P96 Research on Gate Voltage Dependent 1/f Noise Variance Modeling for n-Channel MOSFETs

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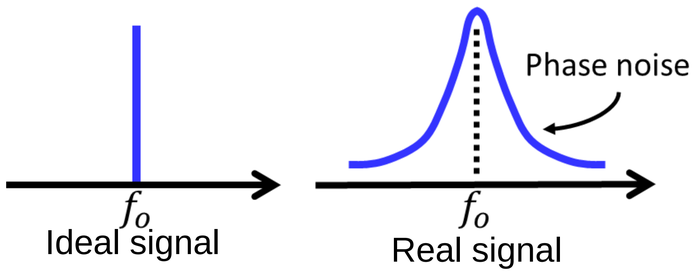
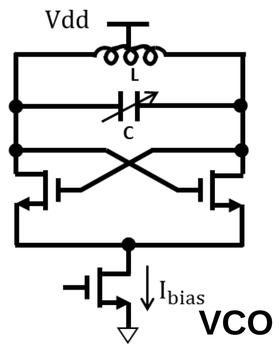
Research Purpose

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

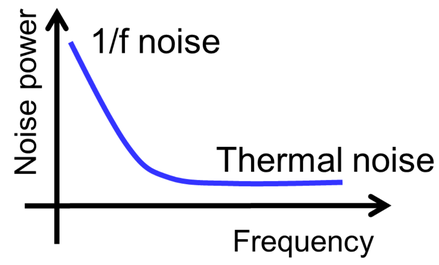




- **Development of an accurate yet simple 1/f noise model**
- **Implementation on SPICE3 (MDW-SPICE) circuit simulator**

Research Background

- Refinement of semiconductor process
  →**Difficulty of analog circuit design**
- Noise have no regularity
  →**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**

Research Approach

SPICE2 type model + **① Interface Trap Number**
② Mobility Fluctuation
③ Process Variation
④ Time & Temperature Degradation = **Proposed Model**

MOSFET 1/f Noise Model Derivations

SPICE2 type model ⟺ Hooge's model mobility fluctuations model

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

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

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

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

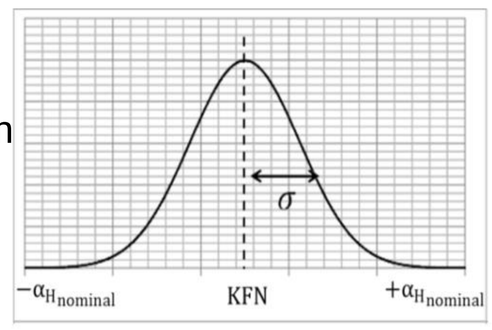
Includes two noise generation mechanisms,
mobility and **interface trap number fluctuations**

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**

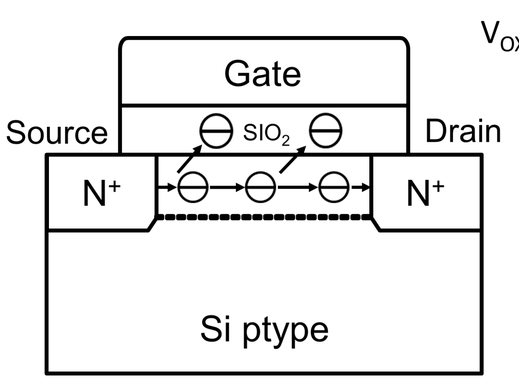


- *D* as Gaussian Normalized Random Number
  ⇒ fluctuates from 0 to 1
  α_H varies ⇒ 1/f noise vary

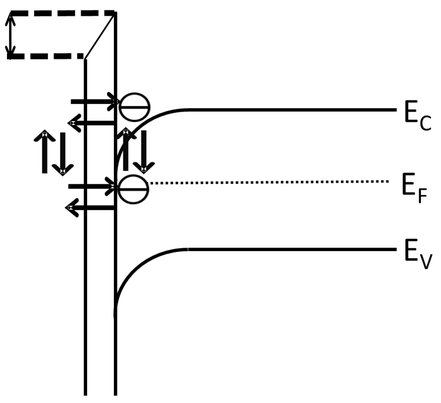
$$\boldsymbol{\alpha_H = \left(2 \cdot \alpha_{H_{nominal}} \cdot (D - 0.5) + KFN\right) \cdot e^{-(V_{gs} - V_{TH})}}$$

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



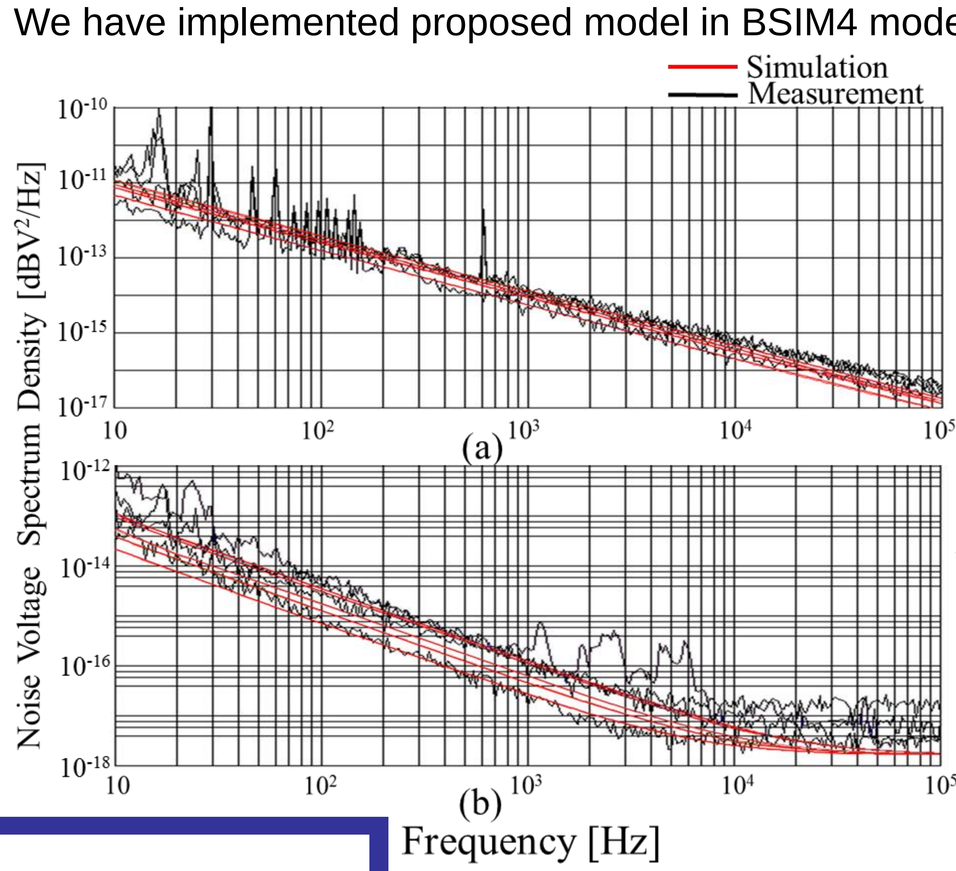
from the Si to the gate oxide



between interface traps

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 = 2.0×10^{-3}, α_H= 8.0×10^{-4}
KFN = 4.0×10^{-3}.

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

Variance is decreased with increasing V_{GS}

Proposed model agreed with measurement results

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

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 !