The PSP compact MOSFET model
An update

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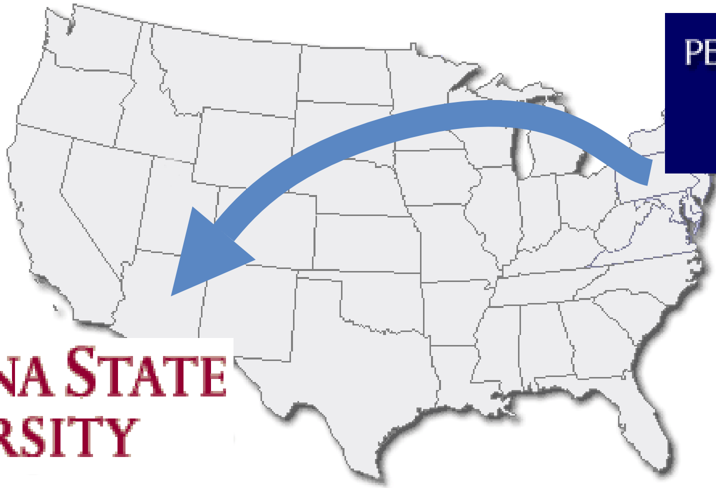
MOS-AK, Montreux, September 22, 2006

Affiliations

NXP founded by Philips

PHILIPS Semiconductors



PENNSTATE

ARIZONA STATE UNIVERSITY

http://pspmodel.asu.edu
http://www.nxp.com/Philips_Models/mos_models/psp/

Outline

- History & overview
- DC verification on 65nm technology
- Symmetry and distortion
- Non-quasi static effects
- Summary & references

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History

- April 2005: First PSP version (100.0) released. Created from
  - MOS Model 11 (Philips)
  - SP (Penn State)
- December 2005: CMC elects PSP as “next generation compact MOSFET model” (i.e. successor of BSIM3/4)
- June 2006: First CMC-standardized version (PSP 102.0) was released
- Future: PSP extended to complete family of models
  - Bulk CMOS
  - Varactor
  - PD-SOI
  - FD-SOI
  - FinFETs
  - …

Model overview

- PSP is a surface potential based compact MOSFET model, suitable for digital, analog and RF design
  - non-uniform lateral/vertical doping
  - field-dependent mobility
  - velocity saturation
  - conductance effects (CLM, DIBL, etc.)
  - series-resistance
  - short-channel effects (incl. RSCE)
  - narrow-width effects
  - gate poly-depletion
  - quantum-mechanical corrections
  - overlap capacitances (ψ_s-based)
  - impact ionization current
  - gate leakage current
  - gate-induced drain/source leakage (GIDL, GISL)
  - junction diode I-V and C-V (forward and reverse)
  - diode reverse breakdown
  - noise (1/f, thermal, induced gate and shot noise)
  - non-quasi-static effects
  - gate and bulk resistances
  - STI stress effect

See also MOS-AK 2005

Update PSP 102.0

- Changes PSP 100.0 → 102.0
  - Binning
  - Improved Gummel symmetry (modified CLM-model and V_B-clamping)
  - Replaced lateral gradient factor
  - More flexible geometry scaling
  - Improved mobility model (CS, FETA, scaling)
  - Improved forward bulk-bias behavior
  - BSIM-like instance parameters for JUNCAP2 (AS, AD, PS, PD)
  - Several minor improvements, bug fixes, and maintenance
  - October 2006: PSP 102.1 includes first C-implementation of NQS-model
- Partly based on useful feedback by Jazz, Infineon, Freescale, STm, RFMD, Analog Devices, …

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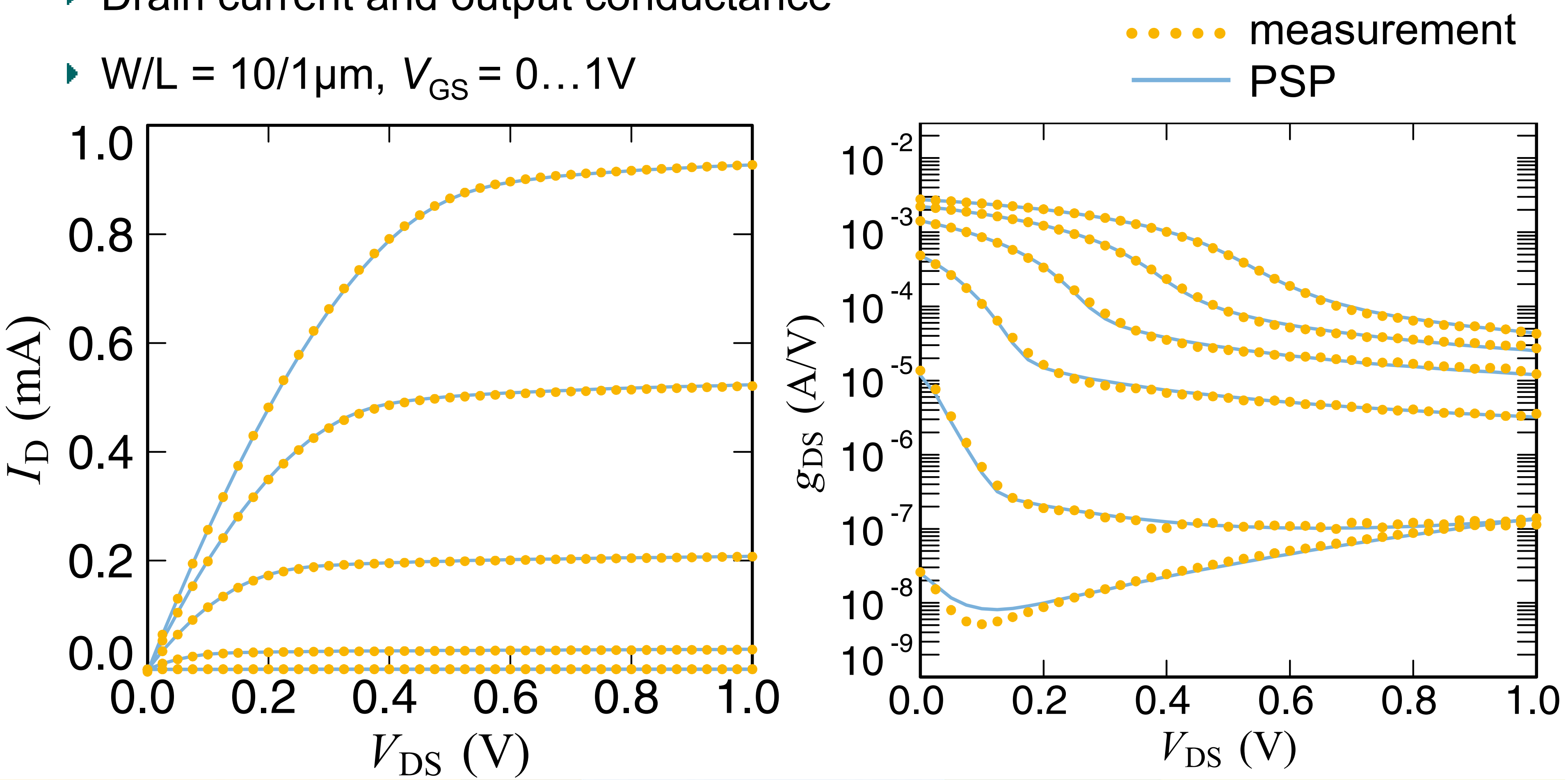
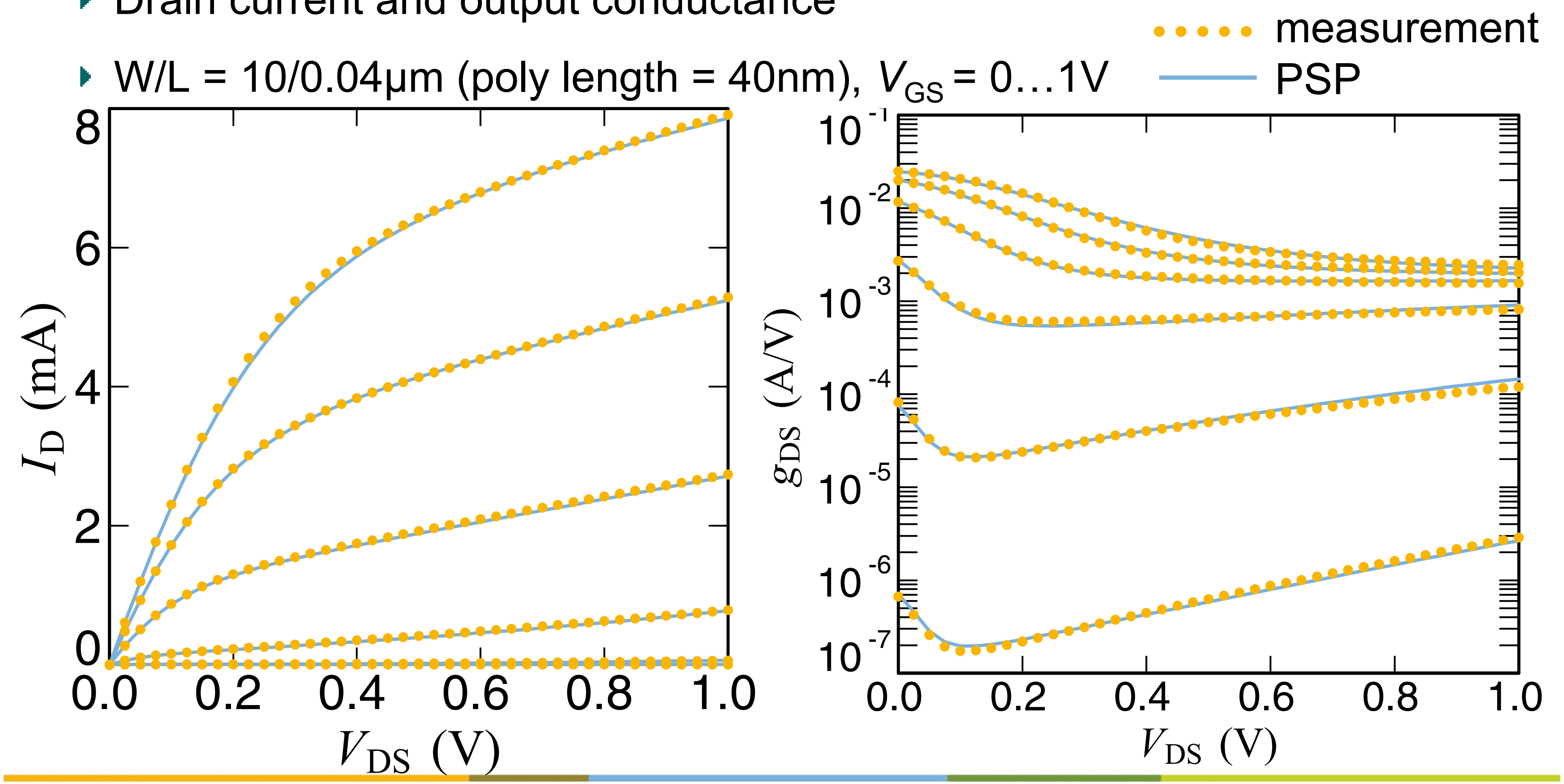
Long channel (65nm technology)

