IMPLEMENTATION OF AN HBT MODEL

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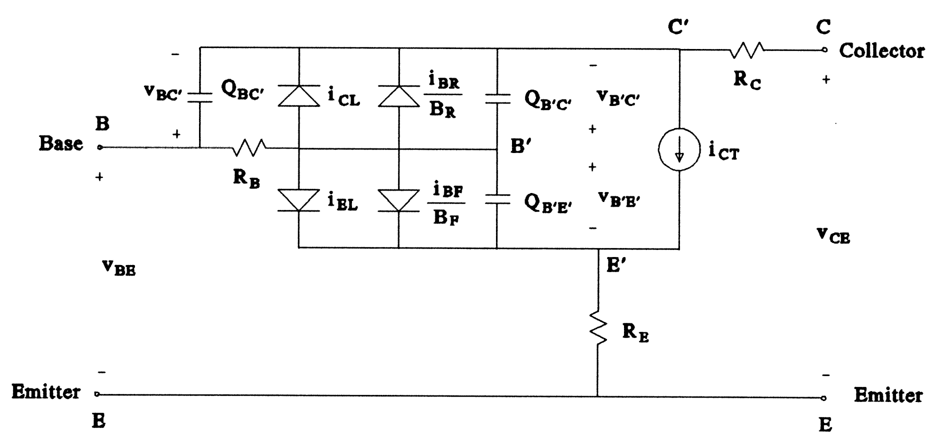
I. INTRODUCTION

A heterojunction bipolar transistor (HBT) model is implemented in HarPE [1] and OSA90/hope [2]. The HBT model is a modification of our BJT model by introducing the temperature effect following the thermal-electrical model of HBTs presented in [3]. A thermal circuit [4] is used to evaluate the device temperature and is integrated into DC, small-signal and large-signal harmonic balance (HB) simulations.

We performed DC, small-signal and large-signal simulations with this HBT model using the parameter values given in [5]. Very similar results to those presented in [5] are observed.

II. MODEL EQUATIONS

The HBT model is implemented according to the model equations given in [3] and [6]. The intrinsic circuit of the model is shown in Fig. 1.



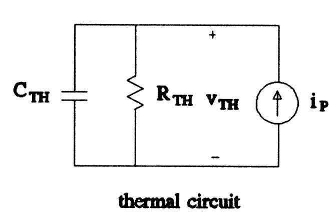


Fig. 1 The intrinsic equivalent circuit of the HBT model.

The model equations for computing the nonlinear currents are as follows.

$$i_{CL} = I_{SC}\left[\exp\left(\frac{v_{B'C'}}{N_C V_T}\right) - 1\right] \tag{1}$$

$$i_{EL} = I_{SE}\left[\exp\left(\frac{v_{B'E'}}{N_E V_T}\right) - 1\right] \tag{2}$$

$$i_{BR} = I_S\left[\exp\left(\frac{v_{B'C'}}{N_R V_T}\right) - 1\right] \tag{3}$$

$$i_{BF} = I_S\left[\exp\left(\frac{v_{B'E'}}{N_F V_T}\right) - 1\right] \tag{4}$$

$$i_{CT} = \frac{i_{BF} - i_{BR}}{K_{qb}} \tag{5}$$

$$i_P = i_B v_{BE} + i_C v_{CE} \tag{6}$$

where

$$V_T = \frac{kT}{q} \tag{7}$$

$$T = T_0 + v_{TH} \tag{8}$$

$$I_S = I_{S0}\left(\frac{T}{T_0}\right)^{X_{TI}} \exp\left(\frac{E_G}{kT_0} - \frac{E_G}{kT}\right) \tag{9}$$

$$I_{SE} = I_{SE0}\frac{B_{F0}}{B_F}\left(\frac{I_S}{I_{S0}}\right)^{\frac{1}{N_E}} \tag{10}$$

$$I_{SC} = I_{SC0}\frac{B_{F0}}{B_F}\left(\frac{I_S}{I_{S0}}\right)^{\frac{1}{N_C}} \tag{11}$$

$$B_F = B_{F0}\left(\frac{T}{T_0}\right)^P \exp\left(\frac{E_{INF}}{kT} - \frac{E_{INF}}{kT_0}\right) \tag{12}$$

