A Simplified Approach for Noise Parameter Transformation between Common Emitter and Common Base InP DHBT

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ABSTRACT

A new approach, based on the typical T-model of InP DHBT, has been developed which uses only a simple set of formulas to transform noise parameters between common emitter and common base configurations. The calculated results are in good agreement with the experimental results demonstrating that this approach is useful for many broadband low noise communication circuit designs.

Indexes: noise figure, noise parameter, InP-HBT, common base, common emitter

1. INTRODUCTION

As is commonly known, the noise performance between the common emitter and common base configurations at very low frequencies are identical [1], [2]. However, there are some differences at RF & microwave frequency due to the B-C feedback capacitance for the common emitter configuration. A circuit configuration in the common emitter mode usually produces more noise than its common base counterpart. This is primarily due to its high input impedance that makes broadband matching more difficult. A common base configuration has the advantages of broadband impedance matching, good gain and low noise performance [3], [4]. Therefore, a common base configuration is generally more suitable in the optical and microwave broadband communication applications. However, current method to calculate common base noise parameters using available common emitter noise parameters have usually been complicated and time consuming [5], [6]. In this paper, we propose a simple but yet effective transformation technique to convert common emitter noise parameters into common base noise parameters. In this work, an InP-based Double-Heterojunction Bipolar Transistor (DHBT) is used to illustrate this new method.

2. MODEL

A. Z-Parameter Transformation between Com-mon Emitter and Common Base.

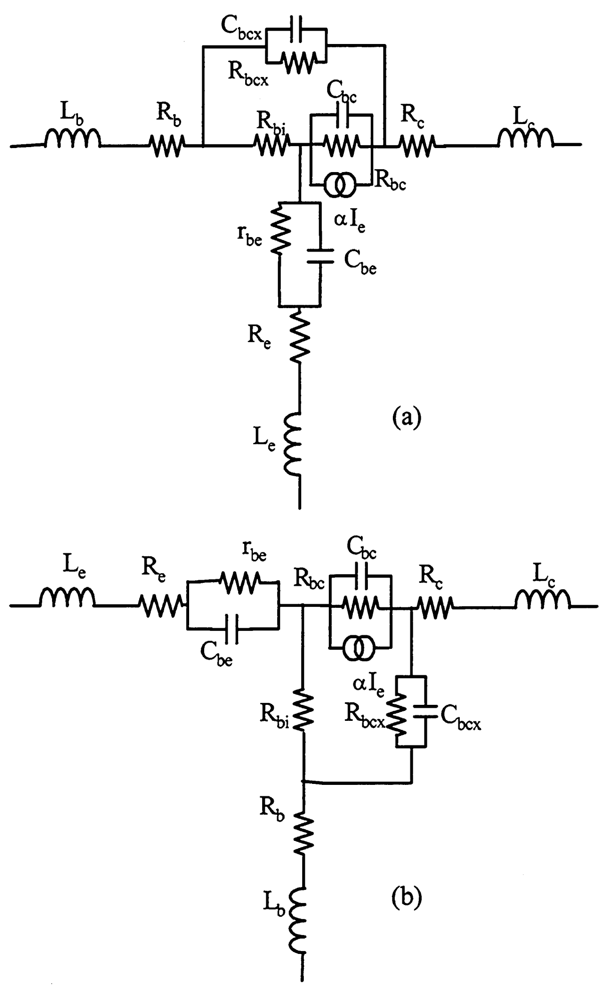

Fig1 (a).T-Model in common emitter configuration. (b) T-Model in common base configuration.

A typical T-model is used for the InP DHBT and its equivalent circuit in the common emitter configuration is shown in Fig. 1(a) [7]. The Z-parameter expressions for the small signal equivalent circuit of HBT's are derived in [8] and is repeated in the appendix for the reader's convenience. The extrinsic capacitances to ground are small for the devices tested which were laid out for on-wafer probing. They are not suspected to significantly influence the results based on the analysis presented. Its corresponding small signal equivalent circuit of the common base configuration is shown in fig.1 (b). The Z-parameter expressions for common base configuration are:

$$Z_{11}^{CB} = z_E + z_B + \frac{(1-\alpha) z_{BC} R_{bi} + z_F R_{bi}}{\Delta} \tag{1}$$

$$Z_{12}^{CB} = z_B + \frac{z_F R_{bi}}{\Delta} \tag{2}$$

$$Z_{21}^{CB} = z_B + \frac{\alpha z_{BC} z_F + z_F R_{bi}}{\Delta} \tag{3}$$

$$Z_{22}^{CB} = z_C + z_B + \frac{(z_{BC} + R_{bi}) z_F}{\Delta} \tag{4}$$

where $\Delta = z_{BC} + z_F + R_{bi}$ and Z_{ij}^{CB} denotes common base Z-parameters.

