EXTRACTION OF LOW-FREQUENCY NOISE MODEL OF SELF-ALIGNED AlGaAs/GaAs HETEROJUNCTION BIPOLAR TRANSISTOR

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ABSTRACT

The first quantitative extraction of low-frequency noise equivalent circuit model of self-aligned AlGaAs/GaAs hetero-junction bipolar transistor has been performed. It is based on a generalized small signal circuit model including the base and emitter series resistance noise sources. The dominant noise sources are emitter-base current noise source and the resistance noise source. The emitter-collector current noise source is negligible.

INTRODUCTION

Due to the very low low-frequency noise and high linearity, HBT is a promising device for low phase noise microwave oscillators. The baseband low-frequency (LF) noises are up-converted to the near-carrier spectra of the oscillator through the nonlinearity of device, and degrade the spectral purity(e.g., phase noise). To design a low phase noise HBT oscillator, it is essential to have an accurate large signal model including bias-dependent LF noise sources. It is of prime importance to exactly locate the noise sources at the proper nodes of circuit model. In this paper, we are reporting on the work of the quantitative extraction of LF noise model of AlGaAs/ GaAs HBT. It is based on a generalized small-signal LF noise equivalent circuit which includes both the GaAs base surface recombination [1] and resistance 1/f noise sources [2].

DEVICE CHARACTERISTICS

We have employed a self-aligned AlGaAs/ GaAs HBT supplied by Kukje Co. in Korea. Emitter is 5 fingers with 2 × 25 μm^2 size. Typical ft and fmax are 30 GHz and 45 GHz, respectively [3]. Materials were grown by MOCVD. DC current gain is 40. Base and collector current ideality factors are 1.46 and 1.10, respectively. Emitter resistance (r_e) and base resistance (r_b) determined from the measured S-parameters are 4 Ω and 10 Ω, respectively. Noise spectra of the HBT were measured from 10 Hz to 100 kHz.

LOW-FREQUENCY NOISE EQUIVALENT CIRCUIT MODEL

Fig.1 is the LF noise equivalent circuit of HBT used for this work. S_{Ibe} represents base-emitter current noise such as surface recombination 1/f noise generated at the extrinsic base GaAs surface [1], g-r noise generated at the AlGaAs emitter [1], and hetero-interface recombination 1/f noise [4]. S_{Ice} represents collector - emitter current

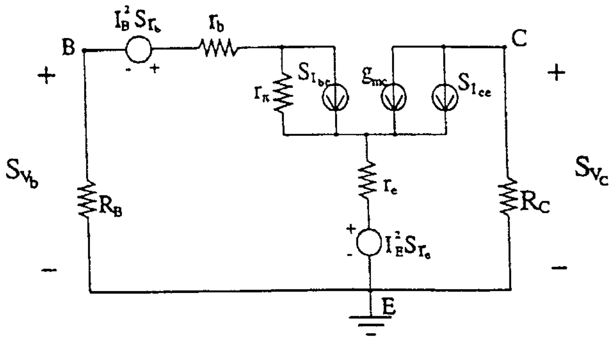

Fig. 1. Low-frequency noise equivalent circuit
($S_{Vr} \equiv I_B^2\ Sr_b + I_E^2\ Sr_e$) [2]

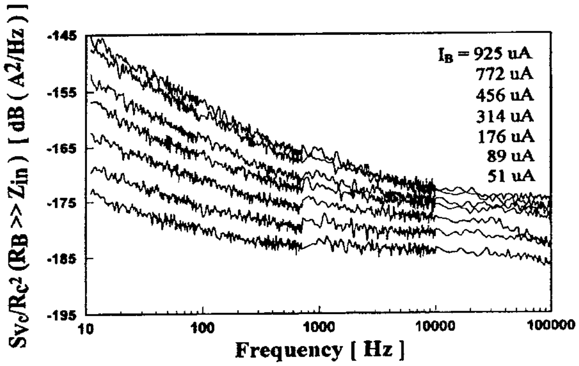

Fig. 2. Measured $S_{Vc}/R_c^2(R_B>>Z_{in})$ .vs. Frequency

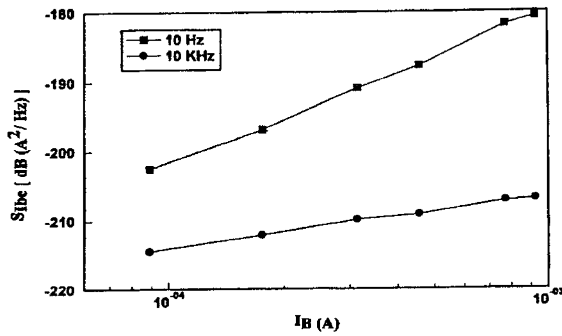

Fig. 3. Extracted S_{Ibe} .vs. Base current

noise stemming from the fluctuation of base diffusivity [5]. Pawlikiewicz, *et al.* [6] and Tutt, *et al.* [7] used these two noise sources for extraction of noise model. But there is another noise source called resistance 1/f noise(S_{Vr}) suggested by Kleinpenning, *et al.*[2] The existence of resistance 1/f noise has been verified further by us, using a very large size AlGaAs HBT [8]. Therefore, S_{Vr} should be included for the extraction of noise model of HBT's.

