The Equivalence of van der Ziel and BSIM4 Models in Modeling the Induced Gate Noise of MOSFETs

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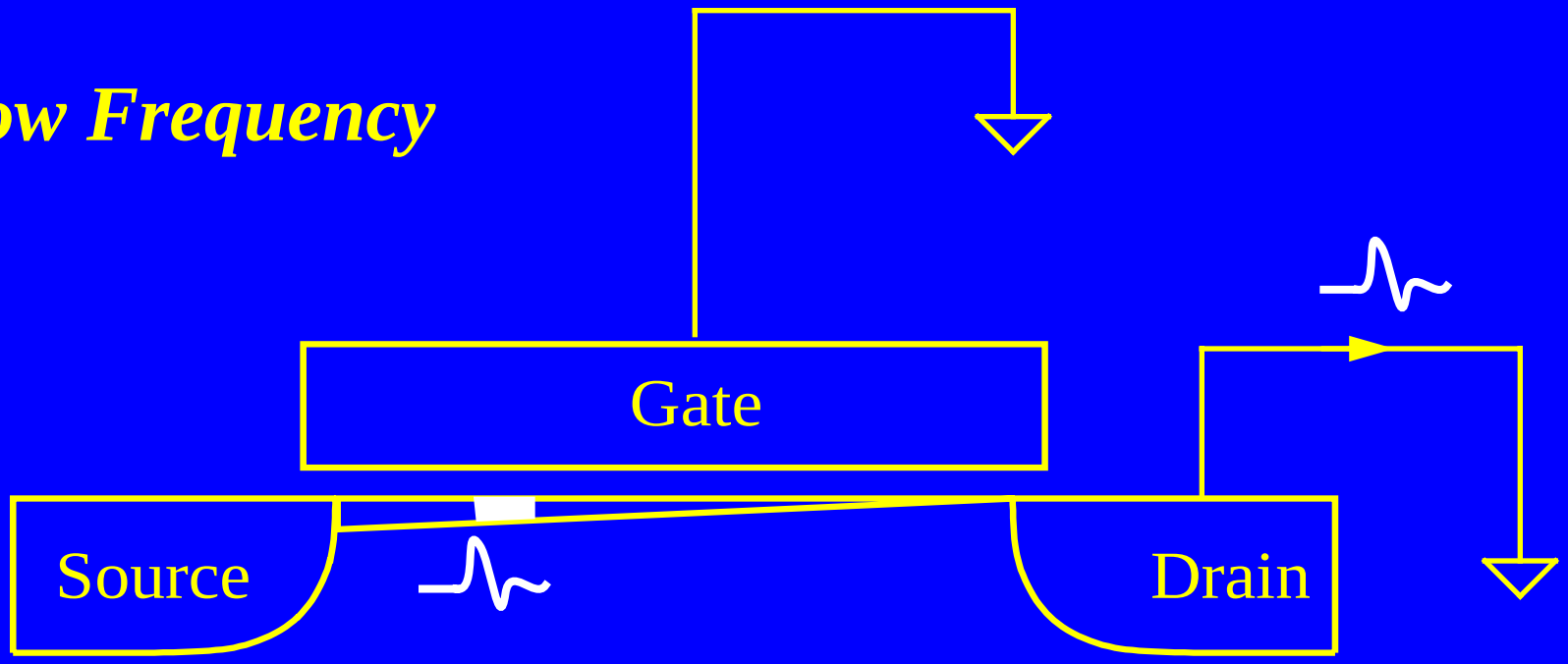
Outline

- Induced Gate Noise
- BSIM4 Noise Model
- Model Comparison Method
- Validation for Device
- Validation for Circuits
- Conclusions

Induced Gate Noise
(Physical Origin)

At Low Frequency



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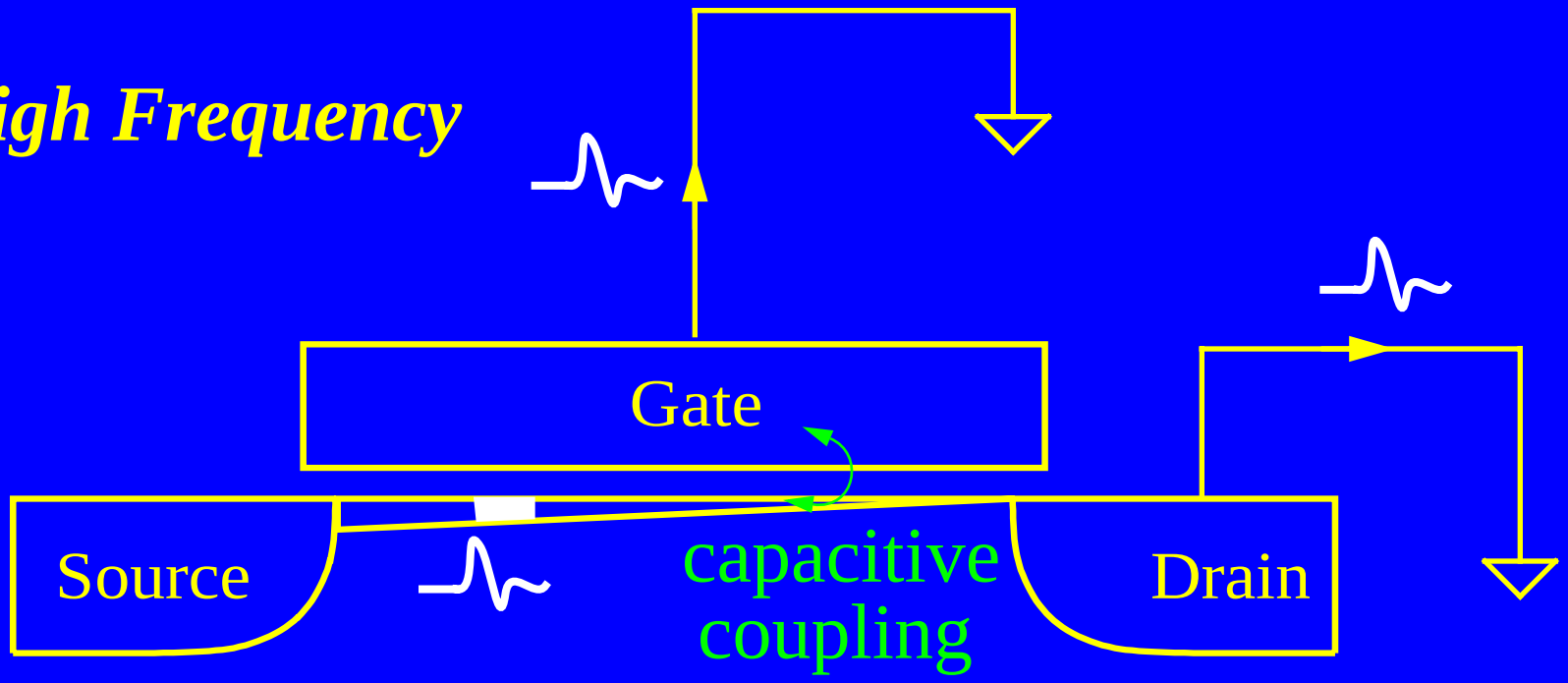
Induced Gate Noise
(Physical Origin)

