



Simulation Study of Non-quasi static Behaviour of MOS Transistors

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Presentation Outline

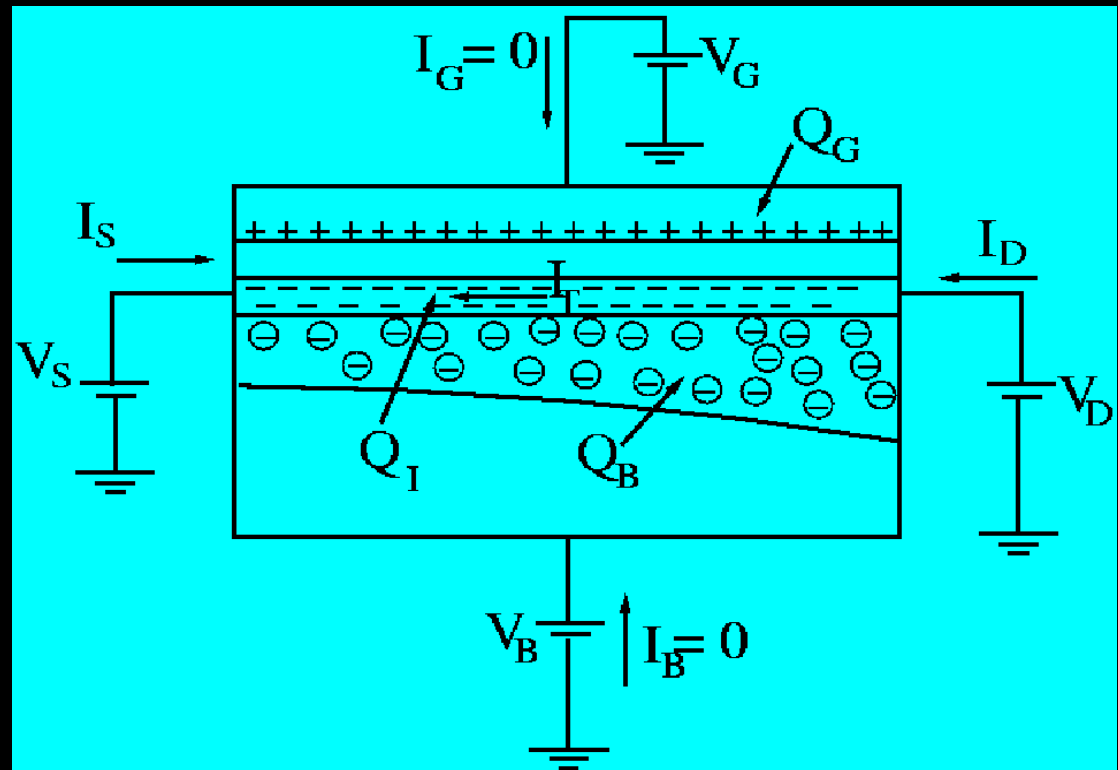
- Quasi-static operation of MOS Transistors
- Channel charge partitioning issues
- BSIM3 Non-quasi-static model
- Look-up Table (LUT) model as the “exact” QS model
- Evaluation of QS/NQS models using LUT approach
- Conclusions



Quasi-static operation of MOS Transistors

In DC case

- $I_D = I_T$
- $I_S = -I_T$
- $I_B = 0$
- $I_G = 0$



I_T is Transport current

In Transient case

$$I_g = I_G + \frac{dq_g}{dt}$$

$$I_d = I_D + \frac{dq_d}{dt}$$

$$I_s = I_S + \frac{dq_s}{dt}$$

$$I_b = I_B + \frac{dq_b}{dt}$$

Inversion layer charge partitioning BSIM3

$$i_d + i_s = \frac{dq_d}{dt} + \frac{dq_s}{dt} = \frac{dq_i}{dt}$$

$$q_d + q_s = q_i$$

$$q_d = X_D q_i, \quad q_s = X_S q_i$$

$$X_D + X_S = 1$$

Charge partitioning schemes (BSIM3)

1. $X_D=0.5$ and $X_S=0.5$ (50/50)
2. $X_D=0.4$ and $X_S=0.6$ (40/60)
3. $X_D=0.0$ and $X_S=1.0$ (0/100)