NOISE SOURCE EXTRACTION

Noise sources can be extracted by measuring the collector noise currents with different base terminations(R_B). Table 1 summarizes the definitions of the noise power with different terminations. S_{Ibe} can be extracted from $S_{Vc}/R_c^2(R_B>>Z_{in})$ due to the virtually open circuited base ($R_B>>Z_{in} = r_b+r_\pi+(1+\beta)r_e$) and large β. Fig. 2 shows the spectra of $S_{Vc}/R_c^2(R_B>>Z_{in})$. The spectra exhibit two distinctive regions, i.e, 1/f noise below 1 kHz and g-r noise plateau above 1 kHz. S_{Ibe} is extracted from the relation of $S_{Ibe} = S_{Vc}/(\beta R_c)^2$. The base current dependency of S_{Ibe} is depicted in Fig. 3. In the 1/f noise region, S_{Ibe} (10 Hz) $\propto I_B^{2.06} \propto I_C^{1.95}$, indicating that the dominant noise source is a surface recombination [1]. Meanwhile, in the g-r noise plateau region, S_{Ibe} (10 kHz) $\propto I_B^{0.77}$, and the source can be attributed to the trapping at the AlGaAs emitter [1].

Fig. 4 shows the measured spectra of S_{Ic}. It is quite different from $S_{Vc}/R_c^2(R_B>>Z_{in})$ in three aspects. First, g-r noise plateau becomes obscured by the 1/f noise at a high I_B. This behavior suggests the existence of 1/f noise source other than S_{Ibe} (surface recombination 1/f noise). Second, g-r noise plateau appears at a low I_B. Since the S_{Ibe} contribution to S_{Ic} is negligible, the g-r noise plateau that appears at a low I_B may stem from another noise source. Third, S_{Ic}(10 Hz) is proportional to $I_B^{2.52}$. The current dependency can be explained not by using the conventional noise theories but by using S_{Vr}, as in our noise analysis, because

Table 1. Definitions and Related Equations of Noise Powers

Noise Power	Definition	Related Equations
$S_{Vc}/R_c^2(R_B>>Z_{in})$	Collector current noise spectra with open base ($R_B>>Z_{in}$)	$S_{Vc}/R_c^2(R_B>>Z_{in}) \approx \beta^2 S_{Ibe} + S_{Ice} + [\beta/(R_B+Z_{in})]^2 S_{Vr}$ $\approx \beta^2 S_{Ibe}$: Eq (1)
S_{Ic}	Collector current noise spectra with shorted base (R_B = 0 Ω)	S_{Ic} $\approx [\beta(r_b+r_e)/Z_{in}]^2 S_{Ibe} + [(r_b+r_\pi+r_e)/Z_{in}]^2 S_{Ice} + (\beta/Z_{in})^2 S_{Vr}$ $\approx [(r_b+r_\pi+r_e)/Z_{in}]^2 S_{Ice} + (\beta/Z_{in})^2 S_{Vr}$: Eq (2) $\approx (\beta/Z_{in})^2 S_{Vr}$
S'_{Ic}	Collector current noise spectra with R_B = R_{BB}	$S'_{Ic} \approx [\beta(r_b+R_{BB}+r_e)/(Z_{in}+R_{BB})]^2 S_{Ibe} + [(r_b+R_{BB}+r_\pi+r_e)/(Z_{in}+R_{BB})]^2 S_{Ice} + [\beta/(Z_{in}+R_{BB})]^2 S_{Vr}$: Eq (3) $\approx [\beta(r_b+R_{BB}+r_e)/(Z_{in}+R_{BB})]^2 S_{Ibe} + [\beta/(Z_{in}+R_{BB})]^2 S_{Vr}$

