RF Noise Simulation for Submicron MOSFET's Based on Hydrodynamic Model

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Outline

- Motivation
- Simulation Method
- Validity Examination
- Drift-Diffusion Model vs. Hydrodynamic Model
- Simulation Results for 0.25μm nMOSFET
- Conclusions

Motivation

(RF CMOS)

- Rapid f_t increase of MOSFETs, driven by the microprocessor industry, attracts RF designers.
- Promise of integrating whole systems on a single chip.
- Noise behavior in short channel MOSFETs is not well understood yet.

Motivation *(Continue)*
(MOSFET Noise)

- Flicker (*1/f*) Noise
  - Dominant up to few MHz range
  - Significant in mixer circuits (Up-conversion Error)
- Shot Noise
  - Dominant in the subthreshold region
- Thermal Noise (Velocity Fluctuation Noise)
  - Dominant in high frequencies

Motivation *(Continue)*
(HF MOSFET Noise - Thermal)

- Excess drain noise in short channel MOSFETs caused by carrier heating near drain junction.
  - A. A. Abidi (IEEE TED, 1986)
  - B. Wang et al. (IEEE JSSC, 1994)
- Induced gate noise due to the distributed nature of MOS devices.
  - Introduced by A. van der Ziel in 1976
  - NO QUANTITATIVE report to date
  - D. K. Shaeffer et al. (IEEE JSSC, 1997)

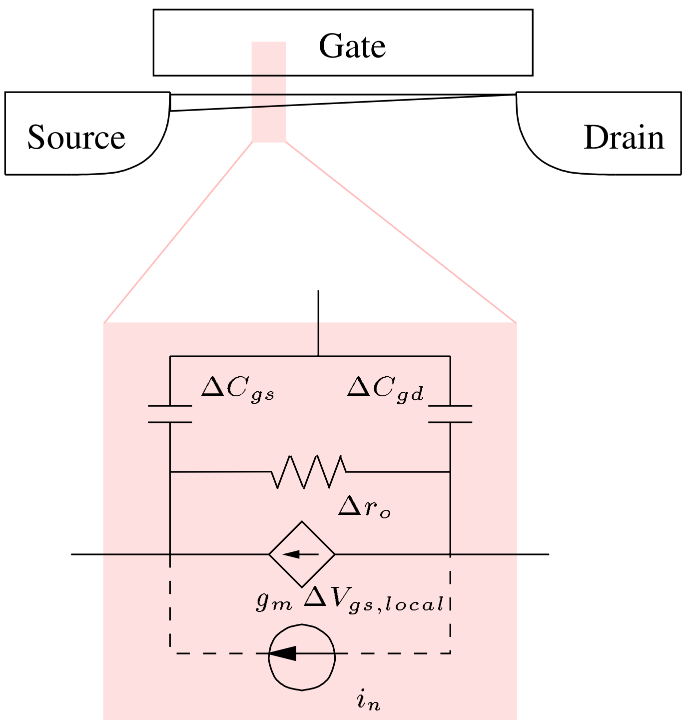
Simulation Method

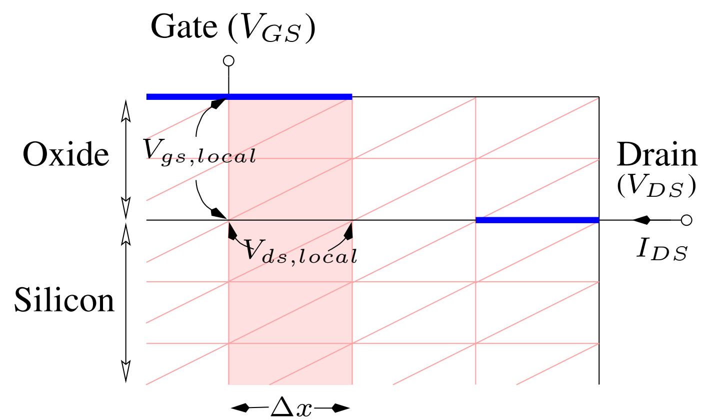
(1D vs. 2D/3D)

