An Approach to Determine R_{bx} and R_{c} for InP HBT Using Cutoff Mode Measurement

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Abstract — **A new method to extract extrinsic base resistance and collector resistance is presented using cutoff mode measurement and open/short test structure without reference to numerical optimization. Good agreement is obtained between measured and modeled results for a 5x5 um^2 InP HBT.**

I. INTRODUCTION

Accurate extraction of small signal equivalent circuit of HBT is important for optimizing device performance. The numerical optimization can vary depending upon the optimization method and the starting values, and may result in nonphysical and non-unique values of the circuit elements. The analytical approach in HBT equivalent circuit parameter extraction has been addressed. Most of the direct extraction methods are based on certain assumptions and approximations [1-8]. Due to the diversity of the process technology, device design, and geometry, these assumptions and approximations need to be modified and adjusted.

In order to overcome these difficulties, an improved method for determining the InP HBT extrinsic elements is proposed in this paper. This method is a combination of the test structure and direct extraction methods. First, the PAD capacitances and series wire inductances can be extracted using normal open, short test structures, then the extrinsic resistances R_{bx} and R_c are obtained using cutoff mode S-parameter measurements (zero V_{CE}, zero I_C, variable V_{CB}). The advantage of this procedure is that no assumptions and approximations are needed.

II. PARAMETER EXTRACTION TECHNIQUE

The small-signal equivalent circuit model for HBT under cutoff bias condition is shown in Fig.1.

The three capacitances elements C_{pb}, C_{pc} and C_{pbc} model the capacitive effects of the measurement probe contacts. The pad capacitances are determined by measuring an open structure which consists of only the pads. The parasitic device- connection inductances are determined by measuring a test pattern which consist of the pads, the device feed and a short replacing the HBT [9].

After the pad capacitances and series inductances have been de-embedded, the capacitance C_{be}, C_{bc} +C_{ex}, are determined by linear regression of Im(Y_{ij}^L), which can be written:

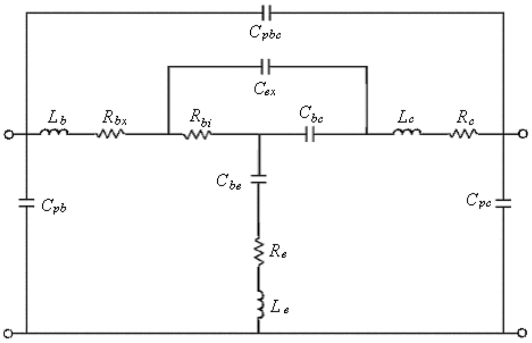

Fig.1. Small signal equivalent circuit under cutoff condition

$$C_{be} = \frac{\mathrm{Im}(Y_{11}^L + Y_{12}^L)}{\omega} \tag{1}$$

$$C_T = C_{bc} + C_{ex} = -\frac{\mathrm{Im}(Y_{12}^L)}{\omega} \tag{2}$$

Superscript *L and H* denote the lower frequency and higher frequency, and C_T means total capacitances of C_{bc} and C_{ex}.

Then the other extrinsic elements are obtained using cutoff mode S-parameter measurement. Because parasitic resistances and inductances are very sensitive to S-parameters at lower frequencies, for frequencies beyond a certain value (for our InP HBT device typically F >17GHz), the capacitance C_{bc} and C_{ex}, the extrinsic resistances R_{bx}, R_c, R_e and intrinsic base resistance R_{bi} can be directly calculated by:

$$C_{ex} = \frac{\mathrm{Im}(Z_{12}^H - Z_{BE})}{\mathrm{Im}(Z_{11}^H - Z_{BE})} C_T \tag{3}$$

$$C_{bc} = \frac{\mathrm{Im}(Z_{11}^H - Z_{12}^H)}{\mathrm{Im}(Z_{11}^H - Z_{BE})} C_T \tag{4}$$

$$R_{bi} = \frac{1}{\omega C_{bc}} \sqrt{\frac{\mathrm{Im}(Z_{11}^H - Z_{12}^H) C_T}{\mathrm{Im}(Z_{22}^H - Z_{12}^H) C_{ex}}} \tag{5}$$

$$R_{bx} = \mathrm{Re}(Z_{11}^H - Z_{12}^H - \frac{C_{bc} R_{bi}}{C_T + j\omega C_{bc} C_{ex} R_{bi}}) \tag{6}$$

III. RESULTS AND DISCUSSION

To illustrate the above method, we present the extracted model parameters for a 5x5 um^2 InP HBT. The detail of the processing and epitaxial structure have been published elsewhere[10].

