Model Verification for a High-Power-Efficiency AlGaAs-GaAs HBT

F. Deshours, E. Bergeault, G. Berghoff, C. Pinatel, and C. Dubon-Chevallier

***Abstract*—Heterojunction bipolar transistors (HBT's) with 2700 μm^2 of emitter area are characterized for model verification using an active load-pull measurement system. The simulation and measurement results (up to 26 dBm) are reported and compared in terms of output power level and power-added efficiency under variable operating conditions. These measurements are performed with the aim of designing power amplifiers for mobile communications.**

I. Introduction

SINCE the publication of the active load-pull technique by Y. Takayama [1], active load-pull measurement systems have been developed to characterize microwave power devices and to verify the accuracy of nonlinear models. The principle of the load-pull measurement consists of changing the load impedance seen by the device under test (DUT) in order to predict circuit design performances in terms of output power and efficiency. For the active load-pull technique, the load variation is realized electronically by injecting an incident wave at the output port of the DUT, varying magnitude and phase.

This letter presents the simulated and experimental results for a high-power-efficiency HBT operating under class AB bias conditions at 2 GHz. The measurements are performed by an active load-pull system while the simulation results are obtained from a modified nonlinear Gummel-Poon model for the HBT, taking into account thermal effects.

II. Load-Pull Measurements

The experimental system for power transistor characterization mainly includes a six-port network analyzer, calibrated for impedance and power measurements (Fig. 1) [2]. The six-port junctions (SP1 and SP2) cover the 1–18 GHz frequency range. It is configured as an active load-pull system to perform an electronic simulation of load impedances. A variable attenuator and a phase shifter control the magnitude and the phase of the signal injected at the output of the DUT. A broadband isolator and a low-pass filter are inserted at each measurement port in order to present the reference impedance to the harmonic components of the emerging waves. The system is fully computer controlled for load variation, data acquisition, and for plotting constant power contours on the Smith Chart.

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F. Deshours, E. Bergeault, and G. Berghoff are with Département Communications, ENST Paris, 75634 Paris Cedex 13, France.
C. Pinatel and C. Dubon-Chevallier are with CNET Bagneux, BP 107–92225, Bagneux Cedex, France.
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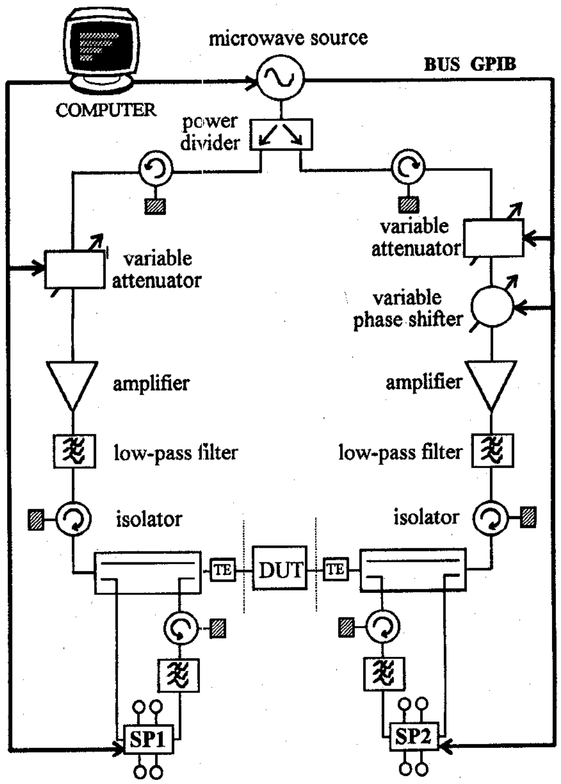

Fig. 1. The active load-pull measurement system.

A high-power-efficiency HBT manufactured by the CNET (Centre National d'Etudes des Télécommunications) was characterized at 2 GHz under class AB bias conditions to verify the accuracy of its nonlinear model. The HBT has a total emitter area of 2700 μm^2 (thirty emitter fingers, 3 $\mu m * 30$ μm each). It is used in a common emitter configuration and biased at constant collector to emitter voltage V_{CE} and constant base current I_B.

III. Power HBT Modeling

A nonlinear thermal electrical power HBT model [3] has been developed up to 6 V by modifying the Gummel-Poon equivalent circuit (Fig. 2). This model is relatively simple and it can be easily incorporated into existing microwave CAD tools (MDS, LIBRA). Typical simulated and measured $I(V)$ curves for the power HBT, taking into account thermal effects, are shown in Figs. 3 and 4. Very good fits were obtained over a wide temperature range for static $I(V)$ characterization and S-parameter measurements [3], [4].