At High Frequency



Noticeable $\overline{i_g^2}$ if $f > f_t/10$

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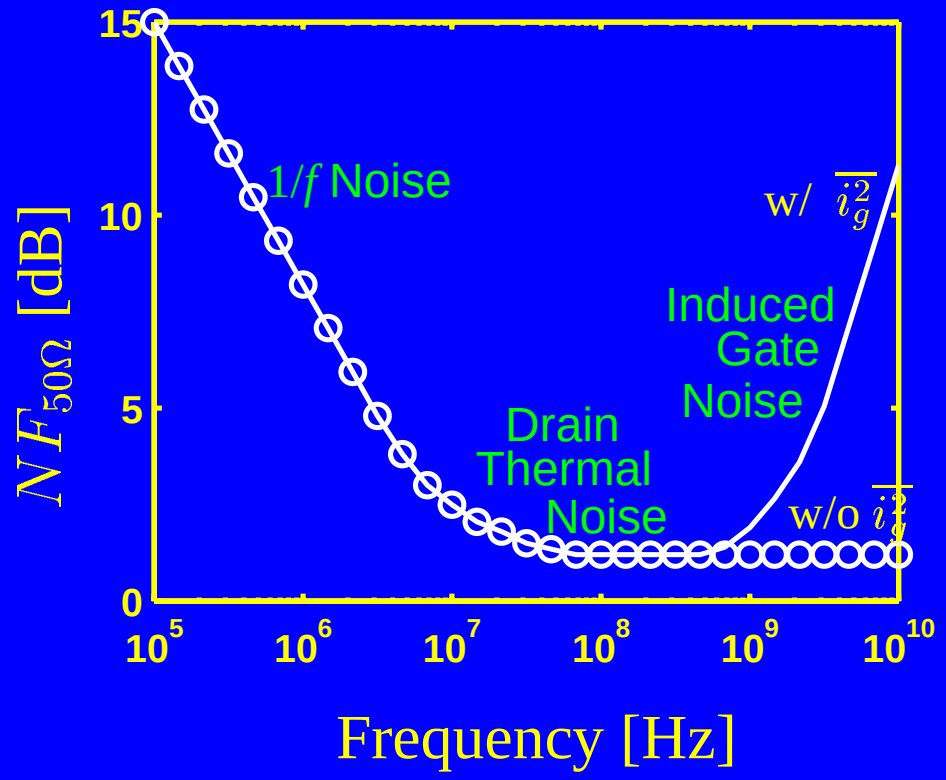
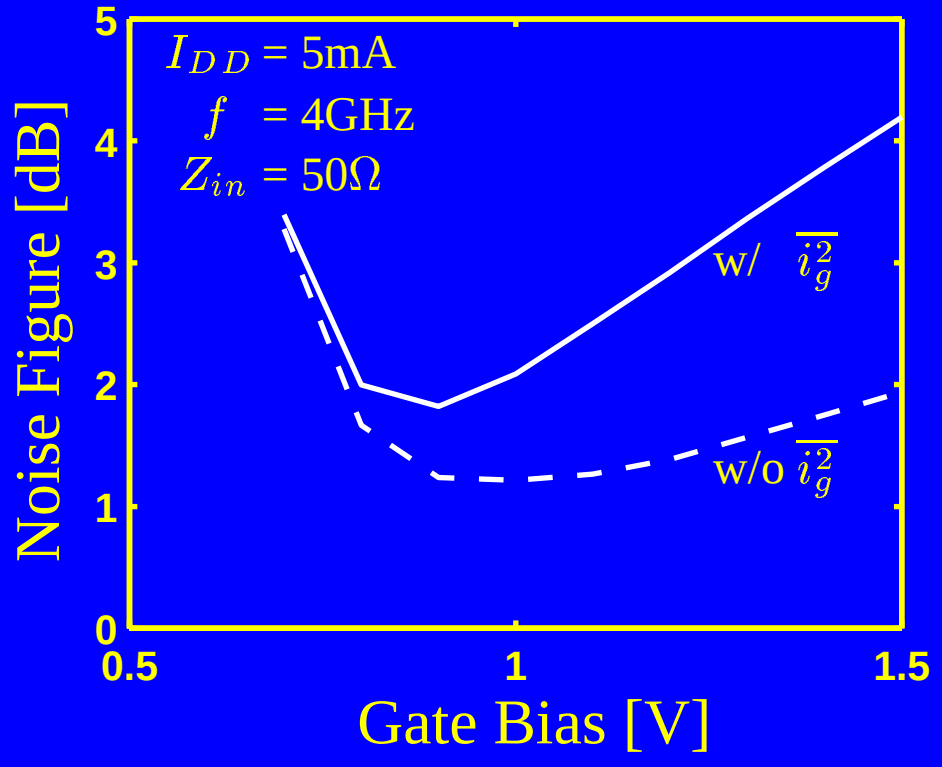
Induced Gate Noise (*Continue*)
(Impact on Noise Figure)

MOSFET $^{*}NF_{50\Omega}$



Power-Constrained LNA



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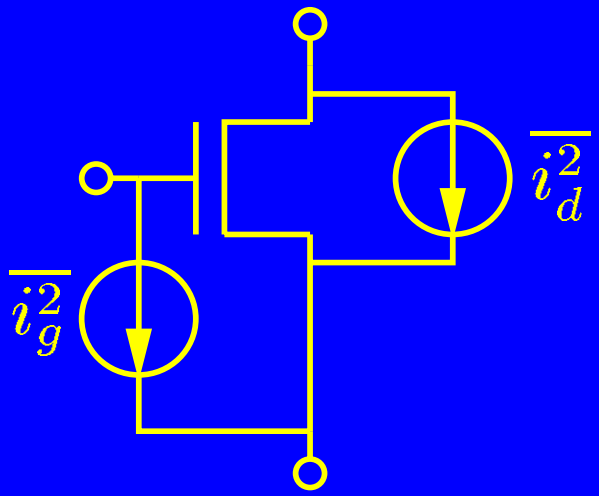
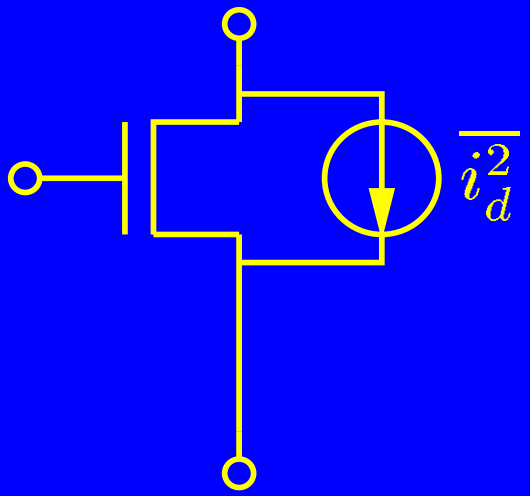
* by A.J. Scholten et al. (*IEDM*, 1999)

Induced Gate Noise (*Continue*)
(SPICE Models)

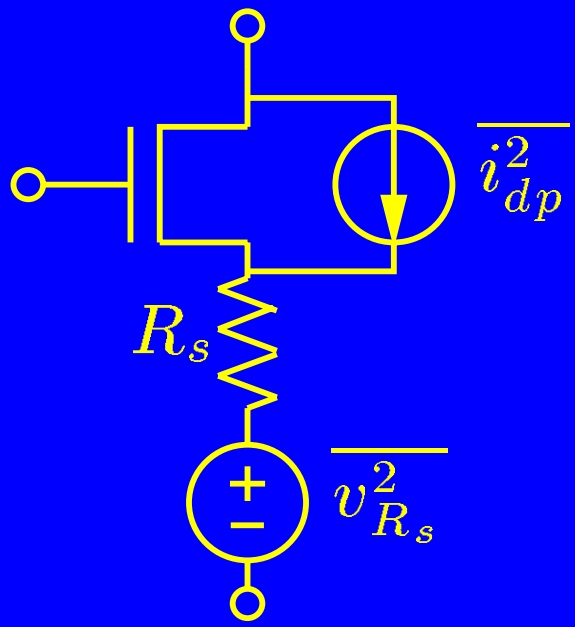
van der Ziel



BSIM3



BSIM4



- **Solid Physical Basis**
- ***de facto* Standard**
- **No Induced Gate Noise**
- **Released in Mar.2000**
- **New Approach**