- Drain current and output conductance
- W/L = 10/1µm, V_{GS} = 0…1V



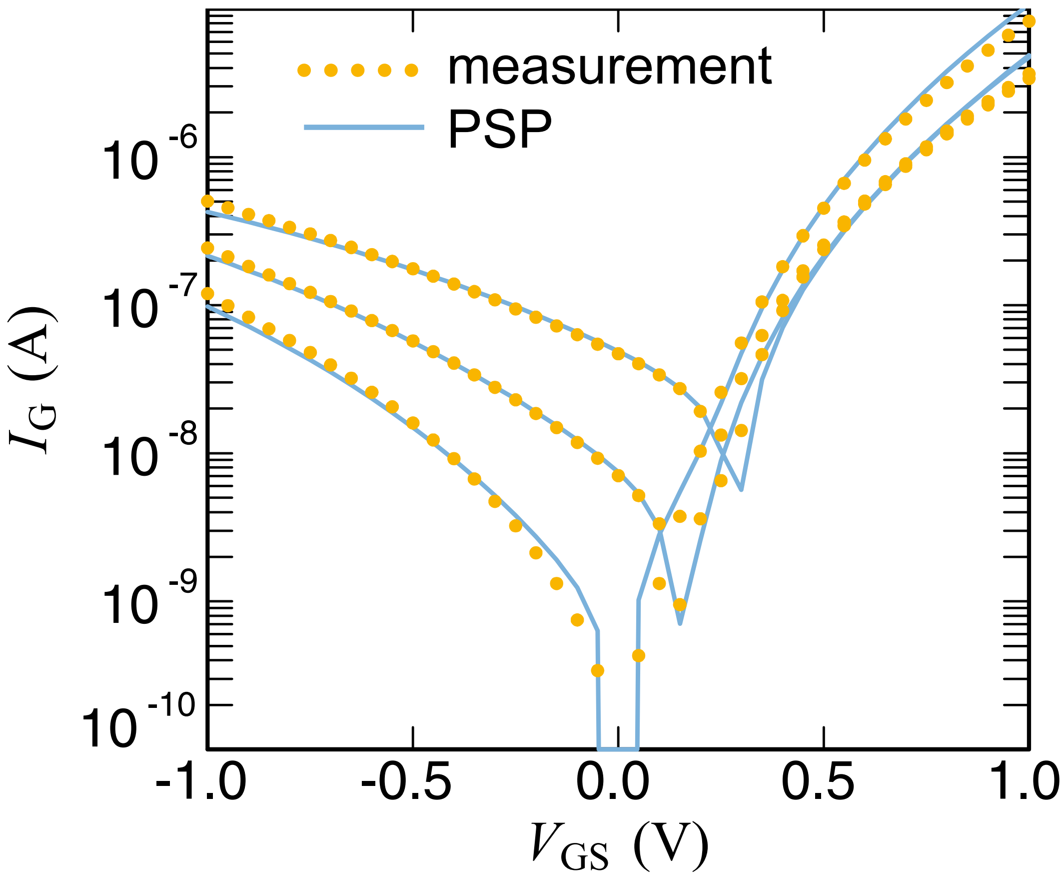
Short channel (65nm technology)

- Drain current and output conductance
- W/L = 10/0.04µm (poly length = 40nm), V_{GS} = 0…1V



Gate current (65nm technology)

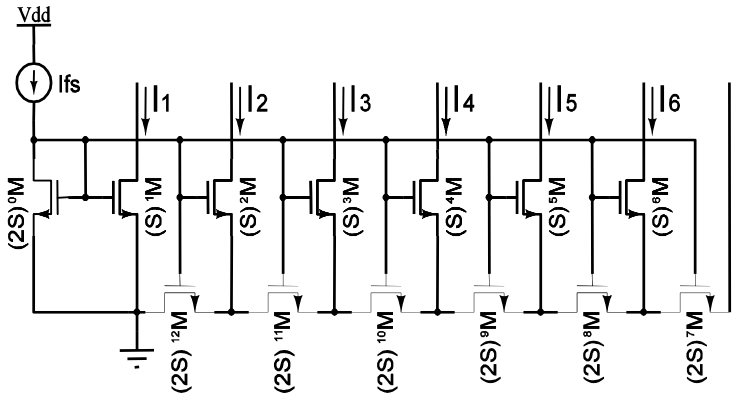
- Gate current
- W/L = 10/1µm, V_{DS} = 0…1V