BSIM3 NQS Model

QS assumption

$$\frac{dQ_{ch}}{dt} = \frac{dQ_{cheq}}{dt}$$

NQS modeling

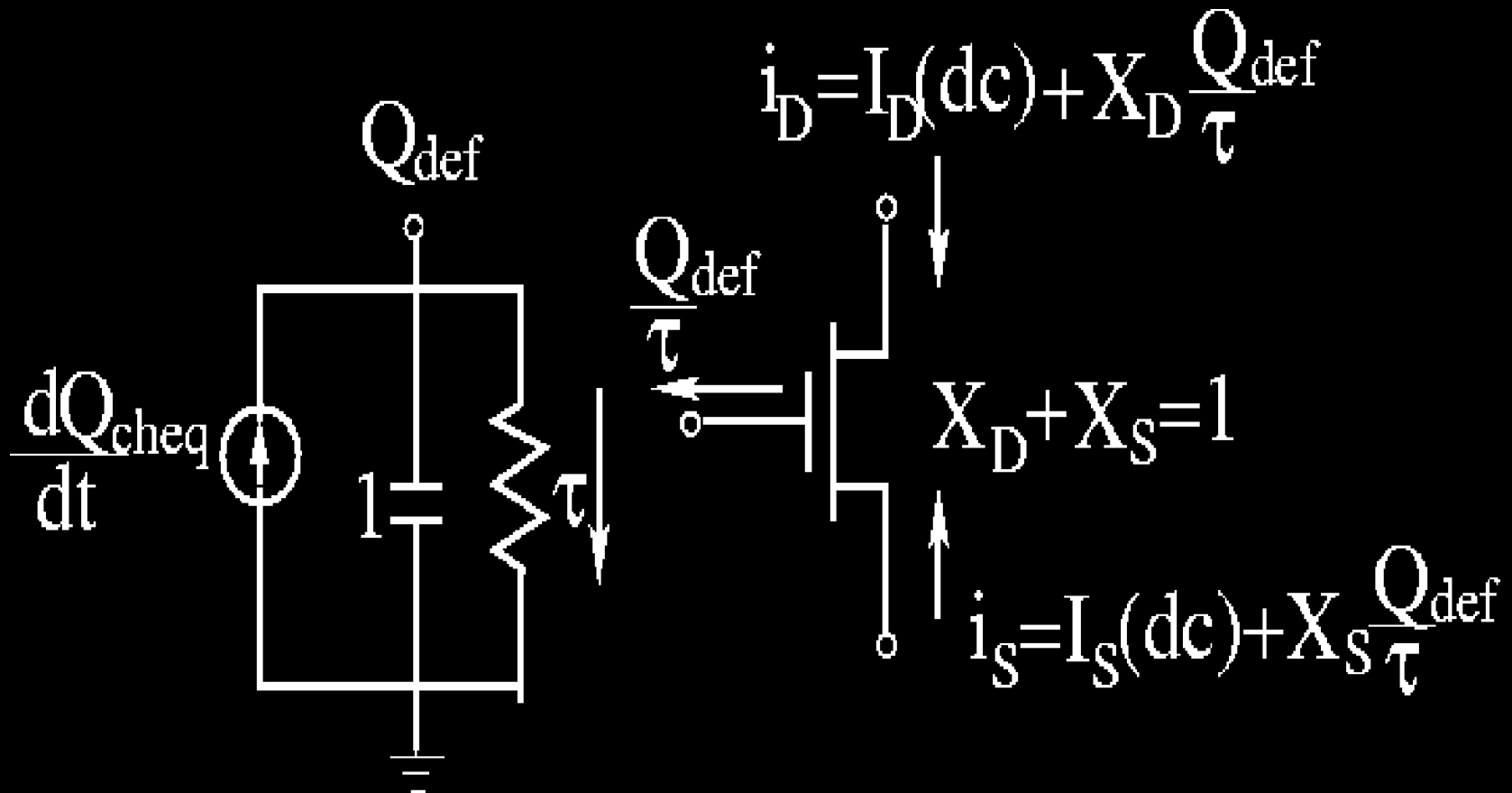
$$Q_{def} = Q_{cheq} - Q_{ch}$$

$$\frac{dQ_{def}}{dt} = \frac{dQ_{cheq}}{dt} - \frac{dQ_{ch}}{dt}$$

$$\frac{dQ_{ch}}{dt} = \frac{Q_{def}}{\tau}$$

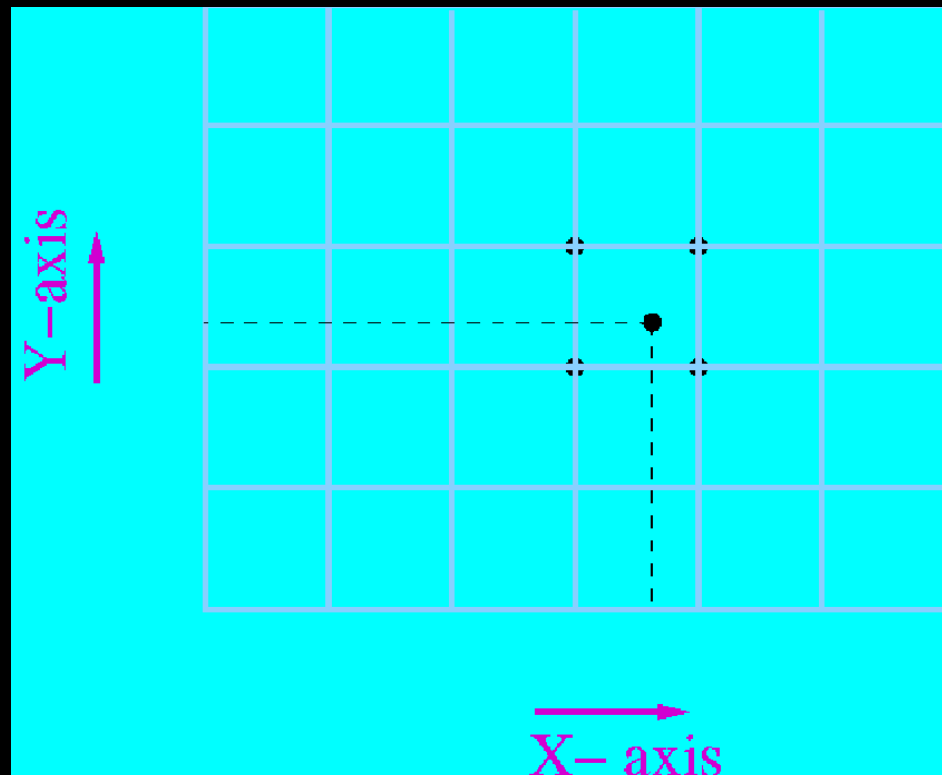
$$\frac{dQ_{def}}{dt} = \frac{dQ_{cheq}}{dt} - \frac{Q_{def}}{\tau}$$

BSIM3 NQS model equivalent circuit



LUT approach

$F(x,y)$



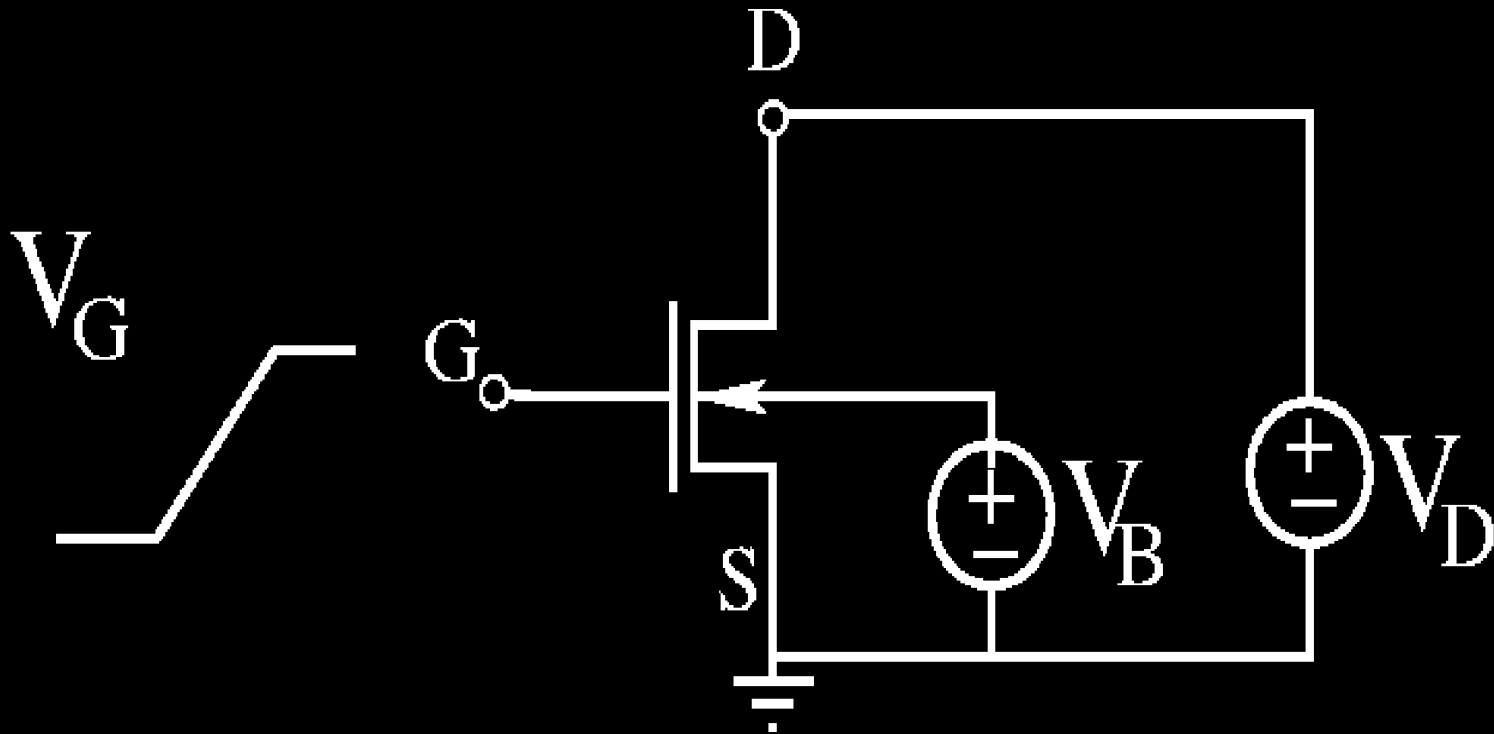
2-D LUT

Need to calculate derivatives of the function w.r.t both the variables

LUT Approach for circuit simulations

- MOSFET is modeled as a table of terminal DC currents and charges.
- A multi-dimensional algorithm is used to interpolate the data in between the grid points.
- Implemented in a general purpose circuit simulator SEQUEL (developed at IIT-Bombay).

Simulation set-up for extracting the terminal charges



Extracting terminal charges

$$I_x(t) = I_X(V_{BS}(t), V_{GS}(t), V_{DS}(t)) + \frac{dQ_X(V_{BS}(t), V_{GS}(t), V_{DS}(t))}{dt}$$

