Parameter Extraction and Evaluation of the Bias Dependence of T_f, for the VBIC Model used on a GaAs HBT.

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ABSTRACT

This paper presents a practical method of extracting the bias dependent parameters of the forward transit time T_f, implemented in the VBIC model used on a GaAs HBT. The work should be of great value for the circuit designers, who want to have an easy practical way of including good model parameters from a few simple measurements. This paper includes an evaluation of the implemented bias dependence of T_f in the VBIC model. The VBIC model is extracted from measurements on a GaAs HBT made by Caswell Technology. The model shows good agreement with these measurements.

I. INTRODUCTION

In the last few years, many papers describing new models for the Hetero-junction Bipolar Transistor (HBT) have been published. The main drawback is that the models are not implemented in commercial simulator software like Agilent ADS. One of the exceptions is the VBIC model developed by McAndrew et al (1). The VBIC model is discussed by Najm (2). In order to use this model in a practical circuit, one must extract values for many of the numerous (total of 86 in ADS) parameters of the model. The method shown by Olavsbråten (3) is used to extract the main model parameters. The present paper describes a practical addition to the method by Olavsbråten (3) to find the *bias dependence* of the forward transit time T_f, using only a few simple measurements.

II. PARAMETER EXTRACTION

The VBIC model includes effects like self-heating, non-ideal current-sources, and distributed base- and collector modeling effects. This model also includes a parasitic substrate transistor, which may be important in silicon technology, but can be neglected in GaAs design due to low substrate losses and high isolation. The symbols used for the model parameters are all taken from the model implementation in Agilent ADS. The parameter extraction is done from measurements of a two-finger InGaP/GaAs HBT, manufactured by Caswell Technology.

A. PARAMETER EXTRACTION OF THE MODEL WITH CONSTANT T_F.

The main parameters are extracted using the method described by Olavsbråten (3). This method does not include the bias dependence of T_f. These results for the constant T_f are used to compare results with the present bias dependent T_f model. The thermal resistance in the model is calculated form the method given by Marsh (4).

B. BIAS DEPENDENCE OF T_F.

In the VBIC model the bias dependence of T_f is described by five parameters (TF, VTF, ITF, XTF, QTF). Equation 1 shows the bias dependence of T_f. This equation has five unknowns. Extraction of these parameters needs at least s-parameter measurements for five different biases. The biases should be chosen to cover the part of the IV-diagram for which the model is to be used. This may be the four corners and the center in the chosen area of the IV-diagram.

$$T_f = \text{TF}\left(1 + \text{QTF} \cdot Q_1\right)\left(1 + \text{XTF}\left(\frac{I_{Fi}}{I_{Fi} + \text{ITF}}\right)^2 e^{\frac{V_{BCi}}{1.44 \cdot \text{VTF}}}\right) \tag{1}$$

Where

Q_1 – change of base charge due to base width mod.	I_{Fi} – ideal forward current.
V_{BCi} – base-collector voltage.	TF – bias independent constant.
VTF – coefficient for the base-collector voltage V_{BCi}.	ITF – coefficient for the ideal forward current I_{Fi}.
XTF – coefficient of voltage and current dependence.	QTF – coefficient for the base width modulation.

There are two practical ways of finding these parameters depending on which software tools that are available.

Method 1: Set XTF=QTF=0, i.e. no bias dependence of T_f. Use a circuit simulator to find the optimized value of T_f for each bias point. This gives a set of values for T_f. Find for each bias points the corresponding V_{BCi} and I_{Fi} from the equations for the VBIC model (public available). It is quite difficult to calculate Q_1 by hand, so this method can only be used if forward and reverse Early voltages (V_{ef} and V_{er}) are large. This is often the case in GaAs HBT, and QTF can be set to zero. Then use Equation 1 and the set of values for T_f to calculate the values of TF, VTF, ITF and XTF. This calculation can be done in MathWorks MATLAB or similar software.

Method 2: This method can be used to find all five parameters. It requires a circuit simulator that have the capability to simulate and optimize a circuit with multiple biases and select different measured s-parameter files for each bias. Agilent ADS is such a simulator. By setting up a global s-parameter optimization for all the bias points, it is possible to optimize all five parameters simultaneously.
The base width modulation parameter QTF can be omitted if the forward and reverse Early voltages (V_{ef} and V_{er}) are large.

III. RESULTS

The optimum (correct) values of T_f are found by finding one value of T_f for each bias point (as in the first part of *Method 1*). These values are shown in Table 1 as a reference.
Using *Method 2*, the optimized values of the bias dependent variables (TF, VTF, ITF, and XTF) were found (QTF was omitted). These values are shown in Table 2. To evaluate these optimized values, Equation 1 was used to estimate the equivalent T_f value at different biases. The optimized equivalent values of T_f are shown in Table 1.
From the parameter extraction method given by Olavsbråten (3), used on the same measurements and bias points as in this paper, an optimized constant value of T_f was found (VTF=ITF=XTF=0). This value is also shown in Table 1.
Evaluation of the bias dependence of T_f is also done by comparing the s-parameters of the model with and without bias dependence of T_f, to the s-parameter measurements. This comparison is done for each measured bias point. Table 3 shows the average deviation, from the measurements, of all four s-parameters of the model with and without bias dependence of T_f. The average deviation is measured in the frequency range from 1 GHz to 40 GHz.
The overall average results from Table 3 shows a considerable decrease of the deviation of $|S21|$. There is also a decrease of the deviation of $|S22|$ and $\angle S22$. The other s-parameters show only minor changes. The bias points with the highest decrease in deviation are highlighted in Table 3.
Two bias points were chosen to illustrate the results from Table 3. The bias points were chosen close to the ends of a possible load line for a class A amplifier. Figure 1 show the s-parameter comparison for the bias point V_{CE}=2V and I_C=40mA. Figure 2 show the s-parameter comparison for the bias point V_{CE}=5V and I_C=4mA. In Figure 1 and Figure 2, the model with and without bias dependent T_f is compared to the measurements.