- 1D Approach
  - Using transmission line analogy
  - Reasonable comutational cost
  - Poor accuracy
- 2D/3D Approach
  - Impedance Field Method + Adjoint analysis
  - Better accuracy, incorporating 2nd order effects
  - Expensive in implementation and simulation (no HD to date)

Simulation Method *(Continue)*

(Hybrid Approach)

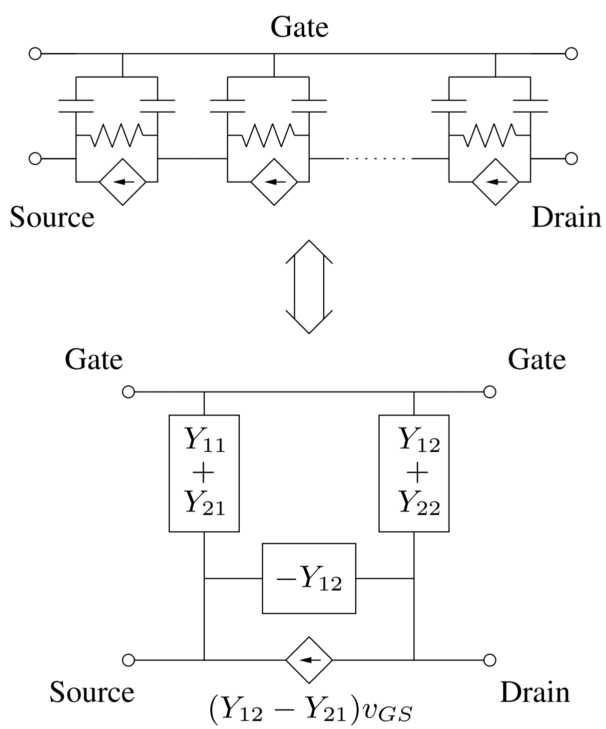




$$
\begin{aligned}
\Delta C_{gs} + \Delta C_{gd} &= \frac{\Delta Q_{inv}}{\Delta V_{gs,local}} \\
\Delta r_o &= \frac{\Delta V_{ds,local}}{\Delta I_{DS}} \\
g_m &= \frac{\Delta I_{DS}}{\Delta V_{gs,local}} \\
\Delta S_{i_n} &= 4\,k\,T_n \,\frac{I_{DS}}{V_{ds,local}}
\end{aligned}
$$