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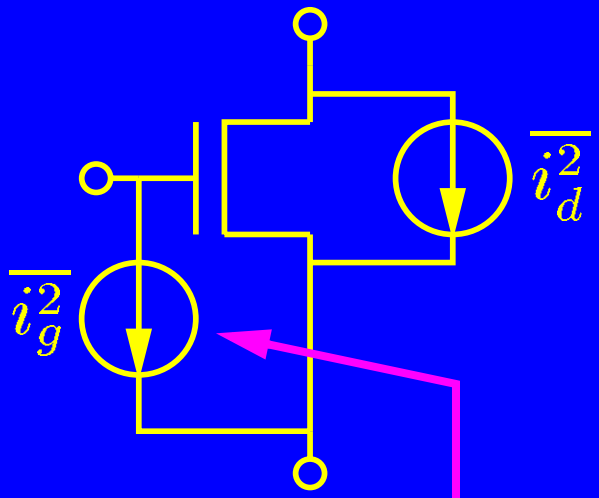
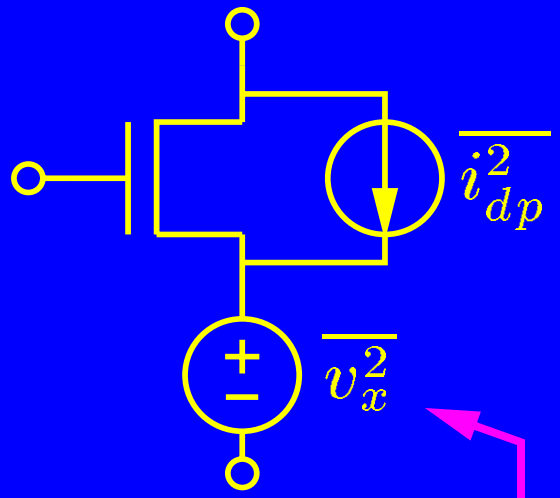
BSIM4 Noise Model
(Modeling Strategy)

van der Ziel



✲ Connected to Gate

BSIM4



✲ Connected to Source

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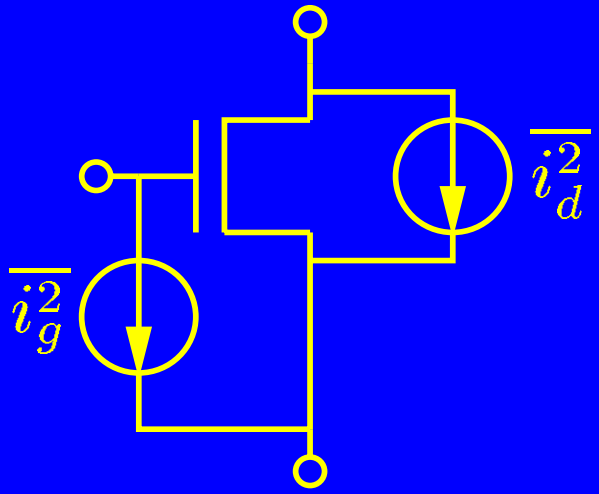
$R_x >> R_s$ is assumed

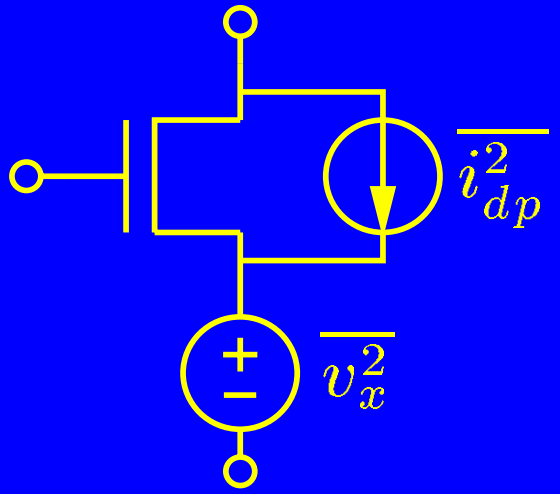
BSIM4 Noise Model
(Modeling Strategy)

van der Ziel



- Connected to Gate
- Frequency Dependent

BSIM4



- Connected to Source
- Frequency Independent

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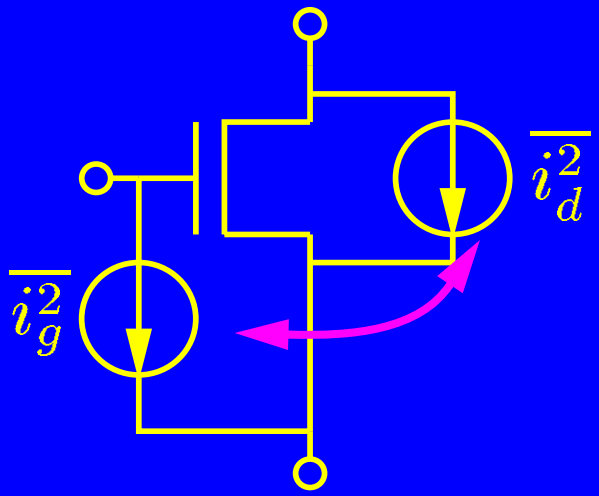
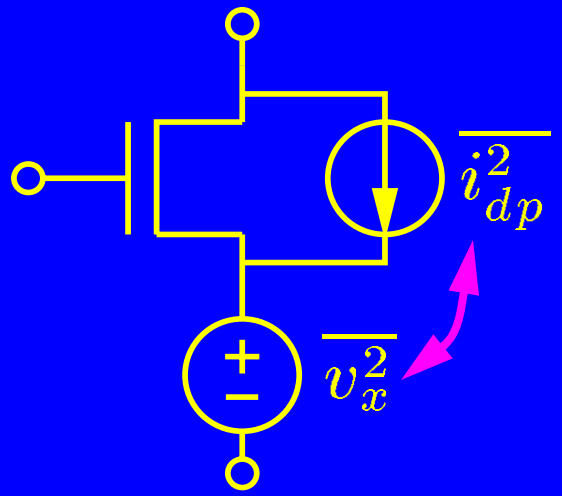
BSIM4 Noise Model
(Modeling Strategy)

van der Ziel



- Connected to Gate
- Frequency Dependent
- Correlated with $\overline{i_d}^2$
  (3 Noise Parameters)

BSIM4



- Connected to Source
- Frequency Independent
- Uncorrelated with $\overline{i_{dp}}^2$
  (2 Noise Parameters)

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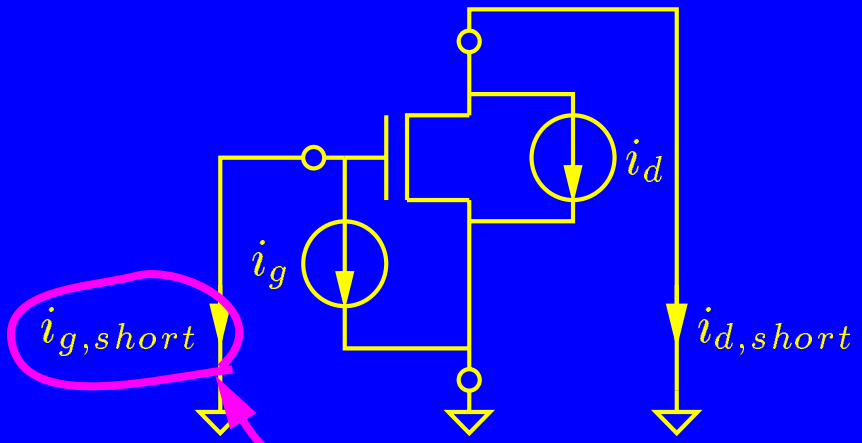
BSIM4 Noise Model (*Continue*)
(Arguments)

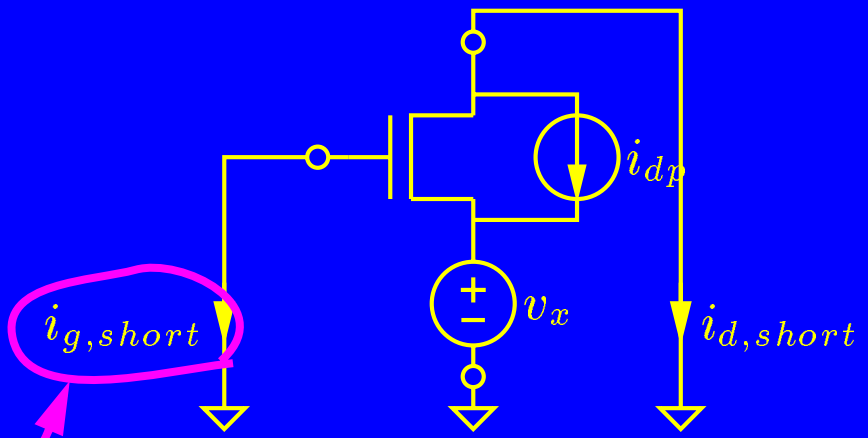
- BSIM4 is easy to implement.
- What is the physical relationship to the van der Ziel model ?
- How to extract the parameters ?
- What is the underlying assumption ?
- How small is the discrepancy ?

