Comparison of a New Modified Gummel-Poon Model 
and VBIC for AlGaAs/GaAs HBTs

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Abstract — A new modified Gummel-Poon (MGP) 
based model has been developed and tested on 
heterojunction bipolar transistors (HBTs). This paper 
focuses on the comparison of the new MGP and the VBIC 
models under DC and small-signal operations. The DC 
parameters of the two models are extracted from Gummel 
forward and reverse measurements at various junction 
temperatures and Ic-Vce measurements. The small-signal 
intrinsic elements are extracted from multi-bias s- 
parameter measurements. DC comparisons between the two 
model predictions and measurements reveal that the new 
MGP model surpasses the VBIC DC performances. The s- 
parameter comparisons of simulated and measurements at 
various bias points, from 1Ghz to 30Ghz, show that the two 
models are equivalent.

I. INTRODUCTION

Heterojunction bipolar transistors (HBTs) have 
become very promising devices for future applications at 
microwave- and millimeter-wave frequencies. A critical 
precondition for any successful design is the availability 
of accurate large-signal model capable of describing the 
device over a broad bias range and signal frequencies. 
This is subjected to an accurate DC model, from one part, 
and to a precise description of the variation of the small-
signal intrinsic elements with bias and signal frequencies, 
from the other part. The VBIC [1] model has been 
developed for bipolar junction transistors and to be as 
similar as possible to the SPICE Gummel-Poon model 
but improved over it in the following aspects [2], [3]:

- Improved Early effect
- Quasi-saturation
- Parasitic substrate
- Parasitic fixed (oxide) capacitance
- Avalanche multiplication
- Temperature
- Decoupled base current from collector current
- Electrothermal (self-heating effect) modeling

Due to the completeness and to the availability on 
commercial simulators of the VBIC, many authors [3]- 
[10] have investigated its applicability in HBTs 
modeling. From these studies, it comes out that VBIC is 
applicable for HBT modeling within certain acceptable 
error and deleting of several equivalent circuit parts to fit 
HBTs requirements:

- Epi-layer resistance and charge
- Parasitic transistor
- No quasi-saturation effect
- Ideal components
- Same forward and reverse transport currents

The reduced VBIC equivalent circuit matches the new 
MGP equivalent circuit but the modeling equations are 
different. The MGP model satisfies all the HBTs 
requirements including the performances of the VBIC 
model and thermally improved to it in the following 
aspects:

- Thermal resistance
- Emission coefficients
- Band-gap energy
- Kirk effect
- Charge modulation (Cbc(Ic,Vbc); Cc(Ic,Vbc); 
  Cbe(Ic,Vce) and intrinsic base resistance )

These improvements are crucial for modern HBT 
modeling in particular for power applications [3], [4].

In the following, comparisons are conducted, for a 
2*25 µm² emitter area AlGaAs/GaAs transistor, between 
measurements and the model simulations using VBIC 
from one side and using MGP from the other side.

II. MODELING EQUATIONS

The large-signal model for AlGaAs/GaAs HBT’s, 
which is developed based on the conventional Gummel-
Poon large-signal BJT model, is shown in Fig. 1. The 
extrinsic capacitances and inductances are not shown on 
the figure for the sake of clarity; they are bias 
independent and they can be removed using an 
electromagnetic or any de-embedding technique.

Fig. 1. Equivalent circuit diagram of the large-signal MGP 
model without parasitic elements

Icn is the electron current injected from the emitter to 
the base in the forward bias condition. Icr is the electron 
current injected from the collector to the base in the 
reverse bias condition. Ibe is the direct base current 
representing all recombination processes taking place in 
the base emitter junction in the forward bias condition. 
Ipc is the base current in reverse bias; hole current 
jected from the base to the collector sometimes
increased by the recombination current in the depletion region. $I_a$ is the Avalanche current, added for the sake of model completeness. Except $I_a$, these currents follow a same type of modeling equation:

$$I = I_s e^{E_{gcn}(T)/N(T)} - 1$$

where $T_o$ is the reference absolute temperature, $I_s$ is the saturation current at $T$, $V_{be}$ is the applied base emitter potential, $N$ is a temperature coefficient, $T$ is the junction absolute temperature, $V_t$ is the thermal voltage and $E_{gcn}(T)$ defines the temperature dependence of the bend gap energy given by:

$$E_{gcn}(T) = E_{gcn}(0) - (a_{gcn1} T^2)/(T + a_{gcn2})$$

Early and Kirk effects are introduced in the model by dividing $I_{cn}$ current by factors $F_e$ and $F_k$ respectively; described by the following equations.

$$F_e = \begin{cases} 1 - \alpha_e \sqrt{V_{bc} - V_{bc}^2} & \text{if } V_{bc} < \phi_{bc} \\ 1 & \text{else} \end{cases}$$

$$F_k = \begin{cases} 1 & \text{if } I_c < 12 = I_{1} + \alpha_{12} (I_{bc} - V_{bc}) \\ 1 + \alpha_{12} (I_{bc} - 1)^m \left( \frac{12}{I_c - I_1} \right) & \text{else} \end{cases}$$

with $\alpha_e$ and $\alpha_{12}$, $I_1$ are Kirk parameters. In the above equations, the junction temperature is computed from:

$$T = T_o + Rth(T) \times P_{diss}$$

where $P_{diss}$ is the total dissipated power in the junction and $Rth(T)$ is the thermal resistance at junction temperature $T$. The thermal resistance $Rth(T)$ is given by:

$$Rth(T) = Rth(T_o) \times (T/T_o)^n$$

Where $Rth(T_o)$ is the thermal resistance at the reference temperature $T_o$ and $n$ is a temperature coefficient depending on fabrication material.

