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Temperature Dependence of High Frequency Noise Behaviors for RF MOSFETs

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***Abstract*—For the first time, the temperature dependences of radio frequency (RF) metal oxide semiconductor field effect transistors' intrinsic noise currents, including the induced gate noise current (i_g), channel noise current (i_d) and their correlation noise current, are experimentally investigated. The power spectral densities for the induced gate noise current and correlation noise current are found to rise as temperature increases, and decline for the channel noise current. Moreover, by using van der Ziel's noise model, our experimental results show that, besides ambient temperature, the channel conductance is the main factor dominating the RF noise behaviors. Finally, bias dependence results are also presented.**

***Index Terms*—Metal oxide semiconductor field effect transistors (MOSFETs), noise, radio frequency (RF), temperature, van der Ziel's model.**

I. INTRODUCTION

THE noise performance of radio frequency metal oxide semiconductor field effect transistors (RF MOSFETs) is critical to RF applications, especially to the design of low noise amplifiers, resulting in a need for the accurate noise modeling [1]. Besides, it is well known that both the small-signal circuit parameters and noise sources play important roles in RF noise modeling. The temperature dependence of small-signal performance has been widely discussed [2], [3], but that of RF noise sources was deficient. Therefore, for the purpose of temperature modeling and understanding the underlying physics, the temperature dependence of noise sources demands investigation.

Pascht *et al.* have presented the temperature noise model by exploiting the circuit simulator [4]. However, only the channel noise source has been included, and its temperature dependence was not clear. In this letter, we will experimentally study the temperature dependence of the power spectral densities (PSDs) for the induced gate noise current (S_{ig}), channel noise current (S_{id}) and their correlation noise current (S_{igd^*}) for the RF MOSFET. The popular van der Ziel's model is also used to check its applicability at different temperatures. Along with the extracted small-signal and van der Ziel's model parameters, their temperature dependences can be well described. Finally, their bias dependence results as a function of temperature are also presented.

II. DEVICES AND MEASUREMENTS

The RF MOSFETs used in this study were fabricated using UMC 0.13 μm bulk technology. The transistor's gate length, finger length, finger number and group number are 0.36 μm, 3.6 μm, 16 and 2, respectively.

The noise parameters of the device under different temperatures were measured using ATN NP5B noise parameter measurement system. The pads and series parasitics were de-embedded to obtain the intrinsic noise parameters. Finally, the intrinsic noise current sources were extracted by following the approach presented in [5].

III. RESULTS AND DISCUSSIONS

The van der Ziel's model widely adopted to characterize S_{ig}, S_{id}, and S_{igd^*} can be expressed as follows [6]:

$$S_{ig} = \frac{\overline{i_g i_g^*}}{\Delta f} = \delta 4kT \frac{\omega^2 C_0^2}{g_{d0}} \tag{1}$$

$$S_{id} = \frac{\overline{i_d i_d^*}}{\Delta f} = \gamma 4kT g_{d0} \tag{2}$$

$$S_{igd^*} = \frac{\overline{i_g i_d^*}}{\Delta f} = j\varepsilon 4kT\omega C_0 \tag{3}$$

where C_0 is the gate capacitance $(=3C_{\rm gs}/2)$, g_{d0} is the channel conductance at zero drain bias, k is Boltzmann constant, and T is the ambient temperature in Kelvin. A fairly good data-model comparison of S_{ig}, S_{id} and S_{igd^*} for the device under study biased at $V_{\rm GS} = V_{\rm DS} = 1.2$ V can be obtained and are shown in Figs. 1 –3, respectively.

In these figures, one can find that S_{ig} and S_{igd^*} would become larger for higher ambient temperature. For S_{id}, however, it tends to decrease with increasing temperature. To explain these different trends, Table I lists the extracted C_0, g_{d0} and their normalizations with respect to their cases at -40°. Besides, the extracted model parameters δ, γ and ε for different temperatures are also shown in Fig. 4. It is also worth noting that the van der Ziel's model was originally derived for long channel devices, and the model parameters should be $\delta_{\rm sat} = 16/135, \gamma_{\rm sat} = 2/3$, and $\varepsilon_{\rm sat} = 1/9$ in the saturation region. It is no surprise that for

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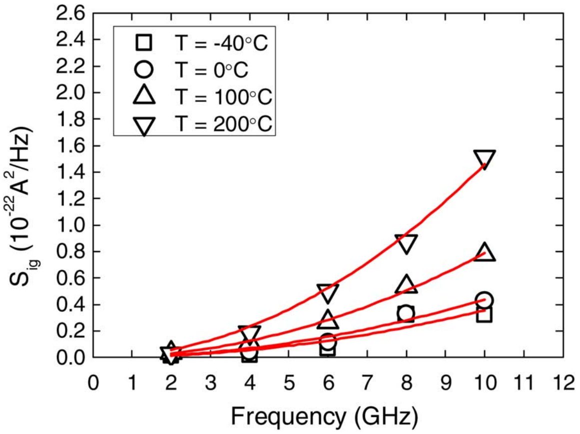


Fig. 1. Induced gate noise (S_{ig}) versus frequency under different temperatures. ($V_{\rm GS} = V_{\rm DS} = 1.2$ V).