$$\frac{dQ_B(V_B^0, V_G(t), V_D^0)}{dt} = I_b(t) -$$

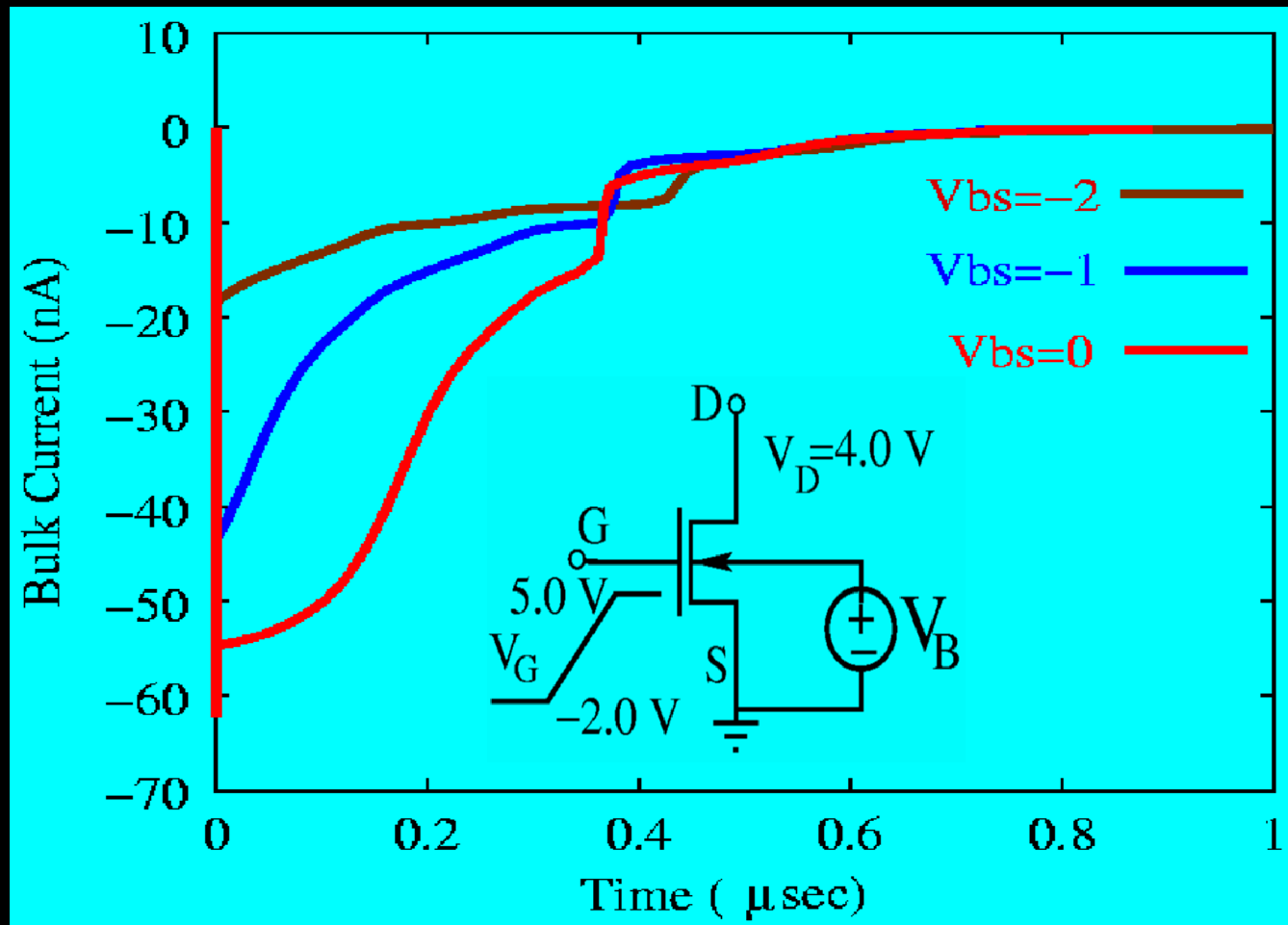
$$I_B(V_B^0, V_G(t), V_D^0)$$

Bulk charge extraction

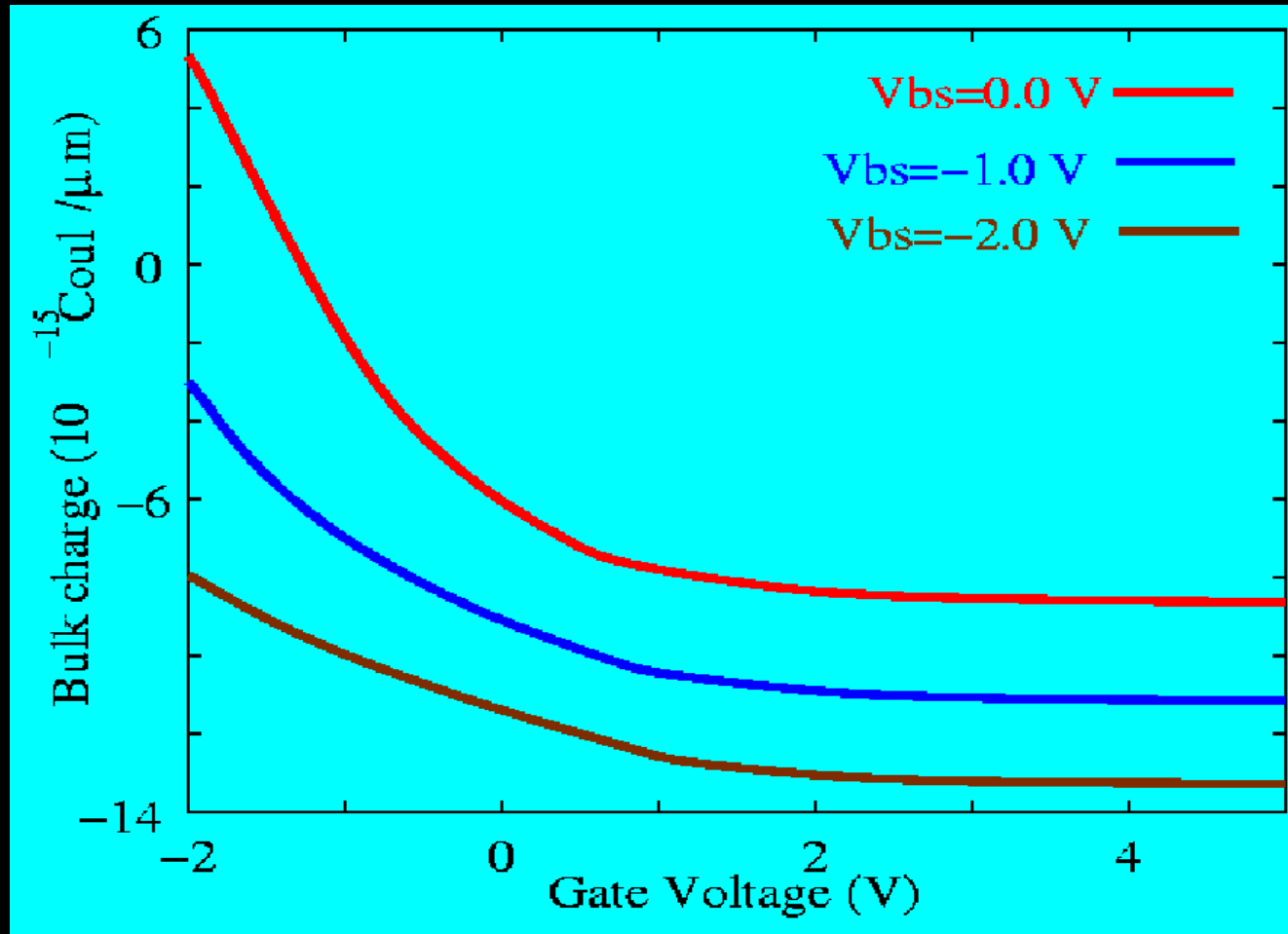
$$\frac{dQ_B}{dt} = \frac{\partial Q_B}{\partial V_G} \frac{dV_G}{dt} = \frac{\partial Q_B}{\partial V_G} \left(\frac{V_{G2} - V_{G1}}{t_2 - t_1} \right)$$

$$\int dQ_B = \left(\frac{t_2 - t_1}{V_{G2} - V_{G1}} \right) \int (I_b - I_B) dV_G$$