BSIM4 Noise Model (*Continue*)
(Physical Relationship to van der Ziel)

van der Ziel



BSIM4

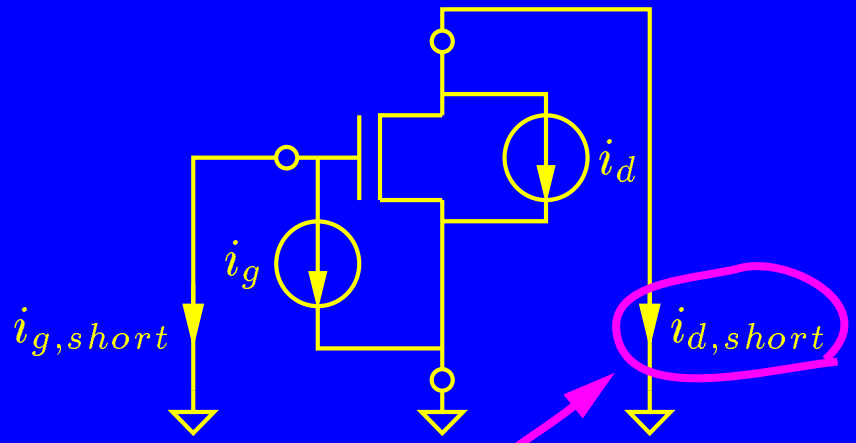


From $i_{g,short}$

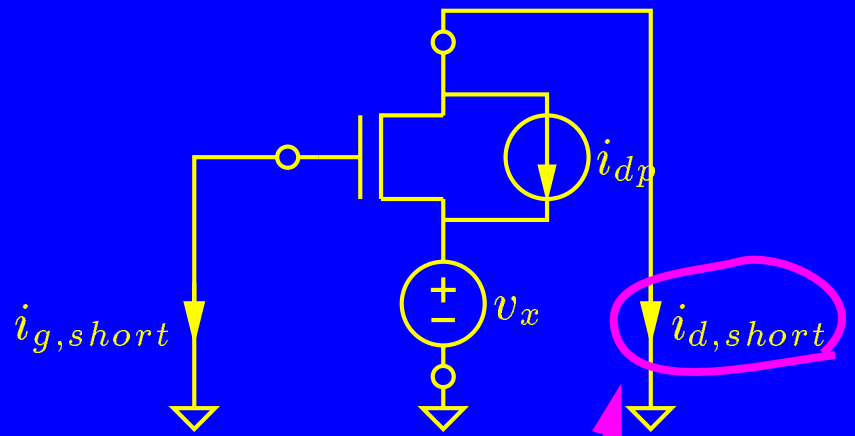
$$i_g = -(Y_{11} + Y_{12})v_x$$

BSIM4 Noise Model *(Continue)*
(Physical Relationship to van der Ziel)

van der Ziel



BSIM4



From $i_{g,short}$

$$i_g = -(Y_{11} + Y_{12})v_x$$

From $i_{d,short}$

$$i_d = -(Y_{21} + Y_{22})v_x + i_{dp}$$

BSIM4 Noise Model (*Continue*)
(Physical Relationship to van der Ziel)

Exact Fit

$$\overline{v_x^2} = \overline{i_g^2} / |Y_{11} + Y_{12}|^2$$

$$\overline{i_{dp}^2} = \overline{i_d^2} - |Y_{21} + Y_{22}|^2 \overline{v_x^2}$$

BSIM4 Noise Model (*Continue*)
(Physical Relationship to van der Ziel)

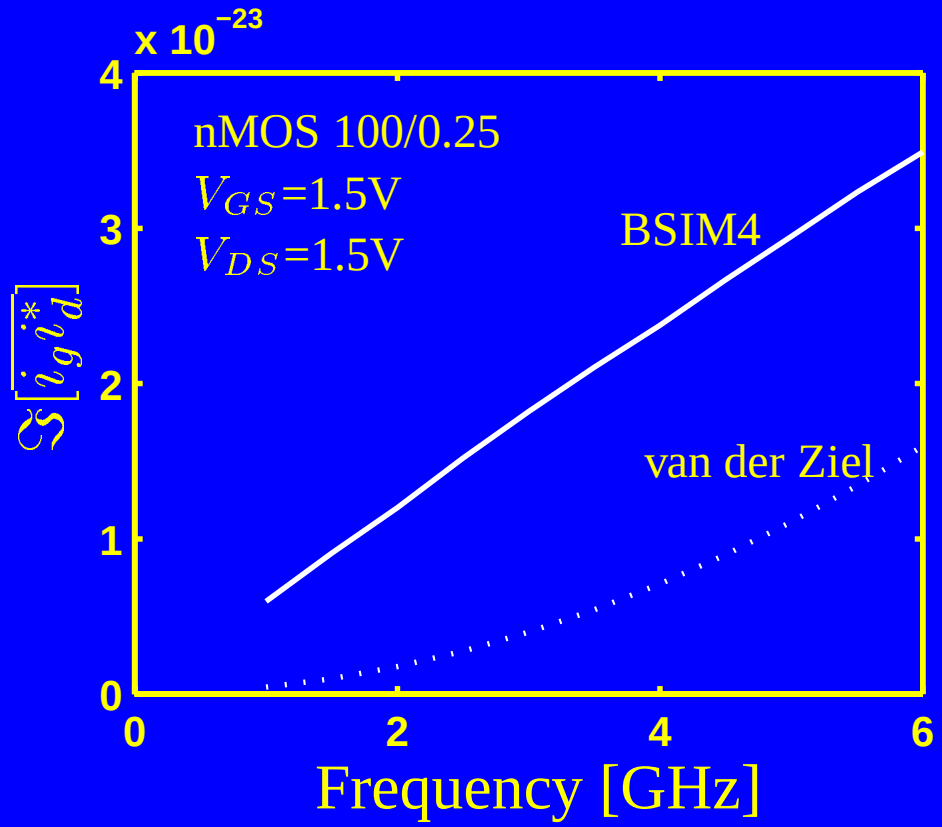
Exact Fit

$$\overline{v_x^2} = \overline{i_g^2}/|Y_{11}+Y_{12}|^2$$
$$\overline{i_{dp}^2} = \overline{i_d^2} - |Y_{21}+Y_{22}|^2\overline{v_x^2}$$

Discrepancy

$$\overline{i_g i_d^*} = \overline{i_g^2}(Y_{21}+Y_{22})^*/(Y_{11}+Y_{12})^*$$

is assumed in BSIM4



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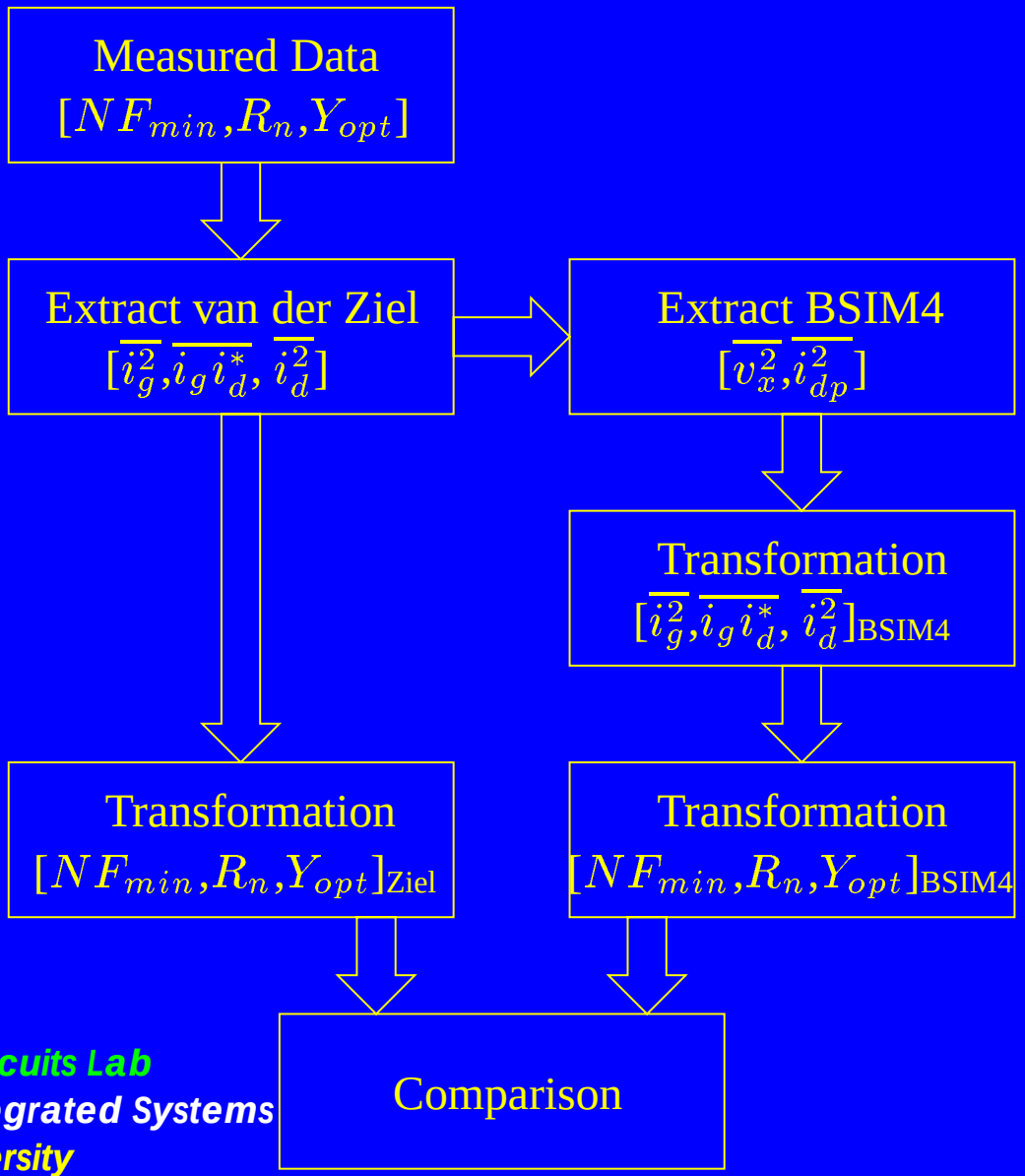
Model Comparison Method
(Parameter Extraction Procedure)



