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Noise Parameter Extraction of GaAs MESFET with Monte-Carlo Simulation

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All the noise parameters of GaAs MESFET are extracted by using 2-dimensional Monte-Carlo simulaion for the first time. The general procedure to extract the noise parameters is presented. The spectrums and correlations of the input-equivalent noise-voltage and noise-current sources are calculated. The y parameters of GaAs MESFET are also extracted to obtain noise parameters and to analyze device characteristics for the first time.

1. Introduction

Submicrometer-gate length GaAs MESFET is becoming very important for low noise applications [1]. Especially, ion-implanted MESFETs are suitable for high yield and high performance MMIC's because they can avoid the poor controllability of recessing gate [2].

Only the Monte Carlo method offers a means to analyze the noise in submicrometer devices incorporating all the structure effects and microscopic transport mechanisms. Therefore, there were many reports on Monte-Carlo simulations of noise in GaAs MESFET's. However, there have been no reports on extracting noise parameters, which are essential to describe low-noise circuitry. In Moglestue's paper [3], an intrinsic noie figure is defined and calculated but this is not the same noise figure as is conventionally used in circuit design.

In this paper, we present how to extract the noise parameters using the 2-dimensional Monte-Carlo simulation, which can be readily used in circuit designs.

2. Physical model

We analyze a prototype planar GaAs MESFET, which has $0.2\mu m$ gate length and $0.2\mu m$ source-gate and drain-gate spacings. The channel thickness of $0.1\mu m$ and the uniform doping density of $10^{17}\ cm^{-3}$ are assumed. Three nonparabolic spherical valleys (Γ, X and L) are assumed to model GaAs conduction band. Acoustic phonon scattering, polar optical phonon scattering and ionized impurity scattering are taken into account [4]. All the material parameters are used as in reference [5]. The lattice temperature is assumed to be 300 K throughout this simulation. The mesh of $0.01\mu m \times 0.01\mu m$ and the time step of 10 fs are assumed to solve Poisson's equation.

The bias point of $V_{gs} = 0.3V$ and $V_{ds} = 2.0V$ is to be in the linear region of MESFET. The gate width is assumed as $100\mu m$. The number of electrons in the device, N, is 6×10^5 particles, but it is assumed the number of superparticles, N_s, is 9600. Therefore, the statistical fluctuation is exaggerated by a factor of $\sqrt{N/N_s}$, which should be considered to estimate the noise [3], [6].

3. Noise parameter extraction

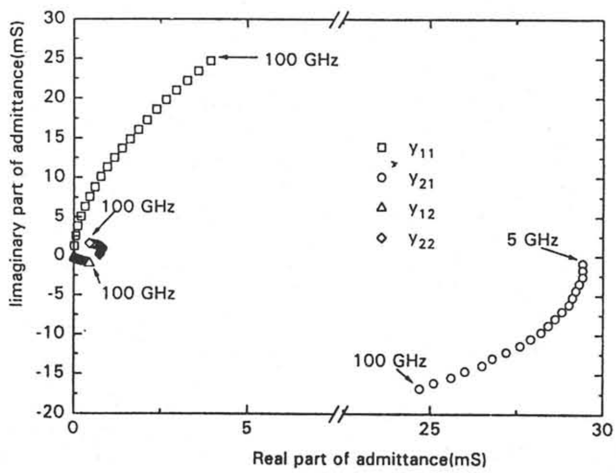

Fig. 1. Plot of y parameters as a function of frequency from 5GHz to 100GHz.

A. y parameters and equivalent gate-current and drain-current noises

Y parameters of a MESFET must be calculated before extracting noise parameters. At a given time, in a steady state, either the gate or the drain voltage is excited by ΔV_{gs} or ΔV_{ds} and returns to the steady state after Δt. The Fourier transforms of the responses in the gate current ΔI_g and the drain current ΔI_d lead to the y parameters [3]. We use fifty pulses of the voltage and average each responses in the current for accurate results. Here, one has to remember that the current at a terminal is composed of both particle current and displacement current [7], [8]. The calculated y parameters are shown in Fig. 1. The behaviors of y parameters with frequency are very similar to that of reference [3]. y21 is larger than the results of reference [3] because of the smaller gate length.