The intrinsic circuit elements are coupled to the DC model as shown in Fig. 1 to construct the large-signal equivalent circuit used in this study, as the VBIC does. The characterizing equations used for these elements are the standard ones.

### III. PARAMETER EXTRACTION

The DC parameter extraction procedure starts by extracting ideality factors and saturation currents from forward and reverse Gummel data measured at reference temperature $T_o$. Second, we repeat the first step for forward ideality factors and saturation currents from forward Gummel data measured at temperatures $T_i$. From the obtained data, we extract the variation of these parameters to temperature. The third step consists on the extraction of the parasitic resistances from Fly_back measurements. Third, we evaluate Kirk, and Early parameters and $Rth(T_o)$ and $n$ from theoretical relations and optimize these values in the high region of the forward Gummel data measured at temperature $T_o$.

The VBIC parameters are extracted from the same measurements using the procedure given in [4].

### IV. RESULTS AND DISCUSSION

We have applied the extraction procedure to various HBT transistors. Tables I and II list the obtained parameters for an AlGaAS / GaAs 2*25 $\mu$m$^2$ emitter area transistor for the MGP and for the VBIC models, respectively. The non-mentioned VBIC parameters are set to values giving no influence on simulation results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
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<td>Iscno</td>
<td>3.03e-24</td>
<td>Xcn</td>
<td>2.17</td>
</tr>
<tr>
<td>Iscro</td>
<td>12.4e-24</td>
<td>Xrsc</td>
<td>9.6</td>
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<td>Ipscro</td>
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<td>Rth(T_o)</td>
<td>84</td>
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<tr>
<td>Isrscro</td>
<td>1.16e-23</td>
<td>n</td>
<td>1.24</td>
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<tr>
<td>Npc</td>
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<td>Egscro</td>
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<td>Ncn</td>
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<td>$\alpha_e$</td>
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<td>Nrsr</td>
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<td>Ncr</td>
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<td>$\alpha_{gcn2}$</td>
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<td>$\phi_{bc}$</td>
<td>0.95</td>
<td>Xk</td>
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<td>$\alpha_{12}$</td>
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<tr>
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<td>$\gamma$</td>
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<tr>
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<td>Rb</td>
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**Table I**

**Extracted parameters for the new MGP model**

**Parameter** | **Value** | **Parameter** | **Value** |
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<td>Nen</td>
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<td>1kV</td>
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<td>Vef</td>
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<td>Xin</td>
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<td>Rth</td>
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**Table II**

**Extracted parameters for VBIC model**

Forward current-voltage characteristics and forward Gummel plots obtained from MGP are compared to measurements and to those obtained from VBIC in Figs 2 and 3, respectively. The superior performances of the MGP model are clearly seen from the observation of Fig. 2, in particular at high currents. The MGP model
reproduces VBIC performances when we neglect the variations of the band gap energy, emission coefficients and thermal resistance with temperature as shown in Figs 4 and 5. As AC performances are related to the DC model, the large-signal shown in Fig. 1 was constructed in HP-ADS simulator using SDD and simulated at fixed bias points with intrinsic elements extracted using procedure [11]. As an example of the obtained results, the measured and the simulated S-parameters are compared in Fig. 6 at two bias points from 1 GHz to 30 GHz; notice the very good agreement obtained.

The values of the intrinsic elements as extracted and used in simulations of Fig. 6 are listed in Table III.

<table>
<thead>
<tr>
<th>Cbe (pF)</th>
<th>Cbc (fF)</th>
<th>Cc (fF)</th>
<th>t_d (ps)</th>
<th>Rbb (\Omega)</th>
<th>Ic (mA)</th>
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<td>0.76</td>
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<td>14.44</td>
<td>1.58</td>
<td>6.7</td>
<td>5</td>
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<td>1.38</td>
<td>13.76</td>
<td>11.78</td>
<td>1.49</td>
<td>7.0</td>
<td>10</td>
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Table III
EXTRACTED INTRINSIC PARAMETERS AT VCE=2.5 V

Fig. 2. Forward current-voltage characteristics obtained from measurements (—), from VBIC model (o) and from MGP (x).

Fig. 3. Forward gummel plots obtained from measurements (—), from VBIC model (o) and from MGP (x).

Fig. 4. Forward current-voltage characteristics obtained from measurements (—), from VBIC model (o) and from MGP (x), Rtho and Ns are not varying with temperature and Rth(T_o)=57, \( X_k=1 \) and \( \alpha_k=4.5 \), \( I_1=0.005 \)

Fig. 5. Forward gummel plots obtained from measurements (—), from VBIC model (o) and from MGP (x), Rtho and Ns are not varying with temperature.
Fig. 6. Small-signal comparison between measurements (→) and model predictions from VBIC (o) and from MGP (x), at two bias points, from 1 GHz to 30 GHz.

IV. CONCLUSION

The new modified Gummel-Poon (MGP) based model was compared to the VBIC under DC and small-signal operations. The MGP performances are clearly seen when comparing simulations resulting from this model to those resulting from the VBIC one, simultaneously to measurements. The MGP performances are due to the improvement of the modeling of the following effects:

- Thermal resistance
- Emission coefficients
- Band-gap energy
- Kirk effect

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REFERENCES


