A SIMPLE EMPIRICAL NOISE MODEL OF SUBMICRON-GATE GaAs MESFET FOR CAD APPLICATIONS

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Abstract

A simple empirical noise model of GaAs MESFETs with submicron gate is presented. From noise parameter measurements on various types of GaAs MESFETs, the intrinsic noise current sources have been found to be represented in simple empirical equations. Hence the noise parameters can be determined only from its small-signal equivalent circuit, and a good agreement is obtained between the model and measurement. The model presented here does not require additional noise measurement, and is suitable especially for microwave CAD applications.

Introduction

GaAs MESFETs are widely used for low-noise applications in microwave and millimeter-wave frequencies. Their noise properties are characterized by the noise parameters; the minimum noise figure Fmin, the effective noise resistance Rn and the optimum source reflection coefficient Γopt.

The noise parameters of GaAs MESFETs are determined by experimental measurement [1]-[3], or by theoretical analysis based on physical model [4], [5], or by empirical model [6]-[11]. Among these, an empirical noise model, if applicable to a wide range of device geometry and operation, would be most preferable, since it provides an efficient and ecomonical means of noise parameter calculation for computer-aided design (CAD) of microwave integrated circuits (MICs) and monolithic MICs (MMICs).

In this paper, a simple empirical noise model of submicron-gate GaAs MESFETs is described. While the previously reported empirical models [8]-[11] require noise measurement in addition to the small-signal equivalent circuit of FETs, the model presented here enables to calculate the noise parameters only from the small-signal equivalent circuit.

Noise Model of GaAs MESFETs

The noise model of GaAs MESFETs can be described by using a small-signal equivalent circuit and noise sources as shown in Fig. 1. The noise due to each parasitic resistance is the thermal noise associated with each resistance at ambient temperature T_0, and is given by

$$\langle vr \cdot vr^* \rangle = 4\ k\ T_0\ B\ Rp \qquad (1)$$

where vr denotes the thermal noise voltage generated in the resistance Rp, $\langle\ \rangle$ a statistical average, * the complex conjugate, and k is the Boltzmann's constant, B the bandwidth. On the other hand, the noise of intrinsic FET is related with two partially correlated noise current sources, ig and id, having the following relations [4];

$$\langle ig \cdot ig^* \rangle = 4\ k\ T_0\ B\ Ggn \qquad (2)$$
$$\langle id \cdot id^* \rangle = 4\ k\ T_0\ B\ Gdn \qquad (3)$$
$$\langle ig^* \cdot id \rangle = 4\ k\ T_0\ B\ (jC(Ggn\ Gdn)^{1/2}) \qquad (4)$$

where Ggn is the gate noise conductance, Gdn the drain noise conductance, C the correlation coefficient of ig and id, and $j^2 = -1$.

Using (1)-(4), noise parameters can be calculated easily by the method in [12].

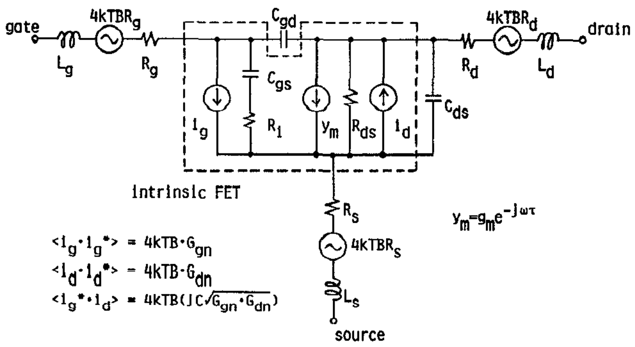

Fig. 1 Noise model of GaAs MESFET.

