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

1/f Noise Variation

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

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

Variability is caused by the device process variation

$\Rightarrow$ Gaussian distribution

- $D$ as Gaussian Normalized Random Number
  - Fluctuates from 0 to 1

$\alpha_H$ varies $\Rightarrow$ 1/f noise vary

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

MOSFET 1/f Noise Model Derivations

SPICE2 type model $\equiv$ Hooge's model

$$S_D(f) = \frac{K_F \cdot I_D^{AF}}{C_{OX} \cdot L_{eff}^2 \cdot f \cdot F_E}$$

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

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

Replacing $K_F$ with a mobility fluctuation equation

We included Hooge’s model in SPICE2 type model!

Proposed Model

$$S_D(f) = \frac{K_F \cdot I_D^{AF}}{C_{OX} \cdot L_{eff}^2 \cdot f \cdot F_E}$$

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

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

1/f noise Generation Mechanisms

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

Simulation and Measurement Results

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

- 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!