main npn transistor, whereas the outer BC base current is considered as the BE base current of the parasitic pnp transistor.

HICUM
Compared to VBIC, the BC base current calculation for HICUM is simplified. Although an inner and an outer component does exist, both are not divided into an ideal and non-ideal component.

MEXTRAM
Another exceptional feature shows the MEXTRAM model: there is no BC base current component assigned to the inner node B2 (see Fig. 2). Instead of this, the model employs two ideal components I_{EX} and XI_{EX}, assigned to the base nodes B and B1. As Table 6 shows, the way to calculate the ideal BC current differs from the other models, using a split factor XEXT, a normalized electron density n_{BEX}, a knee current IK and a reverse current gain BRI.

The non-ideal BC base current component is connected to the node B1, and, it is not divided. It is calculated using an fair unusual way, utilizing an so called cross over voltage VLR.

Table 6: BC Base Current for SGP-, VBIC, HICUM- and MEXTRAM-Model

Model	Equation ideal component	non-ideal component
SGP	$I_{BCI} = \frac{I_R}{BR}$	$I_{BCN} = ISC \cdot \left[\exp\left(\frac{U_{BCI}}{NC \cdot U_T}\right) - 1\right]$
VBIC	$I_{BCI} = IBCI\left(\exp\frac{U_{BCI}}{NCI \cdot U_T} - 1\right)$	$I_{BCN} = IBCN\left(\exp\frac{U_{BCI}}{NCN \cdot U_T} - 1\right)$
HICUM	$I_{JBCI} = IBCIS \cdot \left[\exp\left(\frac{U_{B'C'}}{MBCI \cdot U_T}\right) - 1\right]$	$I_{JBCX} = IBCXS \cdot \left[\exp\left(\frac{U_{B^*C'}}{MBCX \cdot U_T}\right) - 1\right]$
MEX-TRAM	$I_{EX} = (1 - XEXT)\frac{\left(\frac{IK \cdot n_{BEX}}{2} - IS\right)}{BRI}$	$I_{B3} = IBR\frac{\left(\exp\frac{U_{B1C1}}{U_T} - 1\right)}{\exp\left(\frac{U_{B1C1}}{2U_T}\right) + \exp\left(\frac{VLR}{2U_T}\right)}$

The BC avalanche current equation used in VBIC and HICUM is restricted to model the avalanche effect at low current densities (weak avalanche). Contrary to this, in MEXTRAM a much more complicated avalanche model is used. It is able to calculate both the weak and the high current avalanche effect, including the snap back effect. Because it degrades the convergence behavior of the MEXTRAM model, it may be switched on as an optional feature.

Table 7: BC Avalanche Current for SGP, VBIC, HICUM and MEXTRAM

SGP	n/a
VBIC	$I_{GC} = \left(I_{TXF} - I_{TZR} - I_{BCJ}\right) \cdot AVC1 \cdot vl \cdot \exp\left(-AVC2 \cdot vl^{MC-1}\right)$
HICUM	$I_{AVL} = FAVL \cdot I_{TF} \cdot \left(VDCI - U_{B'C'}\right) \exp\left[-\frac{QAVL}{C_{JCI}\left(VDCI - U_{B'C'}\right)}\right]$
MEXTRAM	$I_{AVL} = I_{C1C2} \frac{G_{EM} \cdot G_{MAX}}{G_{EM} \cdot G_{MAX} + G_{EM} + G_{MAX}}$

3.5 Base Resistance

The inner base resistance decreases with increasing collector current. This is caused by different physical reasons:

- Emitter current crowding: The lateral base current flow trough the inner base creates a voltage drop in the lateral direction. The effective BE voltage in the center of the emitter is lowered, compared to emitter perimeter. Consequently, the current density at the perimeter is higher than in the center. This effect is appropriate to an decreasing inner base resistance.
- Base width modulation: The BC space charge layer width changes with the BC junction voltage (Early effect). This creates a change in the base width, affecting the base resistance value.
- Base conductivity modulation: At high current densities the minority concentration reaches the base doping concentration level, lowering the specific base resistance.
- Base widening: At a certain collector current density the base widening appears, because of minority injection into the collector, resulting in a lower effective base resistance.

These effects are accounted for in different ways for the models under consideration.

SGP

The decrease of the internal base resistance with increasing collector current is modeled using the normalized base charge q_B and the two model parameters RB and RBM. Additional, a second equation employing a third parameter IRB may be used.

VBIC

In VBIC the inner base resistance decrease is simulated in a similar way to SGP using the normalized base charge q_B .

HICUM
In the HICUM model different charges are used to model the operating point dependencies of the internal base resistance:

- the depletion charges Q_{JEI} , Q_{JCI} are used to take the base width modulation into account and
- the minority charge Q_F is employed to model the effect of base conductivity modulation and base widening.