$$K_{qb} = \frac{K_{q1}(1 + \sqrt{1 + 4K_{q2}}\ )}{2} \tag{13}$$

$$K_{q1} = \frac{1}{1 - \dfrac{v_{B'C'}}{V_{AF}} - \dfrac{v_{B'E'}}{V_{AR}}} \tag{14}$$

$$K_{q2} = \frac{i_{BF}}{I_{KF}} + \frac{i_{BR}}{I_{KR}} \tag{15}$$

k is the Boltzman constant, q the electron charge, T_0 the room temperature, v_{TH} the temperature increment, and N_E, N_C, N_R, N_F, E_G, E_{INF}, X_{TI}, P, I_{S0}, I_{SE0}, I_{SC0}, B_{F0}, V_{AF}, V_{AR}, I_{KF} and I_{KR} are model parameters.

The model equations for computing the nonlinear charges are as follows.

$$Q_{B'E'} = Q(v_{B'E'}, V_{JE}, M_{JE}, C_{JE}, F_C) + T_F i_{BF} \tag{16}$$

$$Q_{B'C'} = Q(v_{B'C'}, V_{JC}, M_{JC}, C_{JC}, F_C) + T_R i_{BR} \tag{17}$$

$$Q_{BC'} = (1 - X_{CJC})Q(v_{BC'}, V_{JC}, M_{JC}, C_{JC}, F_C) \tag{18}$$

where

$$Q(v, v_j, m_j, c_j, f_c) = \begin{cases} -\dfrac{c_j v_j}{1 - m_j}\left[\left(1 - \dfrac{v}{v_j}\right)^{(1 - m_j)} - 1\right] & \text{for } v \le f_c v_j \\ -\dfrac{c_j v_j}{1 - m_j}\left[(1 - f_c)^{(1 - m_j)} - 1\right] + \dfrac{c_j}{(1 - f_c)^{(1 + m_j)}} \cdot & \\ \left(\left[1 - f_c(1 + m_j)\right](v - f_c v_j) + \dfrac{m_j}{2 v_j}\left[v^2 - (f_c v_j)^2\right]\right) & \text{otherwise} \end{cases} \tag{19}$$

V_{JE}, M_{JE}, C_{JE}, F_C, V_{JC}, M_{JC}, C_{JC}, T_F, T_R and X_{CJC} are model parameters.

In addition to the model parameters described above there are another six parameters including R_B, R_C, R_E, R_{TH}, C_{TH} and B_R, as shown in Fig. 1, to complete the model.

The thermal circuit shown in Fig. 1 is used to calculate the temperature increment represented by v_{TH}. v_{TH} is considered as a state variable and integrated into DC, small-signal and large-signal HB simulations.

III. MODEL RESPONSES

The HBT model implemented is a large-signal model. It can be used for DC, small-signal and large-signal analysis.

We carried out DC, small-signal and large-signal simulations using the parameter values given in [5]. The extrinsic circuit of the model is shown in Fig. 2. The parameter values are listed in Table I. The DC characteristics, small-signal S parameters and the output power versus input power are plotted in Fig. 3, 4 and 5, respectively. The results are similar to those presented in [5].

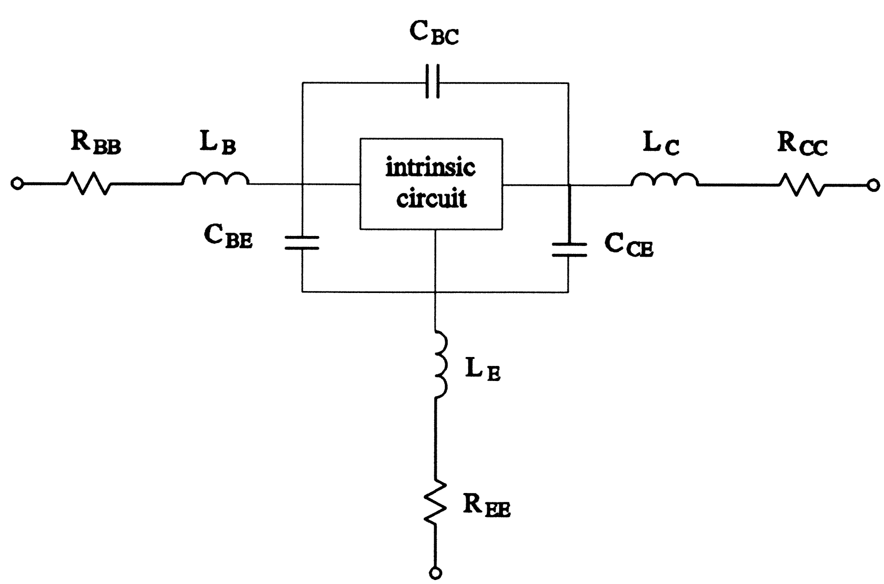


Fig. 2 The extrinsic circuit of the HBT model.