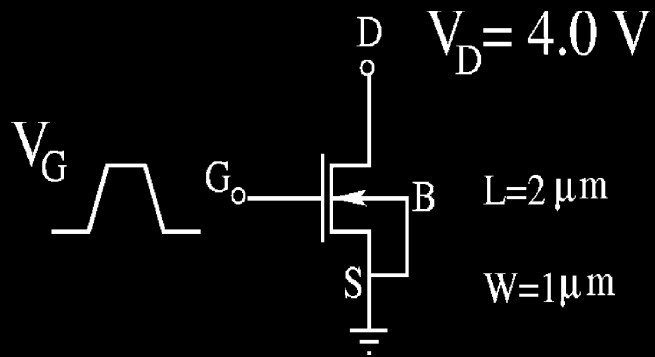
Transient bulk current



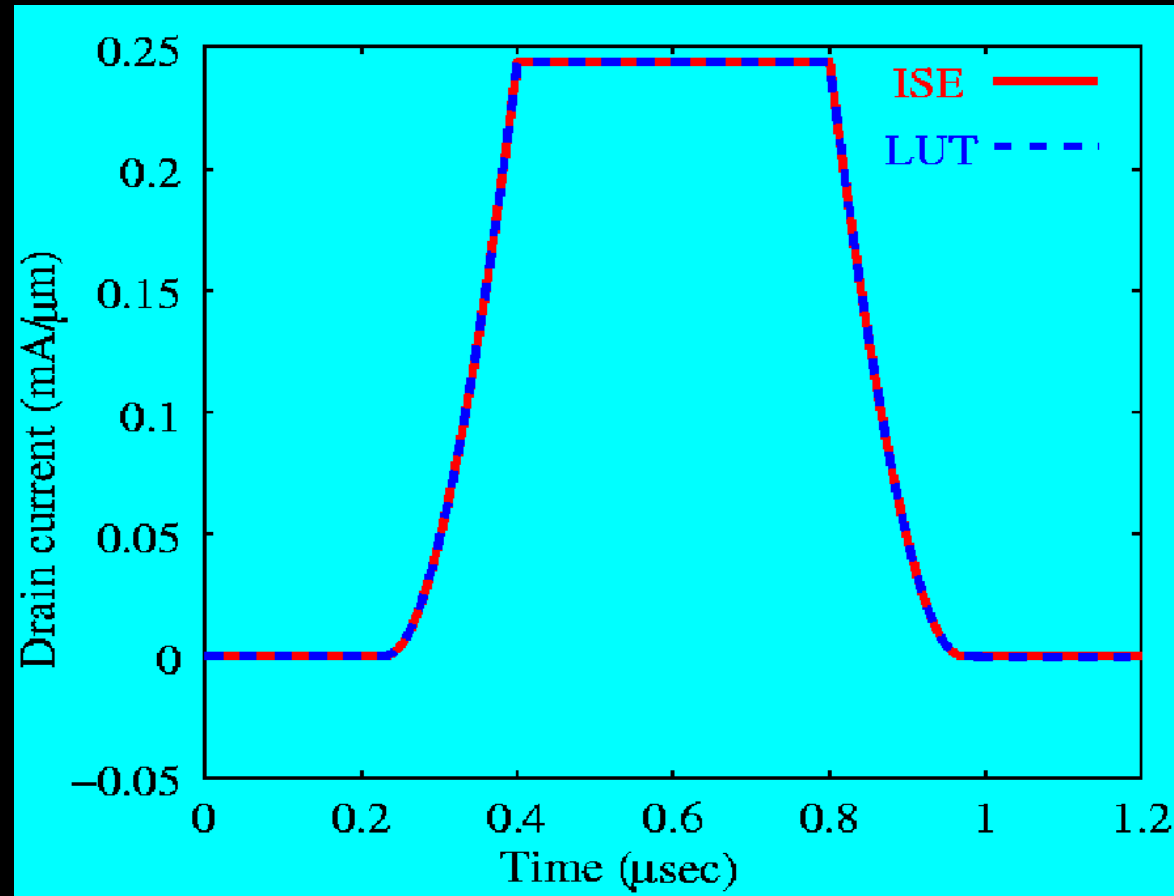
Extracted bulk charge



Validation of LUT model



Rise and fall
time = 0.2 usec



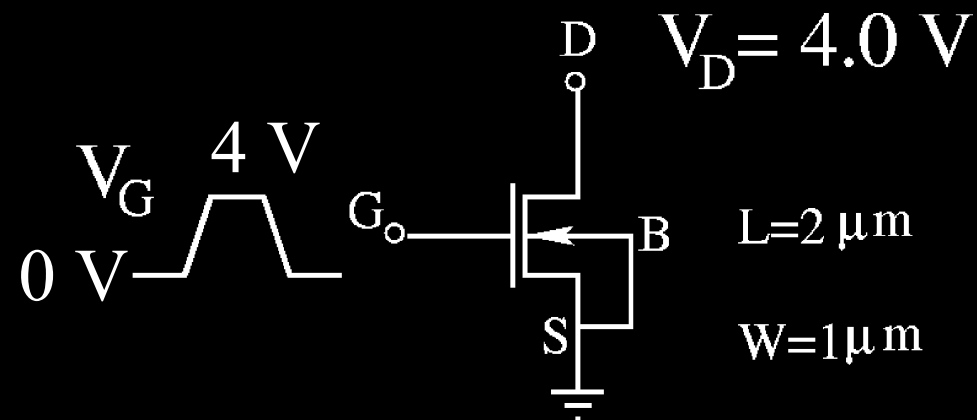
Use of LUT simulator in evaluation of QS/NQS models e.g., BSIM3

- LUT model is an “exact” QS model, since no approximations are made regarding terminal currents and charges.
- Device simulation gives the “exact” NQS behaviour.

Procedure followed:

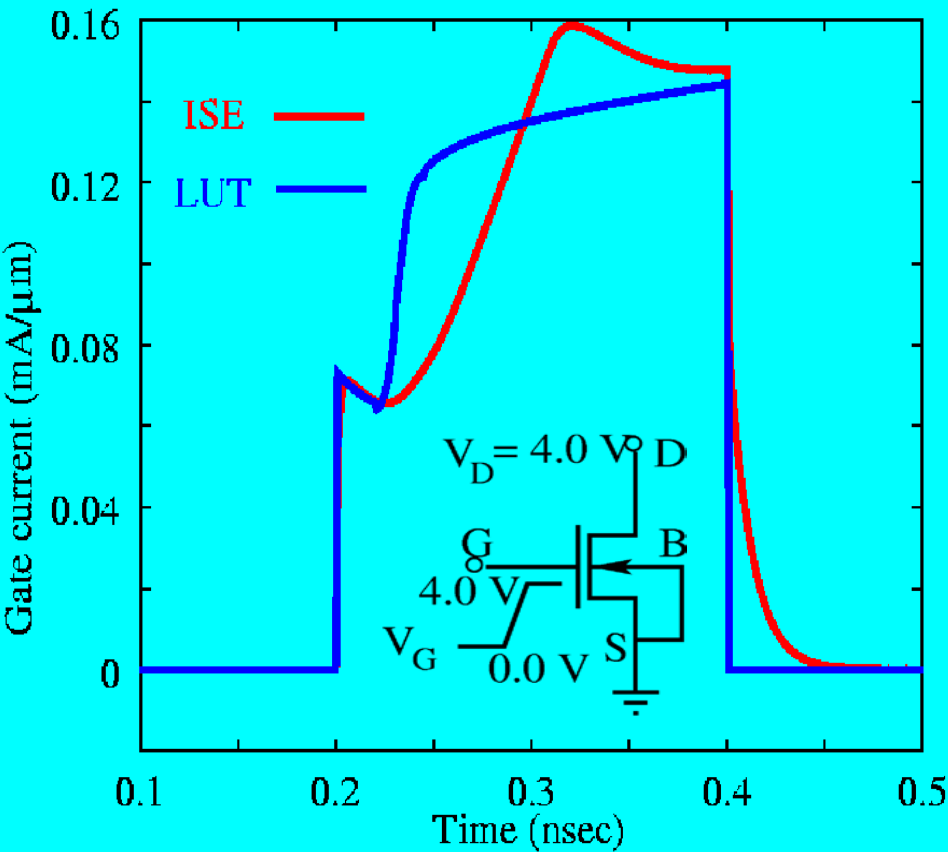
- Extract tables of terminal currents and charges using a 2-D device simulator (ISE-TCAD) => The LUT model or the “exact” QS model.
- Study terminal currents versus time for two cases
 - (i) V_g transient,
 - (ii) V_d transient.
- Compare the results with BSIM3 QS and NQS models.