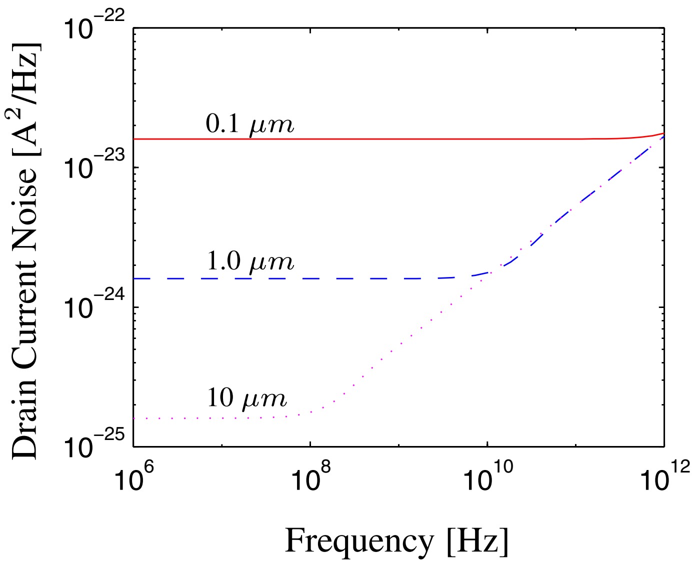
Validity Check - I

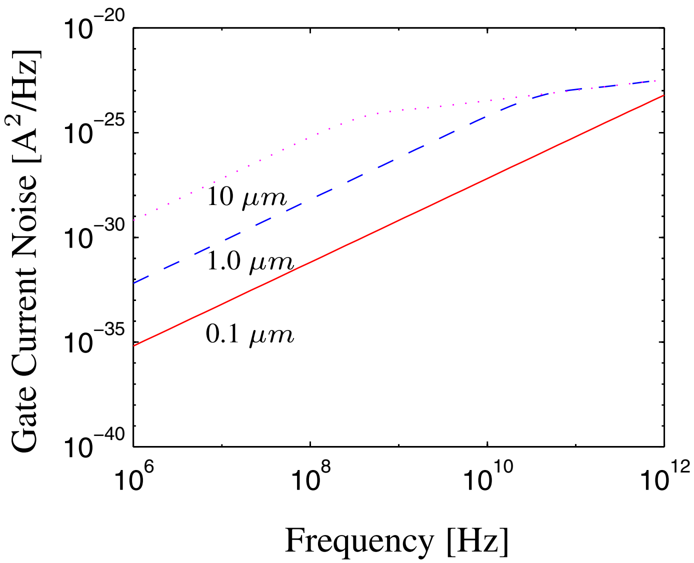
(First-Order Network Parameters)



Validity Check - II

(Non-segmented Uniform Transmission Line)





for V_{DS}=0V

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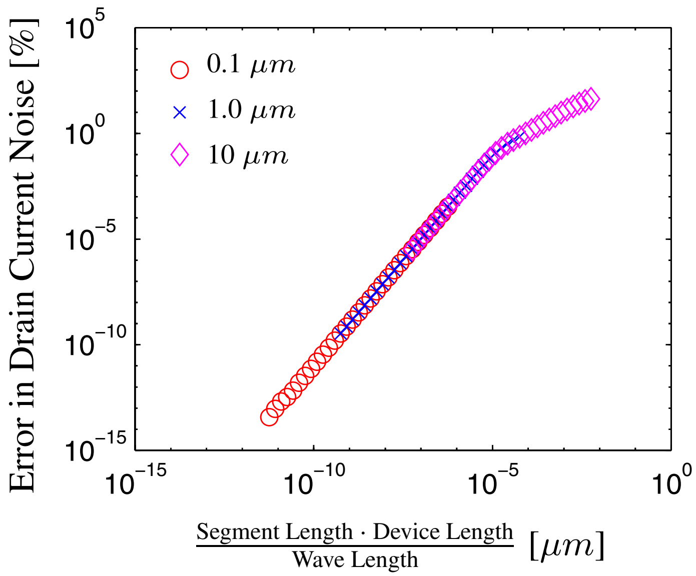
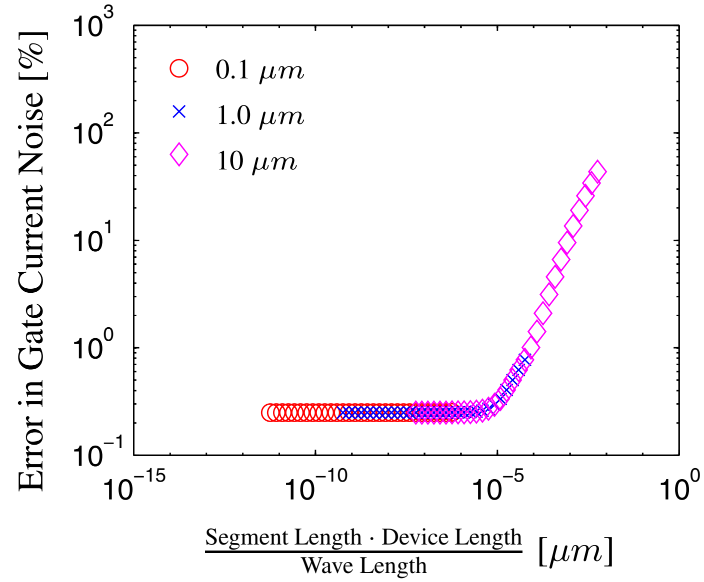
Validity Check - II *(Continue)*

(Segmentation Error for Uniform Transmission Line)





$\Delta x\ L/\lambda = 10^{-5}$µm corresponds to 280GHz for L=0.25µm divided into 20 segments