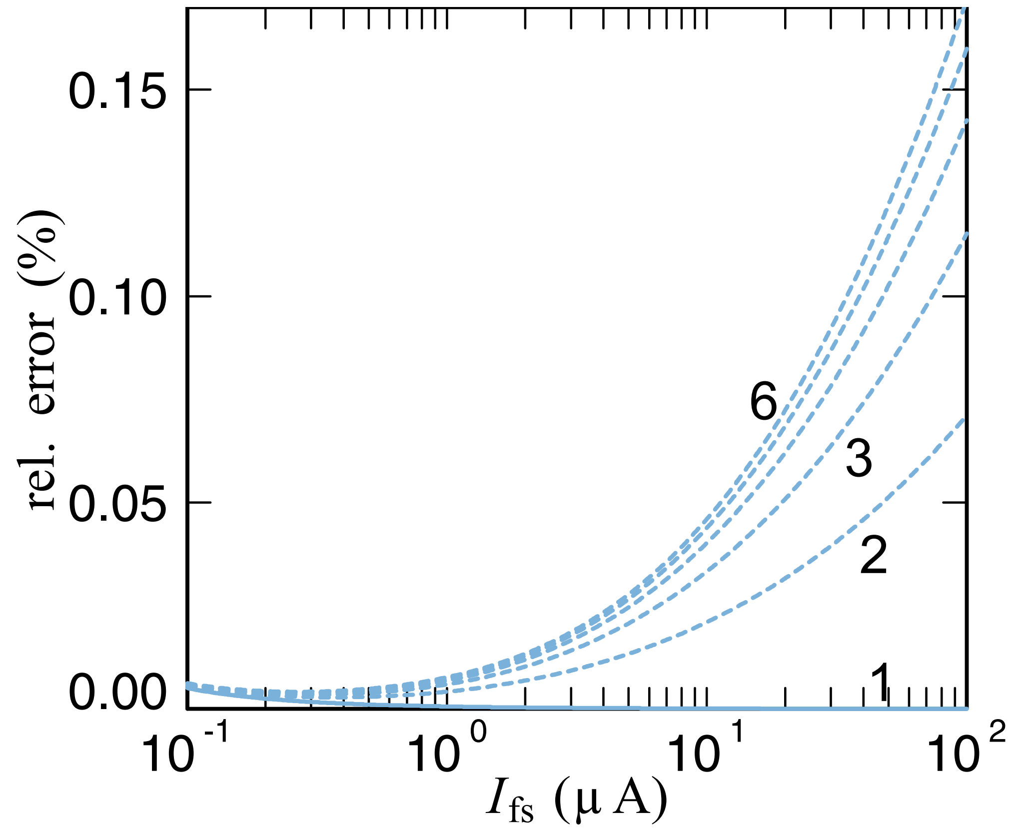
PSP model has been verified to successfully describe various 90nm, 65nm and 45nm processes

R2R-circuit

- Benchmark test for quality of integral along channel $I_{DS} = -\frac{W}{L} \int_{V_{SB}}^{V_{DB}} \mu \cdot q_{inv} \cdot dV$
- Ideal long channel model



$$\text{rel. error} = \frac{2^{n-1} \cdot I_n - I_{fs}}{I_{fs}}$$



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Gummel symmetry (i)

- CMOS devices are symmetric w.r.t. source/drain
- Imposed on the model by applying source/drain interchange

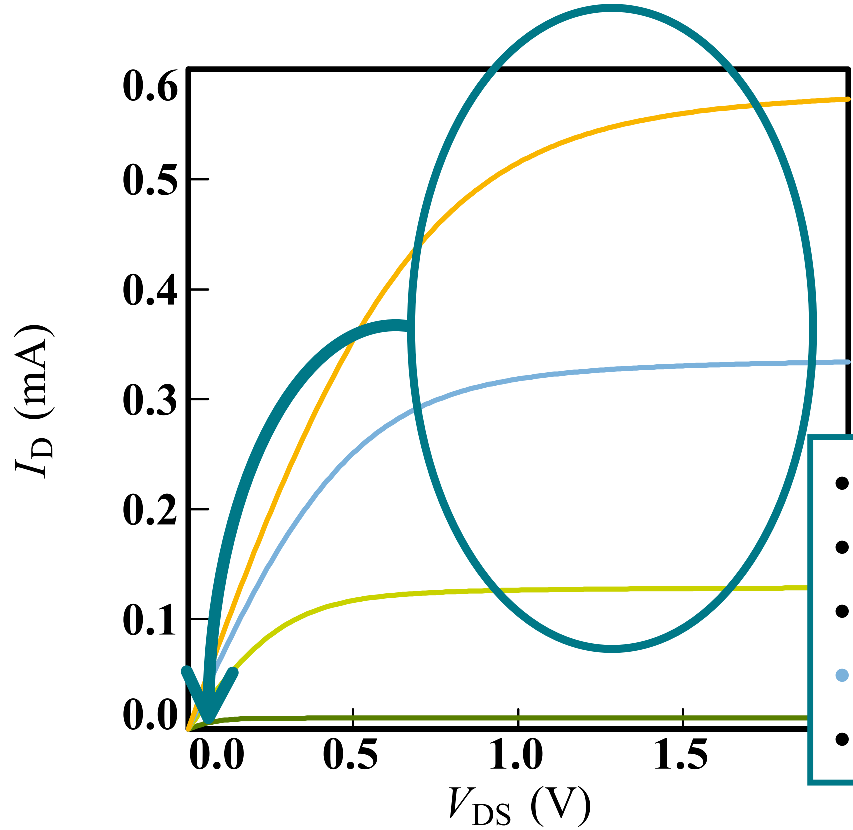
$$V_{DS} \geq 0 : I_{DS}(V_D, V_G, V_S, V_B) = I_{DS}^{+}(V_D, V_G, V_S, V_B)$$

$$V_{DS} < 0 : I_{DS}(V_D, V_G, V_S, V_B) = -I_{DS}^{+}(V_S, V_G, V_D, V_B)$$

- Guaranteeing a smooth connection at V_{DS}=0 is nontrivial

Gummel symmetry (ii)

- Why is Gummel symmetry nontrivial to achieve?