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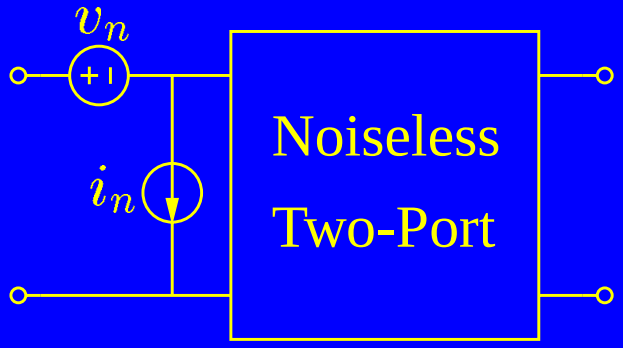
Model Comparison Method (*Continue*)
(Noisy Two-Port Theory)

Cascade Connection (Chain Parameter)



$$A \triangleq \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

$$C_A = A_1 C_{A_2} A_1^{\dagger} + C_{A_1}$$

$$C_A \triangleq \begin{bmatrix} C_{v_n v_n^*} & C_{v_n i_n^*} \\ C_{i_n v_n^*} & C_{i_n i_n^*} \end{bmatrix}$$

$$= 2kT \begin{bmatrix} R_n & \frac{F_{min}-1}{2} - R_n Y_{opt}^* \\ \frac{F_{min}-1}{2} - R_n Y_{opt} & R_n |Y_{opt}|^2 \end{bmatrix}$$

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✲ Measured 4-Noise Parameters

Model Comparison Method (*Continue*)
(Noisy Two-Port Theory)

Parallel Connection (*Y* Parameter)

$$\boldsymbol{Y} \triangleq \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

$$C_Y = C_{Y_1} + C_{Y_2}$$

$$C_Y \triangleq \begin{bmatrix} C_{i_1 i_1^*} & C_{i_1 i_2^*} \\ C_{i_2 i_1^*} & C_{i_2 i_2^*} \end{bmatrix} = 2kT\Re[\boldsymbol{Y}]$$

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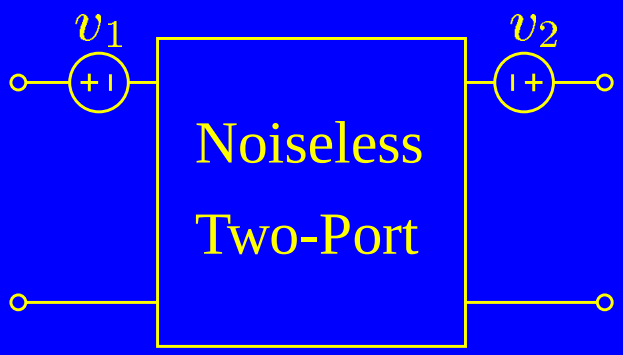
✲ van der Ziel Model

Model Comparison Method (*Continue*)
(Noisy Two-Port Theory)

Series Connection (Z Parameter)



$$Z \triangleq \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix}$$

$$C_Z = C_{Z_1} + C_{Z_2}$$

$$C_Z \triangleq \begin{bmatrix} C_{v_1 v_1^*} & C_{v_1 v_2^*} \\ C_{v_2 v_1^*} & C_{v_2 v_2^*} \end{bmatrix} = 2kT\Re[Z]$$

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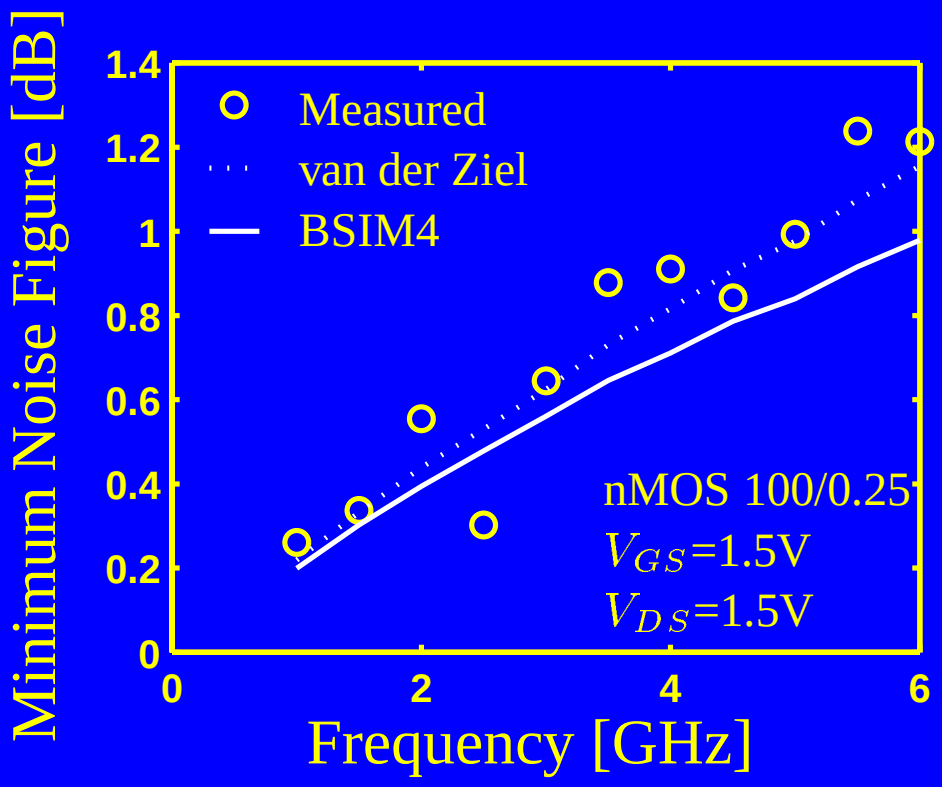
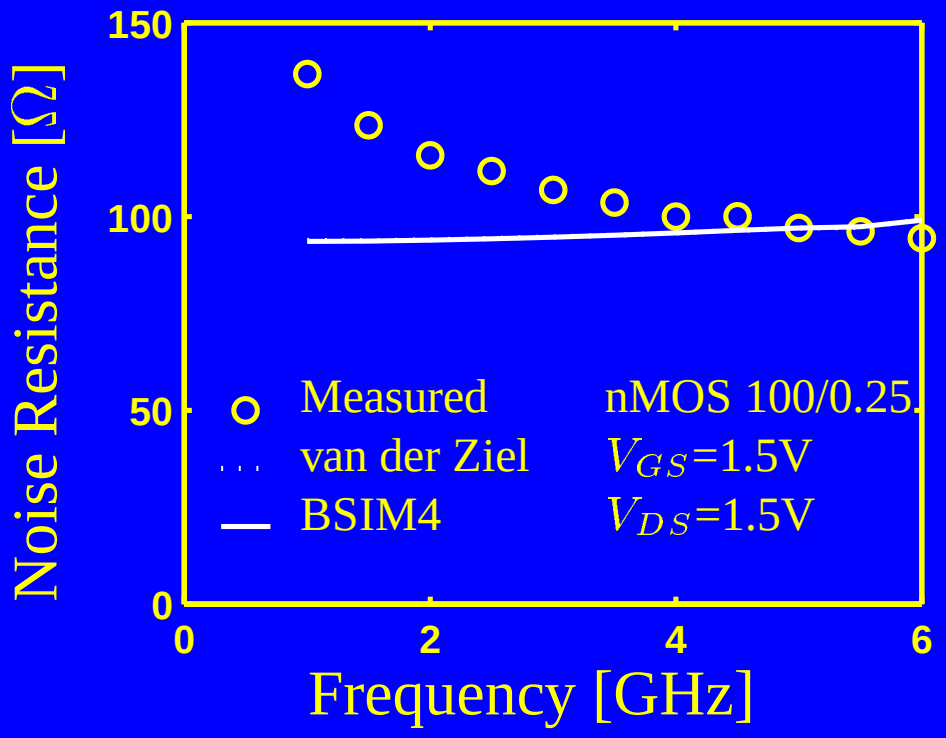
Validation for Device
(4 Noise Parameters)

