Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.1064-1065

I-8-2

Extraction of an Empirical Temperature-Dependence InGaP/GaAs HBT Large-Signal Model

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I.Introduction

Heterojuntion Bipolar Transistors（HBT） has used widespread for wireless communication due to excellent power performance. The complex circuit structures and modulation scheme are employed in the transmitter architecture. Accurate device modeling is necessary for circuit designers to predict results which the circuits operated. In this report, we carried out an InGaP/GaAs HBT modeling, which can accurately predict I-V,self-heating, S-parameters, microwave power, linearity, and high frequency noise, and temperature effect from 85^{o}C to -40^{o}C.

II.Parameter Extraction Procedure

The InGaP/GaAs HBT used in this study owns a single base double emitter and the total emitter area is 240μm^2. f_t is 40GHz and f_{max} is 44GHz. Fig.1 shows the large-signal model equivalent circuit model of HBT. Based on Gummel- Poon model (GP), forward Gummel plot and reverse Gummel *I-V* measurement, the relative parameters of dc characteristic at various bias points under different temperatures can be extracted[1]. Moreover, the C_{BE}, C_{BC}, R_E, R_B, and R_C can be extracted in the forward and reverse region by using R_E flyback and R_C flyback measurement [1]. Devices transit time is extracted by using the s-parameter measurement of common emitter operation [2]. In order to show the temperature effects of GP model, the large-signal equivalent circuit is added extra thermal network. Utilized the extracted GP parameters versus temperatures, the temperature relative parameter can be described as Eq. (1) and (2). The device was measured at -40^{o}C,25^{o}C, and 85^{o}C in the vacuum environment Eqs. (1) and (2), where the parameter T_n is in Kelvin, and X_R is relative to the doping density beneath the metal [2]. From the extracted results, R_B and R_C are increased with the temperature, while the R_E goes to the opposite way. The temperature dependent saturation current fitting function is show in Eq. (2), where X_{IS} is parameter versus temperature, and EA is 1.42eV as the bandgap of GaAs. Therefore, Eqs. (1) and (2) can fully describe the temperature effects in this model.

Additionally, self-heating effect is also important for HBT, this effect will cause the current collapse under high current operation. We used the CW mode *I-V* measurement at various temperatures to directly extract the device thermal resistance due to linearity relativity between power dissipation and temperatures. The thermal resistance was obtained by Eq. (3). Eq. (3) expresses the devices self-heating effect related to power dissipation, and the thermal resistance, θ as where T_{Amb} is substrate-plate temperature [3]. In this study, the extracted junction temperature is 511^{o}C/W.

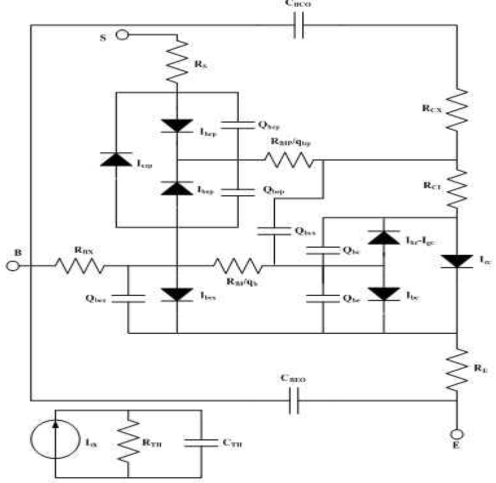

Fig. 1 large-signal equivalent circuit

$$R(T_2) = R(T_1)\left(\frac{T_2}{T_1}\right)^{X_R} \quad (1)$$

$$I_S(T_2) = I_S(T_1)\left\{ r_T^{X_{IS}} \exp\left[-EA\left(\frac{1-T_1/T_2}{V_t}\right)\right]\right\}^{1/n_f} \quad (2)$$

$$T_j - T_{Amb} = \theta P_{diss} \quad (3)$$

Maury load-pull system was employed to measure power characteristic of HBT devices. Figs. (2) and (3) illustrate the the HBT device microwave power performance at the V_{CE} of 3 V and I_B of 70 μA at 2.4 GHz where a load-pull system evolution at -40^{o}C and 85^{o}C, respectively. The output power (Pout), power gain and power added efficiency (PAE) versus the input power (Pin) were obtained, and the both measured and simulated results can reach a good agreement. Efficiency decays about 4% with increasing temperature from -40°C to 85°C, Because the self-heating is more serious under high temperature.

