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DISTRIBUTED MODELING OF BASE POTENTIAL OF BIPOLAR TRANSISTOR INCLUDING HIGH INJECTION EFFECT

Ahmed S. Desouki, Young June Park* and Hong Shick Min

Departement of Electronics Engineering and
Interuniversity Semiconductor Research Center
Seoul National University
Seoul 151, Republic of Korea
Phone: (02) 880-7274, Fax: (02) 885-4459

ABSTRACT- Based on the observation made from numerical simulation that the intrinsic base sheet resistance and the current gain of a bipolar transistor have same functional dependance on the collector current including high injection range, a simple method for modeling the variation of the voltage drop along the emitter-base junction including the high level injection effect by non-linear current controlled voltage sources for distributed circuit analysis using SPICE is described.

SUMMARY- The distributed nature of the base resistance of bipolar transistor plays a significant role in its performance. Therefore, for exact modeling of the bipolar device for circuit analysis we have to use base resistance model including bias dependent physical effects such as base conductivity modulation, base widening, and current crowding effects, which make the mathematics relatively tedious, and may obscure the relevant physical mechanisms. Instead, we may have to use distributed bipolar model with the intrinsic base resistance including the above mentioned bias depended physical effects.

Our bipolar distributed model is composed of 1 demensional bipolar transistors represented by proper model with $R_B=0$ and current controlled voltage sources to represent the different weight of base current flow according to the location of R_{B_i} (i = 1 to 5 in Fig.1(a)), R_{B_i} dependency on collector current, and the variation of the amplification factor β_F along the lateral emitter-base junction. The algorithm to find the current controlled voltage sources is explained as follows.

Referring to Fig.1a, the voltage drop V_{Bi} across each base resistor can be modeled by a non-linear current controlled voltage source in the from of a one-degree multi-dimensional polynomial as

$$V_{B_i} = \alpha_i I_{C_i} + \sum_{j=i+1}^{n} \alpha_{ij} I_{C_j} \tag{1}$$

where α_{ij} represents the polynomial coefficients as

$$\alpha_{ij} = \alpha_i \beta_{ij} \tag{2}$$

Here, V_{B_i} is the voltage drop due to the base current flowing through the base resistor R_{B_i}, $\alpha_i = \dfrac{R_{B_i}}{\beta_{F_i}}$ and assumed to be constant [1], $\beta_{ij} = \dfrac{\beta_i}{\beta_j}$ and n is the number of sections into which the original device is divided. R_{B_i} and β_{F_i} are observed to decrease with same rate as collector current increases [2] so that α_i is set to that of low current level.

In the above expression, β_{ij} represents the ratio of the current amplification factors between section i and section j. This β_{ij} is bias dependent and also can be thought as a parameter representing the current crowding effect. If all sections are divided with equal space(equal emitter area), α_i should be same for all i, and equal to $R_B(0)/\beta_F(0)$, where $R_B(0)$ and $\beta_F(0)$ are for low current values.

The values of α_{ij}'s can be obtained as a function of I_{C_i} by analyzing the distributed model of bipolar device as shown in Fig.1(b) at different bias voltages using SPICE. This is accomplished by initially assuming each β_{ij} equal to 1 and then adjusting the values of α_{ij}'s using the updated β_{F_i} after the SPICE simulation until β_{ij}'s ratios are converged. The conversion process for each bias point is reached after a maximum of 3 SPICE runs.

Once the values of α_{ij}'s are obtained of each section i, a curve fitting for each current controlled voltage source V_{B_i} is conducted to get one-dimensional multi-degree polynomial in the form

$$V_{B_i} = \sum_{j=1}^{N} P_j (I_{C_i})^j \qquad (3)$$

where N is the polynomial degree.

Verification of our model was made by comparison with the result of the 2 dimensional device simulator in term of DC and AC parameters and reasonable agreement is obtained as shown in Fig.2 through Fig.5. To carry out the verification, the base potential of the intrinsic transistor has been taken to be equal to the hole quais fermi potential and the emitter voltage is equal to the external emitter voltage.

In summary, by using the non-linear current controlled voltage source to represent the voitage drop across the lateral base region of the sectioned transistor, the distributed nature of the bipolar transistor including the bias dependent physical effects including high injection range is readily modeled for SPICE in both DC and AC analysis.

REFERENCES

[1] T. H. Ning and D. D. Tang, "Method for Determining the Emitter and Base Series Resistances of Bipolar Trasistors," IEEE Tran. on Electron Devices, Vol. ED-31, No.4, pp.409-412, April 1984.

[2] S. P. Gaur, P. A. Habitz, Y. J. Park, R. K. Cook, Y. S. Huang, and L. F. Wagner, "Two-dimensional device simulation program : 2DP," IBM J. Res. Develop., vol. 29, No.3, pp.242-251, May 1985.