Additional, the effect of emitter current crowding on the internal base resistance is taken into account in HICUM [4].

MEXTRAM
The MEXTRAM inner base resistance model takes into account conductivity modulation using the normalized charge q_B. Additional, the emitter current crowding is accounted for. In the real model the current I_{B1B2} between the nodes B1 and B2 instead of an base resistance R_{B2} is calculated (cf. Fig. 2).

Table 8: Base Resistance for SGP, VBIC, HICUM and MEXTRAM

Model	Equation
SGP	$R_{BB} = RBM + \left[\frac{RB - RBM}{q_B}\right]$
VBIC	$R_{BI} = \frac{RBI}{q_B}$
HICUM	$R_I = R^*_{BI0} \cdot \frac{(1 + FDQR0) \cdot QP0}{(1 + FDQR0) \cdot QP0 + Q_F + Q_{JEI} + Q_{JCI}}$
MEXTRAM	$R_{B2} = \frac{3RBV}{q_B}$ $\qquad I_{B1B2} = \underbrace{\frac{U_{B1B2}}{R_{B2}}}_{Term1} + 2\underbrace{\frac{U_T\left[\exp\left(\frac{\mathrm{U_{B1B2}}}{\mathrm{U_T}}\right) - 1\right]}{R_{B2}}}_{Term2}$

3.6 Transit Time and Quasisaturation

The way to calculate the transit time components an their operation point dependencies is quite different for the models considered here.

SGP
The SGP transit time equation employs a square law for the current dependence, relating the ideal forward current I_F to the model parameter ITF. The voltage dependence is added

by an exponential factor. This approach results in a bad ability to model the high current f_T –decrease as well as it's voltage dependence.

VBIC

The VBIC transit time equation is only a slightly modified SGP equation. The additional term ($1+QTF*q_1$) is introduced to realize an additional voltage dependence via the normalized charge q_1 , but in practice it is often not useful. The quasisaturation is taken into account using a modified Kull model (see Table 10). This works sufficiently for the case of ohmic quasisaturation. High speed devices, however, are often working in the range of non-ohmic quasisaturation. Here are the results are often less accurate.

Table 9: Transit Time for SGP, VBIC, HICUM and MEXTRAM

Model	Equation
SGP	$T_{FF} = TF\left[1+XTF\left(\frac{I_F}{I_F+ITF}\right)^2\cdot\exp\left(\frac{U_{BCI}}{1.44\cdot VTF}\right)\right]$
VBIC	$T_{FF} = TF\left(1+QTF\cdot q_1\right)\left(1+XTF\left[\frac{I_{TF}}{I_{TF}+ITF}\right]^2\exp\left(\frac{U_{BCI}}{1.44\cdot VTF}\right)\right)$
HICUM	$T_{FT} = \underbrace{T_{F0}}_{voltage\ dependent} + \underbrace{\Delta T_{FB} + HFE\cdot\Delta T_{FE} + HFC\cdot T_{FCT}}_{current\ andvoltage\ dependent}$
MEXTRAM	$Q_{BE} = \frac{1}{2}TAUB\cdot IK\cdot n_0\cdot q_1$ $Q_{EPI} = TEPI\,\frac{2U_T}{RCV}\cdot\frac{x_I}{W_{EPI}}\left(p_{0*}+p_W+2\right)$ $Q_E = TAUE\cdot IS\cdot\left(e^{U_{B2E1}}-1\right)$

HICUM

The HICUM transit time approach is completely different to SGP, VBIC and MEXTRAM. The forward transit time T_{FT} is composed by a pure voltage dependent term T_{F0} and a second term, that includes a current dependence. The current dependent parts are calculated using the forward transfer current I_{TF} and a critical current I_{CK}, which one is voltage dependent itself. In this way the parts ΔT_{FB} , ΔT_{FE} and T_{FCT} are both current and voltage dependent. Finally, using the operating point dependent transit time T_{FT}, calculated in this way, the appropriate charge Q_{FT} is calculated in HICUM. The charge affects both the DC- and the AC-behavior. This coupling between DC- and AC behavior is the most important characteristic of the HICUM model.

Moreover, the effect of quasisaturation is included in the operating point dependency of the forward transit time T_{FT}.

MEXTRAM

The MEXTRAM model utilizes a different principle, compared to HICUM. Here are the charges directly calculated using the appropriate model parameters, e.g. TAUB. The operating point dependencies are realized in the charge equations, instead of transit time equations, as in HICUM. Quasi saturation effect is modeled with a modified KULL-model, using an extensive set of additional equations, calculating a modified inner BC voltage U_{B2C2*} [5]. In a certain amount, the DC- and AC-behavior in the MEXTRAM 504 model is de-coupled, compared to version 503. This results in an easier parameter extraction, which advantage should not be underestimated.