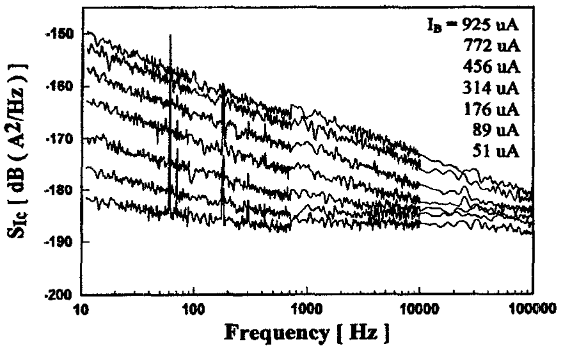

Fig. 4. Measured S_{Ic} .vs. Frequency

$S_{Vr} \propto I_B^2$ [2] and Z_{in} decreases with the increase of I_B. To extract S_{Ice} and S_{Vr}, we have used Eqs. (2) and (3). A proper value of R_{BB} is chosen so that S_{Ibe} term in S'_{Ic} is not dominantly large, and that S_{Ice} or S_{Vr} terms in S'_{Ic} are changed more than 1 dB from those in S_{Ic}. This leads to the solution for S_{Ice} and S_{Vr}. We found that S_{Ice} was negligible and S_{Vr} was dominant. Therefore, S_{Vr} can be extracted from the simple relation of $S_{Ic} = (\beta/Z_{in})^2 S_{Vr}$. In general case of any LF base termination (R_B=R_T), the expression for collector current noise of $S_{Ic}|_{(R_B=R_T)}$ can be written by the following equation:

$$S_{Ic}|_{(R_B=R_T)}=[\beta(r_b+R_T+r_e)/(Z_{in}+R_T)]^2 S_{Ibe} + [\beta/(Z_{in}+R_T)]^2 S_{Vr} \quad (4)$$

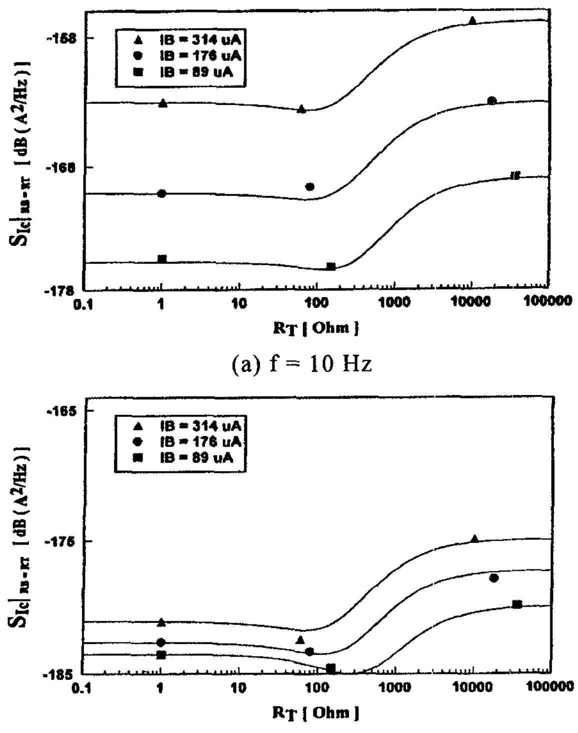

Fig. 5. LF base termination dependencies of collector current noise(Solid line: Calculated using Eq (4);Points: Measured data);(a) 10 Hz (b) 10 kHz

where $S_{Ibe} = S_{Vc}/(\beta R_c)^2$ and $S_{Vr} = (Z_{in}/\beta)^2 S_{Ic}$. The effect of base termination on $S_{Ic}|_{(R_B=R_T)}$ can be calculated by using Eq. (4). Fig. 5 (a) and (b) show the calculated and measured $S_{Ic}|_{(R_B=R_T)}$ data at 10 Hz and 10 kHz, respectively. They agree very well within a noise measurement error bound of about 1 dB. This figure suggests that, for reduced phase noise of an oscillator, the LF base termination impedance should be less than about 100 Ω for our device.

SUMMARY

In summary, we have extracted the LF noise circuit model for AlGaAs/GaAs HBT by using the general LF noise equivalent circuit including the resistance 1/f noise source. The LF noise model can be determined by base-emitter current noise(S_{Ibe}) and resistance noise(S_{Vr}). Collector-emitter current noise(S_{Ice}), though generally considered an important noise source, is negligible. S_{Ibe} and S_{Vr} can be obtained from the measured collector current noise spectra with open base (R_B>>Z_{in}) and with shorted base-emitter (R_B = 0 Ω), respectively. This model suggests that there is an optimum base termination for reduced phase noise, less than 100 Ω for our device. This simple but exact extraction scheme for LF noise equivalent circuit is expected to be very useful for the design of low phase noise HBT oscillator.

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