NF_{min}



R_n



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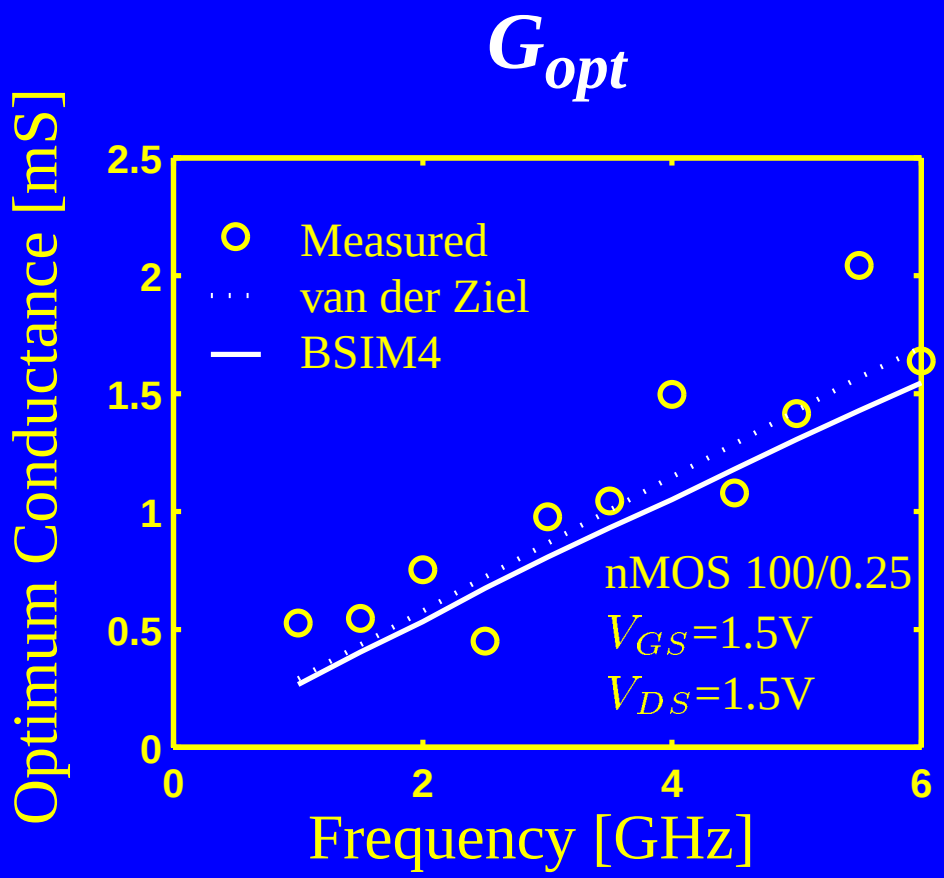
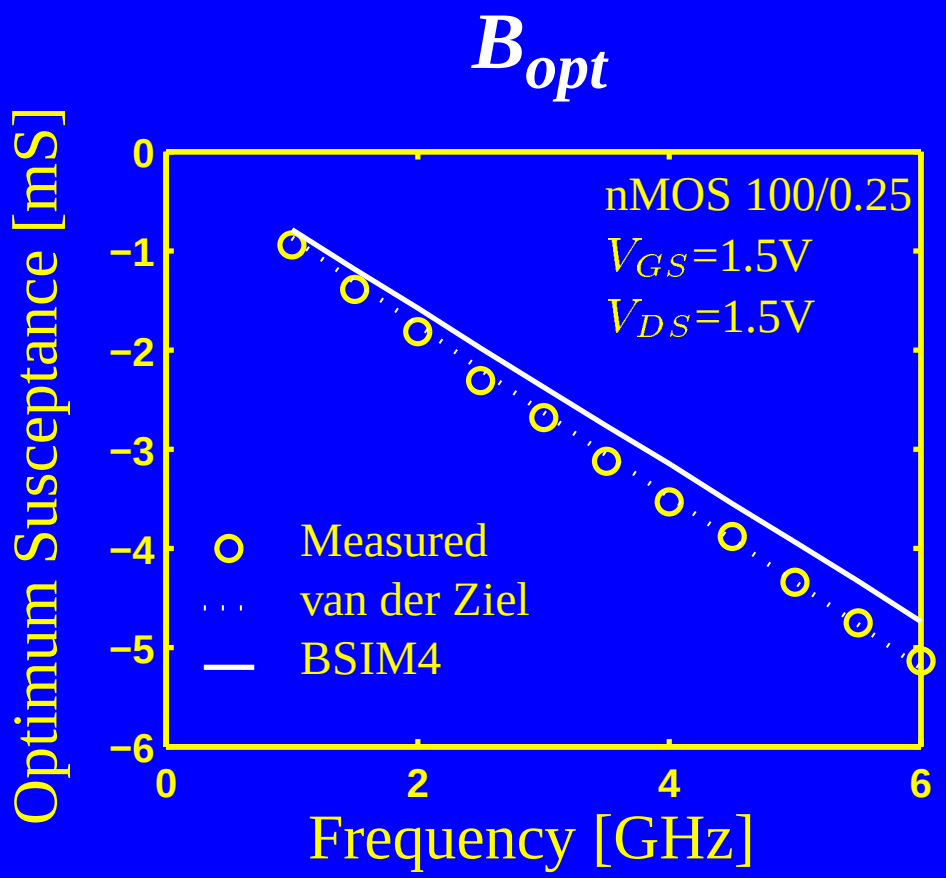
Validation for Device (*Continue*)
(4 Noise Parameters)