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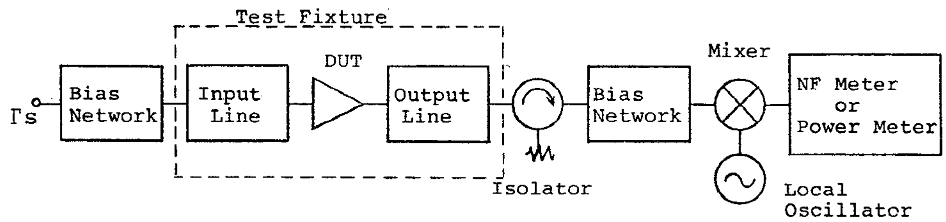


Fig. 2 Diagram of noise parameter measuring system.

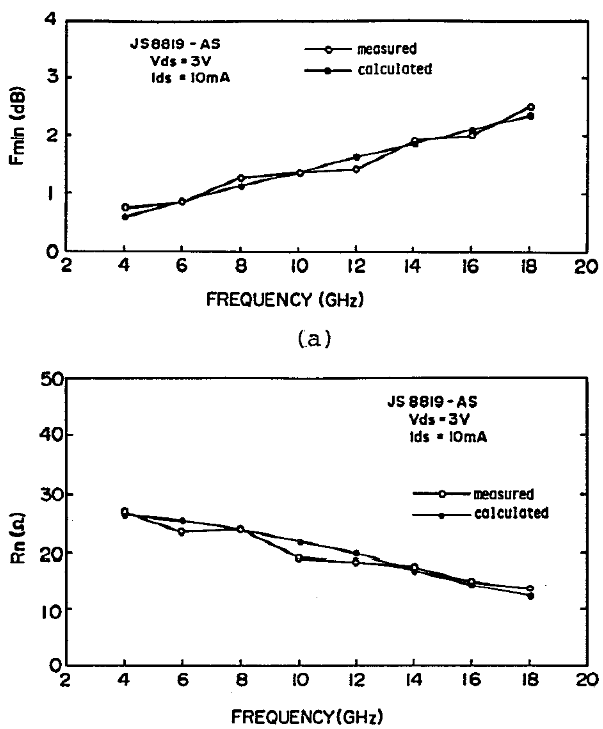
Experimantal Measurement

In order to determine Ggn, Gdn and C, noise parameters and S-parameters have been measured on various types of GaAs MESFETs.

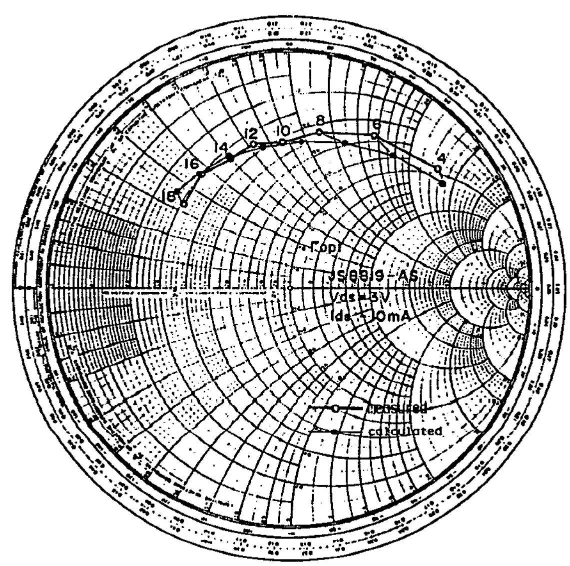
Noise parameter measurement has been done over 4-18 GHz by using the modified method in [3]. Noise parameters have been obtained from the dependence of the output noise power on the source reflection coefficient Γs. The diagram of noise parameter measuring system is shown in Fig. 2. Various values of Γs have been realized using offset shorts and a 50-ohm termination. Noise contribution of test fixture and measurement setup including the mismatch effect between the device under test (DUT) and measuring system has been compensated for using the noise wave concept. This allows to eliminate the use of output tuner, thereby simplifying broadband noise parameter measurement. The DUTs have been mounted in a 50-ohm coplanar waveguide test fixture.

An example of measured noise parameters of Toshiba GaAs MESFET JS8819-AS is shown in Fig. 3, where the drain-source voltage Vds = 3 V and drain current Id = 10 mA.

