COHERENCE OF 1/f VOLTAGE FLUCTUATIONS AT GATE AND DRAIN IN MODFET'S

Theo Kleinpenning, Philippe Hervé and Bas Vermeulen
Eindhoven University of Technology, Dept. EE, P.O. Box 513,
Eindhoven, The Netherlands

ABSTRACT

The gate and drain voltage fluctuations and their coherence have been investigated on MODFET's (HEMT's). New expressions are presented for the coherence. These expressions are compared with experimental results. A fair agreement has been found between theory and experiment.

INTRODUCTION

Recently, Vandamme et al.[1] reported on the coherence γ_I^2 of 1/f fluctuations in the gate and drain current in MESFET's and MODFET's.

$$\gamma_I^2 = S_{I_G I_D}^2 / S_{I_G} . S_{I_D} \quad \text{with } 0 \leq \gamma_I^2 \leq 1 \tag{1}$$

Here $S_{I_G I_D}$ is the cross-power spectrum of gate- and drain-current fluctuations. Some investigated devices showed an absence of coherence, i.e. below the detection limit of 0.01. Other devices showed a coherence as high as 0.55. Vandamme et al. interpreted their results with the help of a fluctuating ohmic leakage conductance between gate electrode and channel. They considered several types of leakage paths. The calculated coherence depends on the type of leakage path. Without leakage conductance there should be no coherence.

In this paper we present calculations of the coherence of ideal MODFET's and MESFET's biased in the ohmic region. There is only a Schottky barrier in between gate and channel, there are no leakage paths. For such devices we found non-negligible values for the coherence. Our calculated results are compared with experimental results.

CALCULATIONS OF THE COHERENCE FOR OPEN CIRCUIT AND SHORT CIRCUIT

Consider a FET in the ohmic region with a homogeneous channel, a homogeneous distributed gate current (thus $V_{DS} < kT/q$) and $I_G << I_D$.

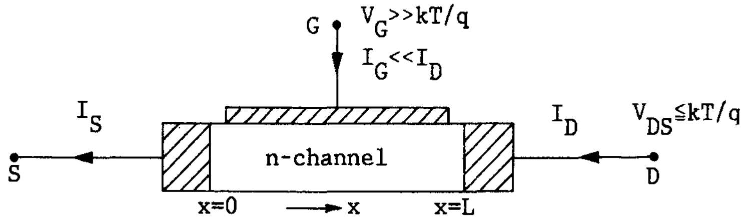

Fig. 1. Diagram of the MODFET (MESFET)

For the fluctuations in the gate current we have

$$\Delta I_G = \Delta I_G^* + \Delta I_G^{ind} = {}_0\int^L \Delta i_g^*(x)dx + {}_0\int^L [di_g(x)/dV_B(x)]\Delta V_B(x)dx \quad (2)$$

where ΔI_G^* is the spontaneous fluctuation and ΔI_G^{ind} the induced one. $V_B(x) = V_G(x) - V(x)$ is the voltage across the Schottky barrier at spot x, and $i_g(x)$ the gate current per unit length. For a homogeneous situation we have $di_g(x)/dV_B(x) = d(I_G/L)/dV_B = 1/(LZ_B)$.
The fluctuations in the channel current $\Delta I(x)$ are given by

$$\Delta I(x) = (I/\sigma)\Delta\sigma^*(x) + (I/\sigma)\Delta\sigma^{ind}(x) + A\sigma\Delta E(x) \quad (3)$$

with $\Delta\sigma^*$ the spontaneous fluctuations in the conductivity, $\Delta\sigma^{ind}(x)= (d\sigma/dV_B)\Delta V_B(x)$ the induced fluctuations, and $\Delta E(x)$ the electric field fluctuations. For the fluctuations $\Delta I(x)$ we can also write

$$\Delta I(x) = \Delta I_D + {}_x\int^L \Delta i_g(y)dy = \Delta I_D + {}_x\int^L \Delta i_g^*(y)dy + \frac{1}{LZ_B}\, {}_x\int^L \Delta V_B(y)dy \quad (4)$$