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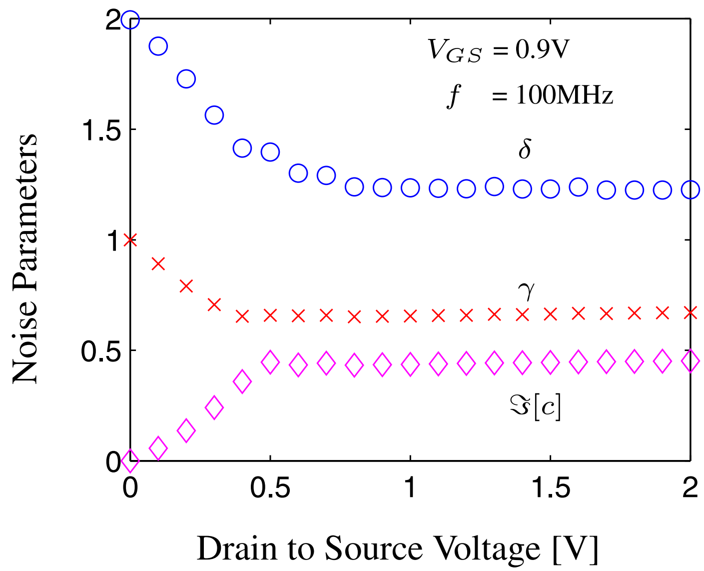
Validity Check - III
(Long Channel MOSFET Case)

5µm nMOSFET



Classical Values

$\gamma = 1.0$ (Linear)

$= 2/3$ (Saturation)

$\delta = 4/3$ (Saturation)

$c = j0.395$ (Saturation)

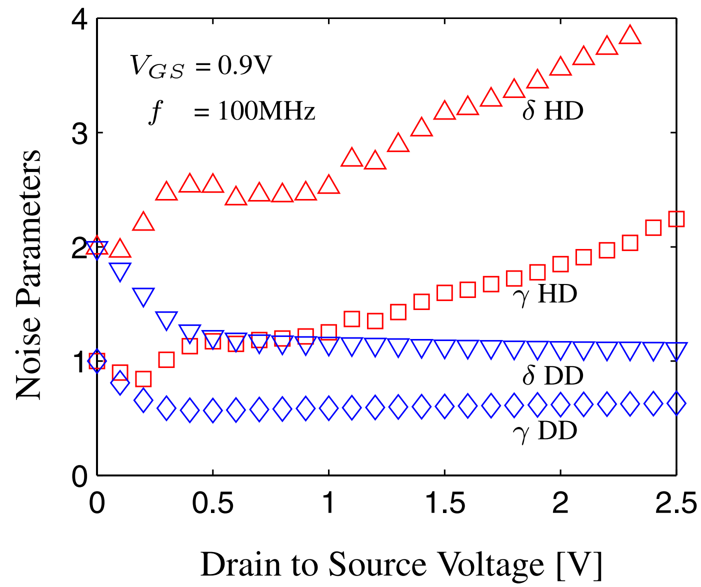
$$\gamma = \frac{\overline{i_d^2}}{4\,k\,T\,\Delta f\,g_{d0}}$$

$$\delta = \frac{\overline{i_g^2}}{4\,k\,T\,\Delta f\,\Re[Y_{GS}]}$$

$$c = \frac{\overline{i_g i_d^*}}{\sqrt{\overline{i_g^2}\,\overline{i_d^2}}}$$

Short Channel Effect
(Drift-Diffusion vs. Hydrodynamic)

