Gate Voltage Dependent 1/f Noise Variance Model in n-Channel MOSFETs

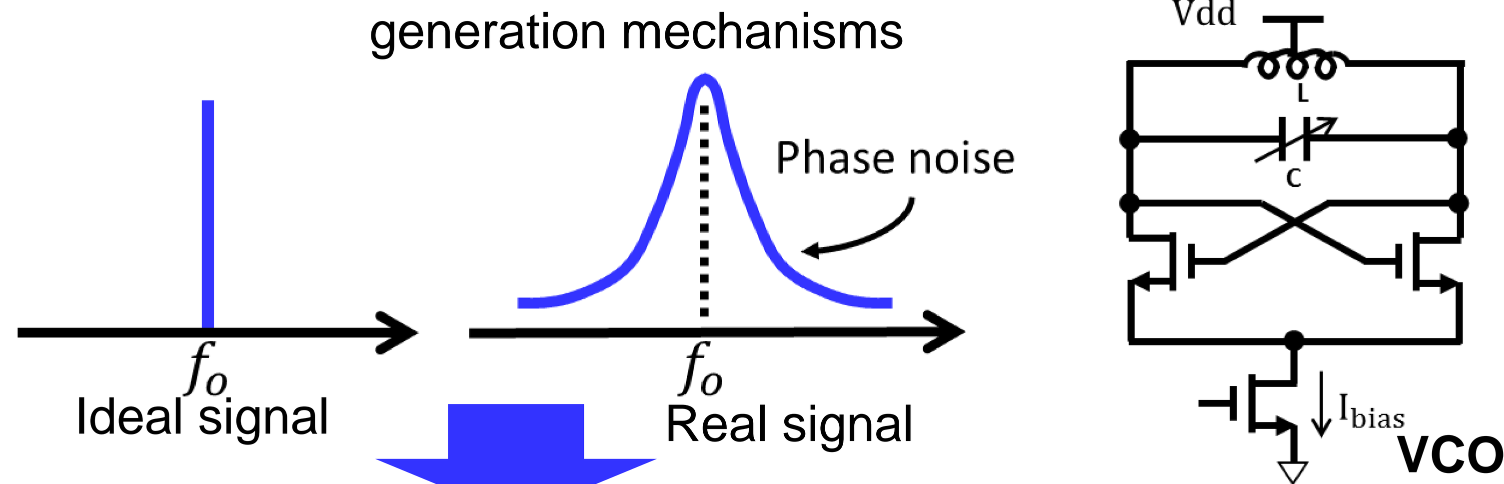
Yukiko Arai, Hitoshi Aoki, Fumitaka Abe, Shunichiro Todoroki, Ramin Khatami, Masaki Kazumi, Takuya Totsuka, Taifeng Wang, Haruo Kobayashi*

Department of Electronic Engineering, Gunma University, 1-5-1 Tenjin-cho, Kiryu 365-8515, Japan

Research Purpose

1/f noise in MOSFETs

- Is an important property for any analog oscillator circuit design
- Induces degradation of phase noise performance in VCOs
- Must be based on correct noise generation mechanisms



- **Development of an accurate yet simple 1/f noise model**
- **Implementation on SPICE3 (MDW-SPICE) circuit simulator**

Research Background

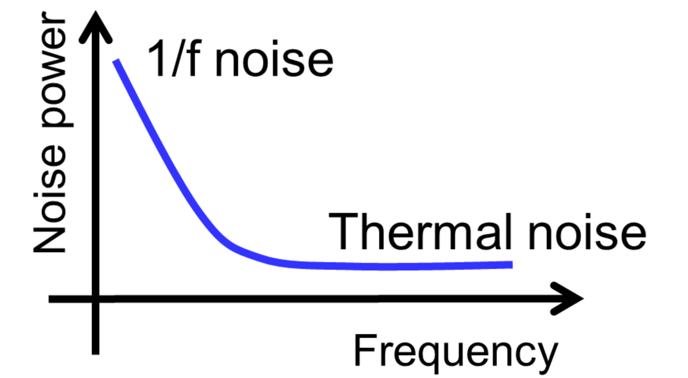
- Refinement of semiconductor process
  - Manufacture characteristic variance
  - Degradation of dynamic range
  - Increase noise