The extracted C_{be} from (1) at different bias values V_{be}={0V,-0.2V,0.2V}, and V_{ce}=0V is shown in Fig.2. Fig.3 shows the total C_{bc} +C_{ex} versus frequency.

Fig.4 shows the variation of the extrinsic base-collector capacitance C_{ex} versus frequency for different V_{be}. It is noted the C_{ex} is a strong function of the base-collector voltage for InP HBT. Fig.5 shows the extracted intrinsic resistance R_{bi} versus frequency at different V_{be}. We can see the R_{bi} is a weak function of the bias voltage.

Fig.6 and Fig.7 show the extracted values of the extrinsic resistances R_{bx}, R_c. It is noted that variations are very small and bias independent. Fig.8 shows the extracted results of extrinsic resistance R_e. However, it is noted that accuracy is not good enough to obtain the precise value. So this method is not suitable for extrinsic emitter resistance extraction.

R_e can be obtained from the real part of Z_{12} at the low frequencies under active condition. The real part of the measured Z_{12} shows linear dependence on $1/I_E$ as shown in Fig.9. R_e can be obtained from the interception.

Once the extrinsic elements are obtained, the intrinsic elements can be determined directly. Fig.10 shows a comparison the measured and modeled S-parameters for the InP HBT in the frequency range 50MHz to 40GHz under three different bias conditions. An excellent agreement over the whole frequency range is obtained.