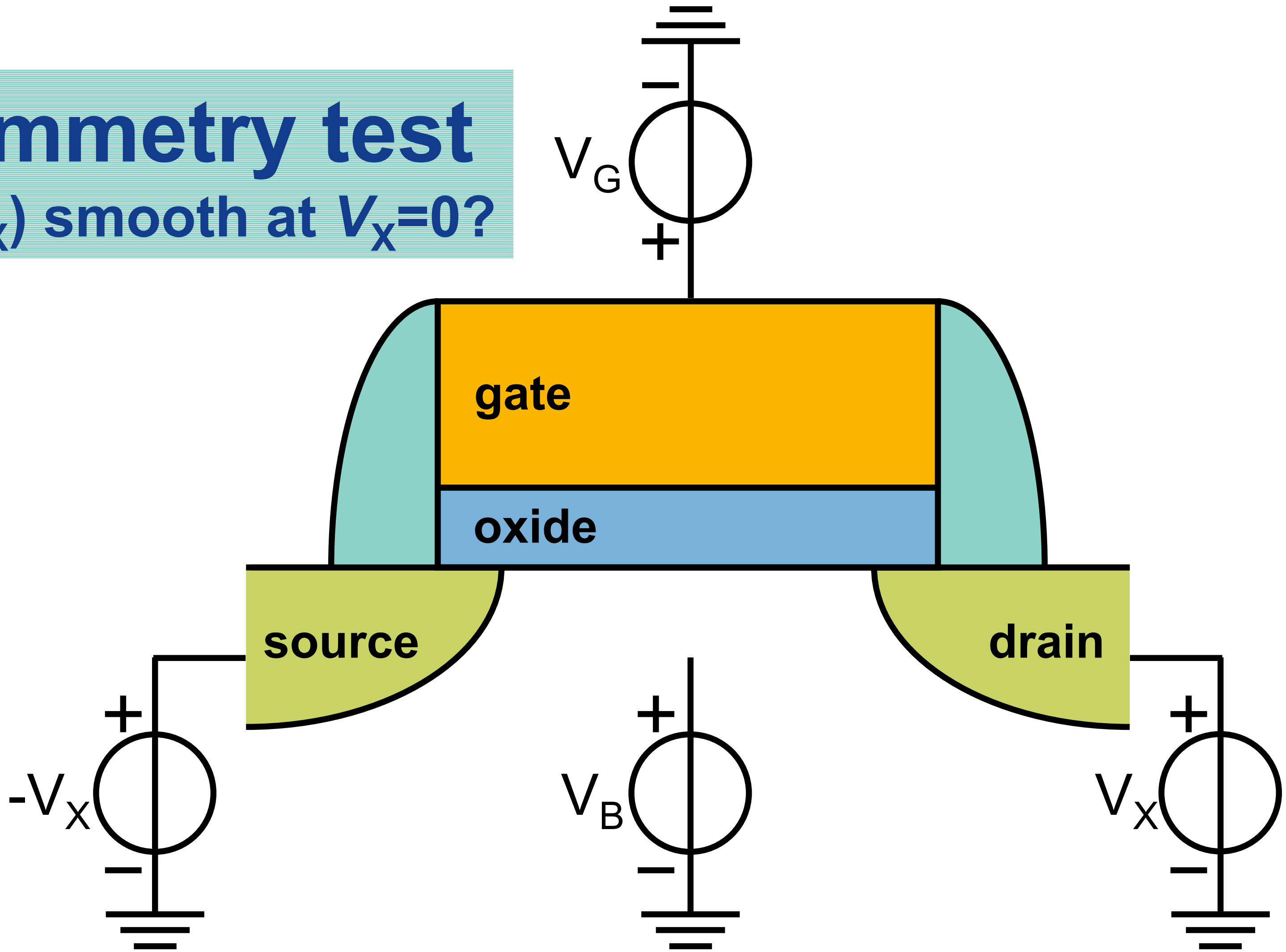


- velocity saturation
- V_{DSAT} calculation
- $V_{DS} \rightarrow V_{DSAT}$ transition
- channel length modulation (CLM)
- ….

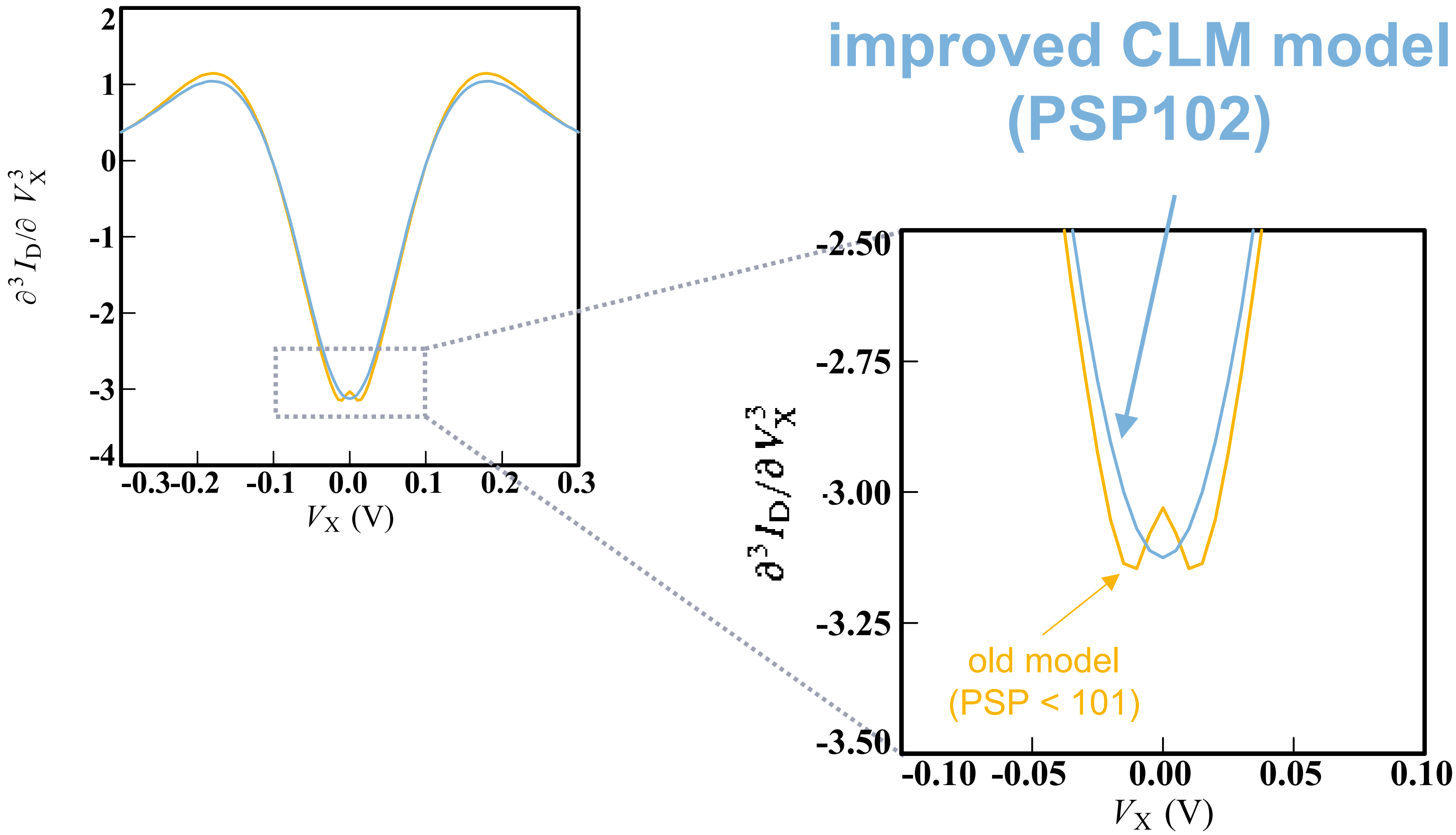
Gummel symmetry (iii)

Symmetry test

$I_D(V_X)$ smooth at $V_X=0$?

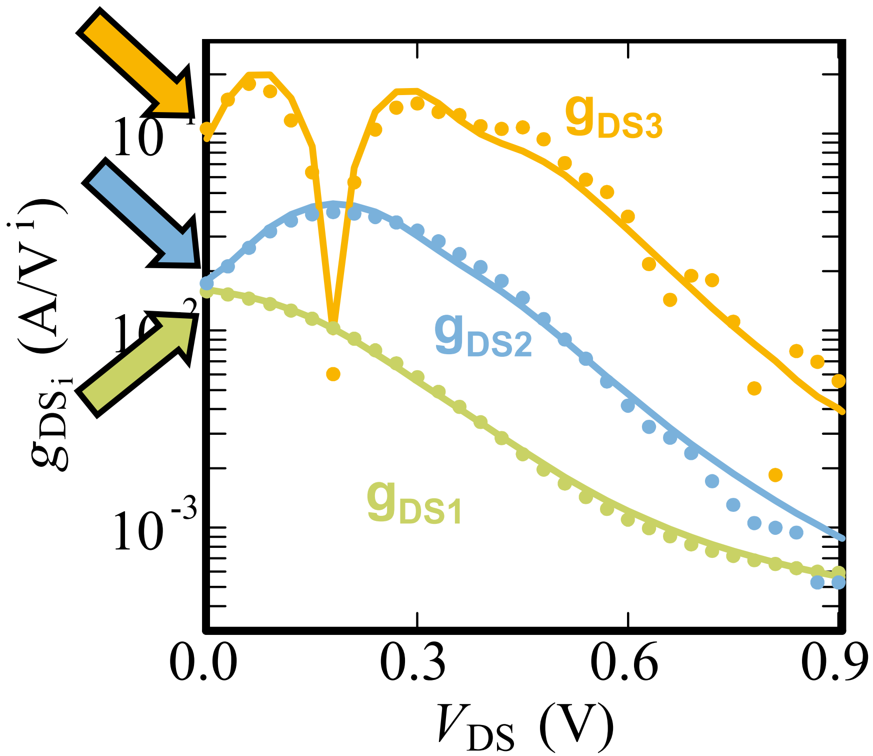


Gummel symmetry (iv)



Distortion (i)