Difficulty of analog circuit design

- Noise have no regularity
  - Excess margin for circuit design
  - Deterioration reliability of products

Necessity of noise simulation

- Thermal noise and 1/f noise influence MOSFET characteristic
  ⇒ **1/f noise is more dominant in low frequencies**



Discussion of 1/f noise

MOSFET 1/f Noise Model Derivations

SPICE2 type model

$$S_{I_D}(f) = \frac{KF \cdot I_D^{AF}}{C_{OX} L_{eff}^2 f^{EF}}$$

Hooge's model mobility fluctuations model

$$S_{I_D}(f) = \frac{\alpha_H \cdot \mu_{eff} \cdot 2kT \cdot I_D}{f L^2}$$

Comparison assuming of $AF = EF = 1$ as ideal 1/f noise

$$\alpha_H \cdot \mu_{eff} \cdot 2kT = \frac{KF}{C_{OX}}$$

Replacing KF with a mobility fluctuation equation

$$\boldsymbol{KF = C_{OX} \cdot \alpha_H \cdot \mu_{eff} \cdot 2kT}$$

We included Hooge's model in SPICE2 type model !

Proposed Model

$$S_{I_D}(f) = \frac{KF \cdot I_D^{AF}}{C_{OX} L_{eff}^2 f^{EF}}$$

$$KF = C_{OX} \cdot \mu_{eff} \cdot 2kT \cdot \left(2 \cdot \alpha_{H_{nominal}} \cdot (D - 0.5) + KFN\right) \cdot e^{-(V_{gs} - V_{TH})}$$

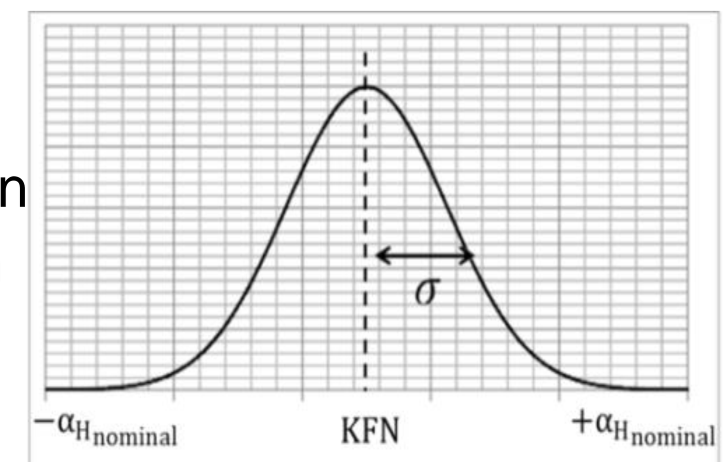
Includes two noise generation mechanisms, **mobility** and **interface trap number fluctuations**

1/f Noise Variation

- α_H is a coefficient caused by phonon scattering
  - Relation to mobility fluctuations
  - Decrease with a function of the effective V_{GS}

$$\boldsymbol{\alpha_H \propto e^{-(V_{gs} - V_{TH})}}$$

Variability is caused by the device process variation
⇒ **Gaussian distribution**