Comparing the Z-parameters of the common emitter and the common base configurations, we can get the transformations as:

$$Z_{11}^{CB} = Z_{11}^{CE} \tag{5}$$

$$Z_{12}^{CB} = Z_{11}^{CE} - Z_{12}^{CE} \tag{6}$$

$$Z_{21}^{CB} = Z_{11}^{CE} - Z_{21}^{CE} \tag{7}$$

$$Z_{22}^{CB} = Z_{11}^{CE} + Z_{22}^{CE} - Z_{12}^{CE} - Z_{21}^{CE} \tag{8}$$

and also the ABCD parameter transforma-tions:

$$A^{CB} = \frac{A^{CE}}{A^{CE} - 1} \tag{9}$$

$$C^{CB} = \frac{C^{CE}}{A^{CE} - 1} \tag{10}$$

where Z_{ij}^{CE} denotes the common emitter Z-parameters, and A^{CB}, C^{CB} and A^{CE}, C^{CE} denote the ABCD parameters of the common base and common emitter configurations, respectively.

B. Noise Parameter Transformation between Common Emitter and Common Base

Fig.2(a) shows the two-port device of a common emitter HBT with its noise represented by an equivalent input source: a current generator and a voltage generator. These sources and their correlation coefficient completely characterize the noise of the device. Normally these sources are specified by the following standard set of noise parameters[9]:

$$R_n^{CE} = \frac{<\bar{v}_A^2>}{4kT_0} \tag{11}$$

$$G_n^{CE} = \frac{<\bar{i}_A^2>}{4kT_0} \tag{12}$$

$$Y_{cor}^{CE} = G_{cor}^{CE} + jB_{cor}^{CE} = \frac{<i_A v_A^*>}{<\bar{v}_A^2>} \tag{13}$$

These parameters are known as the noise resistance, noise conductance, and correlation admittance, respectively. Boltzmann's constant and reference temperature are denoted by k and T_0, respectively . The noise sources are spectral densities, i.e., volts and amperes per root Hz. In terms of these parameters, the noise figure of the device is given by [9]:

$$F^{CE} = F_{MIN}^{CE} + \frac{R_n^{CE}}{G_s} \left| Y_s - (G_{opt}^{CE} + jB_{opt}^{CE}) \right|^2 \tag{14}$$

where $Y_s = G_s + jB_s$ is the admittance of the source, and

$$G_{opt}^{CE\,2} = G_{cor}^{CE\,2} + \frac{G_n^{CE} - R_n^{CE} \left| Y_{cor}^{CE} \right|^2}{R_n^{CE}} \tag{15}$$

$$B_{opt}^{CE} = -B_{cor}^{CE} \tag{16}$$

and

$$F_{MIN}^{CE} = 1 + 2R_n^{CE} (G_{opt}^{CE} + G_{cor}^{CE}) \tag{17}$$

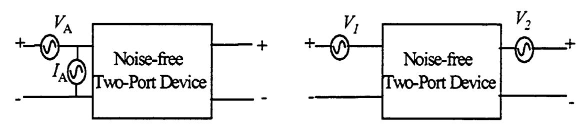

Fig. 2(a) Fig. 2(b)

Fig2 (a) The two-port device of common emitter HBT with its noise represented by equivalent input source: a current gerentor and a voltage gerentor. (b) The two-port device of common emitter HBT with its noise represented by equivalent input source: two voltage gerentors.

The voltage and current noise sources, V_A^{CE} and I_A^{CE} of fig 2(a) are easily transformaed into noise voltage sources, V_1^{CE} and V_2^{CE} of fig. 2(b), given by:

$$V_1^{CE} = V_A^{CE} - \frac{A^{CE}}{C^{CE}} I_A^{CE} \tag{18}$$

$$V_2^{CE} = -\frac{I_A^{CE}}{C^{CE}} \tag{19}$$

where A^{CE} and C^{CE} denote the ABCD parameters of the two-port device of common emitter HBT. Following the method of [5], the common base noise voltage sources, V_1^{CB} and V_2^{CB} are obtained as:

$$V_1^{CB} = -V_1^{CE} \tag{20}$$

$$V_2^{CB} = V_2^{CE} - V_1^{CE} \tag{21}$$

and the voltage and current noise sources, V_A^{CB} and V_A^{CB} for the common base configuration are also obtained as:

$$V_A^{CB} = V_1^{CB} - A^{CB}V_2^{CB} = \frac{V_A^{CE}}{A^{CE}-1} \tag{22}$$

$$I_A^{CB} = -C^{CB}V_2^{CB} = \frac{C^{CE}}{A^{CE}-1}V_A^{CE} - I_A^{CE} \tag{23}$$

where the A^{CB} and C^{CB} denote the ABCD parameters of the two-port device of the common base HBT. Using the definitions of (11) to (13), the common base noise parameters are obtained after some simple calculations:

$$R_n^{CB} = \frac{R_n^{CE}}{\left|A^{CE}-1\right|^2} \tag{24}$$

$$G_n^{CB} = \left|\frac{C^{CE}}{A^{CE}-1}\right|^2 R_n^{CE} + G_n^{CE} - 2\,\mathrm{Re}[\frac{C^{CE}}{A^{CE}-1}R_n^{CE}Y_{cor}^{CE}] \tag{25}$$

$$Y_{cor}^{CE} = C^{CE} - (A^{CE}-1)Y_{cor}^{CE} \tag{26}$$

where R_n^{CE}, G_n^{CE}, Y_{cor}^{CE} and R_n^{CB}, G_n^{CB}, Y_{cor}^{CB} are noise resistance, noise conductance, and correlation admittance of the common emitter and common base configurations, respectively.