TABLE I
PARAMETER VALUES FOR HBT MODEL

Intrinsic		Extrinsic	
I_{SC0}(A)	3.2573E-14	L_B(nH)	0.0623
I_{SE0}(A)	1.2017E-18	L_C(nH)	0.054
I_{S0}(A)	2.0224E-22	L_E(nH)	0.0023
N_E	1.5741	R_{BB}(Ω)	0.1*
N_C	1.7664	R_{CC}(Ω)	0.1*
N_R	1.1204	R_{EE}(Ω)	0.1*
N_F	1.1473	C_{BE}(pF)	0.1339
R_B(Ω)	1.6952	C_{CE}(pF)	0.0974
R_E(Ω)	1.0796	C_{BC}(pF)	0.1333
R_C(Ω)	1.1884		
B_{F0}	46.39		
B_R	0.168		
X_{TI}	6.4961		
P	-1.2252		
E_G	1.4162E-19		
E_{INF}	0.0545E-19		
R_{TH}(°/W)	182		
C_{TH}	1E-6/R_{TH}		
C_{JE}(pF)	0.4002		
V_{JE}(V)	2.0452		
M_{JE}	0.3333		
C_{JC}(pF)	0.197		
V_{JC}(V)	1.524		
M_{JC}	0.5		
T_F(pS)	8.2152		

* Parameter values are assumed for these parameters.