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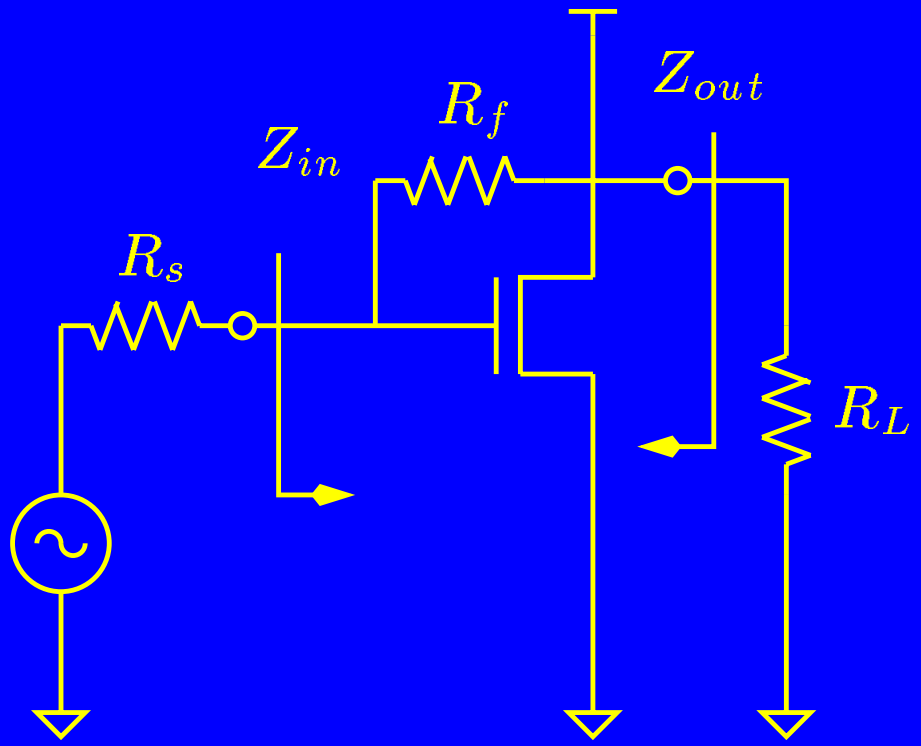
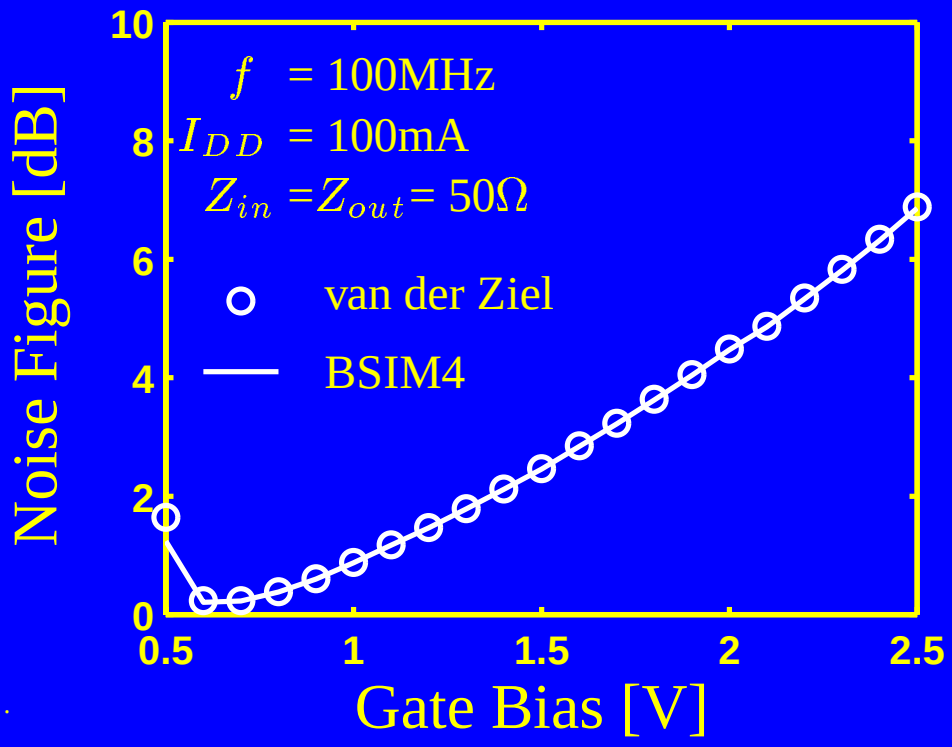
Validation for Circuits
(Shunt-series Feedback Amplifier)





$$NF \triangleq NF_{min} + \frac{(Y_s - Y_{opt})^2 R_n}{G_s} \quad (\tilde{0})$$

$Y_s >> Y_{opt}$

$$\approx \frac{|Y_s|^2 R_n}{G_s}$$

Same

Constant

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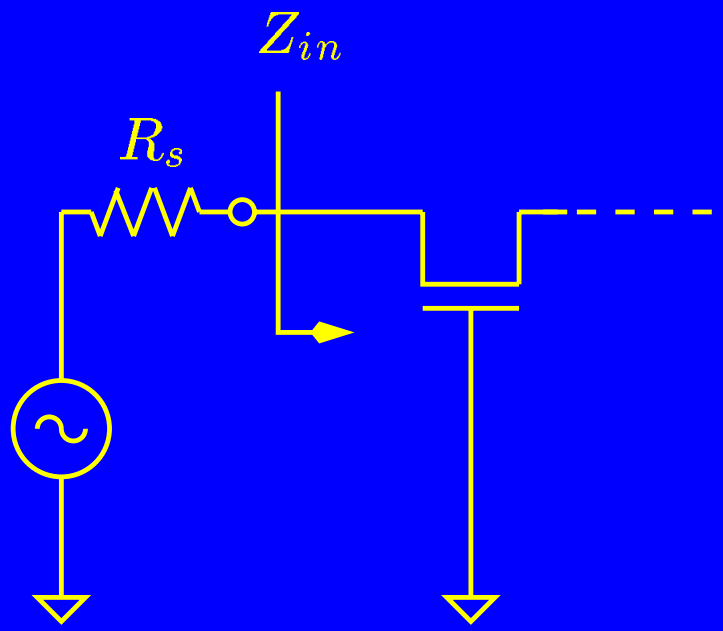
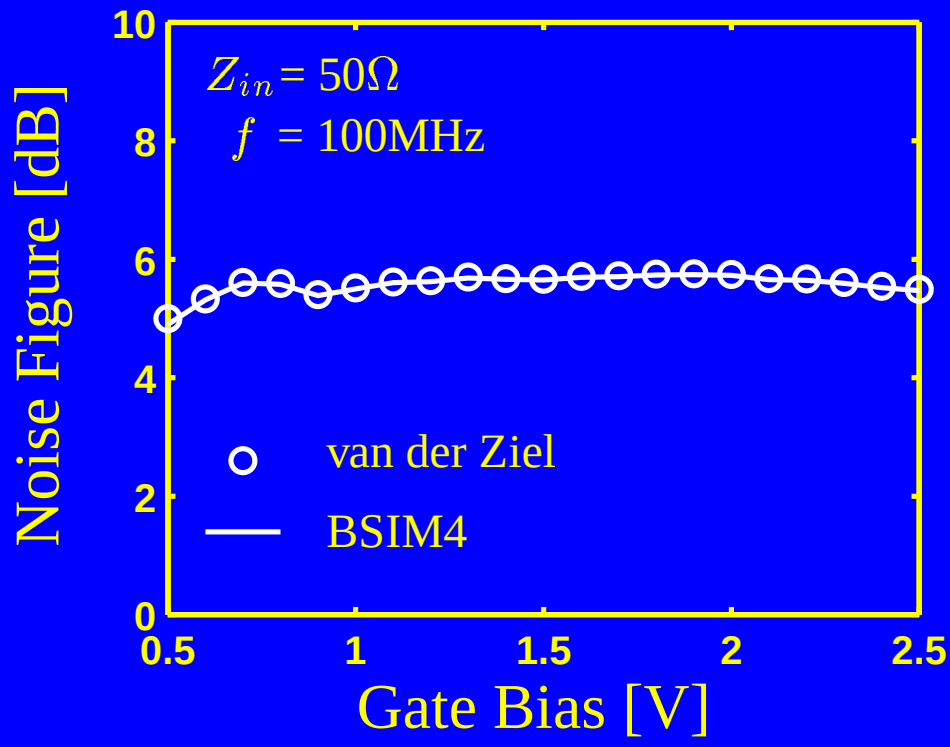
Validation for Circuits (*Continue*)
($1/g_m$ Termination Amplifier)





- By the same reason.
- Validates a non-grounded source electrode condition.