3. RESULTS AND DISSCUSIONS

To verify the accuracy of the above noise transformations, InP/InGaAs common-emitter and common base DHBTs with an emitter area of 5x20μm^2 were used for this work. Details of the device structure and performance were described in [10]. The microwave noise parameters were measured from 2-20GHz. The measurement system consisted of an ATN-NP5 wafer probe test set, HP8970C noise figure test set, HP8970B noise figure meter, and HP8510C network analyzer and the signal source for noise figure test set is shared with HP8510C. Then the minimum noise figure, noise resistance and the optimal source impedance (NF_{MIN}, R_N, G_{OPT} and B_{OPT}) were extracted from the measured noise figure and S-parameters at a particular DC bias for the these device with common emitter and common base configurations. Fig. 3 shows the comparison of the measured and calculated minimum noise figure for the common base configurations. Good agreement was obtained between the measured and calculated minimum noise figure from 2 to 20GHz. To further illustrate the effectiveness and accuracy of this approach, we also compared the measured R_n^{CB} and the calculated R_n^{CB} from the measured R_n^{CE}. As shown in Fig. 4, good agreement is observed between the measured and calculated results despite the fact that the equivalent noise resistance is a difficult parameter to obtain because of the uncertainty in the S-parameter measurement.

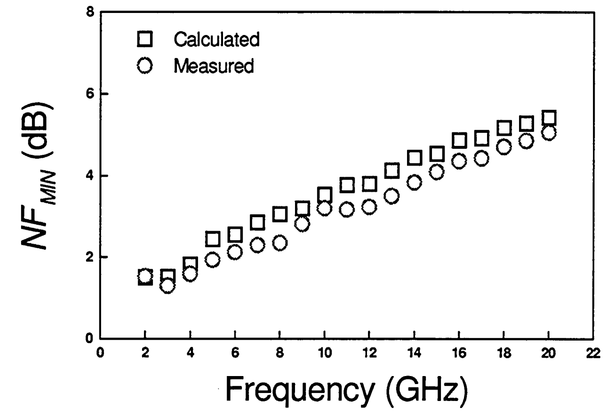

Fig3 Measured and calculated common base noise figure versus frequency.

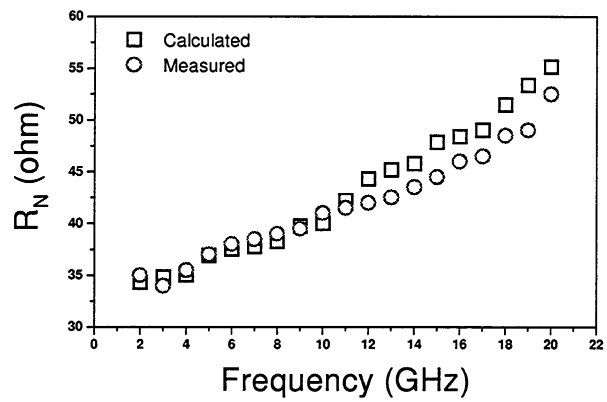

Fig4 Measured and calculated common base noise resistance versus frequency

4. SUMMARY

A set of simplified calculation formulas for noise parameter transformation based on the ABCD representation between the common emitter and common base configurations has been presented. The measured microwave noise performances of an InP-based DHBT for the common base and common emitter configurations were demonstrated to confirm these transformation. At the frequency range of 2-20GHz, a good agreement between the measured and calculated results is obtained. These show that the new approach for noise parameter transformation can be used for the application of the low noise and board band amplifier design. We believe that this approach also can be used for noise transformation between common base and common collector configuration or/and common emitter and common collector configurations. Therefore, a low noise amplifier (LNA) can be built with any of the common emitter, the common base and common collector configurations or combination thereof.

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APPENDIX

Consider the HBT small signal equivalent circuit of common emitter configuration shown in fig. 1(a). The Z-parameter relations are following as:

$$Z_{11}^{CE} = z_E + z_B + \frac{(1-\alpha) z_{BC} R_{bi} + z_F R_{bi}}{\Delta} \quad (1)$$

$$Z_{12}^{CE} = z_E + \frac{(1-\alpha) z_{BC} R_{bi}}{\Delta} \quad (2)$$

$$Z_{21}^{CE} = z_E + \frac{(1-\alpha) z_{BC} R_{bi} - \alpha z_F z_{BC}}{\Delta} \quad (3)$$

$$Z_{zz}^{CE} = z_C + z_E + \frac{(1-\alpha)(z_F + R_{bi}) z_{BC}}{\Delta} \quad (4)$$

where $\Delta = z_{BC} + z_F + R_{bi}$.

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