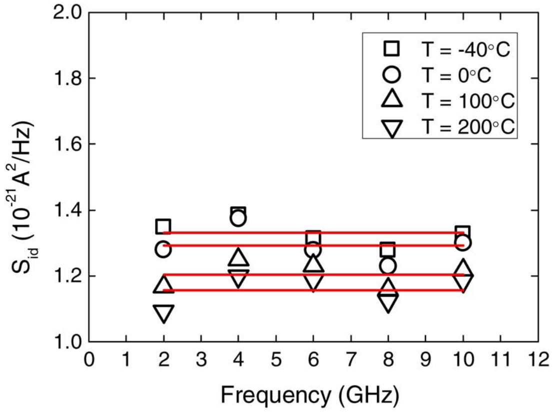


Fig. 2. Channel noise (S_{id}) versus frequency under different temperatures. ($V_{\rm GS} = V_{\rm DS} = 1.2$ V).

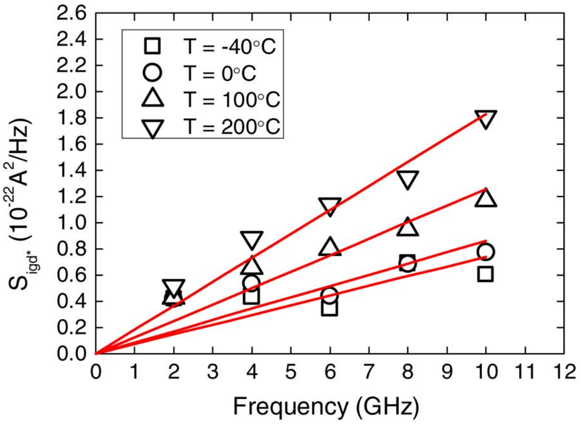


Fig. 3. Correlation noise (S_{igd*}) versus frequency under different temperatures. ($V_{\rm GS} = V_{\rm DS} = 1.2$ V).

TABLE I
EXTRACTED g_{d0}, C_0 AND THEIR NORMALIZATIONS WITH RESPECT TO CASES AT $-40°$

	T(K)	$\|T$(K)$\|$	g_{d0} (mS)	$\|g_{d0}\|$	C_0 (fF)	$\|C_0\|$
T = –40 ℃	233	× 1	112.4	× 1	520	× 1
T = 0 ℃	273	× 1.17	96	× 0.85	517	× 0.99
T = 100 ℃	373	× 1.60	66	× 0.59	508	× 0.98
T = 200 ℃	473	× 2.03	51	× 0.45	506	× 0.97

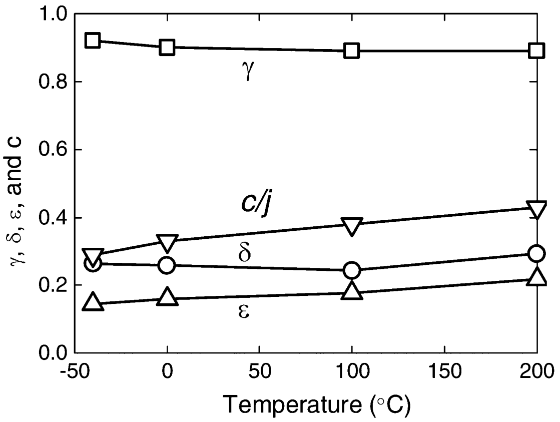


Fig. 4. Model parameters $\delta, \gamma, \varepsilon$ and correlation coefficient versus temperature.

the short channel device as in our study, the parameters could deviate from these theoretical values [5], [7], [8].

The small variations for δ, γ and ε shown in Fig. 4 reveal that they are less temperature-dependent, and may not be the main contribution to the temperature dependence of these three PSDs. In addition, C_0 in Table I is shown to be insensitive to temperature. Therefore, for a given operating frequency, the following approximations can be achieved:

$$S_{ig} \propto \frac{T}{g_{d0}} \tag{4}$$

$$S_{id} \propto T g_{d0} \tag{5}$$

$$S_{igd^*} \propto T. \tag{6}$$

Equation (6) directly captures the positive temperature coefficient observed for S_{igd^*}.

