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Simulation of Temperature Dependence of Microwave Noise in MOS Transistors

Michael Obrecht* and Tajinder Manku
RF Technology Group, Electrical and Computer Engineering Department, University of Waterloo
Waterloo, Ontario, N2L 3G1 Canada
Phone: 519-888-4567 ext. 2082 Fax: 519-746-5195 e-mail: obrecht@siborg.ca

1. Introduction

2D transient device simulation was used to evaluate temperature dependence of the microwave noise in MOS transistors. The method had proven to predict realistically noise parameters of MOS transistors. Results for a 0.5 μm LDD NMOS transistor are presented. The results show strong temperature effect on the noise that is not described by existing models.

Improved characteristics of sub-micron MOS transistors (see e.g. [1]) made CMOS a viable RF technology for portable wireless systems. For RF circuits, low noise design is one of the key issues. Unavailability of a good MOSFET high frequency noise model in commonly used circuit simulators makes RF circuit design very difficult. A limited amount of information on this subject is published and it is primarily experimental data [2,3].

A two-dimensional device simulation is usually used to predict characteristics of short channel MOSFETs. Recently it has been demonstrated that two-dimensional noise simulation can be successfully used to predict noise in practical semiconductor devices [4-6]. It has also been shown [5,6] that conventional expression for the channel noise fails for short channel MOSFETs indicating that the nature of carrier transport changes for short channel MOSFETs.

To further investigate possible causes of this change and possibly to characterize the main cause it seems appropriate to vary other parameters affecting the noise, for example the temperature. Besides, this study would also have a practical application such as design issues for equipment operating in extreme conditions, for example onboard an aircraft.

In this paper, we use transient 2-D device simulation to characterize the microwave noise performance of a MOSFET at temperatures ranging from 200 to 400 degrees Kelvin. The method allows not only to calculate the device noise performance but also to visualize an internal noise sources inside the device. Therefore, the method can be used to optimize the device structure/process for better noise performance.

*also with Siborg Systems Inc, www.siborg.ca

2. Simulation Method

The 2-D noise simulation has been implemented into the framework of the device simulator developed by Siborg Systems Inc. The noise spectra are obtained using a method similar to the Impedance Field Method (see e.g. [4]).

In this procedure, a noise current is injected at each grid point within a 2-D device structure and the terminal currents are recorded as a function of the position in which they were injected. For each injected source, the induced noise current at the terminals can be obtained using,

$$i_\alpha(t) = \int_{-\infty}^{t}\int_{\Omega} G_\alpha(\bar{r},t,t_1)s(\bar{r},t_1)d\bar{r}dt_1 \tag{1}$$

where i_α (t) is the induced noise current at the terminal α, ***s(r,t)*** is the electron injection rate caused by the noise at the location ***r***, Ω is the domain of the device, and $G_\alpha(\bar{r},t,t_1)$ is the current transfer function. This function represents the fraction of current emerging through terminal α due to the injected current at position ***r***. This interpretation of the function $G_\alpha(\bar{r},t,t_1)$ becomes clear when we apply a Fourier transformation to (1), obtaining,

$$i_\alpha(\omega) = \int_{\Omega} G_\alpha(\bar{r},\omega)s(\bar{r},\omega)d\bar{r} \tag{2}$$

where we have assumed a stationary condition. From this interpretation, it clear that G_α is closely related to the Green's function (Impedance Field) defined in [4].

After $G_\alpha(\bar{r},\omega)$ is constructed, the power spectrum density and the noise correlation are determined using,

$$<i_\alpha i_\beta^*> = \int_{\Omega} \nabla_{\bar{r}} G_\alpha(\bar{r},\omega)\cdot \hat{K}(\bar{r},\omega)\cdot \nabla_{\bar{r}} G_\beta^*(\bar{r},\omega)d\bar{r} \tag{3}$$

where $\hat{K}(\bar{r},\omega) = 4q^2\hat{D}(\bar{r})n(\bar{r})$ and $\hat{D}(\bar{r})$ is the diffusivity tensor, $n(\bar{r})$ is the electron density at the DC operating point.

Using the technique described in equations (1-3), the current noise sources $<i_g^2>$, $<i_d^2>$ and the correlation term $<i_g^* \cdot i_d>$ are calculated and can be easily translated into the measurable noise parameters [5,6].

3. Results and Discussion

An industrial 0.5 µm CMOS LDD MOSFET was simulated. The process parameters were first entered into the 2-D device simulation program and the simulated I-V curves were calibrated using measured I-V data. For further comparison, the simulated f_t's of the device were compared to the measured results. A maximum f_t of 21 GHz was measured, which agreed with our simulated results. Five different bias conditions were used in evaluating the noise parameters of the device and they appeared in reasonable agreement with the measured data [5,6]. The results also indicated very high values (of the order of 6) of the noise factor γ defined as follows

$$< i_d^2 >= 4kT\gamma g_{d0}\Delta f \qquad (5)$$

Where g_{d0} is the zero voltage drain-source conductance, k is Boltzmann's constant, T is the temperature of the carriers and Δf is the noise bandwidth.

This shows that short channel MOSFETs behave very differently compared to long channel MOSFETs for that γ should be equal to 2/3 in saturation and to 1 in linear regime.

To further investigate the difference in noise characteristics of short and long channel MOSFETs we simulated noise spectra of a 0.5 channel NMOSFET for temperatures from 200 to 400 degrees Kelvin.

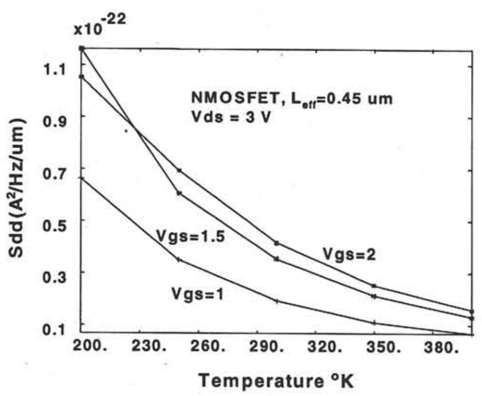

Fig. 1 Temperature dependence of the drain noise spectrum at three different biases.

The results presented in Fig.2 show that temperature affects channel noise much stronger than it would be expected. For the NMOSFET under consideration g_{d0} decreases with the temperature slightly slower than $T^{-3/2}$. That is, according to (5), $<i_d^2>$ should be roughly proportional to $T^{-1/2}$ but we see almost exponential dependence in Fig.1 instead.

Fig. 2 shows the effect of the temperature on the distribution of the local drain noise in the channel. The noise is primarily localized on the source side of the channel.

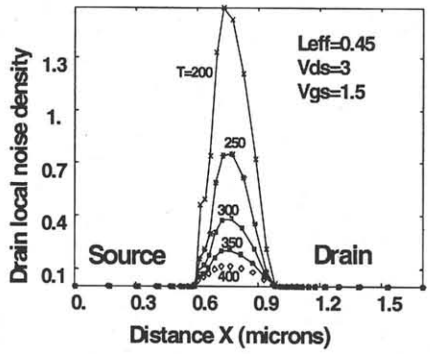

Fig. 2 Drain local noise density distribution for different temperatures in relative units.

4. Conclusions

Transient semiconductor device simulator calibrated using measurement data has been used for channel noise analysis in a NMOSFET at different temperatures. The results show that conventional formula based on thermal nature of the channel noise is inadequate for short channel MOSFETs. Hot electron effects that appear to be insignificant for the device studied cannot explain this difference. It is likely that shot noise dominates the conventionally assumed thermal noise in short channel MOSFETs.

Acknowledgements

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Reference

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