Simulation set-up for V_g transient

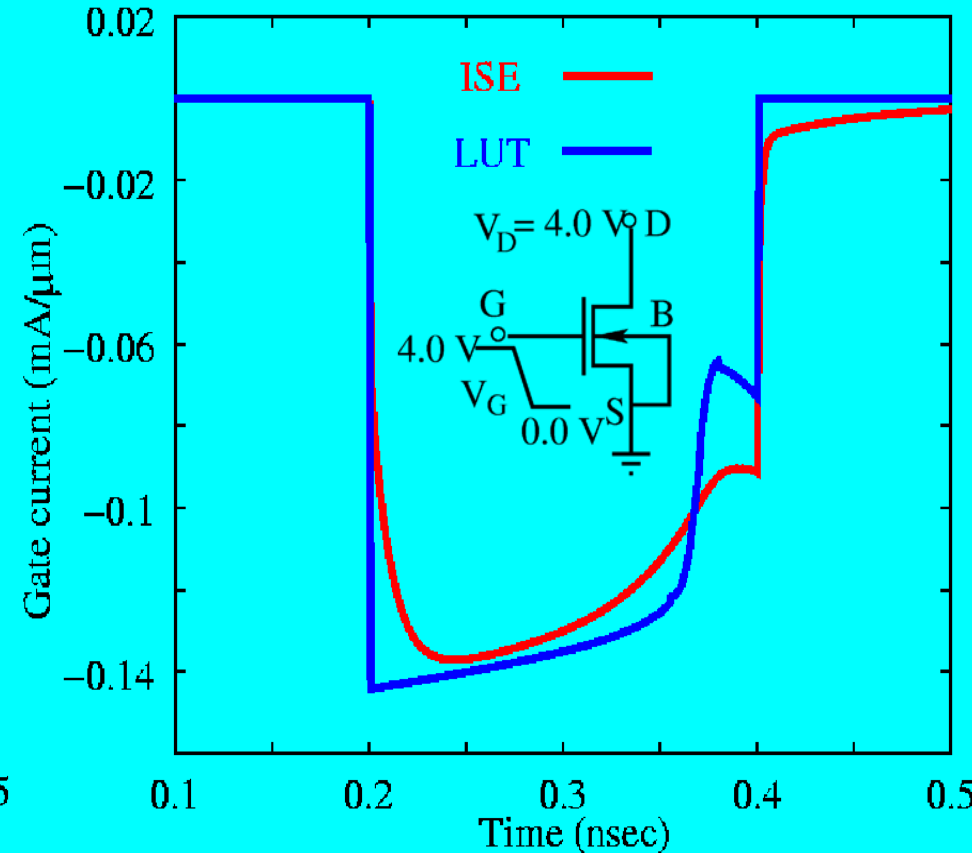


Rise and fall time = 0.2 nsec

Gate current for the V_g transient

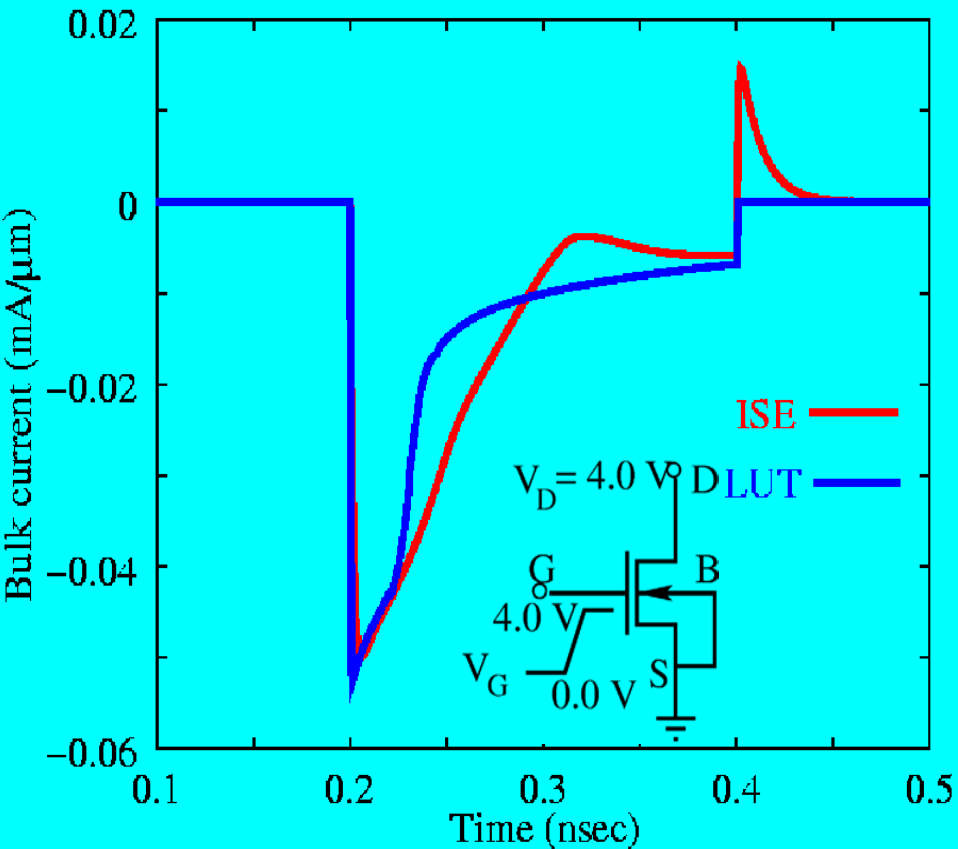


Input rising

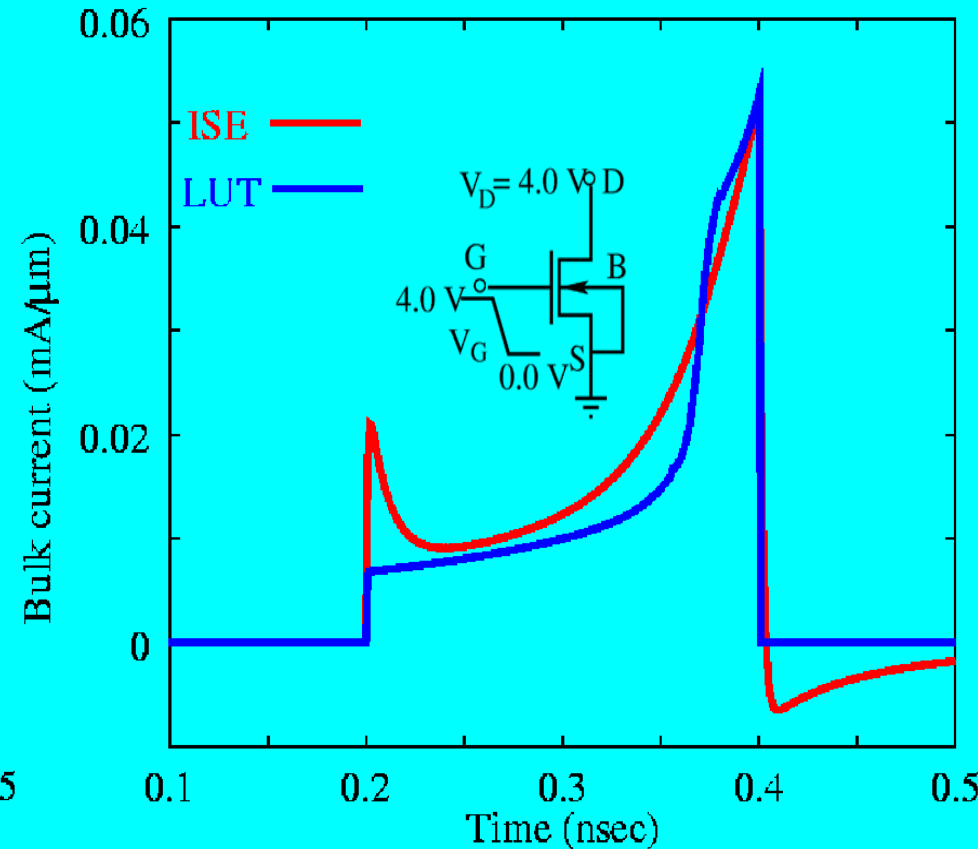


Input falling

Bulk current for the V_G transient

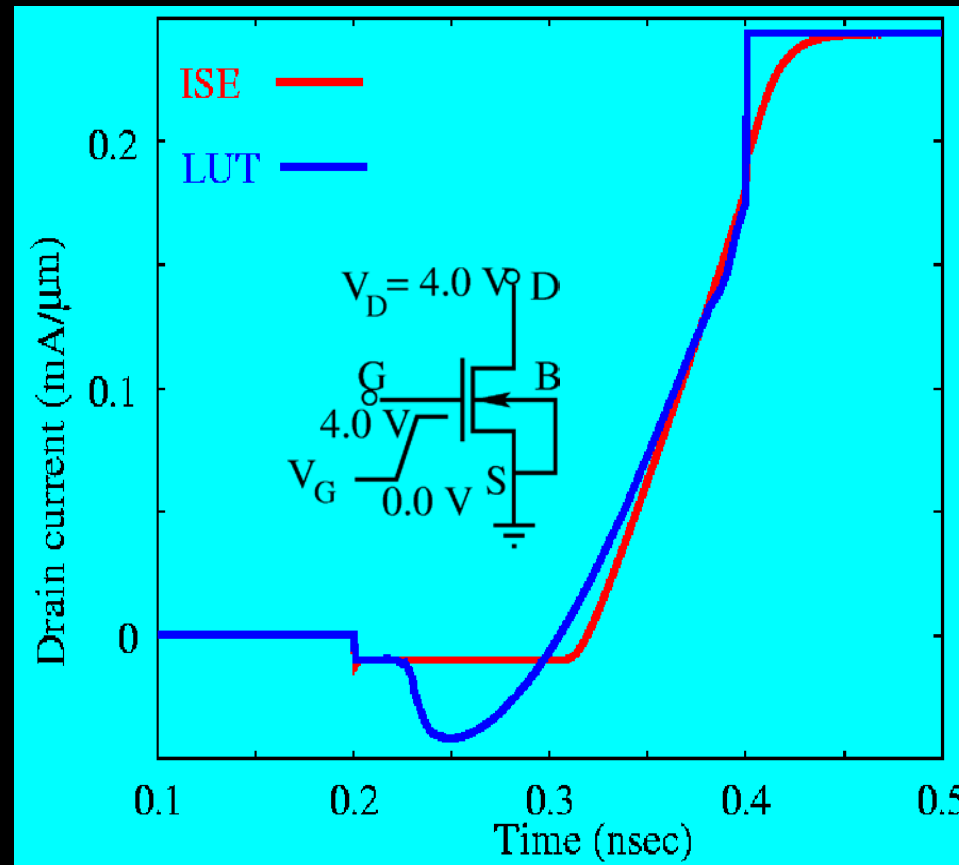


