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 µm² 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 capacitance elements $C_{phb}$, $C_{pc}$ and $C_{phc}$ 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 consists 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 $\text{Im}(Y_{ij}^{L})$, which can be written:

$$C_{bc} = \frac{\text{Im}(Y_{11}^{L} + Y_{12}^{L})}{\omega} \quad (1)$$

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

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 $F > 17$GHz), the capacitance $C_{bc}$ and $C_{ex}$, the extrinsic resistances $R_{hx}$, $R_c$, $R_e$ and intrinsic base resistance $R_{bi}$ can be directly calculated by:

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

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

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

$$R_{hx} = \frac{\text{Re}(Z_{11}^{H} - Z_{12}^{H}) - \frac{C_{bc} R_{bi}}{C_T + j \omega C_{bc} C_{ex} R_{bi}}}{C_T} \quad (6)$$
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 $R_{ex}$. 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.
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.

### 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.

### REFERENCES