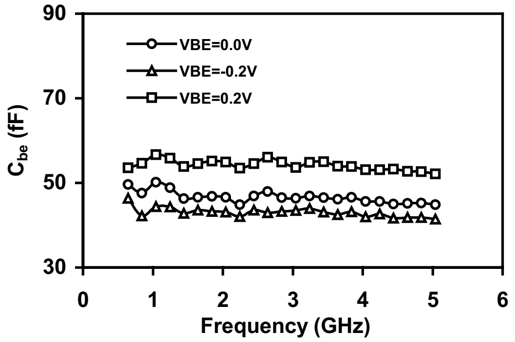

Fig.2. Extracted C_{be} versus frequency

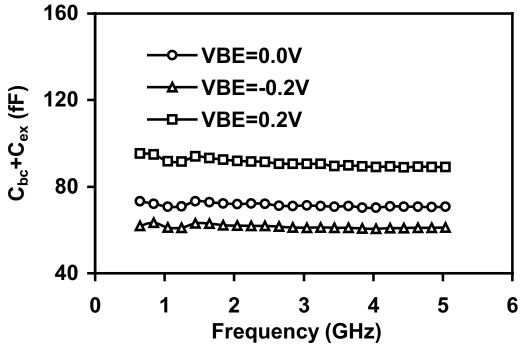

Fig.3. Extracted $C_{bc} + C_{ex}$ versus frequency

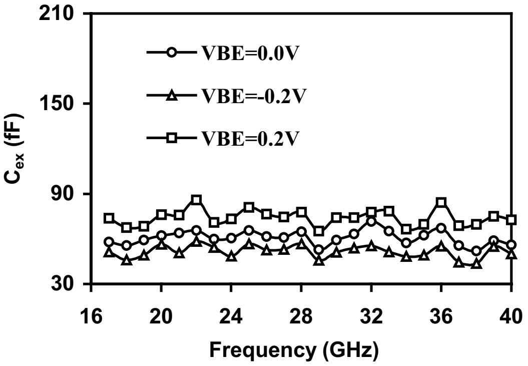

Fig.4. Extracted C_{ex} versus frequency

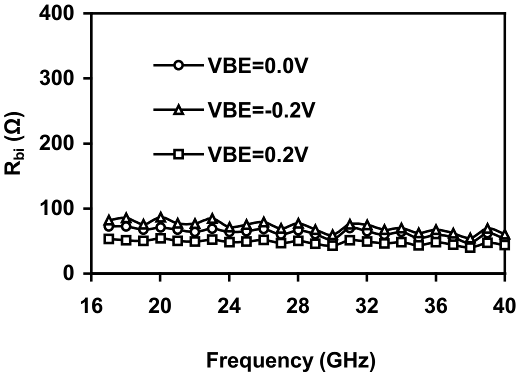

Fig.5. Extracted R_{bi} versus frequency

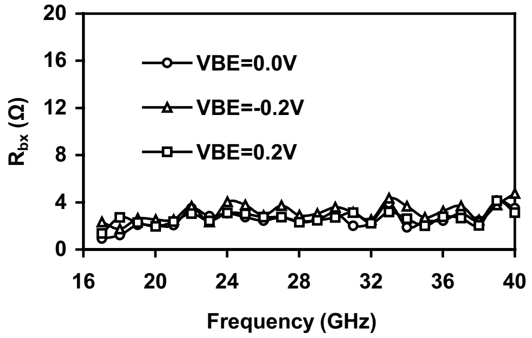

Fig.6. Extracted R_{bx} versus frequency

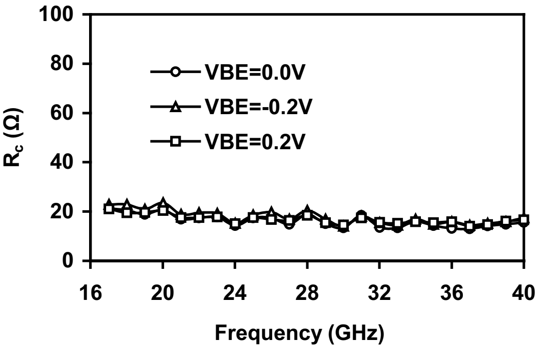

Fig.7. Extracted R_c versus frequency

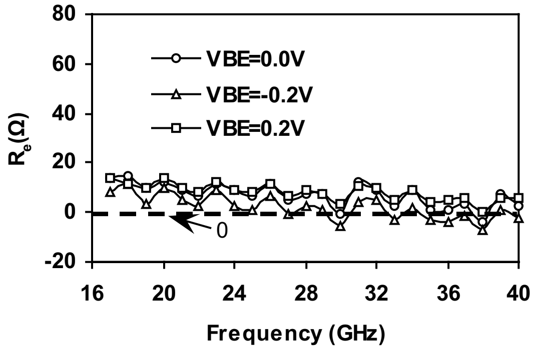

Fig.8. Extracted R_e versus frequency

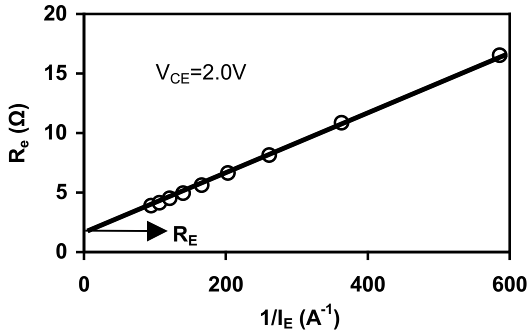

Fig.9. Plot of $\mathrm{Re}(Z_{12})$ versus $1/I_E$, freq=1GHz

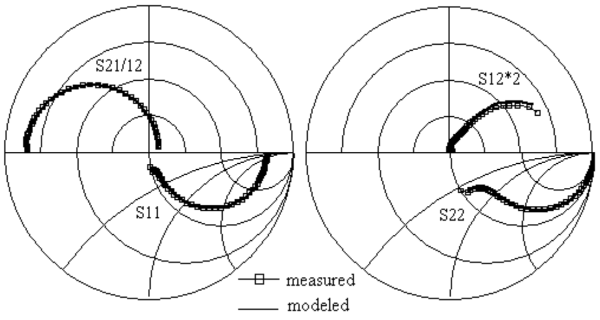

Fig.10. Comparison of modeled and measured S-parameter for the InP HBT, Bias: $I_B = 120uA, V_{CE} = 2V$

IV. CONCLUSION

An approach for extracting extrinsic elements R_{bx} and R_c for a 5x5 InP HBT has been proposed. An excellent agreement over the whole frequency range is obtained

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