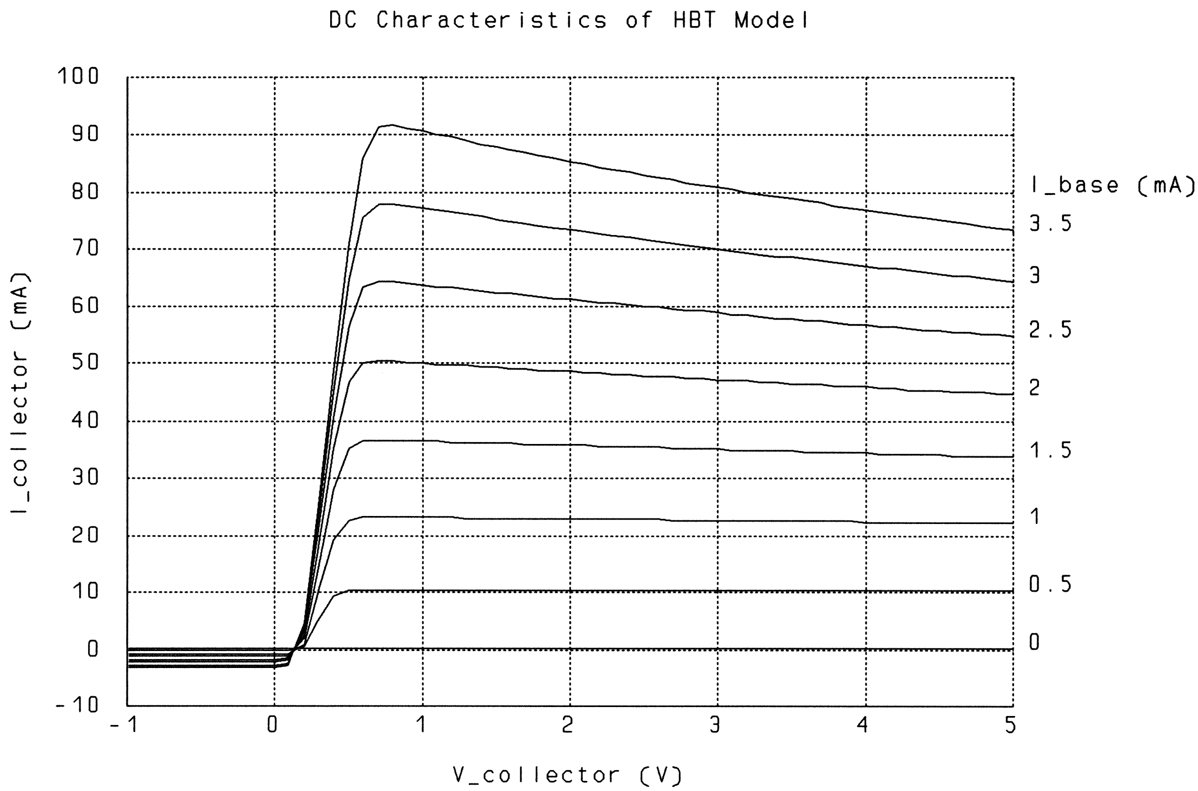
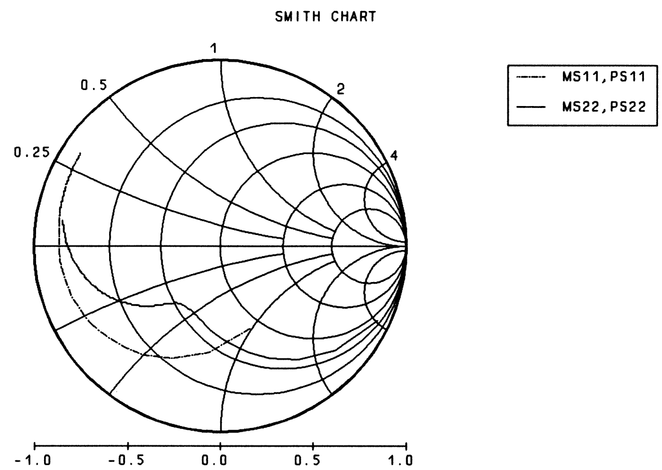
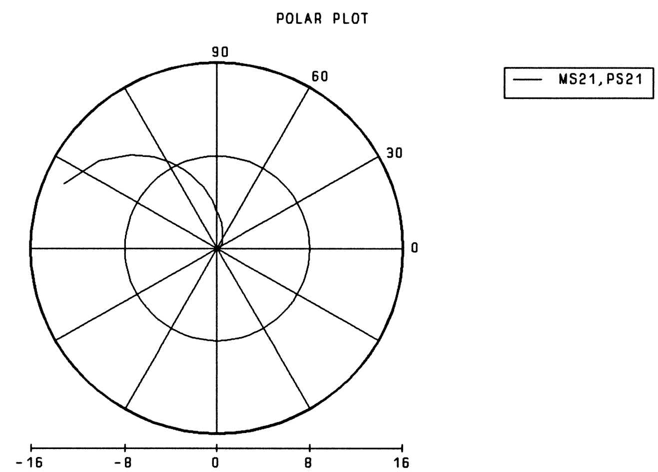


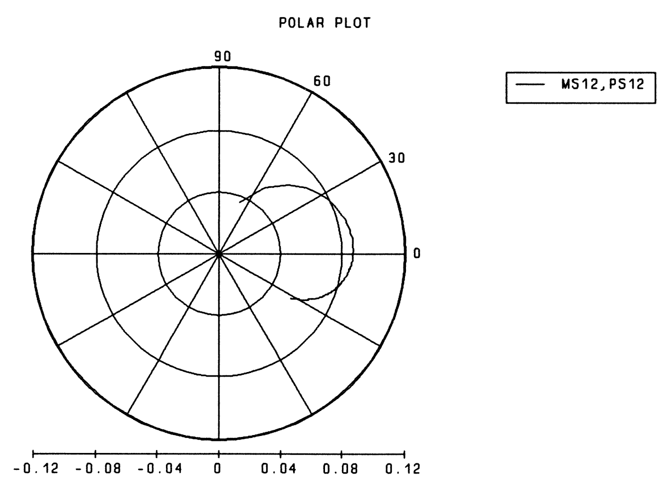
Fig. 3 DC characteristics of the HBT model.



(a)



(b)



(c)

Fig. 4 S parameters at bias point: $I_B = 0.5$ mA and $V_C = 2.0$ V, (a) S_{11} and S_{22}, (b) S_{21} and (c) S_{12}.