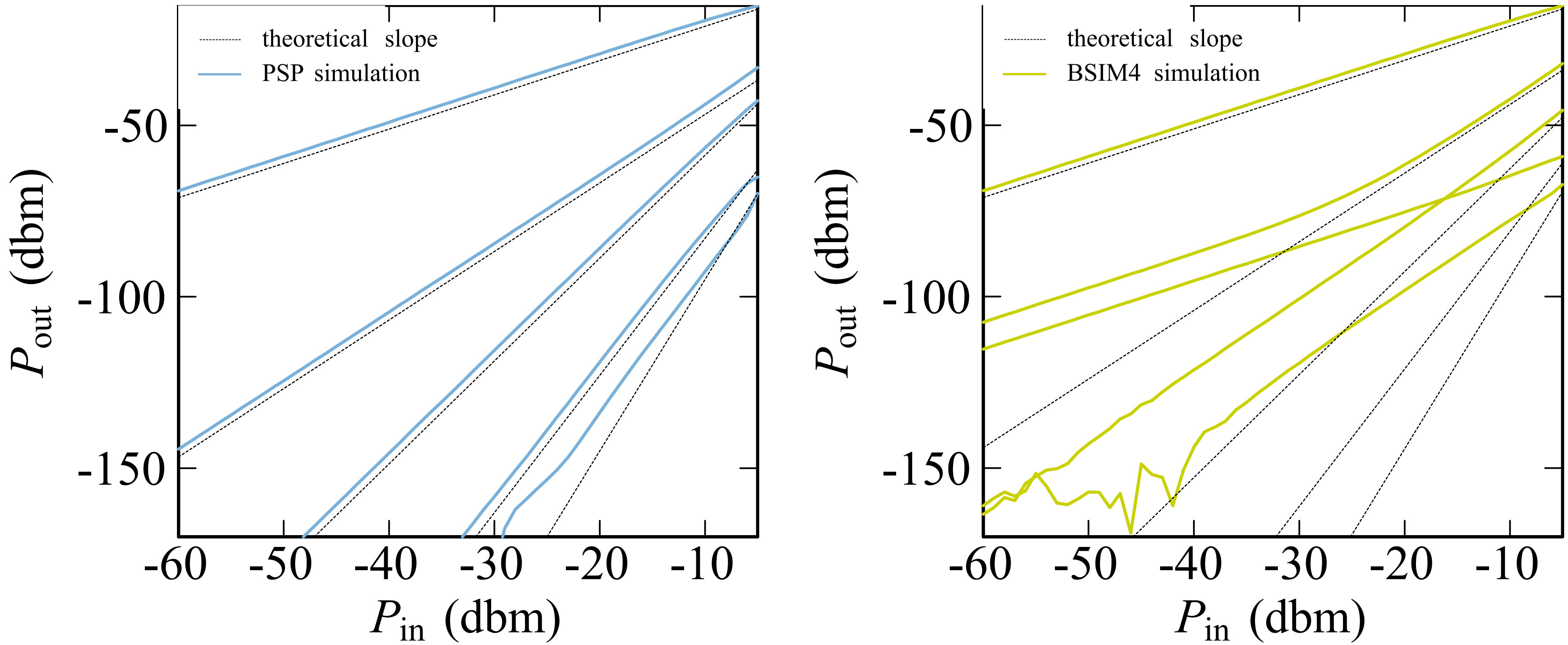
- Gummel symmetry is important for RF-CMOS circuit design (distortion)
- PSP gives excellent description up to at least 3rd order derivatives



NMOS
10/0.12

Distortion (ii)

- Two-tone intermodulation distortion simulation (1.8 and 1.9 GHz)
- V_{GS}=1V, V_{DS}=V_{SB}=0V, W/L=5/0.3µm NMOS, 90nm technology)



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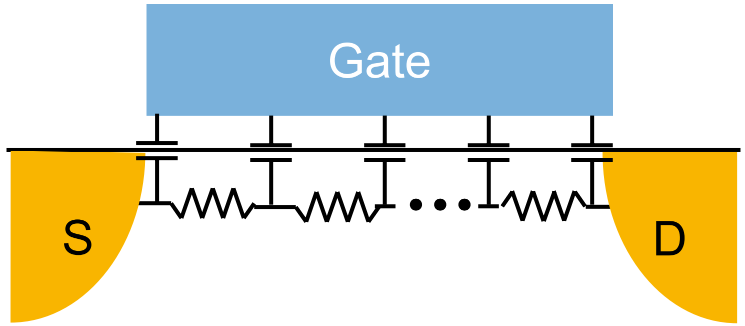
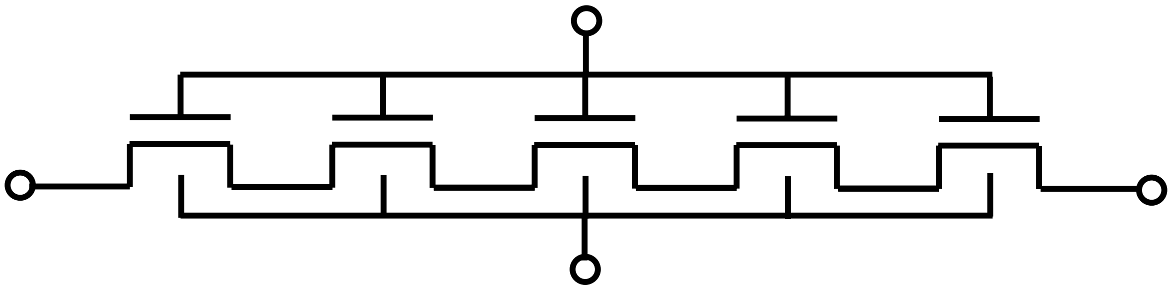
PSP NQS model (i)

- Non-quasi static effects:
  it takes time for charge to
  move trough the channel
  - distributed effect
  - “memory” effect
  - continuity equation: dQ/d$t \propto$ dI/dx



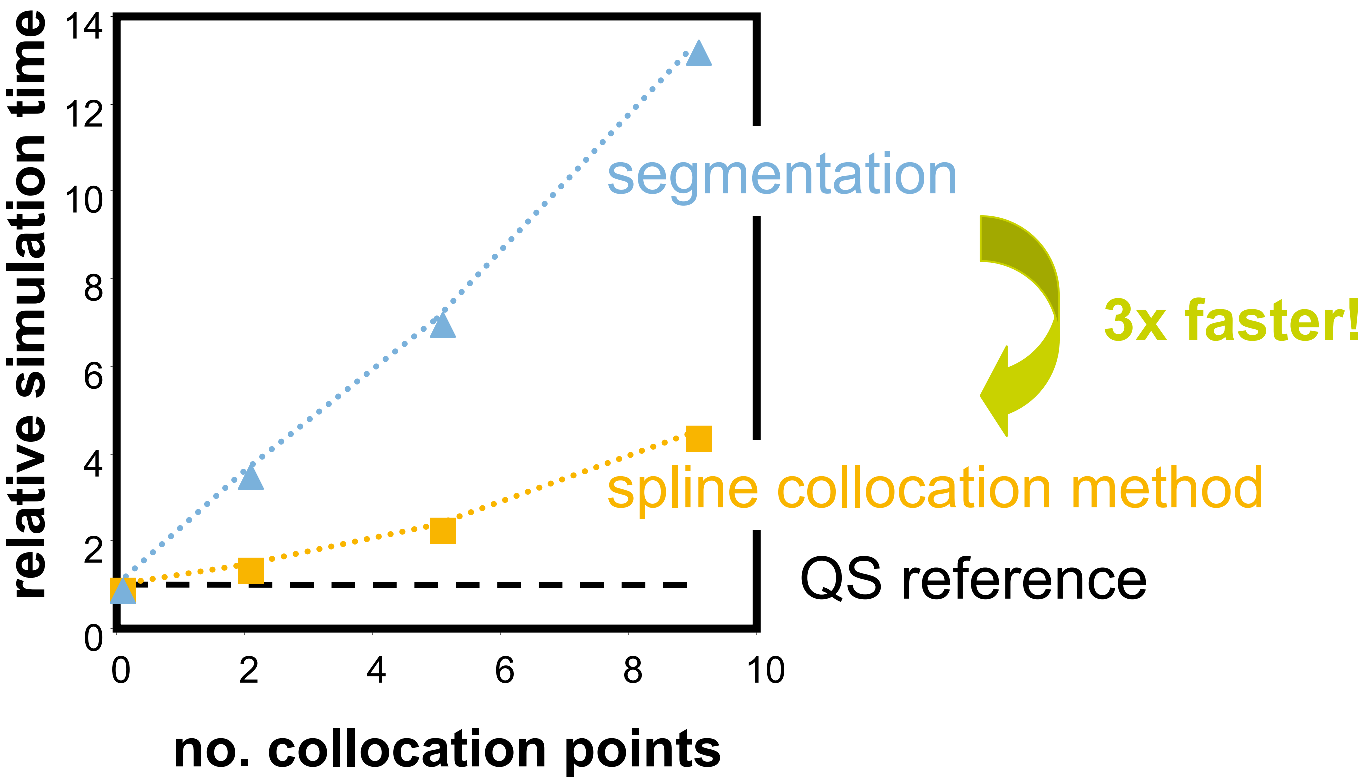
- Previously: channel segmentation (still good benchmark!)