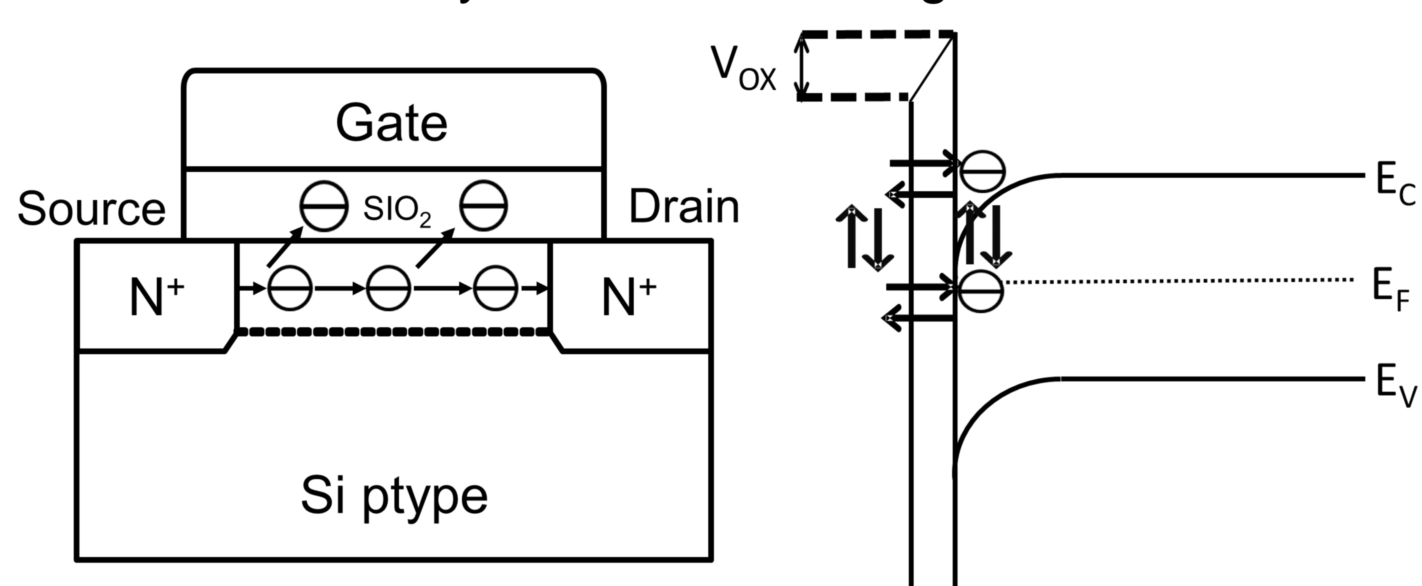


- ***D*** as Gaussian Normalized Random Number
  ⇒ fluctuates from 0 to 1
  α_H varies ⇒ 1/f noise vary

$$\boldsymbol{\alpha_H = \left(2 \cdot \alpha_{H_{nominal}} \cdot (D - 0.5) + KFN\right) \cdot e^{-(V_{gs} - V_{TH})}}$$

1/f noise Generation Mechanisms

- Mobility Fluctuations
  - Caused by phonon scattering
  - Dependent on V_{GS}
  - Mobility fluctuation ⇒ 1/f noise variability
- Interface traps
  - Caused by electron tunneling transitions