IV. CONCLUSION

A parameter extraction method for the VBIC model has been applied to an InGaP/GaAs HBT. The model fits the measured data quite well. Two methods for extracting the bias dependence of T_f have been presented. By including the bias dependence of T_f, the overall average deviations from the measurements are reduced. This is especially the case for the magnitude of S21. This is shown in Table 3, Figure 1 and Figure 2. The implementation of Equation 1, which gives the bias dependence of T_f, results in more accurate values of T_f, as seen in Table 1. But Equation 1 still gives some deviation from the correct values. An implementation of a more complex equation may result in even more accurate values. Overall, compared to the results with a constant T_f, the VBIC model with the bias dependence of T_f gives a more accurate result for a larger bias range.

ACKNOWLEDGEMENT

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TABLE 1: Different Values of T_f for Different Biases.

Vce	2 V				3 V				5 V			
Ic	4 mA	8 mA	20 mA	40 mA	4 mA	8 mA	20 mA	40 mA	4 mA	8 mA	20 mA	40 mA
Optimal T_f (ps)	6.63	5.37	3.58	1.71	7.21	6.05	4.45	2.30	8.44	7.22	5.68	4.14
Optimized equivalent T_f (ps)	7.92	7.23	5.75	4.55	8.00	7.42	6.18	5.19	8.12	7.71	6.85	6.17
Optimized Constant T_f (ps)	5.705											

TABLE 2: Extracted Values for Bias Dependence Of T_f.

	TF	VTF	ITF	XTF
Dependent T_f	$8.45 \cdot 10^{-12}$	3.92	0.0100	-0.795

TABLE 3:

The Average Deviation from the Measured S-Parameters for the Model with And Without Bias Dependence of T_f.

Bias V_{ce}/I_c	Bias Dep.	|S11|	∠S11 °	|S21|	∠S21 °	|S12|	∠S12 °	|S22|	∠S22 °
2V 4mA	With	0,026	2,5	0,103	8,1	0,020	12,8	0,034	11,5
	Without	0,017	2,7	0,058	9,8	0,014	10,3	0,025	5,8
2V 8mA	With	0,011	2,8	0,080	6,3	0,011	10,4	0,019	15,6
	Without	0,010	2,8	0,073	6,6	0,010	9,7	0,016	12,7
2V 20mA	With	0,017	5,5	**0,085**	7,3	0,011	2,8	0,024	**4,2**
	Without	0,007	3,2	**0,310**	4,0	0,008	5,6	0,013	**19,9**
2V 40mA	With	0,022	7,6	**0,143**	4,4	0,020	2,4	0,025	**5,1**
	Without	0,012	3,0	**0,792**	2,2	0,015	3,1	0,016	**37,2**
3V 4mA	With	0,017	2,3	0,079	11,4	0,015	12,2	0,035	4,9
	Without	0,017	3,5	0,110	13,5	0,008	8,1	0,044	4,7
3V 8mA	With	0,012	3,0	0,055	9,8	0,008	8,9	0,030	4,9
	Without	0,009	3,5	0,023	10,7	0,006	7,2	0,030	4,3
3V 20mA	With	0,014	5,7	0,089	9,9	0,014	2,4	0,036	10,6
	Without	0,008	4,1	0,197	8,5	0,012	3,3	0,025	5,4
3V 40mA	With	0,022	7,5	**0,123**	5,2	0,018	1,8	0,032	3,8
	Without	0,011	3,7	**0,665**	2,4	0,017	2,0	0,038	9,9
5V 4mA	With	0,030	2,6	**0,040**	16,9	0,008	9,2	**0,051**	6,9
	Without	0,019	5,5	**0,224**	19,3	0,005	5,1	**0,108**	11,3
5V 8mA	With	0,014	3,7	**0,017**	15,0	0,006	6,3	0,051	8,3
	Without	0,008	5,3	**0,172**	16,7	0,009	3,7	0,099	12,7
5V 20mA	With	0,009	5,7	0,086	13,7	0,014	1,8	0,064	11,8
	Without	0,010	5,6	0,074	14,2	0,015	1,8	0,088	14,2
5V 40mA	With	0,012	7,2	0,129	8,7	0,016	1,5	0,041	7,7
	Without	0,010	5,4	0,288	8,8	0,018	3,2	0,053	11,2
Average deviation with		0,017	4,7	**0,09**	9,7	0,013	6,0	**0,037**	**7,9**
Average deviation without		0,012	4,0	**0,25**	9,7	0,011	5,3	**0,046**	**12,4**

Figure 1: S-Parameters VCE=2V, IC=40mA. Measured data is indicated by dots.

Figure 2: S-Parameters VCE=5V, IC=4mA. Measured data is indicated by dots.