Next, the gate and drain voltages remain constant and the fluctuations of the short-circuit gate and drain currents and their correlation are calculated. The current noise sources are represented as two (correlated) current generators connected in parallel at the input(I_G) and the output(I_D) [9] (Fig. 2. a)) The fluctuations which come from gate-current and drain-current noises are analyzed through the caculation of the respective auto correla-

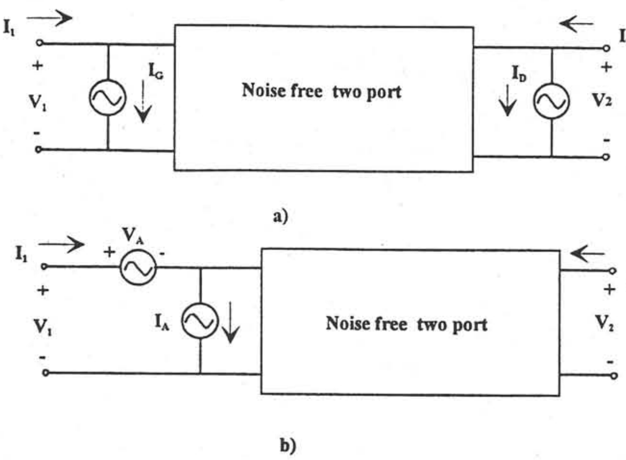

Fig. 2. Noisy linear two port a) admittance form b) chain matrix form.

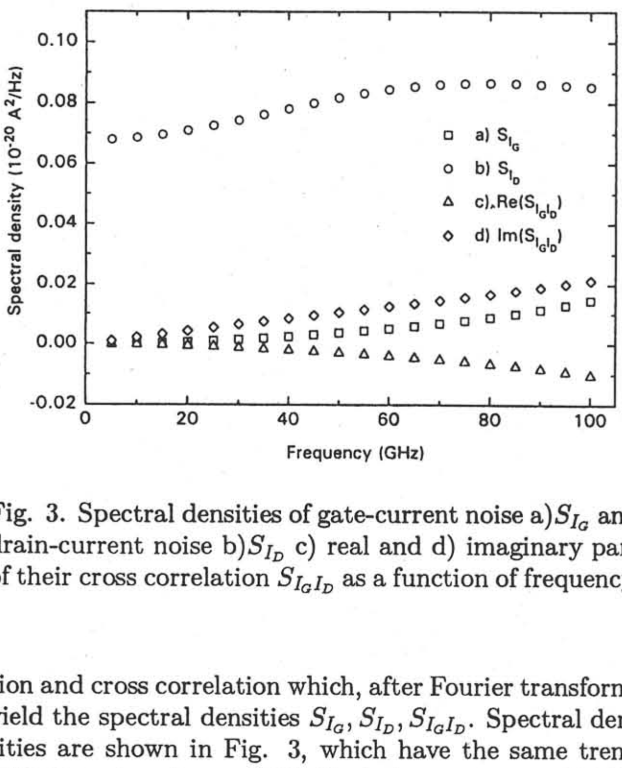

Fig. 3. Spectral densities of gate-current noise a)S_{I_G} and drain-current noise b)S_{I_D} c) real and d) imaginary part of their cross correlation $S_{I_GI_D}$ as a function of frequency.

tion and cross correlation which, after Fourier transform, yield the spectral densities $S_{I_G}, S_{I_D}, S_{I_GI_D}$. Spectral densities are shown in Fig. 3, which have the same trend with those in reference [10]. S_{I_D} is decreases very slightly with frequency and S_{I_G} exhibits a f^2 behavior and magnitudes of real and imaginary part of $S_{I_GI_D}$ increase with frequency.