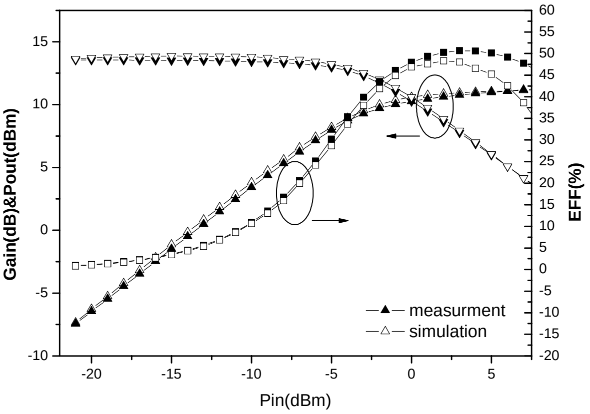

Fig. 2. Gain, Pout and PAE at 2.4GHz, -40°C with V_C=3V, I_B=70μA biasing, optimal load is: 0.064∠19.3°.

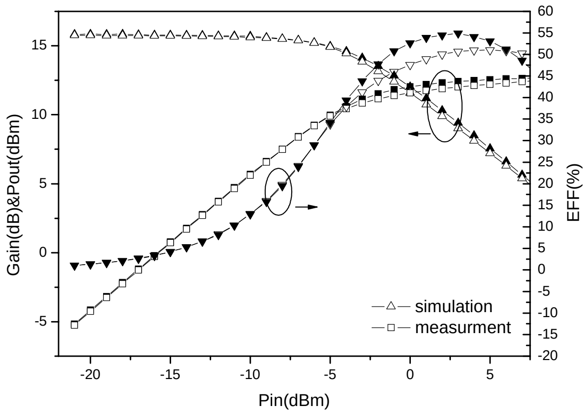

Fig. 3. Gain, Pout and PAE at 2.4GHz, 85°Cwith V_C=3V, I_B=70μA biasing, optimal load is: 0.089∠47°.

On the other hand, the noise parameters are also employed into this HBT model to predict the high frequency noise characteristics. The HBT noise mainly is consisted of shot noise, flicker noise, burst noise, and thermal noise), so we defined two dominate noise current sources in B-E junction and C-E junction Eqs. (4) and (5) [4]. Additionally, defined the four noise source represent the noisy behavior of access resistance R_{BX}, R_{BI}, R_E, and total R_C (R_{CX}+R_{CI}) and simply given by eq. (6)

$$\overline{i_b^2} = 2qI_b\Delta f \tag{4}$$

$$\overline{i_c^2} = 2qI_c\Delta f \tag{5}$$

$$\overline{e_i^2} = 4KTR_i\Delta f, i = BX, BI, C, E \tag{6}$$

The large-signal model can be carried out by symbolically Defined Device (SDD) provided by Agilent™ in our platform. Figs. (4) and (5) demonstrated the model simulated and measured microwave noise characteristics, where there is a good agreement between simulation and measurement .

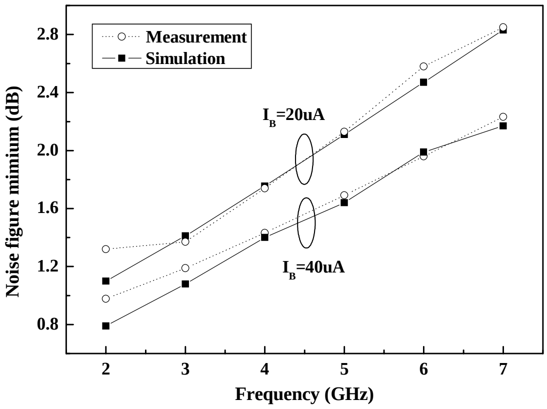

Fig. 4. Noise figure minimum at V_C=3V versus operational frequencies.

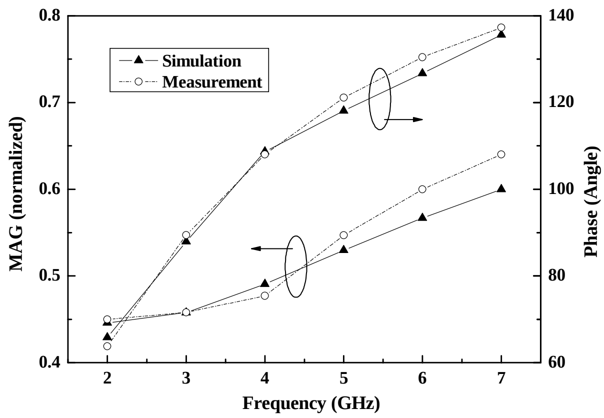

Fig. 5. Magnitude and phase in noise equation expression.

III. CONCULSIONS

In this report, we presented a large-signal HBT model, where the microwave noise and temperature effects are included.

ACKNOWLEDGMENT

The authors gratefully acknowledge Microwave and Optical Semiconductor Taiwan CO.,LTD（MOST）to provide the InGaP/GaAs HBT deices.

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