A 90% Power-Added-Efficiency GaInP/GaAs HBT for L-Band Radar and Mobile Communication Systems

A. Mallet, D. Floriot, J. P. Viaud, F. Blache, J. M. Nebus, and S. Delage

***Abstract*—A very high 90% power-added efficiency (PAE) with an output power (P_{out}) of 200 mW and a power gain of 18 dB has been achieved at 1.8 GHz with a 240-μm^2 GaInP/GaAs HBT (Thomson-CSF/LCR). The transistor (common emitter) was biased in class C mode ($I_c = 0$ mA; $V_{be} = 1$ V; $V_{ce} = 7$ V) and the load termination at the signal harmonics was optimized. First, a heterojunction bipolar transistor (HBT) nonlinear model has been extracted from pulsed I–V and pulsed S parameter measurements. A harmonic balance simulation was performed and suitable collector current/voltage waveforms were determined in order to optimize PAE. Second, a multiharmonic active load-pull system was used in order to measure and optimize the transistor efficiency. Measurement data were found to be in good agreement with simulated results. The main use of this HBT is expected to be in mobile communication systems and T/R modules for active array radars.**

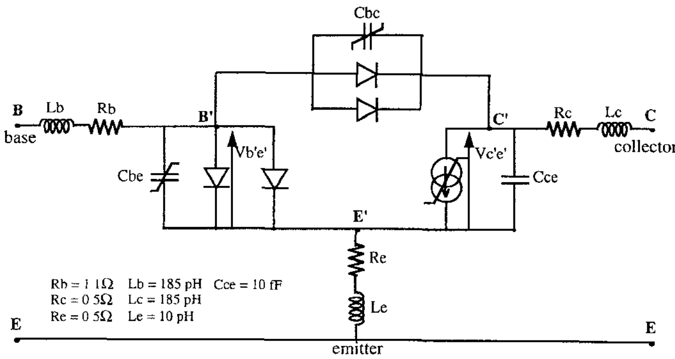

Fig. 1. HBT nonlinear model.

I. Introduction

Heterojunction bipolar transistors (HBT's) have emerged as valuable devices for microwave power amplification. Class C operation of HBT's is well suited for the design of high-efficiency power amplifiers [1]. GaAs HBT's with 84% power-added efficiency (PAE) operating in C–X band have been reported [2], [3].

Class C operation of HBT's is attractive for the following two reasons:

1) HBT's biased in class C mode remain cold under low and high RF drive.
   a) When the RF signal is absent, the transistor is obviously cold since it is turned off.
   b) It is cold under low and medium RF power levels because the dc collector current remains low.
   c) It is almost cold in large signal operation mode because power-added-efficiency increases drastically versus output RF power.
2) The small-signal gain of the transistor decreases in class C when compared to class AB or class B, thus ensuring stability at low microwave frequencies (L band).

Furthermore, harmonic tuning significantly enhances transistor efficiency. This letter presents a four-emitter finger GaInP/GaAs HBT ($4 \times 2 \times 30\,\mu m^2$) exhibiting 90% PAE at 1.8 GHz when operated in class C mode with appropriate harmonic terminations.

Manuscript received September 25, 1995.

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Publisher Item Identifier S 1051-8207(96)02064-8.

II. HBT Large-Signal Model

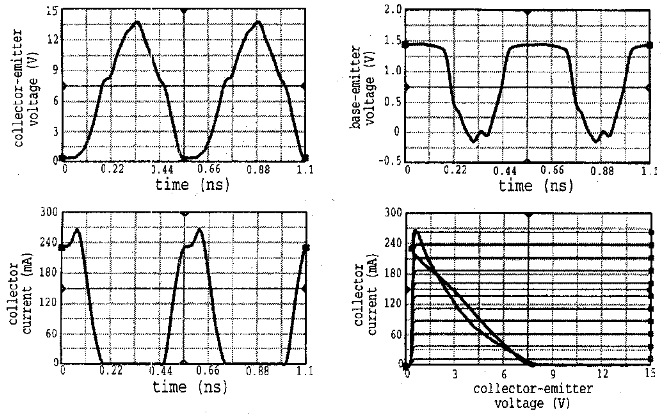
The HBT equivalent circuit model is shown in Fig. 1. The device model parameters were extracted from pulsed I–V and pulsed S parameter measurements (300-ns pulse width; 10% duty cycle) [4]–[7]. Under pulsed conditions, the thermal state of the transistor is imposed by the dc quiescent bias point.

The quiescent bias point ($V_{ce} = 7$ V, $I_c = 5$ mA) was chosen by design in order to impose a quasicold thermal state of the HBT. The associated dissipated power (35 mW) was in the same order of the dissipated power measured under large signal conditions as shown in Fig. 4.

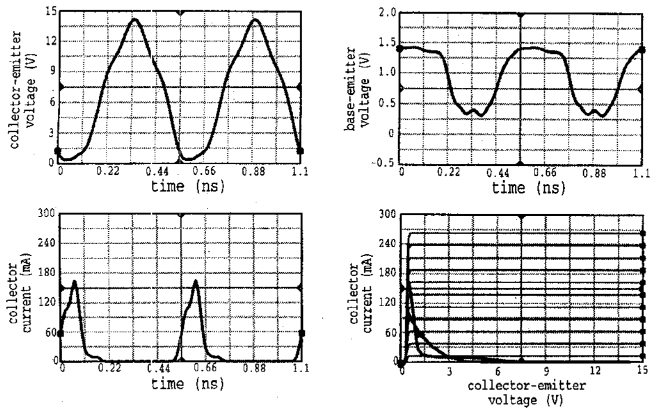
Therefore, we did not need for the purpose of our study a temperature dependent model.