- PSP: spline collocation method (adopted from SP model)
- No parameter fitting!

PSP NQS model (ii)

- Same physics as segmentation model, but much faster:



PSP NQS model (iii)

current continuity equation + spline approximation

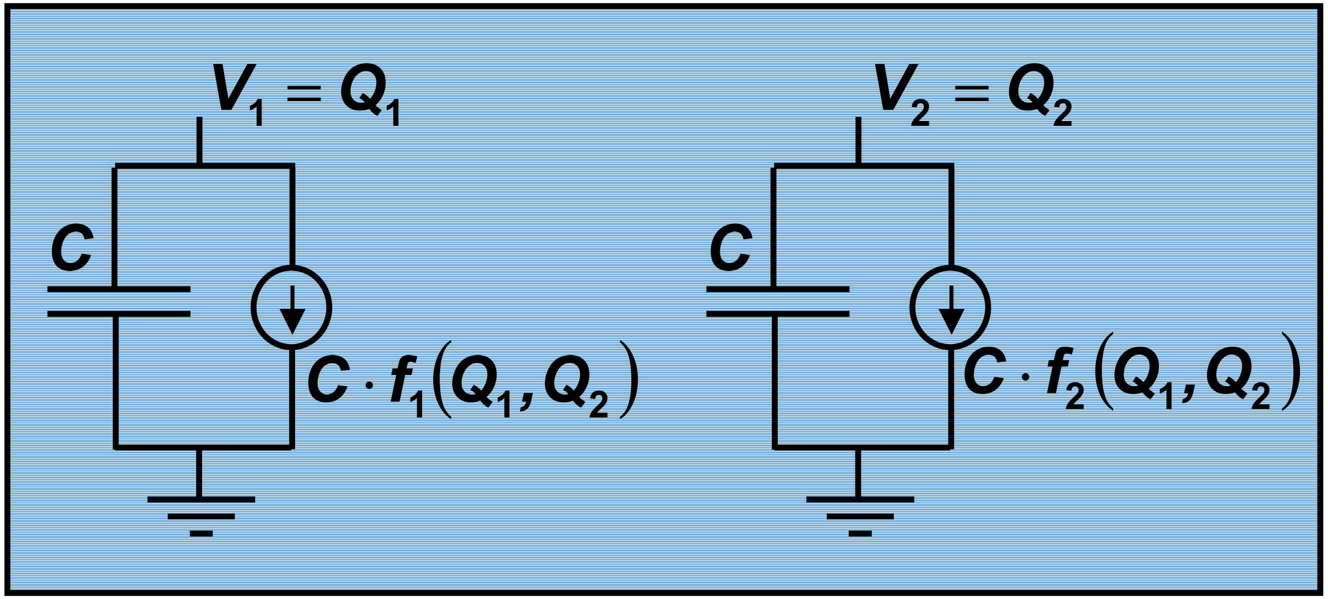
→ system of (coupled) ordinary differential equations

$$\frac{dQ_k}{dt} = -f_k\left(Q_1,\ldots,Q_N\right)$$

Q_k: **charge densities along channel**

implemented as sub-circuits, solved by circuit simulator:

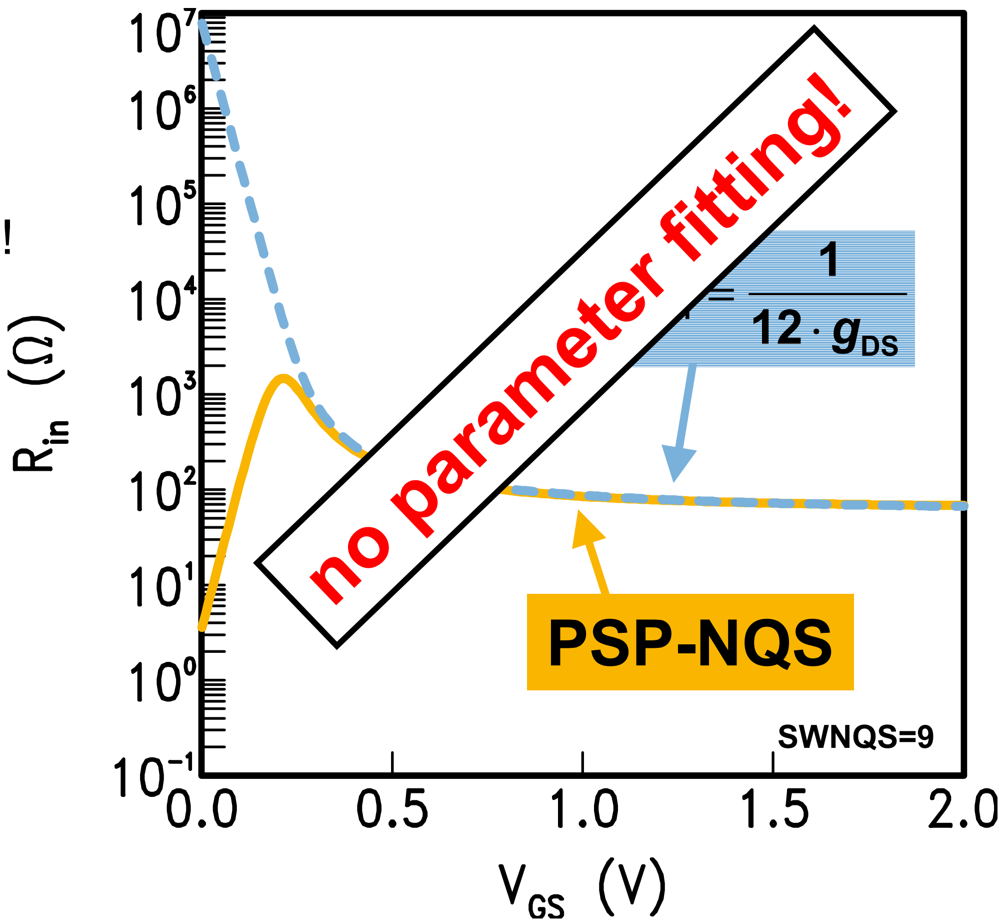
example:
(N = 2)



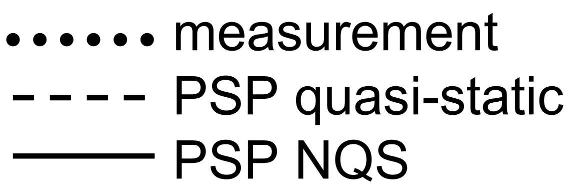
PSP NQS model (iii)

- Does model preserve basic physics?
- NQS model sanity check
  - Important for varactor modeling!
- Basic NQS physics
  - strong inversion
  - $V_{DS}=0$
  - $f \rightarrow 0$