Input rising

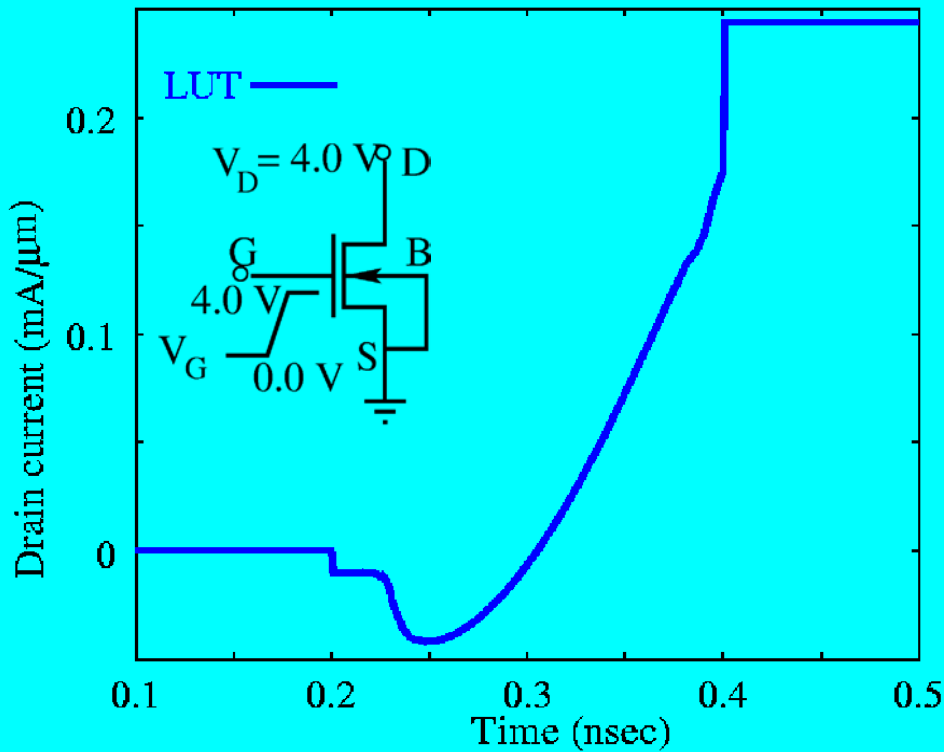


Input falling

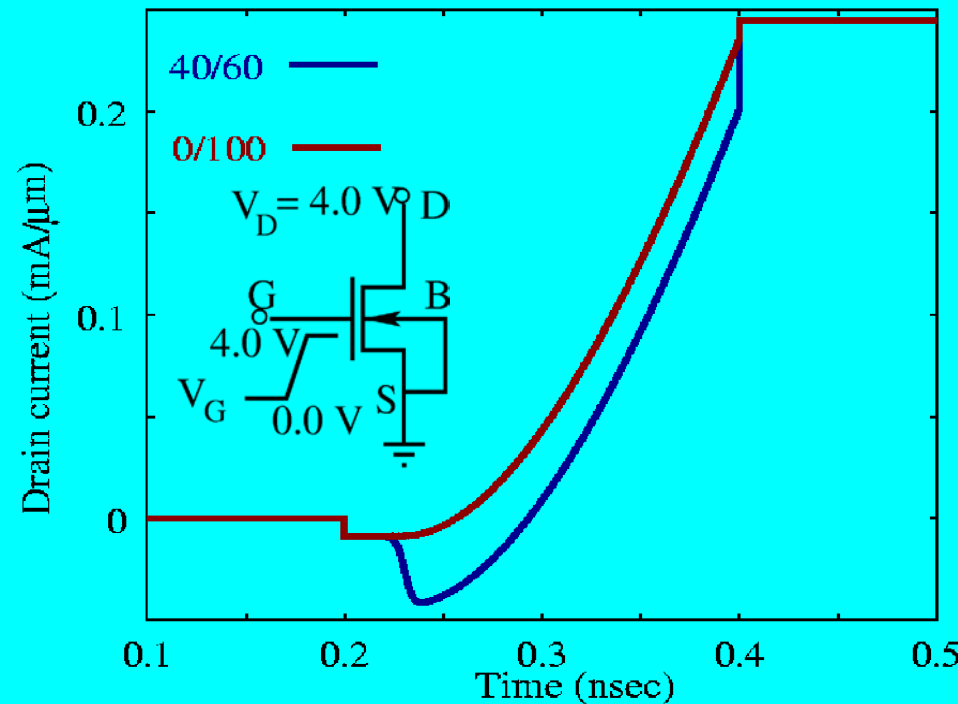
Drain current with ISE/LUT



Drain current with LUT and BSIM3 QS

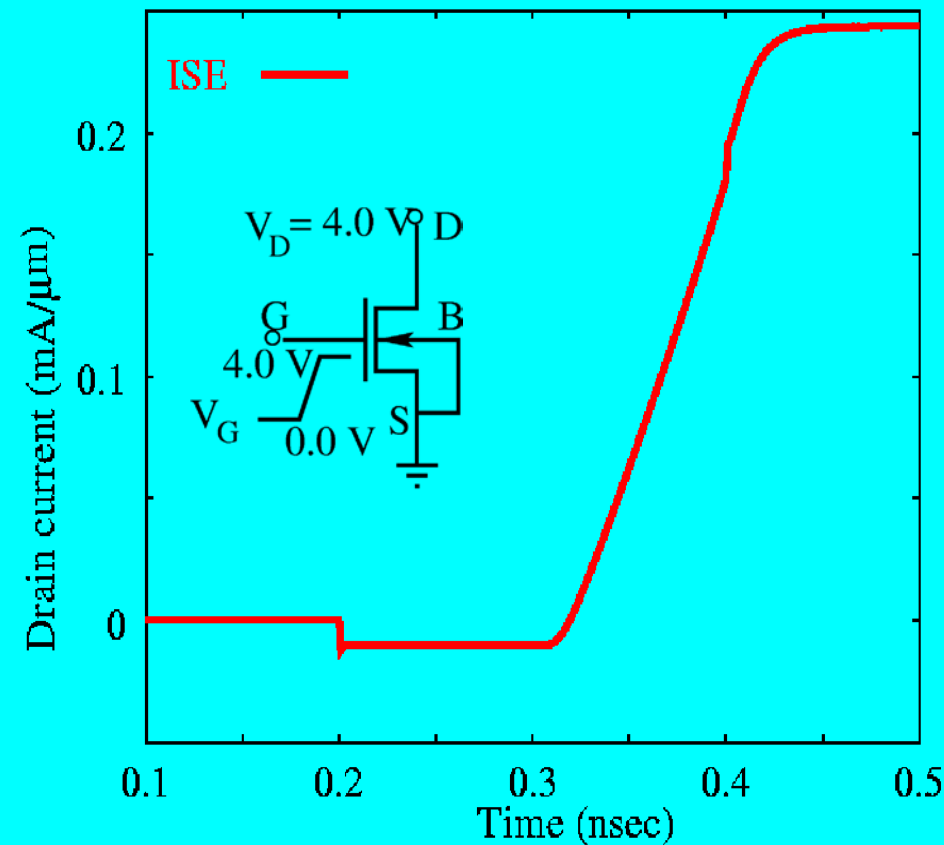


LUT (Rising input)

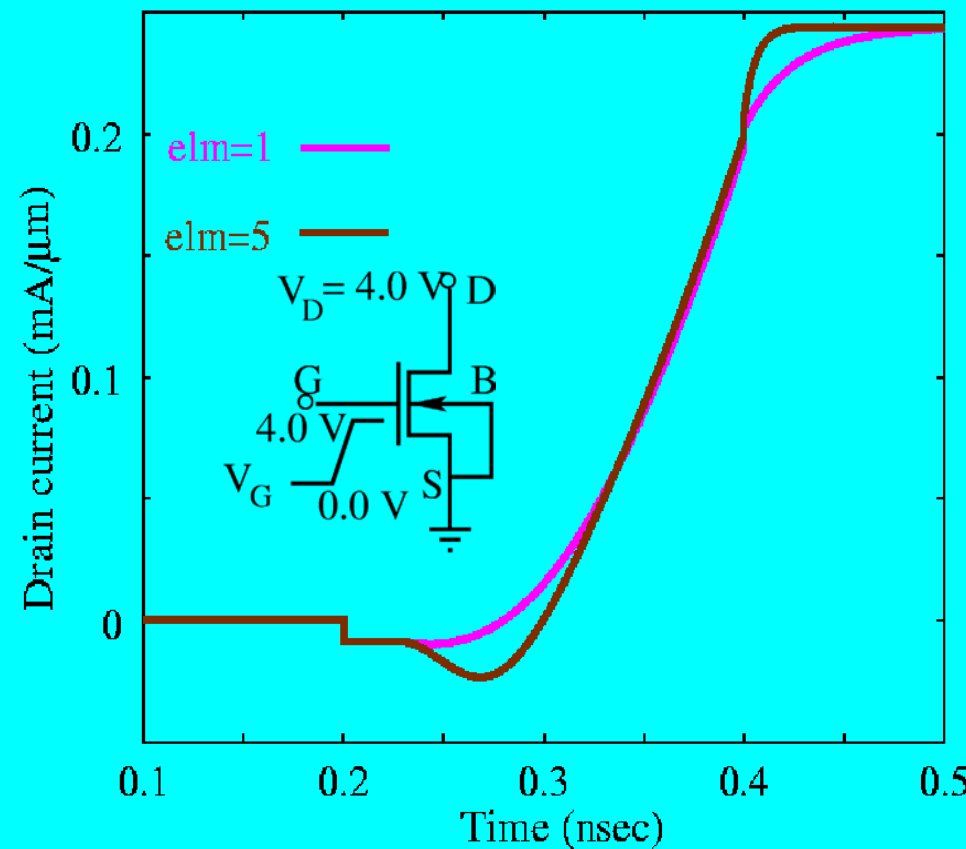


BSIM3 QS (Rising input)