B. Input-equivalent current-noise and voltage-noise sources.

The noise property of a GaAs MESFET can be described by considering it as two parts. One is input noise sources and the other is noiseless MESFET. The input noises are composed of series voltage source(V_A) and shunt current source(I_A). Once the equivalent-current noises are obtained from the Monte Carlo Method, it is easy to calculate the input noises (Fig. 2. b)). The relations between equivalent current noises and input noises

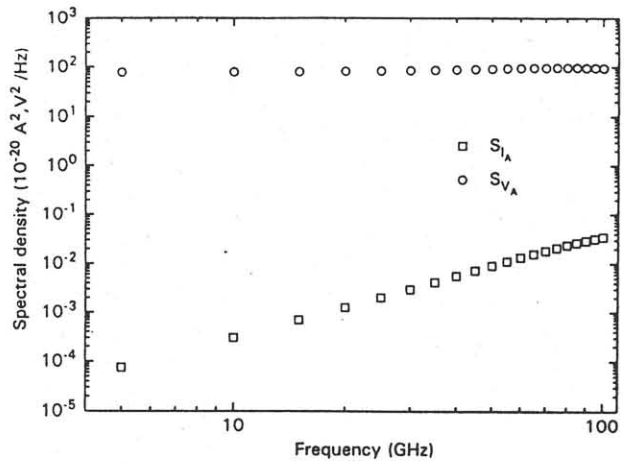

Fig. 4. Spectral densities of equivalent input current noise a) S_{I_A} and equivalent input voltage noise b) S_{V_A}.

are written as follows [9],

$$V_A = \frac{-1}{y_{21}} I_D, \tag{1}$$

$$I_A = I_G - \frac{y_{11}}{y_{21}} I_D, \tag{2}$$

and spectral densities of equivalent input noises are taken to be as

$$S_{V_A} = \overline{V_A V_A^*} = \frac{1}{|y_{21}|^2} S_{I_D}, \tag{3}$$

$$S_{I_A} = \overline{I_A I_A^*} = S_{I_G} + |\frac{y_{11}}{y_{21}}|^2 S_{I_D}$$
$$-2Re(\frac{y_{11}}{y_{21}})Re(S_{I_GI_D}) - 2Im(\frac{y_{11}}{y_{21}})Im(S_{I_GI_D}), \tag{4}$$

and are shown in Fig. 4. S_{I_A} increases linearly with frequency in the log-log figure and S_{V_A} is almost constant with frequency. The correlation impedance is given by

$$Z_{cor} = \frac{\overline{V_A I_A^*}}{\overline{|I_A|^2}}, \tag{5}$$

$$R_{cor} = (-\frac{Re(y_{21})}{|y_{21}|^2} Re(S_{I_GI_D}) + \frac{Im(y_{21})}{|y_{21}|^2} Im(S_{I_GI_D})$$
$$+ \frac{Re(y_{11})}{|y_{21}|^2} S_{I_D})/S_{I_G}, \tag{6}$$

$$X_{cor} = (\frac{Im(y_{21})}{|y_{21}|^2} Re(S_{I_GI_D}) + \frac{Re(y_{21})}{|y_{21}|^2} Im(S_{I_GI_D})$$
$$- \frac{Im(y_{11})}{|y_{21}|^2} S_{I_D})/S_{I_G}, \tag{7}$$