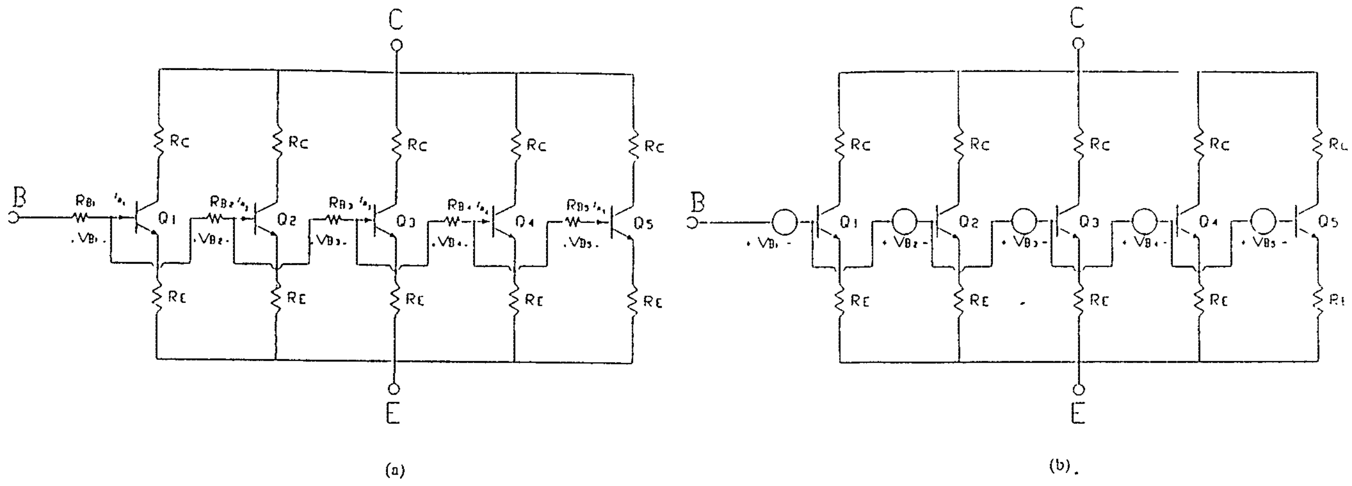

Fig.1 Distributed bipolar transistor model. (a) represented by 5 sections with base resistances. Note that R_{B_1}, for example, is not lumped in Q_1 so that the debiasing effect from I_{B_i} (i = 1 to 5) to Q_1 can be included. (b) the ohmic voltage drops between adjacent sections are modeled by nonlinear current controlled voltage sources.

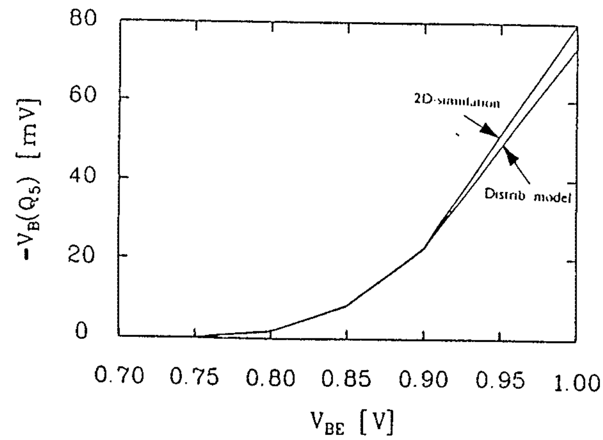

Fig.2 Variation of the internal base potential of Q_5 with the external applied voltage.

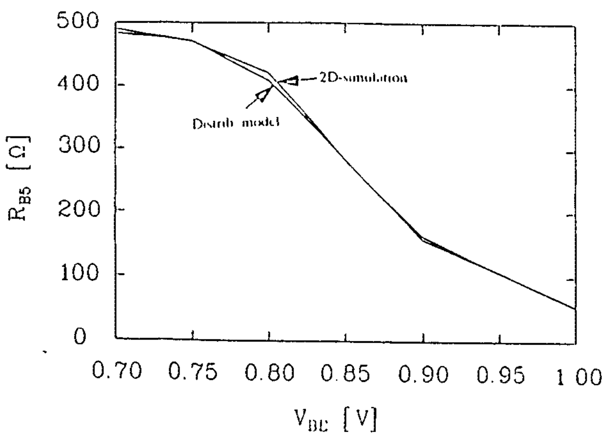

Fig.3 2D-simulated R_{B_5} and model equivalent R_{B_5} as a function of the external applied voltage.

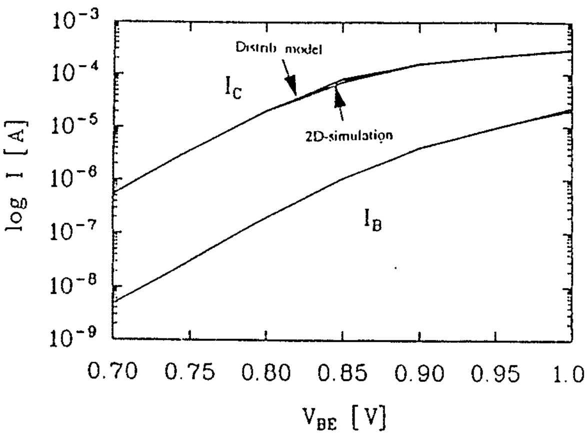

Fig.4 The Gummel plot

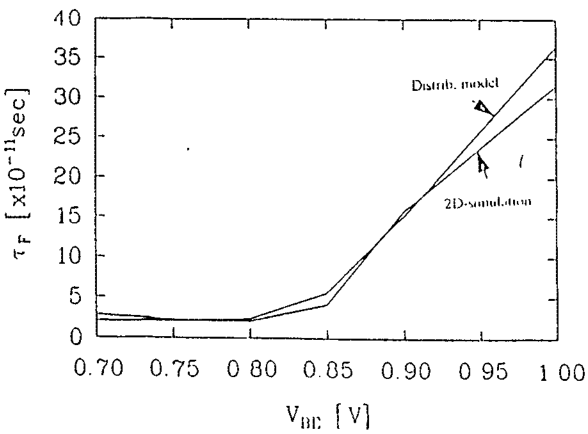

Fig.5 Variation of the forward transit time of Q_5 (τ_F) as a function of external applied voltage.