Drain current with ISE and BSIM3 NQS



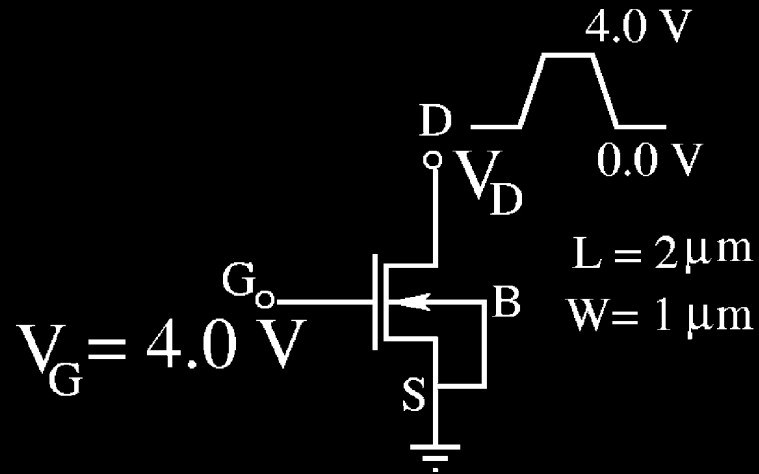
ISE (Rising input)



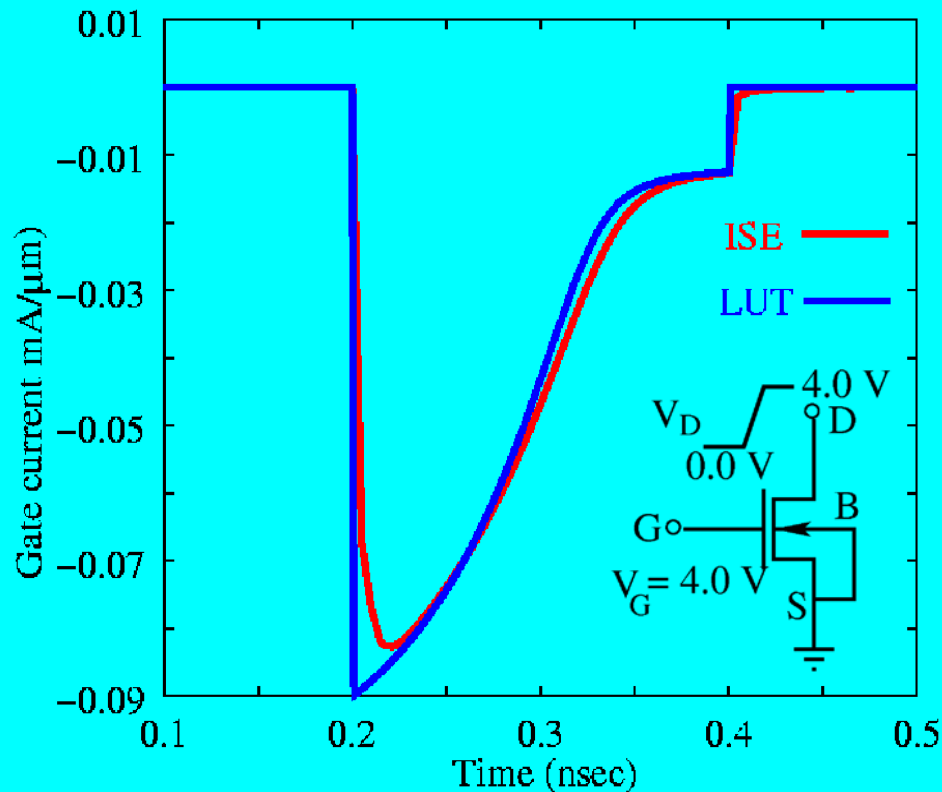
BSIM3 NQS (Rising input)