0.25µm nMOSFET



Comparison to Measured Data

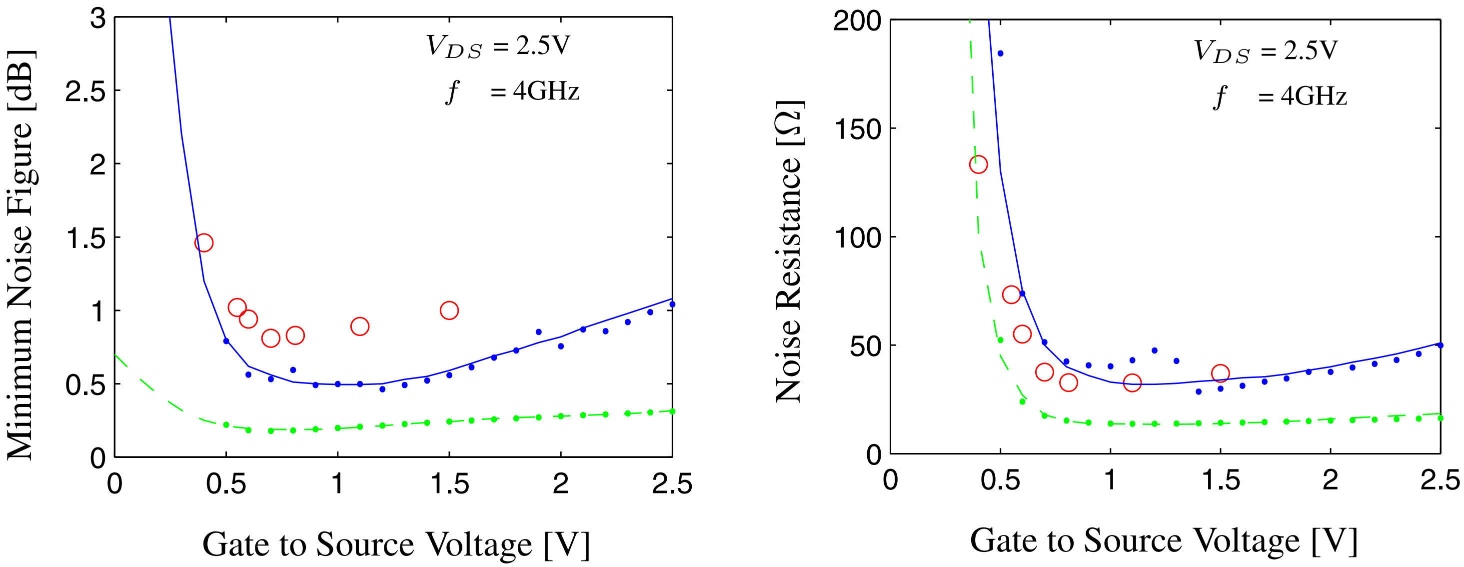
(γ–δ–c vs. F_{min}-R_n-Y_{opt})

- Intrinsic
  - ✧ Drain Noise
  - ✧ Gate Noise
  - ✧ Correlation
- Extrinsic
  - ✧ Interlayer Capacitance
  - ✧ Gate Resistance
- Parasitic
  - ✧ Pad Loss
  - ✧ Routing Inductance

$$\begin{aligned}
F_{min} &= 1 + 2R_n(G_{opt} + G_c) \\
&\approx 1 + 2R_n G_{opt} \\
R_n &= |B|^2 \frac{\overline{i_d^2}}{4\,k\,T\,\Delta f} \\
G_{opt} &= \sqrt{\frac{G_u}{R_n} + G_c^2} \approx \sqrt{\frac{G_u}{R_n}} \\
B_{opt} &= -B_c \\
Y_c &= \frac{D}{B} - \frac{c}{B}\sqrt{\frac{\overline{i_g^2}}{\overline{i_d^2}}} \approx \frac{D}{B} \\
G_u &= (1 - |c|^2)\frac{\overline{i_g^2}}{4\,k\,T\,\Delta f} \\
B &= \frac{1}{Y_{21} + Y_{22}} \\
D &= \frac{Y_{11} + Y_{12}}{Y_{21} + Y_{22}} + 1
\end{aligned}$$

Four Noise Parameters I
(Intrinsic)