Table 10: Quasi Saturation Model for SGP, VBIC, HICUM and MEXTRAM

Model	Equation
SGP	n/a
VBIC	$K_{BCI} = \sqrt{1 + GAMM \cdot \exp\frac{U_{BCI}}{U_T}}$ $K_{BCX} = \sqrt{1 + GAMM \cdot \exp\frac{U_{BCX}}{U_T}}$ $I_{Ohm} = \frac{U_{RCI} + U_T \cdot \left[K_{BCI} - K_{BCX} - \log\left[\frac{1+K_{BCI}}{1+K_{BCX}}\right]\right]}{RCI}$
HICUM	Quasi saturation effect is included in the operating point dependency of the forward minority charge Q_{FT}
MEXTRAM	Quasi saturation effect is modeled with a modified KULL-Model, using an extensive set of equations [2][5]

4 Summary

So far, the main model equations of the SGP, VBIC, HICUM and MEXTRAM model were compared. Other equations where left out, for reasons of space shortage, e.g. the equations for temperature behavior and the space charge calculation.

Table 11 gives a main feature comparison for the four compact models. The features 1 to 12 are realized in all the new models. The topics “Non quasistatic effects” (13) and “Improved f_T model” (14) are realized only in HICUM and MEXTRAM, whereas a substrate model (15) and the BE break down model (16) are only available for VBIC and HICUM. Finally, the MEXTRAM model is the only one, realizing a current dependent BC capacitance.

The VBIC and the HICUM model use the largest number of model parameters (108 resp. 101). The number of internal nodes is seven for VBIC and five for HICUM and MEXTRAM.

Table 11: Comparison of important features for the SGP, VBIC, HICUM and MEXTRAM compact models

	Feature	SGP	VBIC	HICUM	MEXTRAM
1	Separation of I_B and I_C (no beta)	-	+	+	+ (fwd only)
2	External BE junction	-	+	+	+
3	Improved Early effect model	-	+	+	+
4	Single piece depletion cap. model	-	+	+	+
5	Reach through capacitance model	-	+	+	+
6	BC avalanche model	-	+	+	+ +
7	Parasitic pnp	-	+	+	+ +
8	Quasi saturation	-	+	+	+
9	HBT modeling capability	-	+	+	+
10	Improved temperature model	-	+	+	+
11	Self heating	-	+	+	+
12	Overlap capacitances	-	+	+	+
13	Non quasistatic effects	-	-	+	+
14	Improved f_T model	-	-	+	+
15	Substrate model	-	+	+	-
16	BE break down	-	+	+	-
17	Current dependent BC depletion cap.	-	-	-	+
18	Internal nodes	3	7	5	5
19	Parameters	41	108	101	73

In the previous sections many equations were compared, advantages and disadvantages of today's most important bipolar models where shown. Now the question "Which model one is the best one ?" pops up again. The Compact Model Council (CMC) has tried to answer this question too. But, the situation in the CMC regarding the declaration of one model as definitive standard model for the future is blocked since years now. Especially MEXTRAM and HICUM have collected nearly the same number of arguments on every side, creating a tie situation.

From the users as well as the simulator vendors point of view the best way out of this situation would be probably the definition of a "Best of Bipolar" model. The contributions of the models SGP, VBIC, HICUM and MEXTRAM to the "Best of Bipolar" model could be defined as follows:

SGP

The Gummel Poon model delivers

- the basic noise equations.

VBIC

The VBIC model may contribute

- the principles of separate base current modeling (no beta parameters),
- the split of the BE junction,
- the self heating network,
- the overlap capacitances,
- the BE tunnel current equation and
- the clear and understandable defined model structure and parameter names.

HICUM

The HICUM model may add

- the charge concept, that is, the calculation of the operating point dependencies of the forward transit time resp. the appropriate absolute charge parts,
- the weak BC avalanche model,
- the depletion charge and capacitance model and
- the substrate model.

MEXTRAM

The MEXTRAM model may contribute

- the extended BC avalanche model,
- the temperature modeling,
- the extended pnp transistor and inverse beta modeling and
- the base current HBT modeling feature.

Such a “Best of Bipolar” model could show a way out of the blocked situation regarding the standard model definition in the CMC. The preconditions for such a “Best of Bipolar” model are:

- The CMC supports the BoB model development process.
- The CMC coordinates the maintenance for the BoB model.
- The CMC delivers the financial base for such a BoB model.
- The model development and maintenance is realized by a non-commercial organization, e.g. a university.

However, considering today’s situation, a cooperation between the developer of VBIC, HICUM and MEXTRAM to create a new “Best of Bipolar” standard seems to be absolutely impossible. There are many arguments possible against such project, e.g. proprietary interests and today’s competition between model developers.

That is why the bipolar modeling community obviously has to live with two or three models in future.

5 Literature

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