The small-signal equivalent circuit has been determined from S-parameters and DC measurements. The S-parameters have been measured over the frequency range of from 2 GHz to 18 GHz with an automatic network analyzer. In order to obtain the accurate value of parasitic resistances Rg, Rs and Rd, which generate thermal noise, the DC measurements have been done [13]. The equivalent circuit parameters have been determined by optimum fitting of the calculated S-parameters to the measured data.



(b)



(c)

Fig. 3 Frequency dependence of the measured and calculated noise parameters of a GaAs MESFET JS8819-AS. (a) Minimum noise figure Fmin; (b) Effective noise resistance Rn; (c) Optimum source reflection coefficient Γs.

Experimental Results

Using the measured noise parameters and the small-signal equivalent circuit parameters, intrinsic noise parameters, Ggn, Gdn and C have been obtained by fitting the calculated results by Fig. 1 to the measured data. Gdn and C have been found to depend strongly upon the drain current Id and gate width Wg, and have little dependence on the gate length for GaAs MESFETs with 0.25-0.5 μm. It is also found that Gdn per unit gate width (Gdn/Wg) and C are nearly determined by the drain current per unit gate width (Id/Wg). On the other hand, Ggn has been found nearly equal to the input conductance of FETs. Thus we have

$$Ggn = Ri\ \omega^2 Cgs^2/(1 + \omega^2 Cgs^2 Ri^2) \quad (5)$$

where ω denotes the radian frequency.

The measured Id/Wg dependences of Gdn/Wg and C are shown in Fig. 4 and Fig. 5, respectively, where Vds = 3 V, ambient temperature T_0 = 298 K and Ggn is given by eq. (5). The measurements have been done on Toshiba GaAs MESFETs of JS8819-AS, JS8818-AS, JS8830-AS and JS8870-AS, with a gate length of 0.5 μm and a gate width of 300 μm, 0.3 μm and 300 μm, 0.25 μm and 200 μm, and 0.5 μm and 300 μm, respectively. JS8870-AS is fabricated on ion-implanted wafers, and others on epi-wafers. From Fig. 4 and 5, the following experimental formulas have been obtained by least-square fitting;

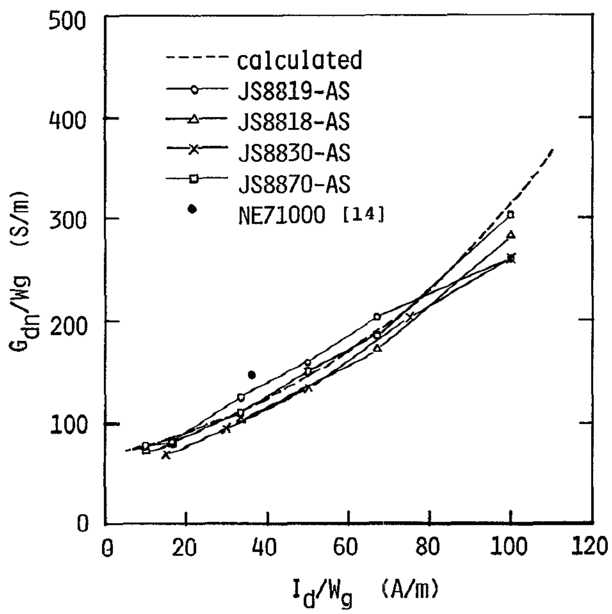


Fig. 4 Id/Wg dependence of Gdn/Wg on various types of GaAs MESFETs at drain-source voltage of 3 V.

$$Gdn = 67.6\ Wg\ \exp(0.0154\ Id/Wg) \quad (6)$$
$$C = 1.8 - 0.9\ \exp(0.00245\ Id/Wg) \quad (7)$$

where Gdn is in S, Id in A and Wg in m. In the figures, the calculated values from (6) and (7) are shown in broken lines. Furthermore an NEC GaAs MESFET NE71000 with 0.3 μm gate length and 280 μm gate width fabricated on epi-wafer also exhibits almost the same values as ours as plotted in Fig. 4 and 5. The data of NE71000 have been obtained from the noise parameters and S-parameters in technical data sheets [14]. These figures indicate that the formulas (5)-(7) give good approximations for the noise in intrinsic FETs.