0.25µm nMOSFET

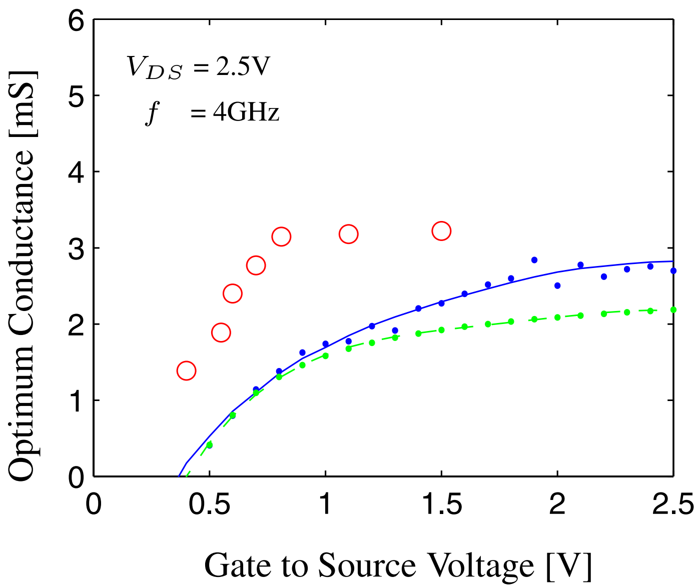


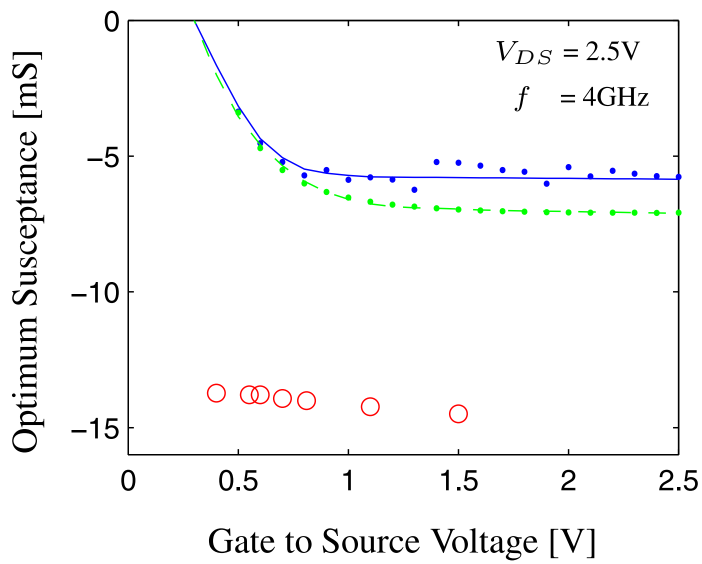
Red : Measured Data
Blue : Hydrodynamic Simulation
Green : Drift-Diffusion Simulation

Four Noise Parameters II

(Intrinsic)

0.25μm nMOSFET





Red : Measured Data
Blue : Hydrodynamic Simulation
Green : Drift-Diffusion Simulation

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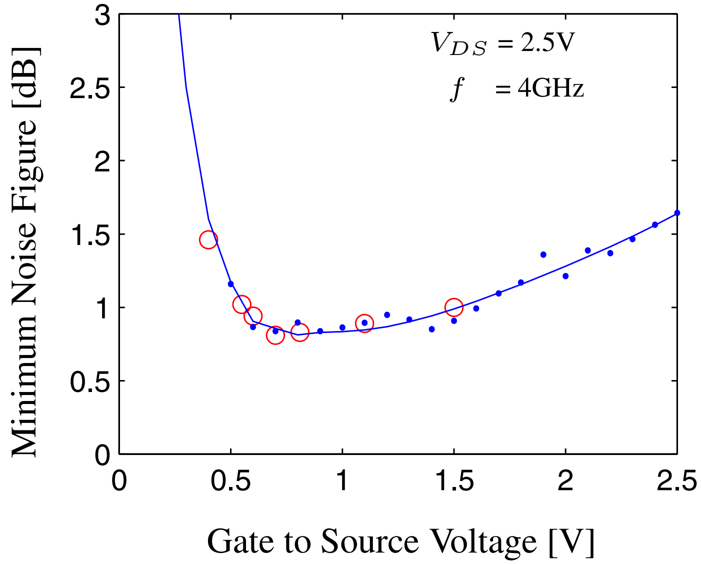
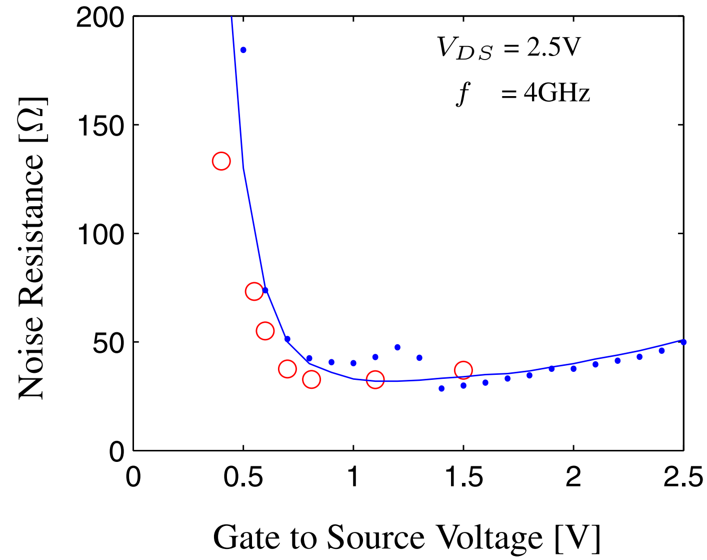
Four Noise Parameters I

