

P11-7

## A Genetic Algorithm Approach to InGaP/GaAs HBT Parameters Extraction and RF Characterization

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### 1. Introduction

Due to heterojunction bipolar transistors (HBTs) have good carrier transport properties, they operated at high frequency with high power output have been of great interests for RF power amplifier, wireless communication, and high-speed applications [1-3]. One of the most favorite properties of the HBT devices is the unusually high linearity at relatively low levels of DC power. Various approaches have been proposed to calculate the intermodulation distortion and two-tone characteristics for a HBT device both in time and in frequency domain [1-5]. However, the equivalent circuit model as well as its parameters extraction and optimization for HBTs' both DC characteristics and RF property are typically accomplished in either of two fundamental approaches: numerical optimization or direct parameter extraction [3,4]. In this paper, we present a novel computational intelligent method for HBT parameters extraction, RF OIP3 and two-tone properties simulation. This approach is based on the genetic algorithm (GA), the waveform relaxation (WR) method, and the monotone iterative (MI) method [5-7]. Compared with conventional approaches, the major features of the method include: (1) converges fast and globally, (2) less sensitive in parameter variations, (3) automatic extraction, and (4) providing an alternative for industrial applications.

### 2. Modeling and Simulation Methodology

In modeling of a HBT under DC and AC operations; first of all, with the equivalent circuit of the Gummel-Poon model [5], the governing nodal equations of the HBT circuit (see Fig. 1) are formulated and solved with the WR and MI methods to obtain the DC and AC characteristics [5]. Second, to extract and optimize the model parameters (more than 30 parameters) for a set of  $I_C$ - $V_{CE}$  curves automatically, we develop a family multi-objective GA simulation technique to evolve the parameters. The approaches enable us to extract a set of I-V family curves at the same time. The errors of extracted parameters are less than 0.5% for all I-V curves. The evolutionary processes will be terminated when all the  $I_C$ - $V_{CE}$  curves converge to the measured data. The extracted optimal model parameters are directly applied for the RF HBT simulation in time domain [5]. The computed time domain data is analyzed with the fast Fourier transformation

(FFT) to obtain the necessary information. We investigate the two-tone properties, third-order intermodulation (IM3), and output third-order intercept point (OIP3). Results are also compared to HSPICE and measured to show the robustness and accuracy of the method.

### 3. Results and Discussion

Fig. 2 is an evolutionary process for an  $I_C$ - $V_{CE}$  curve of the simulated HBT. It confirms the automatic extraction efficiency. Fig. 3 presents the fitness convergence of the GA method. The  $W$ ,  $T$ , and  $G$  in the fitness are the weighted, target, and evolved functions, respectively. Fig. 4 shows the simulated and measured  $I_C$ - $V_{CE}$  curves. A set of model parameters are extracted automatically for all I-V curves. The comparison also shows the accuracy of the method. Figs. 5 and 6 are our and the HSPICE RF results, respectively. In contrary to the unstable output of HSPICE; our simulator presents the robustness in the large signal analysis. With the time domain results, we calculate the spectrums of the output power by the FFT. Figs. 7 and 8 are the corresponding spectra. We find the IM3 products at  $2f_1-f_2$  and  $2f_2-f_1$  are clearly observed in Fig. 7. However, as shown in Fig. 8, it is difficult to identify the two IM3 products. Fig. 9 is the output powers at the fundamental frequencies and the two IM3s. The lines' slopes are 0.99726 and 3.00606 and closed to theoretical values 1 and 3. The results of the HI-IM3 and LO-IM3 are closed and have the same value in the OIP3 calculation at 36.9 dBm. For the same calculation, the slopes computed with the HSPICE were 0.99 and -0.29. We also have found these two methods have good accuracy for DC analysis; however, the HSPICE simulator does not suit for large signal RF characterization.

### 4. Conclusions

In conclusion, based on the family multi-objective GA simulation approach, a novel automatic parameters extraction technique for RF HBT simulation is proposed. With this method, the extracted model parameters have been used for the analyses of the HBT intermodulation distortion and the two-tone characteristics. Simulation and characterization results for a realistic  $\text{In}_{0.49}\text{Ga}_{0.51}\text{P}/\text{GaAs}$  HBT with  $20 \mu\text{m}^2$  emitter area are presented to show the accuracy and efficiency of the method.

## Acknowledgments

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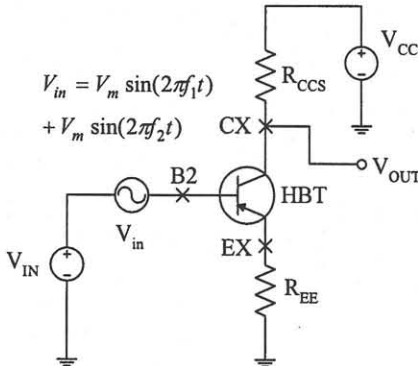


Fig. 1. The HBT circuit for model parameters extraction and high frequency characterization.