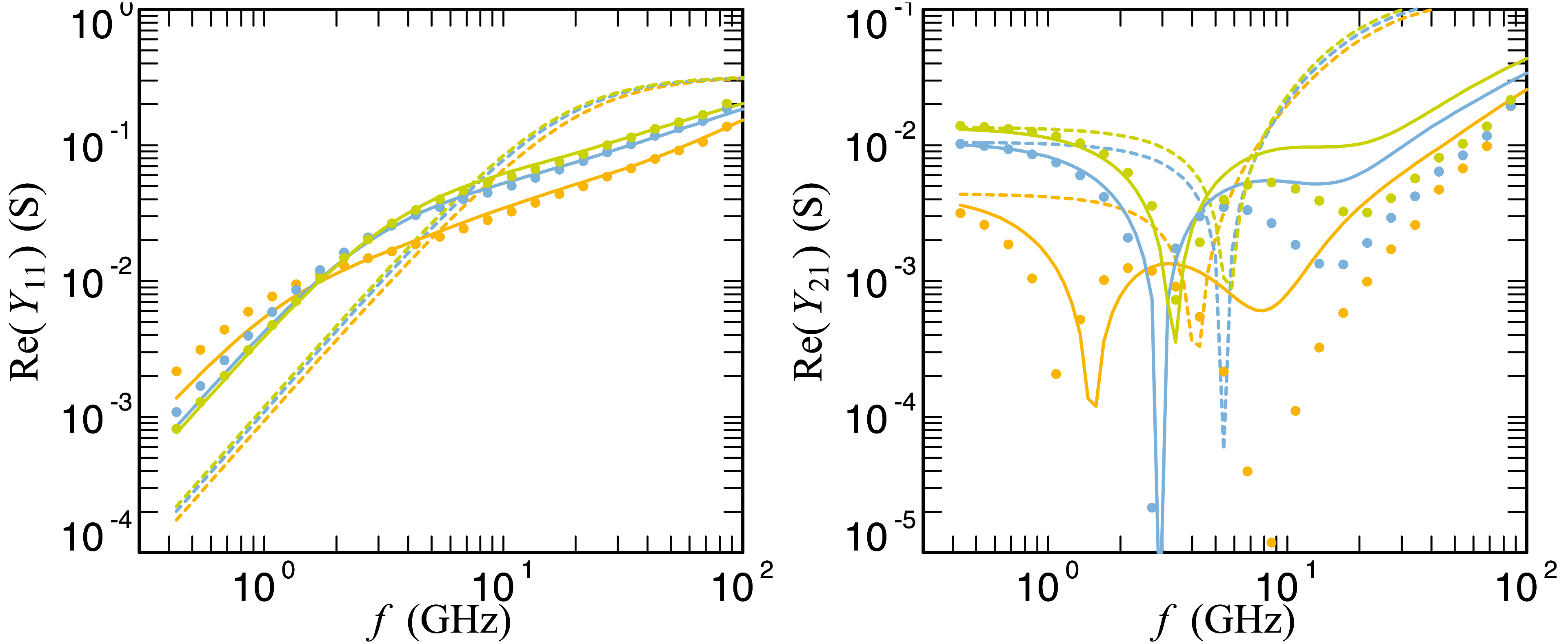
$$R_{in} = \frac{1}{12 \cdot g_{DS}}$$



PSP NQS model (v)

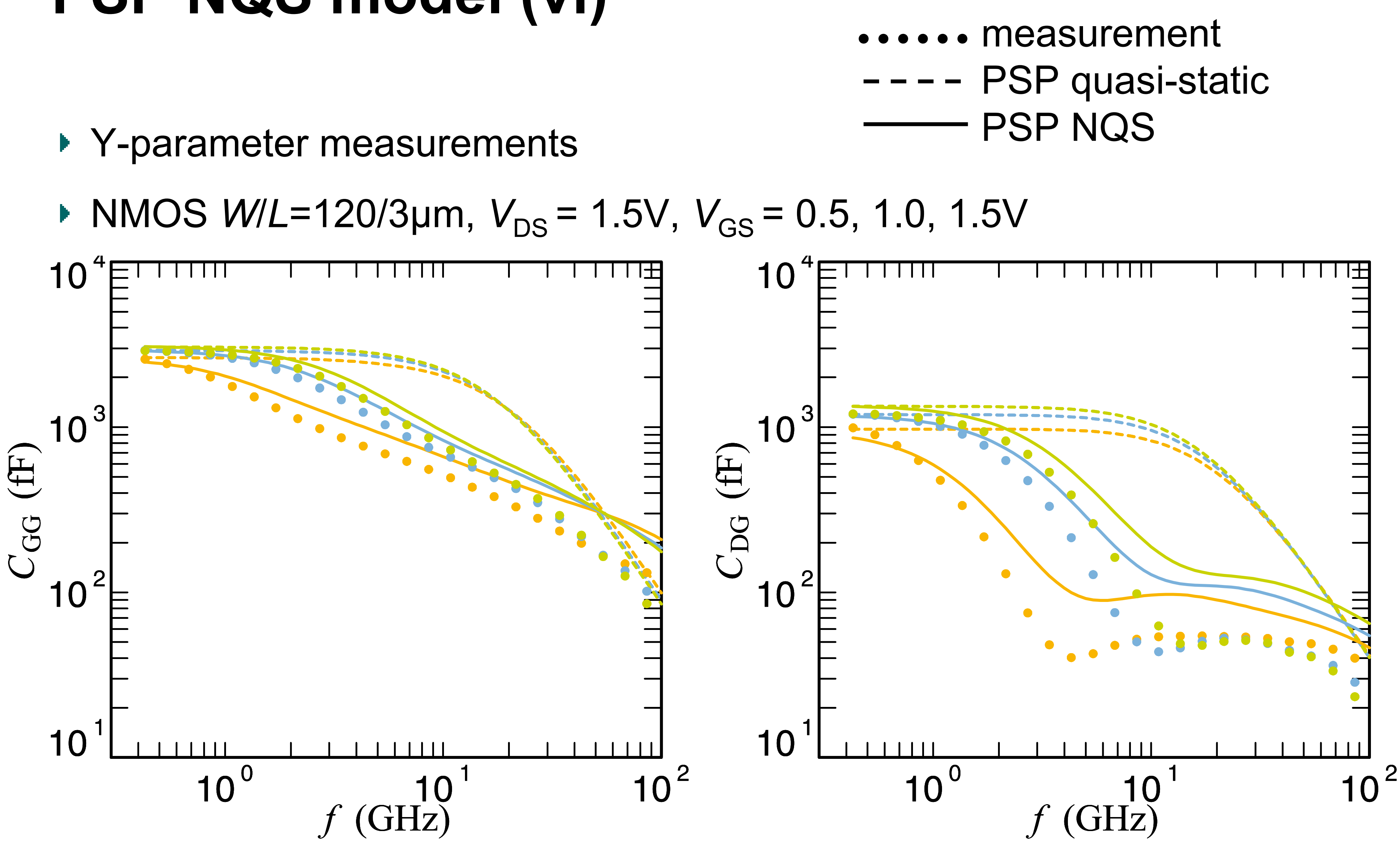


- Y-parameter measurements
- NMOS *W*/*L*=120/3µm, V_{DS} = 1.5V, V_{GS} = 0.5, 1.0, 1.5V