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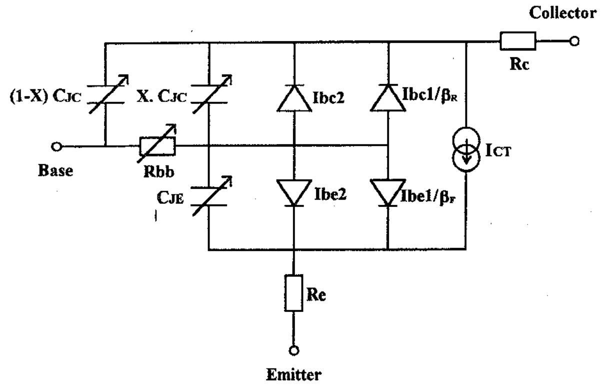

Ibe1 = forward diffusion current : $Ibe1 = Is\,(e^{Vbe/(NF.VT)} - 1)$
Ibe2 = non-ideal base-emitter current : $Ibe2 = I_{SE}\,(e^{Vbe/(NE.VT)} - 1)$
$I_{CT} = (Ibe1 - Ibe2) / Kqb$
Ibc1 = reverse diffusion current : $Ibc1 = Is\,(e^{Vbc/(NR.VT)} - 1)$
Ibc2 = non-ideal base-collector current : $Ibc2 = I_{SC}\,(e^{Vbc/(NC.VT)} - 1)$
Kqb = base charge factor
Rbb, Rc, Re = base, collector and emitter resistances
C_{JE}, C_{JC} = junction capacitances
$X.C_{JC}$ = fraction of C_{BC} connected internal to Rbb

Fig. 2. Nonlinear Gummel-Poon GaAs HBT model.

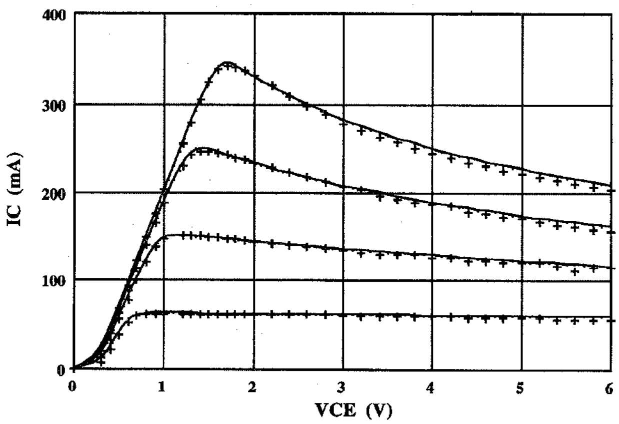

Fig. 3. Collector current (I_C) versus the collector to emitter voltage (V_{CE}) with base current ranging from 1–4 mA with step size of 1 mA. + measured points; — simulated.

IV. Model Verification

Using a harmonic balance nonlinear simulator, the added power has been optimized for a given collector bias voltage [4]. The optimization parameters include the complex input and output impedances at the fundamental frequency; the impedances were set to a 50 Ω load for all the harmonic components to simulate under the same operation conditions as when performing load-pull measurements.

Model verification is performed by comparing the simulated responses of the HBT to those obtained with the load-pull system at 2 GHz. For two different AB operating classes ($V_{CE0} = 3$ V, $I_{CE0} = 100$ mA or $I_{CE0} = 230$ mA) and different input power levels ($P_{in} = 20$, 25, and 40 mW),

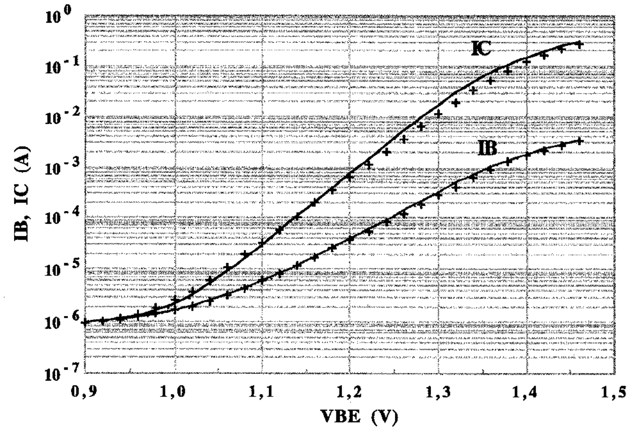

Fig. 4. Gummel curves for forward operating region ($V_{BC} = 0$ V). + measured points; — simulated.