(After correction for the loss due to G_{opt})

0.25µm nMOSFET





Red : Measured Data

Blue : Hydrodynamic Simulation

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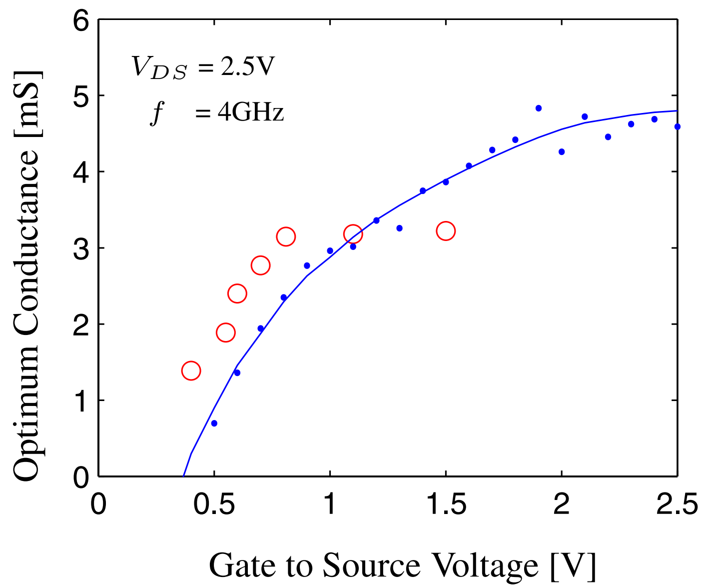
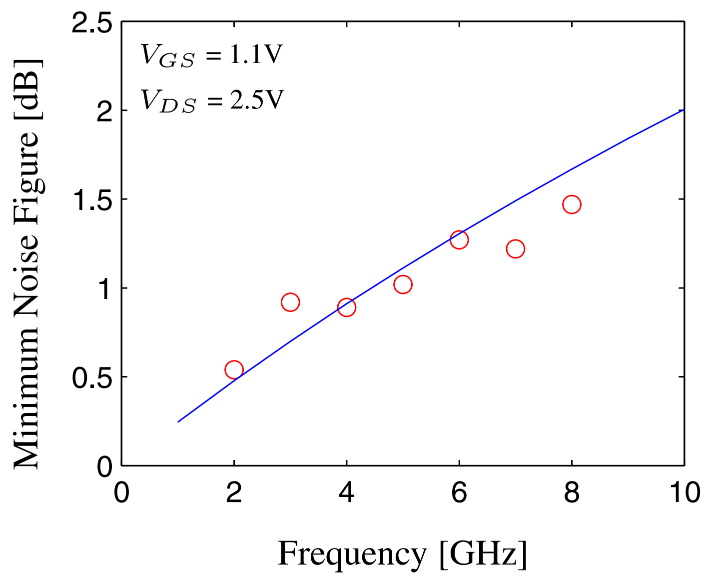
Four Noise Parameters II

(After correction for the loss due to G_{opt})

0.25μm nMOSFET





Red : Measured Data
Blue : Hydrodynamic Simulation

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Conclusions

- Accurate and efficient noise simulation technique : 1D active transmission line + 2D device simulation
- First known attempt to use an advanced (HD) transport model for 2D noise analysis
- First successful noise simulation results for deep submicron MOSFETs