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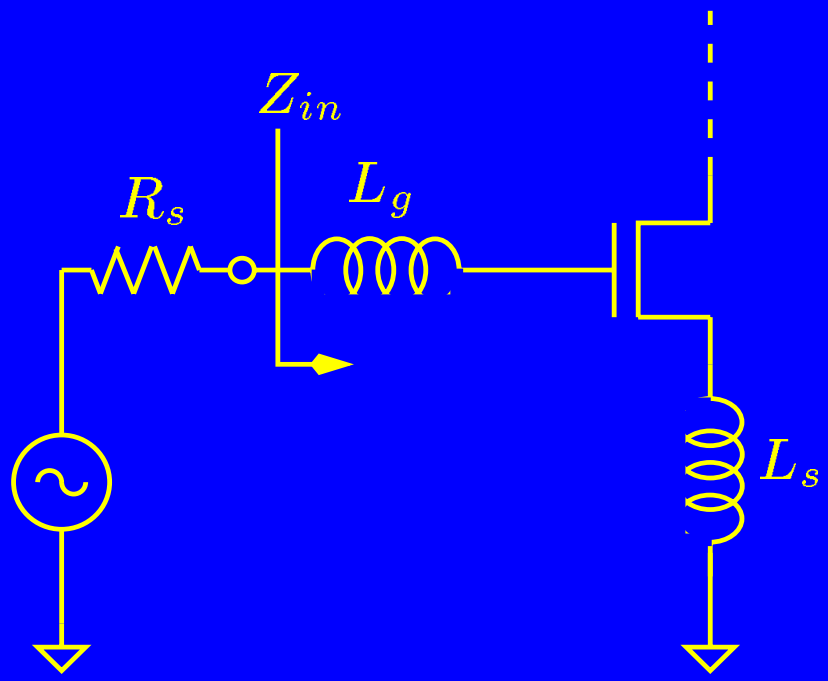
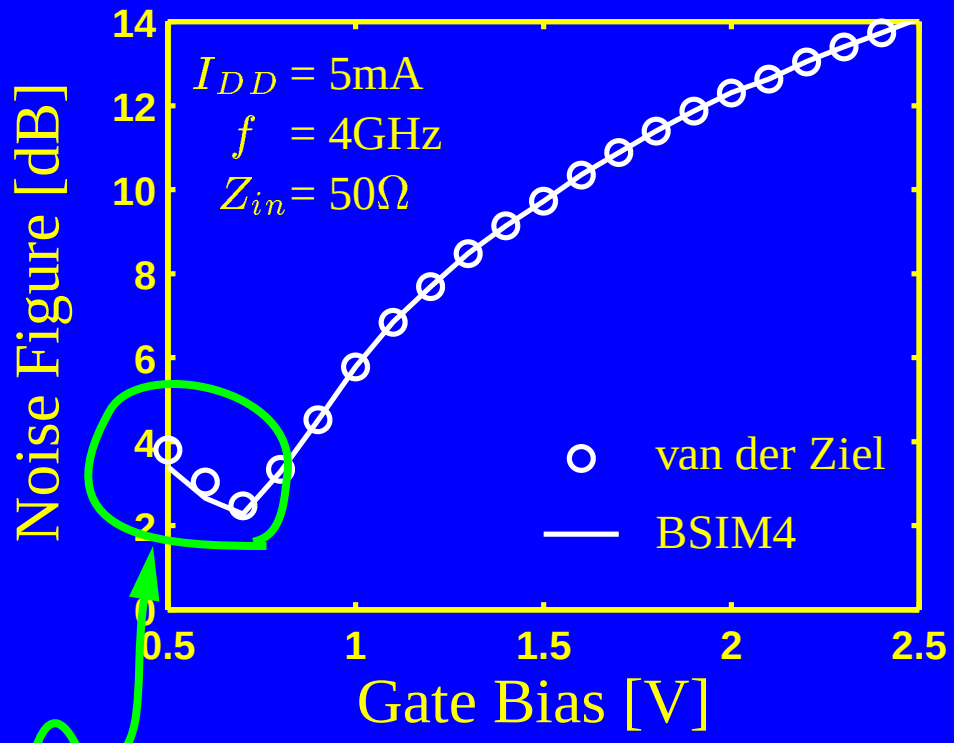
Validation for Circuits (*Continue*)
(Inductive Degeneration Tuned Amplifier)





- Y_{opt} is comparable to Y_s.
- Another non-grounded source electrode case.

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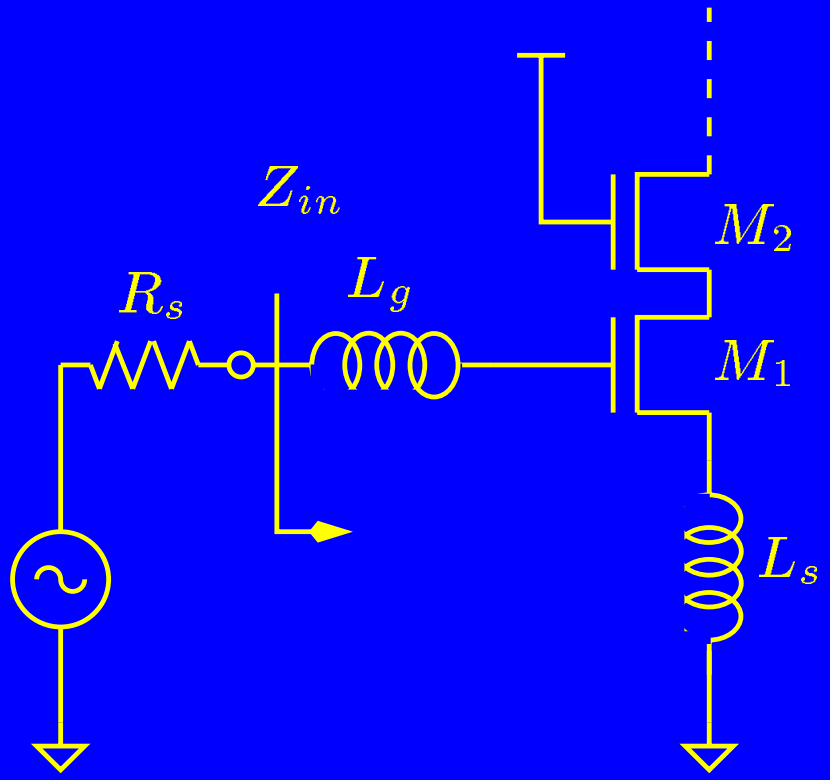
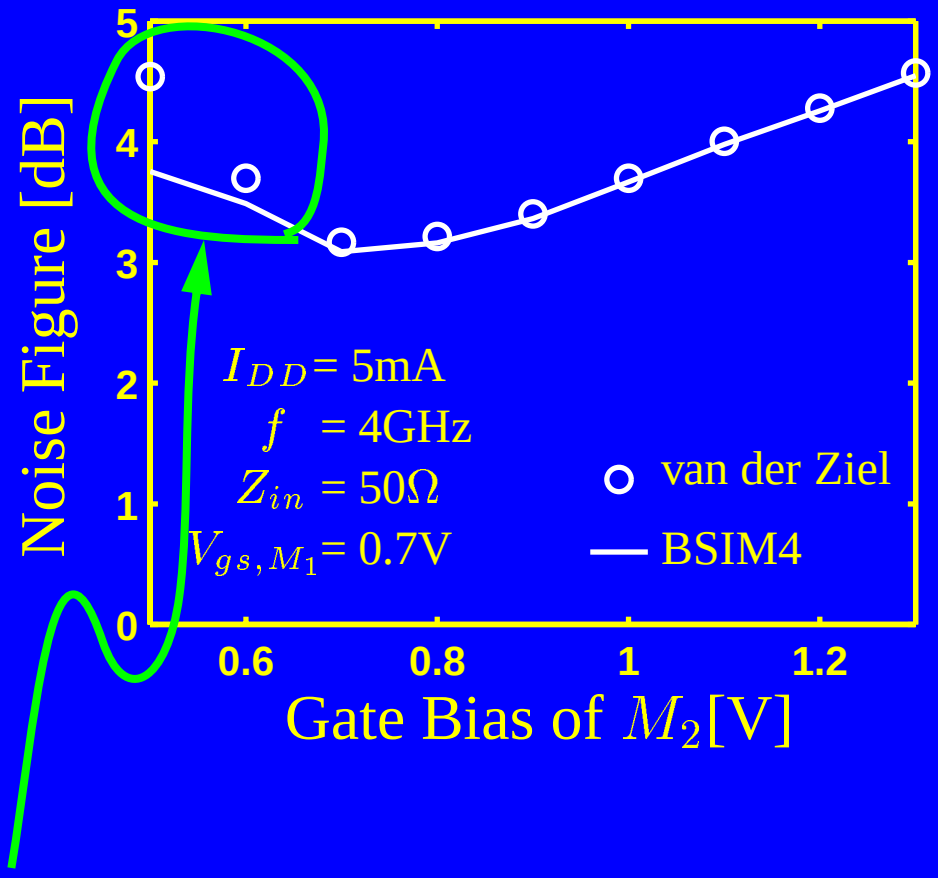
Validation for Circuits (*Continue*)
(Tuned Amplifier with Cascode Stage)





✲ More noticeable discrepancy.

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Conclusions

- First independent comparison between BSIM4 and van der Ziel models for induced gate noise.
- BSIM4 reproduces the van der Ziel model but introduces errors in the correlated term.
- In practical circuits, noticeable errors arise for very low gate bias conditions only.
- The two models are equivalent in most practical circuits.