TABLE I
Optimum Load Impedances and Load-Pull Parameters

	V_{CE0} = 3 V, I_{CE0} = 100 mA		V_{CE0} = 3 V, I_{CE0} = 230 mA		V_{CE0} = 3 V, I_{CE0} = 230 mA	
	measured	*simulated*	*measured*	*simulated*	*measured*	*simulated*
P_{in} (mW)	25	25	20	20	40	40
P_{out} (mW)	190	190	215	210	340	370
P_{ad} (mW)	165	165	195	190	300	330
PAE (%)	45.6	44.7	25.6	25.2	38	42.7
G_p (dB)	8.9	8.9	10.2	10.1	9.2	9.6
Z_L (Ω)	8.2 + j 4.1	6.6 + j 3.2	6.2 - j 0.6	5 - j 0.9	7.2 - j 1.6	6.3 - j 0.3

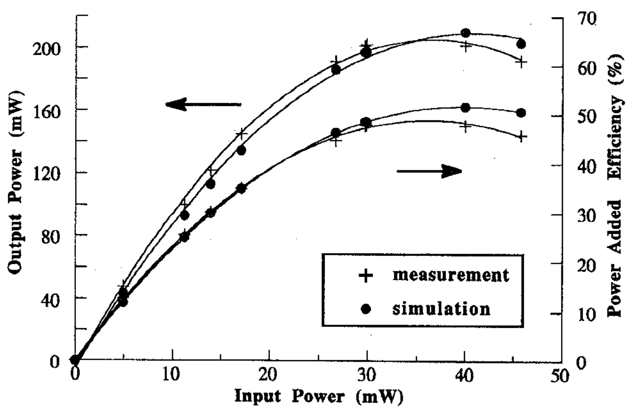

Fig. 5. Comparison of simulated and measured data $V_{CE0} = 3$ V $I_{CE0} = 100$ mA – $Z_L = (8.2 + j4.1)$ Ω.

the load impedances for maximum added power have been measured and simulated. These optimum impedances Z_L reported on Table I are very close. They change with input power level and with operating class, showing the nonlinear behavior of the HBT. All characterization parameters (input power P_{in}, output power P_{out}, added power P_{ad}, power-added efficiency PAE, operating power gain G_p) are also given in Table I. The device delivered 190, 210, and 360 mW, respectively, for the different optimum loads.

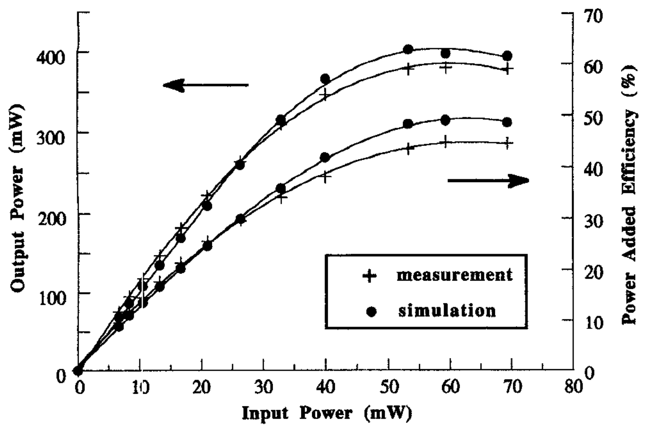

Fig. 6. Comparison of simulated and measured data $V_{CE0} = 3$ V $I_{CE0} = 230$ mA $- Z_L = (7.2 + j1.6)\ \Omega$.

HBT's model verification can also be obtained from gain compression curves [5]–[7] (the maximum output power was 15 dBm). Figs. 5 and 6 compare output power and added power efficiency versus input power level for these optimum load impedances. Good agreement is obtained between prediction by the model and measurements because maximum deviations are found to be only 0.3 dB for P_{out} and 5% for PAE in the saturation region. This result is very significant and confirms the accuracy of the proposed model in predicting the performances of the HBT. The model for the HBT was used in a design of a power amplifier for mobile communications (DCS 1800).

V. Conclusion

The comparison results between measurements and simulation of the HBT show small deviations in the locations of optimum load impedances and good agreement for power performances. This comparison is of great interest and imply that the proposed nonlinear model for the HBT is fully verified by load-pull measurements.

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