The noise parameters of JS8819-AS calculated using (5)-(7) are shown in Fig. 3. The equivalent circuit element values of JS8819-AS at Vds = 3 V and Id = 10 mA are shown in Table 1. Fig. 6 shows the

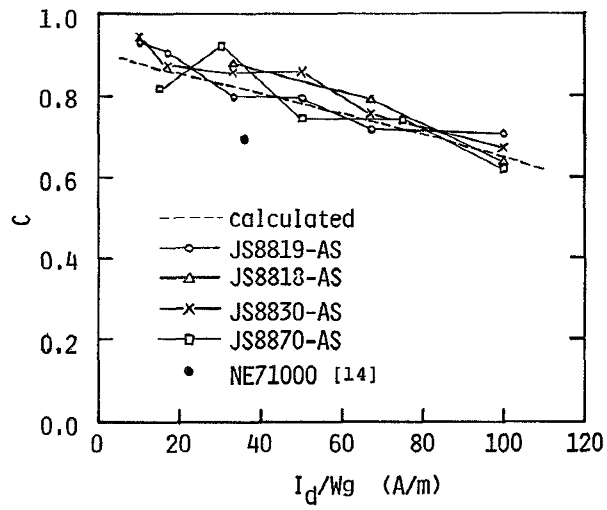


Fig. 5 Id/Wg dependence of C on various types of GaAs MESFETs at drain-source voltage of 3 V.

Table 1 Equivalent circuit element values of JS8819-AS at Vds = 3 V and Id = 10 mA.

intrinsic elements			parasitic elements		
g_m	44.7	(mS)	R_g	3.32	(Ω)
τ	3.24	(ps)	R_s	1.49	(Ω)
C_{gs}	0.347	(pF)	R_d	2.57	(Ω)
R_i	2.78	(Ω)	C_{gd}	0.034	(pF)
R_{ds}	289	(Ω)	C_{ds}	0.127	(pF)
			L_g	0.119	(nH)
			L_s	0.018	(nH)
			L_d	0.077	(nH)

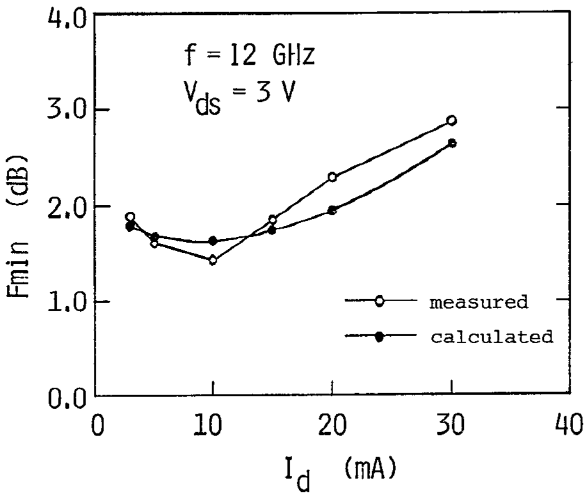


Fig. 6 Id dependence of minimum noise figure Fmin of JS8819-AS at a frequency of 12 GHz and Vds of 3 V.

drain current dependence of the measured and calculated minimum noise figure Fmin at a frequency of 12 GHz and Vds = 3 V. As shown in Fig. 3 and Fig. 6, a good agreement is obtained between the model and measurement. This means that noise parameters are well characterized by using the formulas (5)-(7). Hence the model proposed here is suitable for efficient calculation of noise characteristics of GaAs MESFET.

Conclusion

A simple empirical noise model of GaAs MESFETs with submicron gate has been presented. The intrinsic noise currnt sources can be described by simple experimental formulas from the measured results on various types of GaAs MESFETs, and hence the noise parameters can be calculated without additional noise measurement. Thus the model gives an efficient means for computer-aided design of microwave integrated circuits in terms of noise optimum design.

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