The spectral density of uncorrelated voltage V_u is expressed as

$$S_{V_u} = S_{V_A} - |Z_{cor}|^2 S_{I_A} \tag{8}$$

Correlation coefficient

$$c = \frac{S_{V_A I_A}}{\sqrt{S_{V_A} S_{I_A}}}, \tag{9}$$

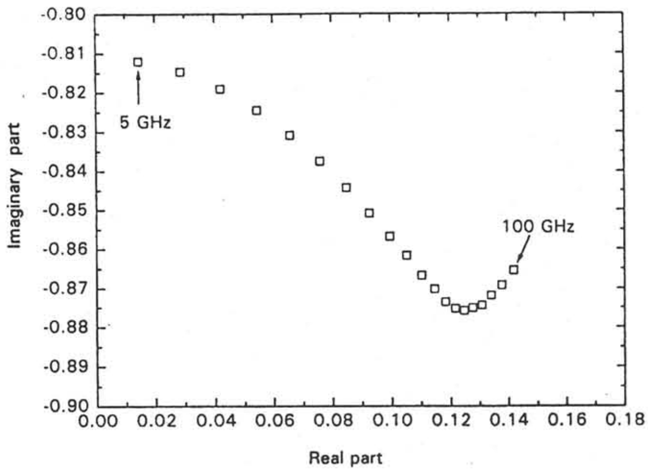

Fig. 5. Correlation coefficient versus frequency.

Frequency (GHz)	NFmin (dB)	Mag. (Γ)	Ang. (Γ)	r_n
10	0.6336564	0.8931553	9.151689	0.1381752
20	1.243109	0.8463390	18.63930	0.1402799
30	1.825872	0.7356056	28.55507	0.1432572
40	2.368925	0.6859367	38.67533	0.1464294
50	2.865246	0.6516768	48.53139	0.1493080
60	3.304677	0.6296222	57.83477	0.1514839
70	3.690338	0.6148225	66.28894	0.1527366
80	4.051513	0.6011160	73.89053	0.1531398
90	4.380895	0.5890011	80.64871	0.1527680
100	4.698034	0.5770005	86.73903	0.1519323

Table 1. Noise parameters of $0.2\mu m$ gate length plannar MESFET.

is shown in Fig. 5.

C. Noise parameters

We can extracted all the noise parameters(noise figure minimum, normalized equivalent noise resistance, optimal noise input generator reflection coefficient) by use of above results. Table 1. shows calculated noise parameters. Noise figure minimum is slightly smaller than the reported experiment [11], because external resistance is excluded in this calculation.

We believe that the parameter extraction scheme is quite useful to optimize low noise devices, because the parameters are readily used in low noise-circuit design.

4. Conclusions

We have extracted all the noise parameters of a submicrometer MESFET with 2-D Monte Carlo Method for the first time. The general scheme to extract the noise parameters is presented. This allows us to analyze the noise and the gain characteristics completely. Also we believe that this can be also used in optimizing low noise devices and circuits.

References

1) N. Shiga, S. Nakajima, K. Otobe, T. Sekiguchi, N. Kuwata, Ken-ichiro Matsuzaki, and H. Hayashi, IEEE MMWMCS. (1991) 65.

2) D. C. Wang, R. G. Pauley, Shing-Kuo Wang, and L. C. T. Liu, IEEE Trans.Elec. Dev. **33** (1986) 2084.

3) C. Moglestue, IEEE Trans. Elec. Dev. **32** (1985) 2092.

4) C. Jacoboni and P. Lugli, " The Monte-Calro method for semiconductor device simulation," Springer-Verlag New York (1989).

5) M. A. Littlejohn, J. R. Hauser, and T. H. Glisson, J. Appl. Phys. **48** (1977) 4587.

6) V. Gruzinskis, S. Kersulis and A. Reklaitis, Semicond. Sci. Technol. **6** (1991) 602.

7) C. K. Williams, T. H. Glisson, J. R. Hauser, M. A. Littlejohn, and M. F. Abusaid, Solid-St. Elec. **28** (1985) 1105.

8) Y. Awano, K. Tomizawa, and N. Hashizme, IEEE Trans. Elec. Dev. **31** (1984) 448.

9) G. D. Vendelin, A. M. Pavio, and U. L. Rohde, " Microwave circuit design using linear and nonlinear techniques," Wiley (1990).

10) T. Gonzalez, D. Pardo, L. Varani, and L. Reggiani, IEEE Trans. Elec. Dev. **42** (1995) 991.

11) M. Feng, and J. Laskar, IEEE Trans. Elec. Dev. **40** (1993) 9.