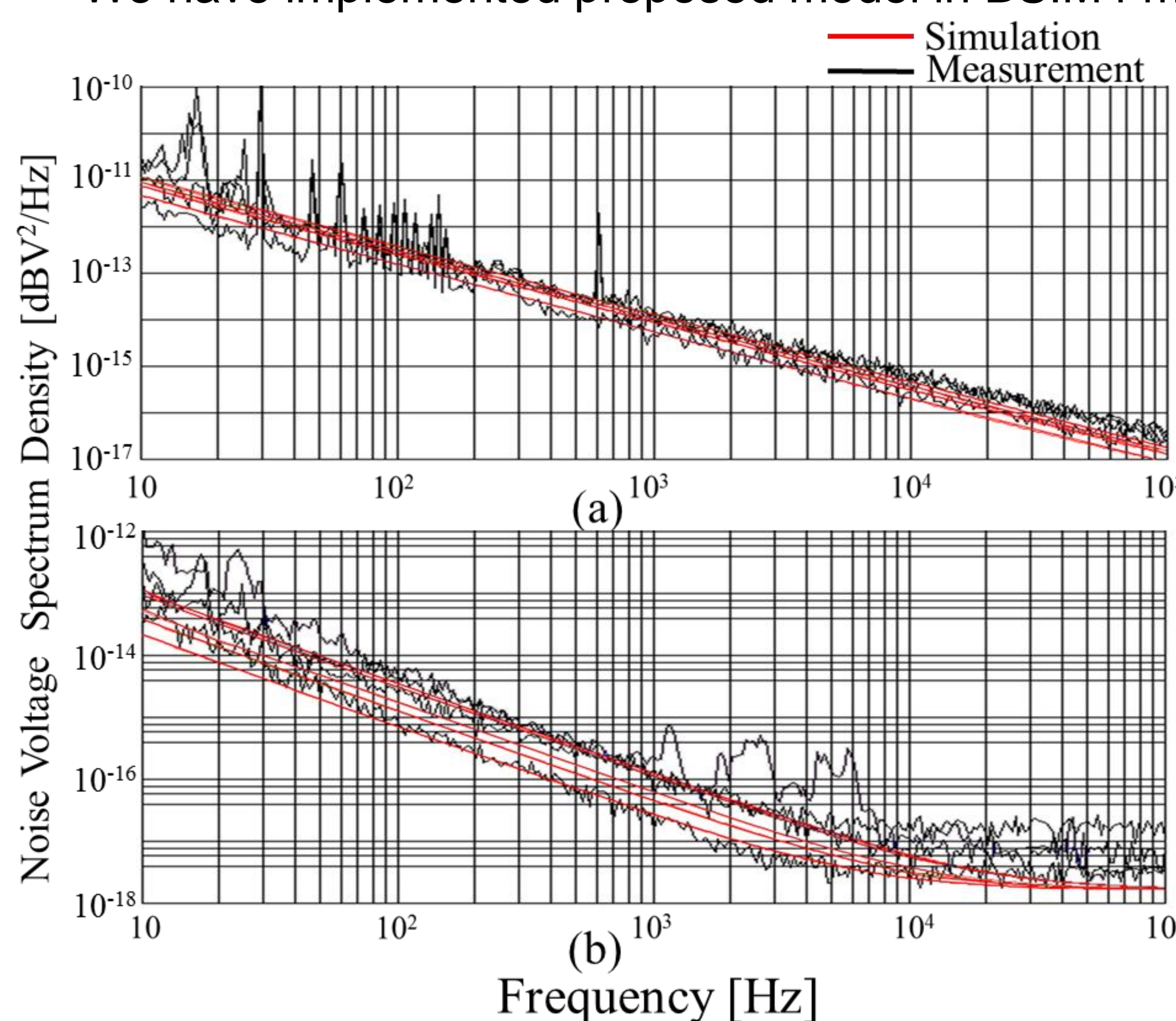


from the Si to the gate oxide — between interface traps

1/f noise is inversely proportional to the frequency

Simulation and Measurement Results

We have implemented proposed model in BSIM4 model with our MDW-SPICE



$V_{DS} = 1.0$ V
$AF = 0.3$, $EF = 1.45$
$KF = 2.0\times10^{-3}$, $\alpha_H = 8.0\times10^{-4}$
$KFN = 4.0\times10^{-3}$.

(a) $V_{GS} = 1.41$ V
(b) $V_{GS} = 0.45$ V

Variance is decreased with increasing V_{GS}

Conclusion

- 1/f noise causes degradation of phase noise performance in oscillators
  - ⇒ Development of new 1/f noise model
  - ⇒ Inclusion of mobility and interface trap fluctuations with process variations
- Implementation on our MDW-SPICE circuit simulator
  - ⇒ Excellent agreements with measurement results
- Circuit design margin can be minimum !

Proposed model agreed with measurement results

Gate voltage dependent 1/f noise variations are included in our model !