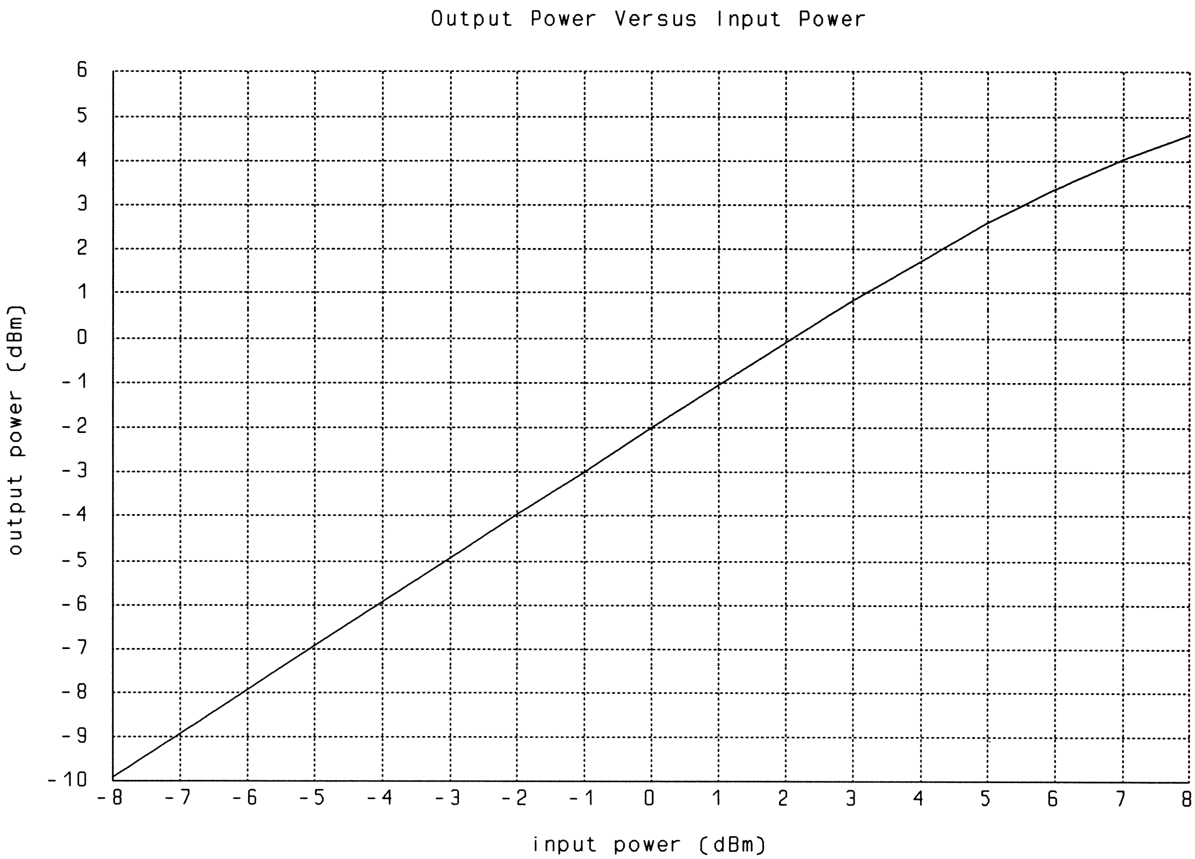


Fig. 5 Output power versus input power at bias: I_B = 0.6 mA and V_C = 5 V.

VI. CONCLUSIONS

A temperature dependent HBT model has been implemented in HarPE and OSA90/hope. Promising results have been observed. The model can be used for DC, small-signal and large-signal simulations. A further model verification should be carried out if we have measurements on HBTs.

V. REFERENCES

[1] *HarPE*™, Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, 1994.

[2] *OSA90/hope*™, Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, 1994.

[3] H. Wang, C. Algani, A. Konczykowska and W. Zuberek, "Temperature dependence of DC currents in HBT," *IEEE MTT-S Int. Microwave Symp. Digest* (Albuquerque, NM), 1992, pp. 731-734.

[4] P.C. Grossman and J. Choma, "Large signal modeling of HBT's including self-heating and transit time effects," *IEEE Trans. Microwave Theory Tech.*, vol. 40, 1992, pp. 449-464.

[5] H. Do-Ky, T. Laneve, S. Sychaleun, M. Stubbs and J.S. Wight, "Linear and non-linear modelling verification of power HBTs," 1994.

[6] P. Antognetti and G. Massobrio, *Semiconductor Device Modeling with SPICE*, New York: McGraw-Hill, 1988.