where ΔI_D is the fluctuation in the drain current. With the help of Eqs. (2-4) the coherence can be calculated for a FET operating in the strong inversion region where $\sigma \sim V_G - V_T = V_G^* > 0$. Here V_T is the threshold voltage. Then we obtain $d\sigma/dV_B = d\sigma/dV_G^* = \sigma/V_G^*$. Furthermore, we make the approximation

$$V_G^*/Z_B \approx V_B/Z_B \approx (qV_B/kT)I_G << I_D \approx I$$

which implies that the Schottky barrier is forward-biased ($V_B > 0$). The open-circuit gate- and drain-voltage 1/f fluctuations can be calculated with the help of Eqs. (2-4) and taking $\Delta I_D = \Delta I_G = 0$. We obtain with Eqs. (3) and (4)

$$\Delta V_{DS} = {}_0\int^L \Delta E(x)dx \simeq \frac{I}{A}\, {}_0\int^L \Delta\rho^*(x)dx + \frac{\rho}{A}\, {}_0\int^L x\Delta i_g^*(x)dx - \frac{V_{DS}}{LV_G^*}\, {}_0\int^L \Delta V_B(x)dx \quad (5)$$

with $\rho = 1/\sigma$ and $V_{DS} = I\rho L/A$. From Eq. (2) we find

$${}_0\int^L \Delta V_B(x)dx = -\, LZ_B\, {}_0\int^L \Delta i_g^*(x)dx = -\, LZ_B\Delta I_G^* \quad (6)$$

Combining Eqs. (5) and (6) yields

$$\Delta V_{DS} \simeq (I/A)\, {}_0\int^L \Delta\rho^*(x)dx + (V_{DS}Z_B/V_G^*)\Delta I_G^* \quad (7)$$

The fluctuations in V_{GS} are given by

$$\Delta V_{GS} = \frac{1}{L}\, {}_0\int^L \left[\Delta V_B(x) + \Delta V(x)\right]dx = -\, Z_B\Delta I_G^* + {}_0\int^L \left(1 - \frac{x}{L}\right)\Delta E(x)dx \quad (8)$$

The last integral in Eq. (8) consists of two contributions. According to Eqs. (5) and (7) the first contribution is given by

$$\frac{I}{A}\int_0^L \left(1 - \frac{x}{L}\right)\Delta\rho^*(x)dx \tag{9}$$

and the second one is lower than $(V_{DS}Z_B/V_G^*)\Delta I_G^*$ due to the factor $(1 - x/L) \leq 1$. Since $V_{DS} \ll V_G^*$ the second contribution can be neglected with respect to the term $Z_B\Delta I_G^*$ in Eq. (8). Hence we have the approximation

$$\Delta V_{GS} = - Z_B\Delta I_G^* + \frac{I}{A}\int_0^L \left(1 - \frac{x}{L}\right)\Delta\rho^*(x)dx \tag{10}$$

For the open-circuit gate- and drain-voltage 1/f noise we then obtain with Eqs. (7) and (10) and $\Delta R^* = \int\Delta\rho^*(x)dx/A$

$$S_{V_{GS}} = (1/3)I^2S_{R^*} + Z_B^2S_{I_G^*} \tag{11}$$

$$S_{V_{DS}} = I^2S_{R^*} + (V_{DS}/V_G^*)^2Z_B^2S_{I_G^*} \tag{12}$$

$$\gamma_V^2 = \frac{S^2_{V_{DS}V_{GS}}}{S_{V_{DS}}.S_{V_{GS}}} = \frac{\left[(1/2)I^2S_{R^*} - (V_{DS}/V_G^*)Z_B^2S_{I_G^*}\right]^2}{S_{V_{DS}}\,.\,S_{V_{GS}}} \tag{13}$$

Here γ_V^2 is the coherence between gate- and drain-voltage 1/f noise, $S_{I_G^*}$ the spontaneous noise in the gate current and S_{R^*} the spontaneous noise of the channel resistance.