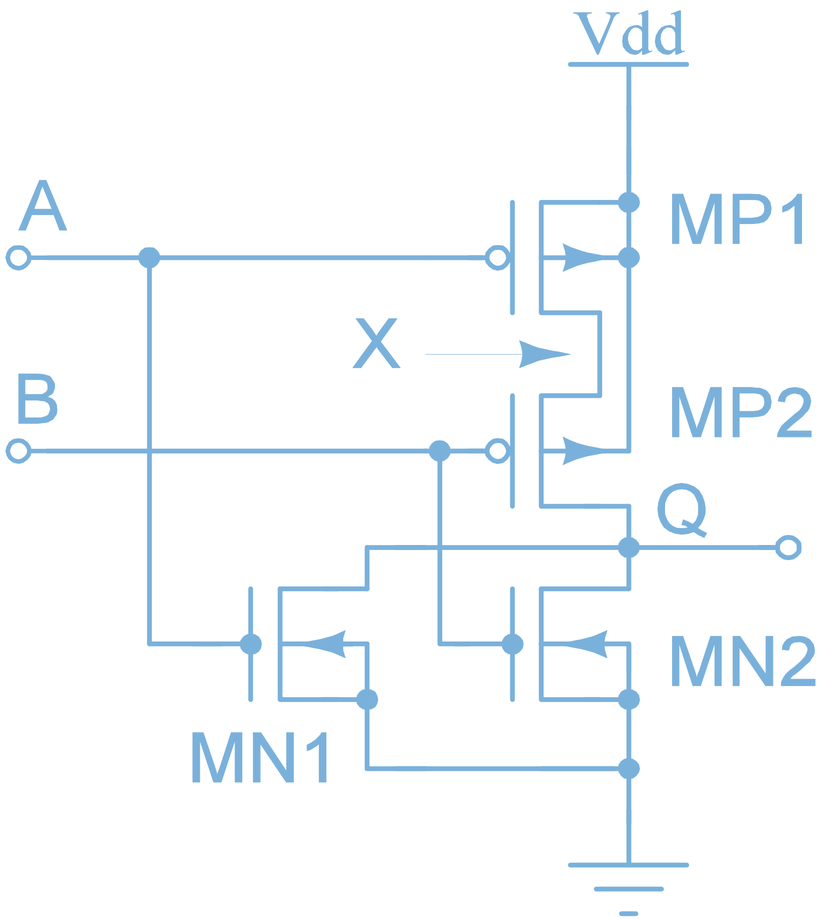


PSP NQS model (vi)

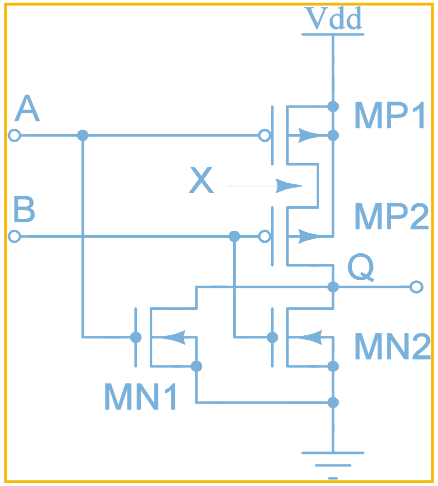
- Y-parameter measurements
- NMOS W/L=120/3μm, V_{DS} = 1.5V, V_{GS} = 0.5, 1.0, 1.5V

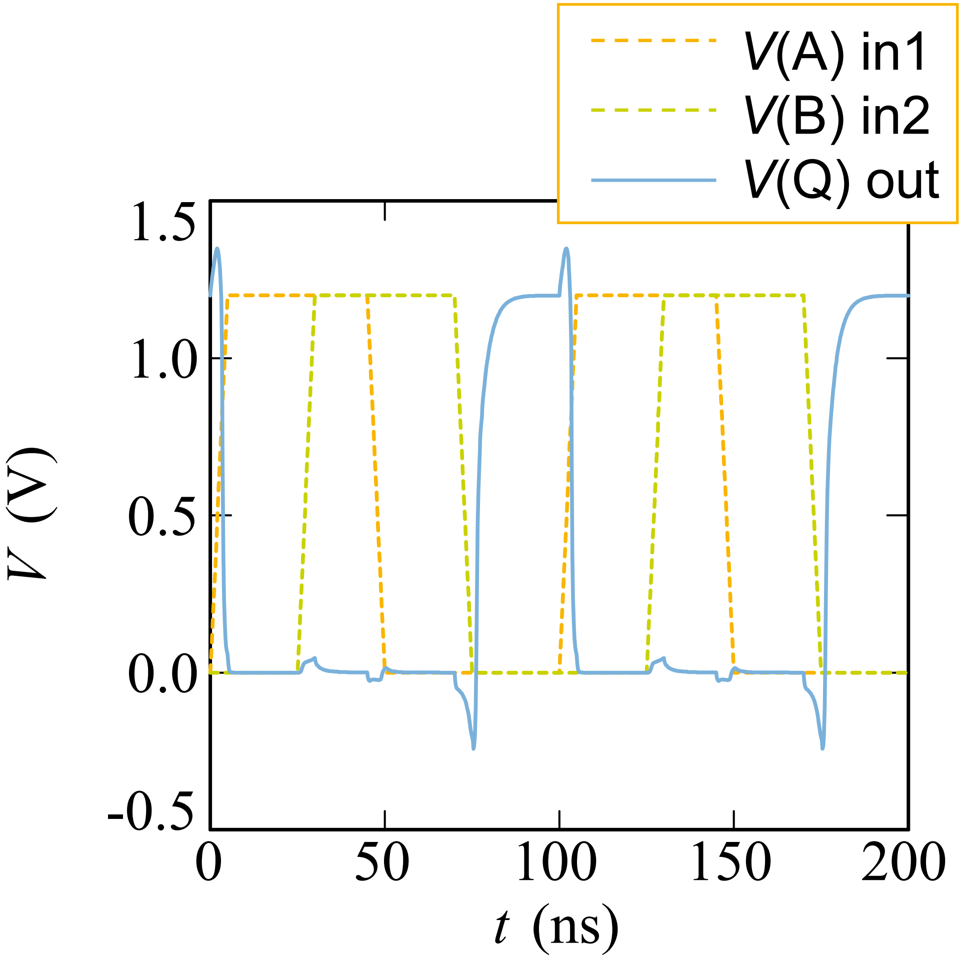


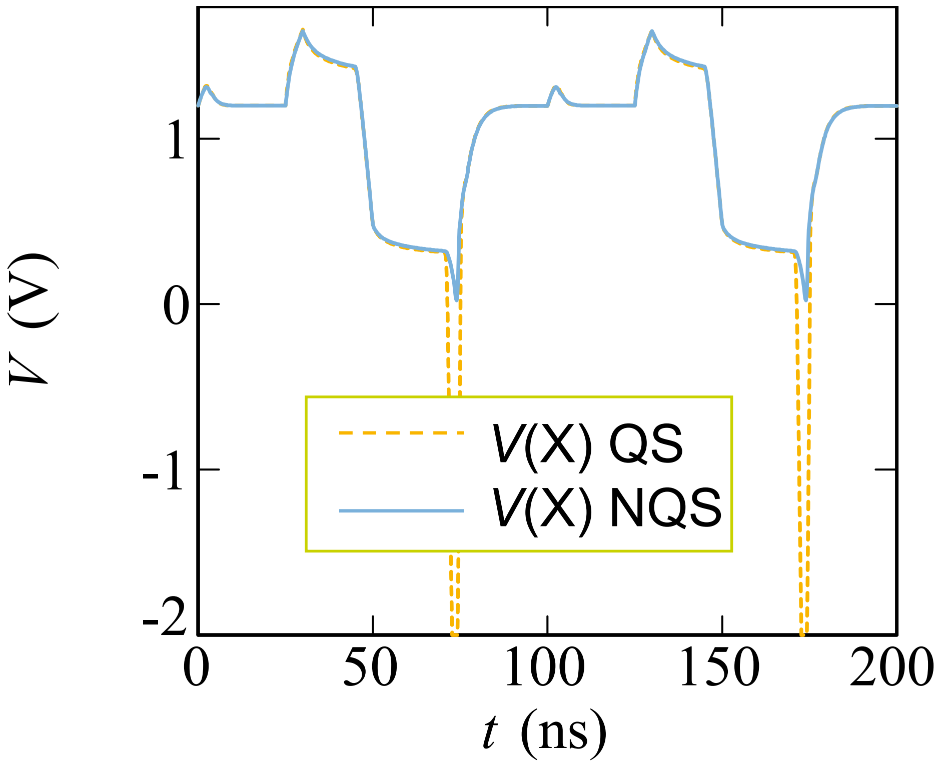
“Killer” NOR circuit (i)



“Killer” NOR circuit (ii)







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Summary

- Affiliation change:
  - Philips → NXP
  - Penn State → Arizona State
- PSP is the new CMC industrial standard MOSFET model
- PSP has an excellent description of distortion
- PSP has a unique physics based NQS-extension

References

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