Simulation set-up for V_d transient

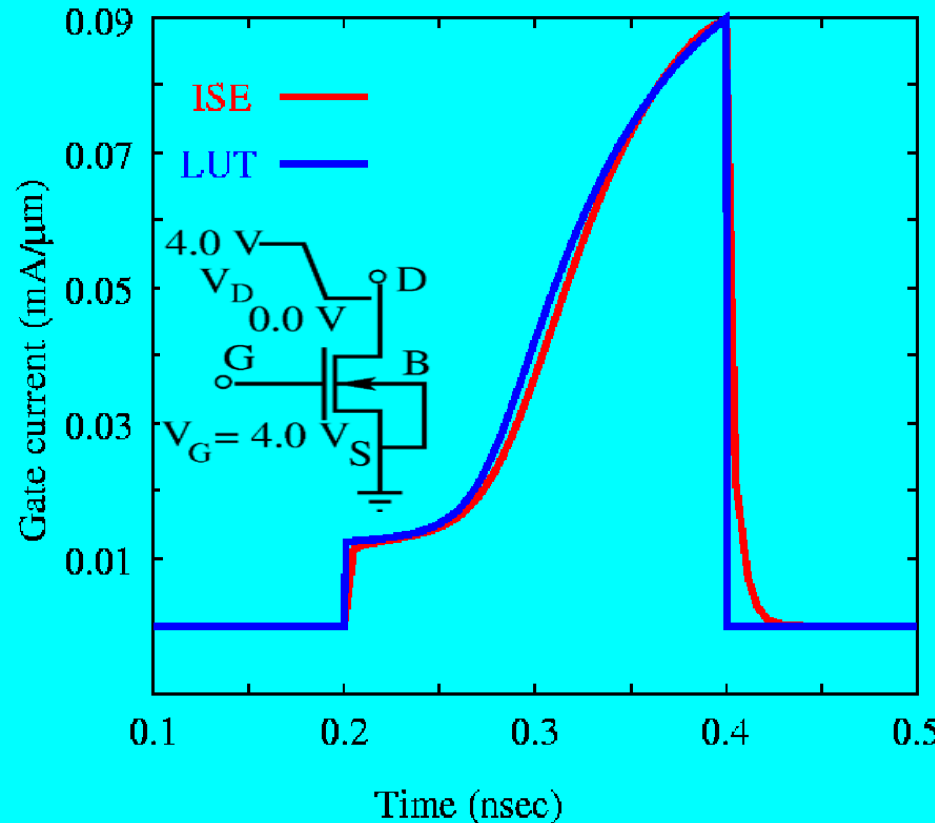
Rise and fall time=0.2 nsec



Gate current for the V_d transient

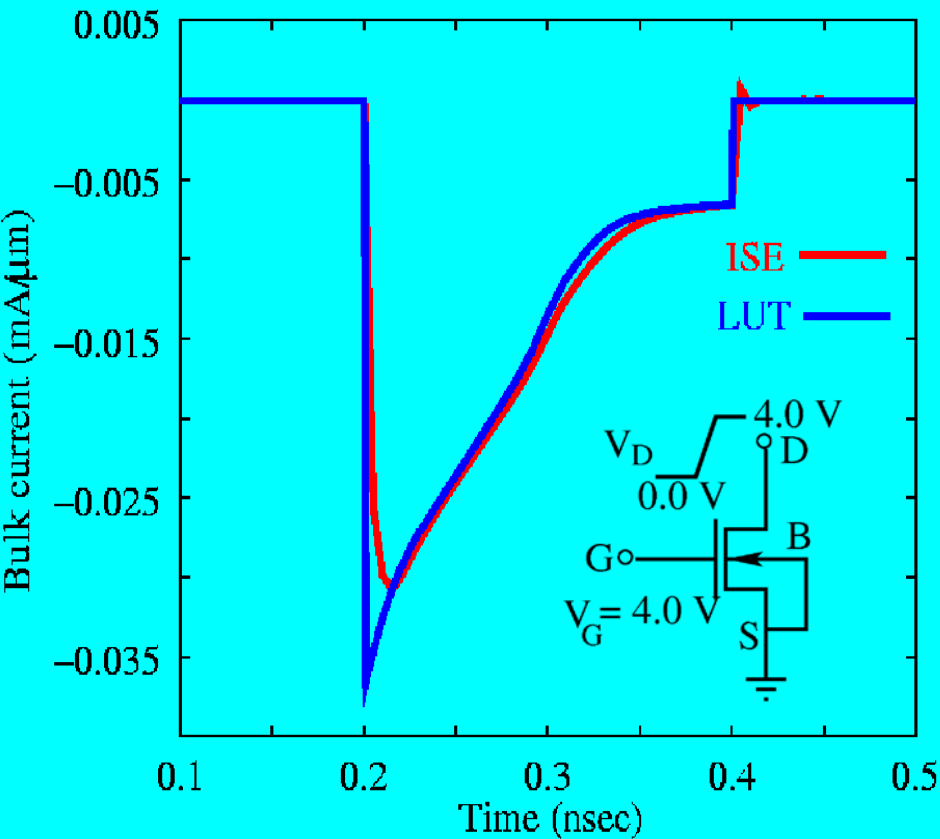


Input rising

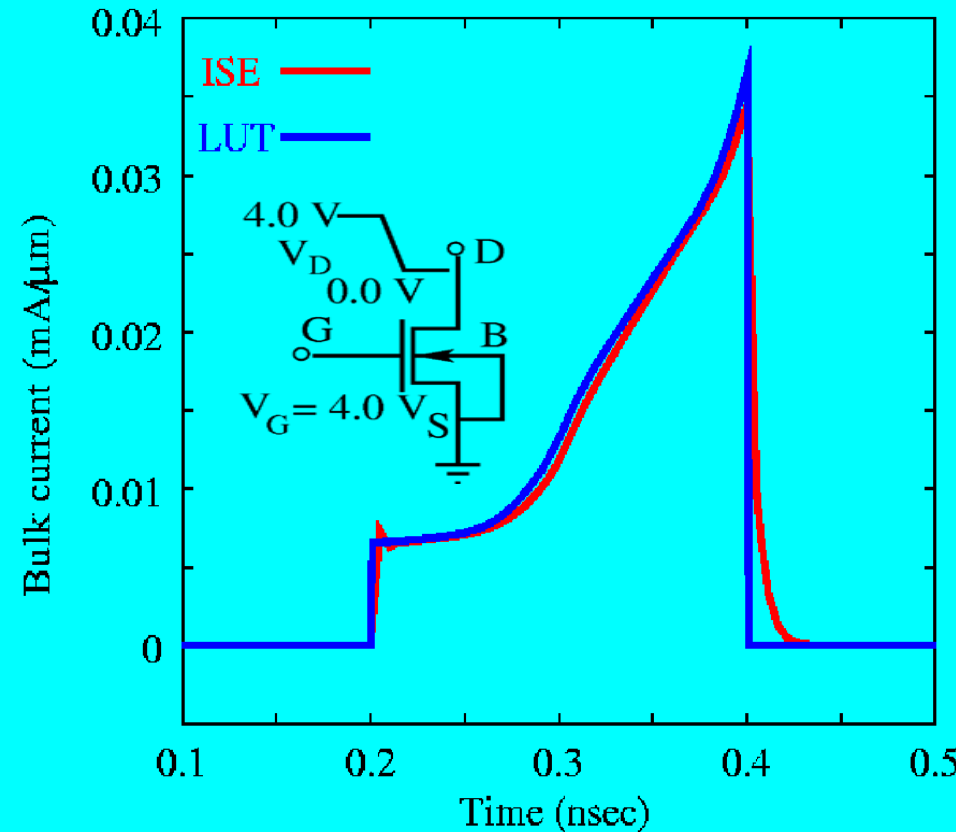


Input falling

Bulk current for the V_D transient

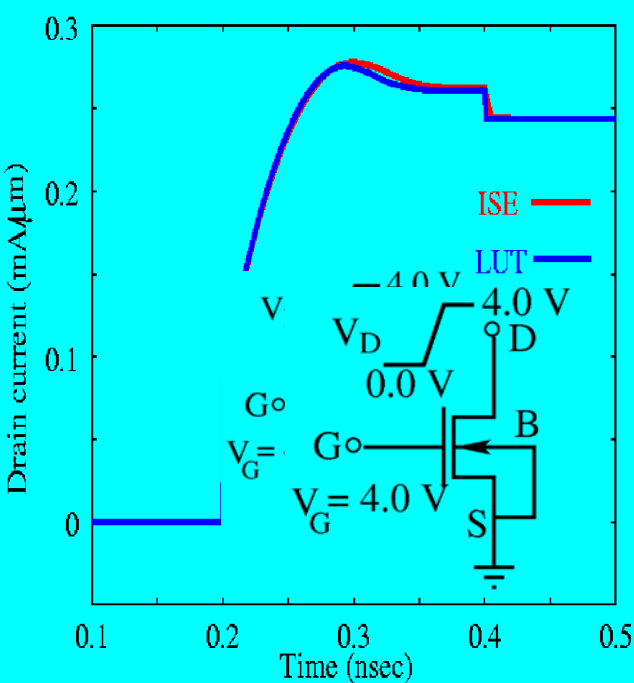


Input rising

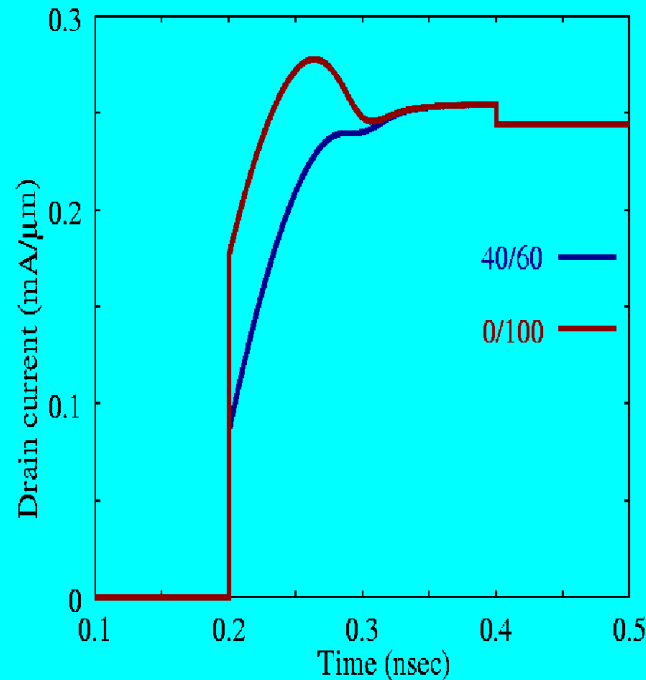


Input falling

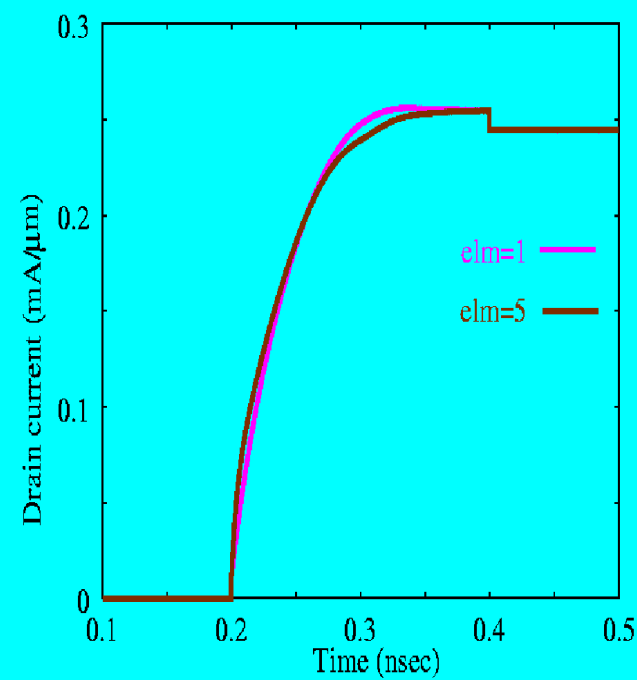
Drain current with ISE/LUT and BSIM3



ISE/LUT



BSIM3 QS



BSIM3 NQS

Conclusions

- Use of the LUT approach as a powerful tool to evaluate QS/NQS MOSFET models
- Terminal currents for a V_g transient in QS and NQS cases are very different (when the rise/fall times are small), but for V_d transient they match closely
- BSIM3 QS model with 40/60 partitioning scheme predicts the correct QS behaviour when a V_g transient is applied



- BSIM3 QS/NQS models show difference in I_d for the V_d transient, while the exact QS/NQS results are very close.

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