On the other hand, as temperature increases, the channel mobility would decline [2], causing g_{d0} to decrease with increasing temperature as shown in Table I. This explains the positive temperature coefficient for S_{ig} (4). Moreover, since the decrease of g_{d0} overwhelms the increase of ambient temperature in Kelvin (Table I), S_{id} would have negative temperature coefficient (5). Besides, the correlation coefficient between noise currents i_g and i_d (denoted as) can be expressed as

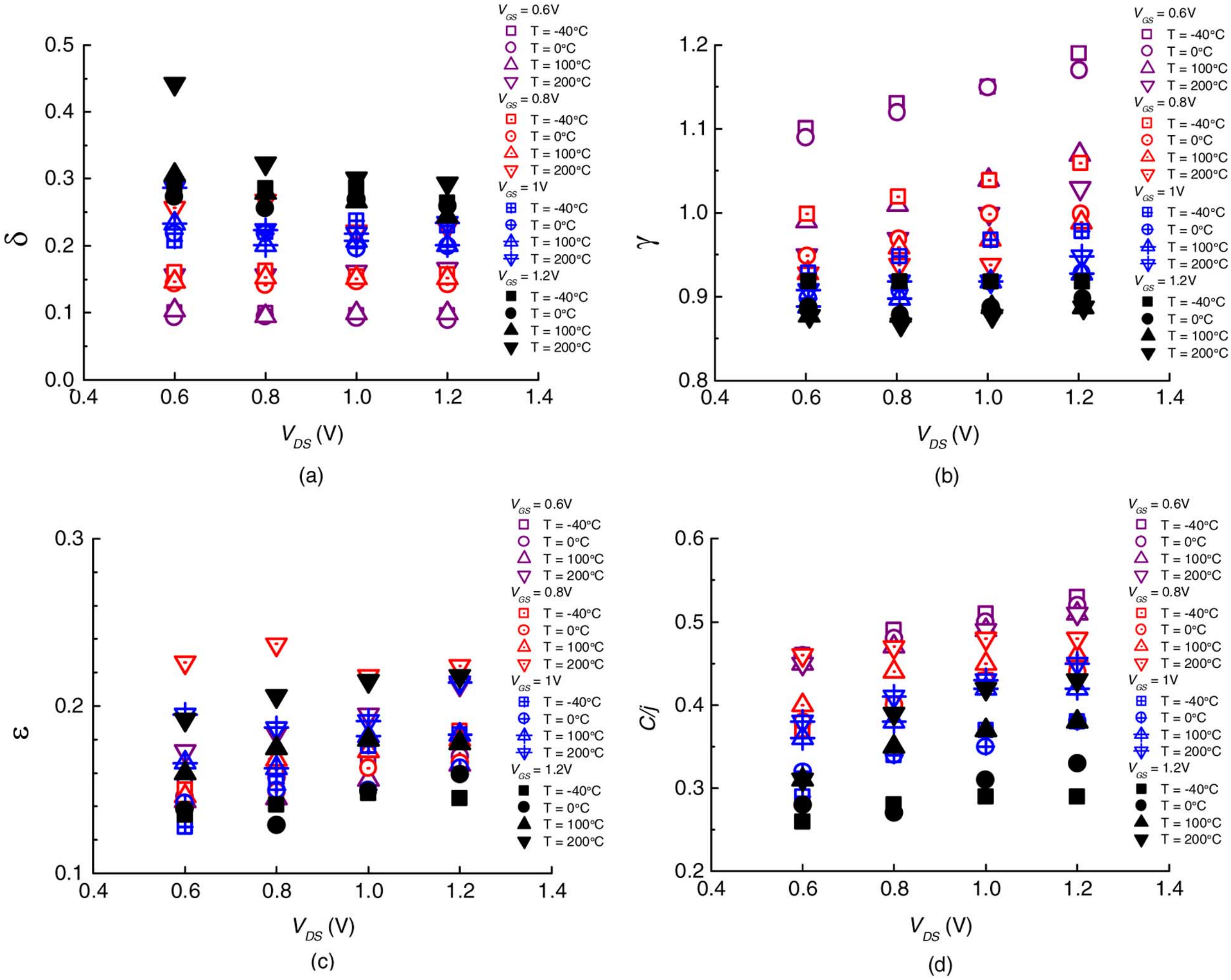
$$c \equiv \frac{\overline{i_g i_d^*}}{\sqrt{\overline{i_g i_g^*} \cdot \overline{i_d i_d^*}}} = j\frac{\varepsilon}{\sqrt{\delta\gamma}}. \tag{7}$$

Since δ, γ, and ε are shown to be less temperature-dependent, the temperature dependence of shown in Fig. 4 is also weak.

Finally, the extracted values for the model parameters and the correlation coefficient for various gate and drain biases are shown in Fig. 5(a)–(d). It suggests that in the wide temperature range between $-40°$ and $200°$, δ, ε, and c/j have a greater temperature dependence at higher $V_{\rm GS}$, while γ has a greater temperature dependence only for a lower $V_{\rm GS}$.

IV. CONCLUSION

In this letter, we have investigated the temperature dependence of S_{ig}, S_{id} and S_{igd^*} for the RF MOSFET. S_{ig} and S_{igd^*} are found to have positive correlation with ambient temperature, while S_{id} has negative one due to much lower channel conductance at higher temperature. Our experimental results show that



(a) (b)

(c) (d)

Fig. 5. Noise model parameters (a) δ, (b) γ, (c) ε, and (d) c/j versus drain bias for different temperature and gate bias conditions.

an accurate temperature model of the channel conductance is crucial to the RF noise temperature modeling.

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