EXPERIMENTAL RESULTS

We have performed coherence measurements on MODFET's from Fujitsu at 300 K. The measurements were carried out at low frequencies and with open-circuit gate and drain. At frequencies below 1 kHz the 1/f noise prevails both at the gate and at the drain. We have measured γ_V^2 as a function of V_{DS}. According to Eq. (13) we have

$$\gamma_V^2 = \frac{[(1/2)V_{DS} - V_o^2/V_G^*]^2}{[1 + V_o^2/V_G^{*2}][(1/3)V_{DS}^2 + V_o^2]} \approx \left[\frac{V_{DS} - 2V_o^2/V_G^*}{2V_o}\right]^2 \tag{14}$$

with

$$V_o = \left[Z_B^2S_{I_G^*}/(S_R^*/R^2)\right]^{\frac{1}{2}} \sim N_{ch}^{\frac{1}{2}} \sim V_G^{*\frac{1}{2}} \tag{15}$$

The approximation made in Eq. (14) is justified for $V_{DS} \ll V_o \ll V_G^*$.

For the MODFET (type FHX05LG) at $f = 1$ Hz we found experimentally $Z_B^2 S_{I_G^*} \approx 10^{-12}$ V^2/Hz to be almost independent of the gate current hence $V_o \sim [S_R^*/R^2]^{-\frac{1}{2}} \sim N_{ch}^{\frac{1}{2}} \sim V_G^{*\frac{1}{2}}$. The coherence measurements were carried out at $V_G^* \approx 1$ V and with $V_{DS} < kT/q$. The relative channel resistance noise at $f = 1$ Hz is found to be $S_R^*/R^2 \approx 10^{-10}\,Hz^{-1}$, hence $V_o \approx 0.1$ V. For $V_{DS} << 2V_o^2/V_G^*$ we calculate $|\gamma_V|$ to be $V_o/V_G^* \approx 0.1$. In Fig. 2 we have plotted both the calculated and the experimental results of $|\gamma_V|$ versus V_{DS} of the MODFET with $2V_o^2/V_G^* = 12$ mV.

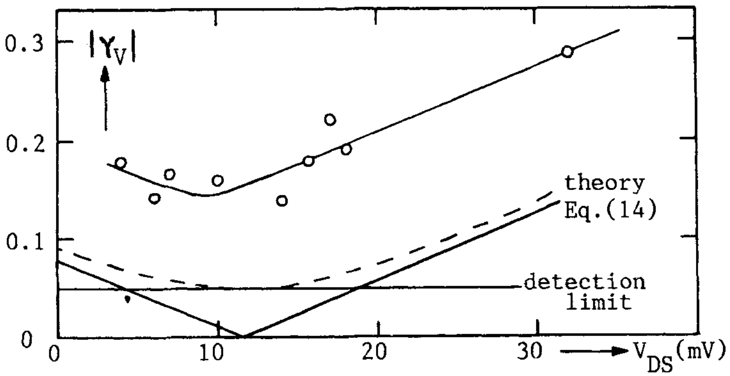

Fig. 2. Coherence $|\gamma_V|$ as a function of V_{DS} for MODFET FHX05LG

We have also measured γ_V as a function of V_{DS} ($\leq kT/q$) of two MODFET's of type FHX35LG. Here we found $V_o = 0.3$ V at $V_G^* = 0.7$V and thus $2V_o^2/V_G^* = 0.26$V. For both devices we found experimentally $\gamma_V \approx 0.1$ and theoretically $\gamma_V \approx V_o/V_G^* \approx 0.4$.

In Fig. 2 there is a fair agreement between theory and experiment. However, for the FHX35LG's we find a rather low value for γ_V^{exp}. This can be caused by imperfections in the MODFET. For example, if the 1/f noise in V_{DS} is determined by the internal series resistances, then Eq. (13) does not apply. Fluctuating leakage conductances between gate and channel, as observed by Vandamme et al.[1], make Eq. (13) also invalid. Nevertheless, it is obvious that ideal devices have non-negligible coherences.

REFERENCES

1. L.K.J. Vandamme, D. Rigaud and J.-M. Peransin, IEEE-ED 39, 2377, (1992).