III. Harmonic Balance Analysis and Load-Pull Measurements

On the one hand, an extensive analysis of voltage/current waveforms at both ports of the transistor was performed by using harmonic balance software [8]. Fig. 2(a) shows suitable waveforms for maximum added power while Fig. 2(b) shows suitable waveforms for maximum power added efficiency. Associated dynamic load-line trajectories overlaid on intrinsic I–V characteristics are given.



(a)



(b)

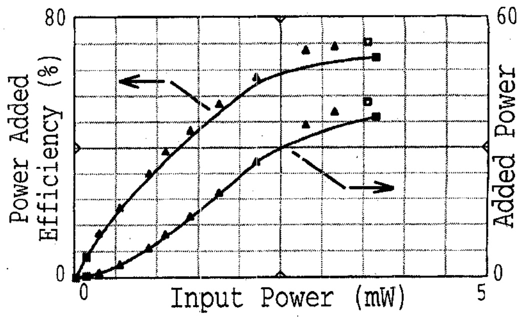
Fig. 2. (a) Time-domain waveforms and associated load-line (optimum added power) and (b) time-domain waveforms and associated load-line (optimum PAE).

On the other hand, multiharmonic load-pull measurements were performed in order to validate the simulated results [9]. Added power and PAE were optimized, respectively, by properly tuning the load termination at the signal harmonics ($f_o - 2f_o - 3f_o$). Fig. 3(a) and (b) shows added power and PAE versus input power. Fig. 4 shows the variation in the measured dc power and dissipated power with input power. The mean value of the dissipated power (35 mW) confirms the quasicold thermal state of the transistor.

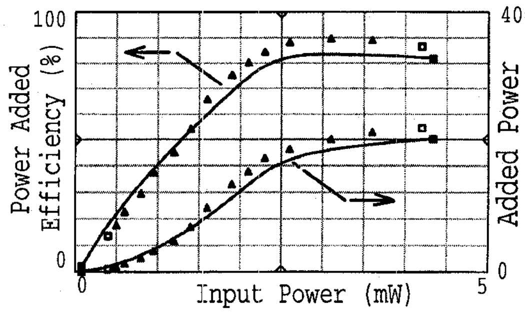
IV. Conclusion

A 240-μm^2 GaInP/GaAs HBT exhibiting 90% PAE at 1.8 GHz has been reported. The proposed operating mode (i.e., class C and suitable harmonic terminations) is very attractive since the dissipated power is low under both small signal and large signal conditions.

As a consequence, the thermal state of the transistor is "quasicold." This operating mode is particularly well suited for the design of high power and high-efficiency narrow band microwave amplifiers. Harmonic load-pull measurements were found to be in good agreement with simulated results, thus validating the robustness our HBT nonlinear model.



(a)



(b)

Fig. 3. (a) Power characteristics (optimum load impedance for added power) △ measured; —— simulated. (b) Power characteristics (optimum load impedance for PAE) △ measured; —— simulated.

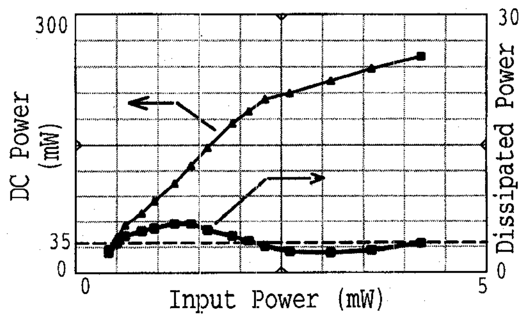


Fig. 4. Measured dc power and dissipated power versus input power (optimum load impedance for PAE) △ measured; —— simulated.

Appropriate voltage/current waveforms required at both ports of HBT's to optimize added power or PAE have also been shown.

Acknowledgment

The authors would like to express their special thanks to M. Lajugie and D. Pons (Thomson-CSF) and J. P. Villotte, R. Quere, and J. Obregon (IRCOM), who contributed to the success of this work.

References

[1] M. Khatibzadeh and B. Bayraktaroglu, "High efficiency, class B, S band power amplifier," in *IEEE MTT-S Dig.*, 1990, pp. 993–993.

[2] F. Ali, C. Aitchison, and B. Henitt, "GaAs power HBT's with 84% power-added efficiency operating in C–X band," in *European Microwave Conf.*, 1995, pp. 1023–1027.

[3] F. Ali *et al.*, "A study of class C operation of GaAs power HBT's," in *IEEE MTT-S Dig.,* 1995, pp. 721–724.
[4] S. Delage *et al.*, "Power GAINP/GaAs HBT MMIC's," in *European Microwave Conf.,* 1994, pp. 1143–1148.
[5] J. P. Teyssier *et al.*, "Fully integrated nonlinear modeling and characterization system of microwave transistors with on-wafer pulsed measurements," in *IEEE MTT-S Dig.,* 1995, pp. 1033–1036.
[6] J. P. Viaud *et al.*, "Nonlinear RF characterization and modeling of heterojunction bipolar transistors under pulsed conditions," in *European Microwave Conf.,* 1994, pp. 1610–1615.
[7] I. Getreu, *Modeling the Bipolar Transistor.* Beaverton, OR: Elsevier, Tektronix, 1976.
[8] C. Duvanaud *et al.*, "High efficiency class F GaAs FET amplifiers operating with very low bias voltages for use in mobile telephones at 1.75 GHz," *IEEE Microwave Guided Wave Lett.,* vol. 3, no 8, pp. 268–270, Aug. 1993.
[9] F. Blache *et al.*, "A novel computerized multiharmonic active load-pull system for the optimization of high efficiency operating classes in power transistors," in *IEEE MTT-S Dig.,* 1995, pp. 1037–1040.