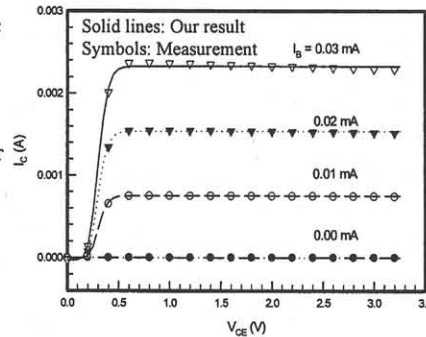


Fig. 4. The  $I_C$ - $V_{CE}$  family curves of the InGaP HBT. The automatic parameters extraction technique is used in the simulation.

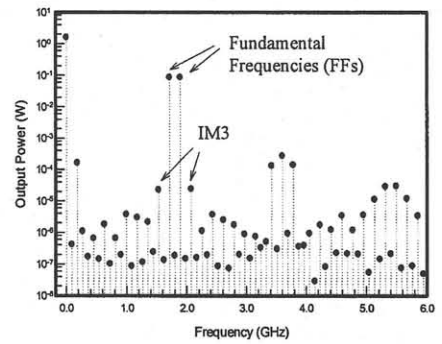


Fig. 7. The output power,  $P_{OUT}$ , spectrum. The computed DC/AC data and extracted parameters are applied for the calculation.

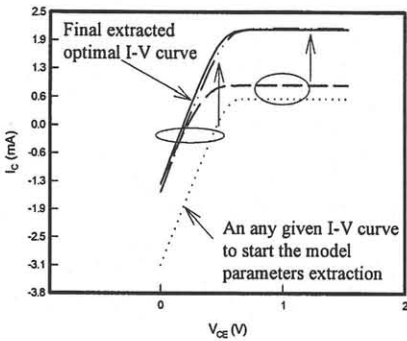


Fig. 2. An illustration for the evolutionary process. The dot line is an arbitrary curve and the solid line is the final result.

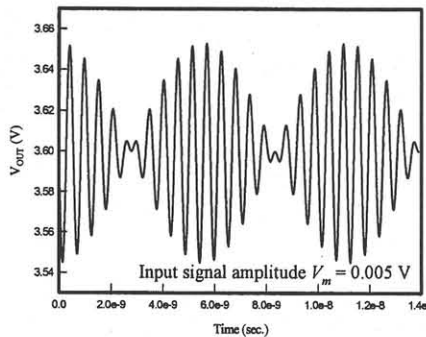


Fig. 5. Our time domain result  $V_{out}$ . More than 25 periods are directly calculated in time domain with the input two-tone excitations.

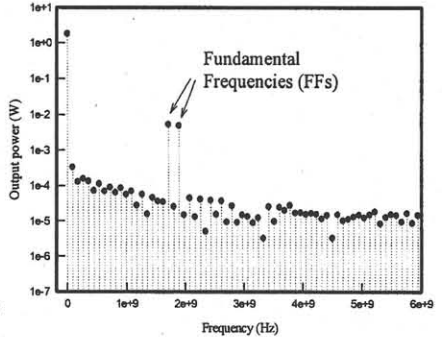


Fig. 8. The spectrum of the output power with the HSPICE time domain data.

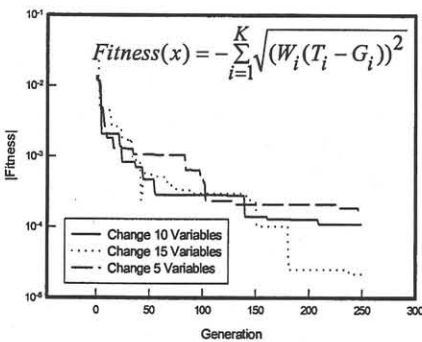


Fig. 3. The fitness convergence behavior vs. generation of the evolution.

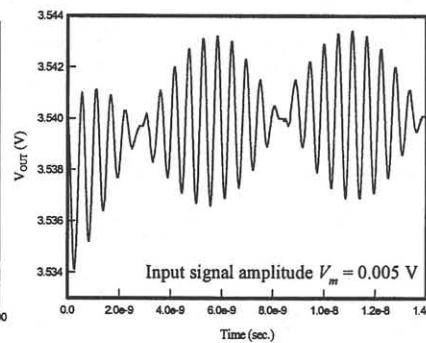


Fig. 6. The HSPICE time domain result of the output voltage. We found the unstable  $V_{out}$  at the beginning of calculation.

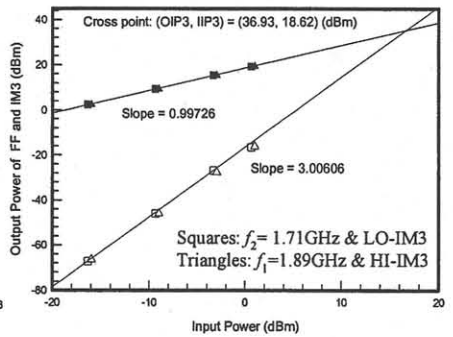


Fig. 9. A plot of the output power of FFs (black fill-in) and IM3s (white fill-in) as a function of the input power.