



# Simulation Study of Non-quasi static Behaviour of MOS Transistors

D . V. Kumar, R. A. Thakker,  
M. B. Patil, and V. R. Rao.

Department of Electrical Engineering,  
IIT-Bombay.



# Presentation Outline

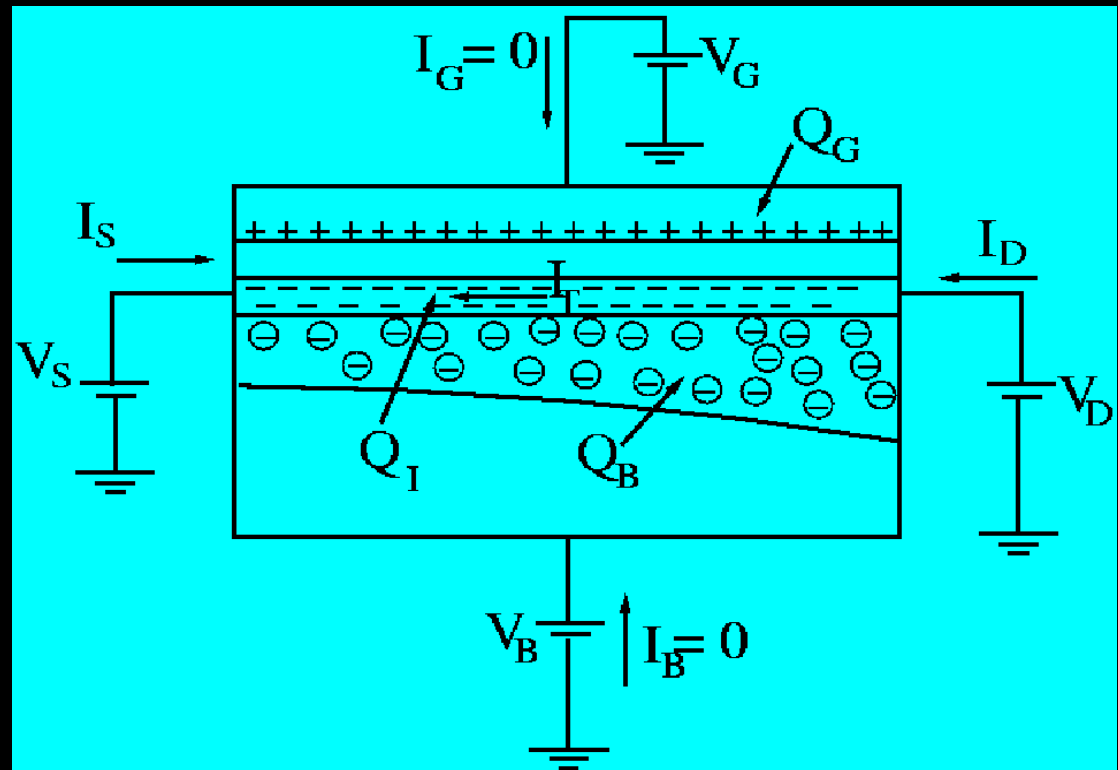
- Quasi-static operation of MOS Transistors
- Channel charge partitioning issues
- BSIM3 Non-quasi-static model
- Look-up Table (LUT) model as the “exact” QS model
- Evaluation of QS/NQS models using LUT approach
- Conclusions



# 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

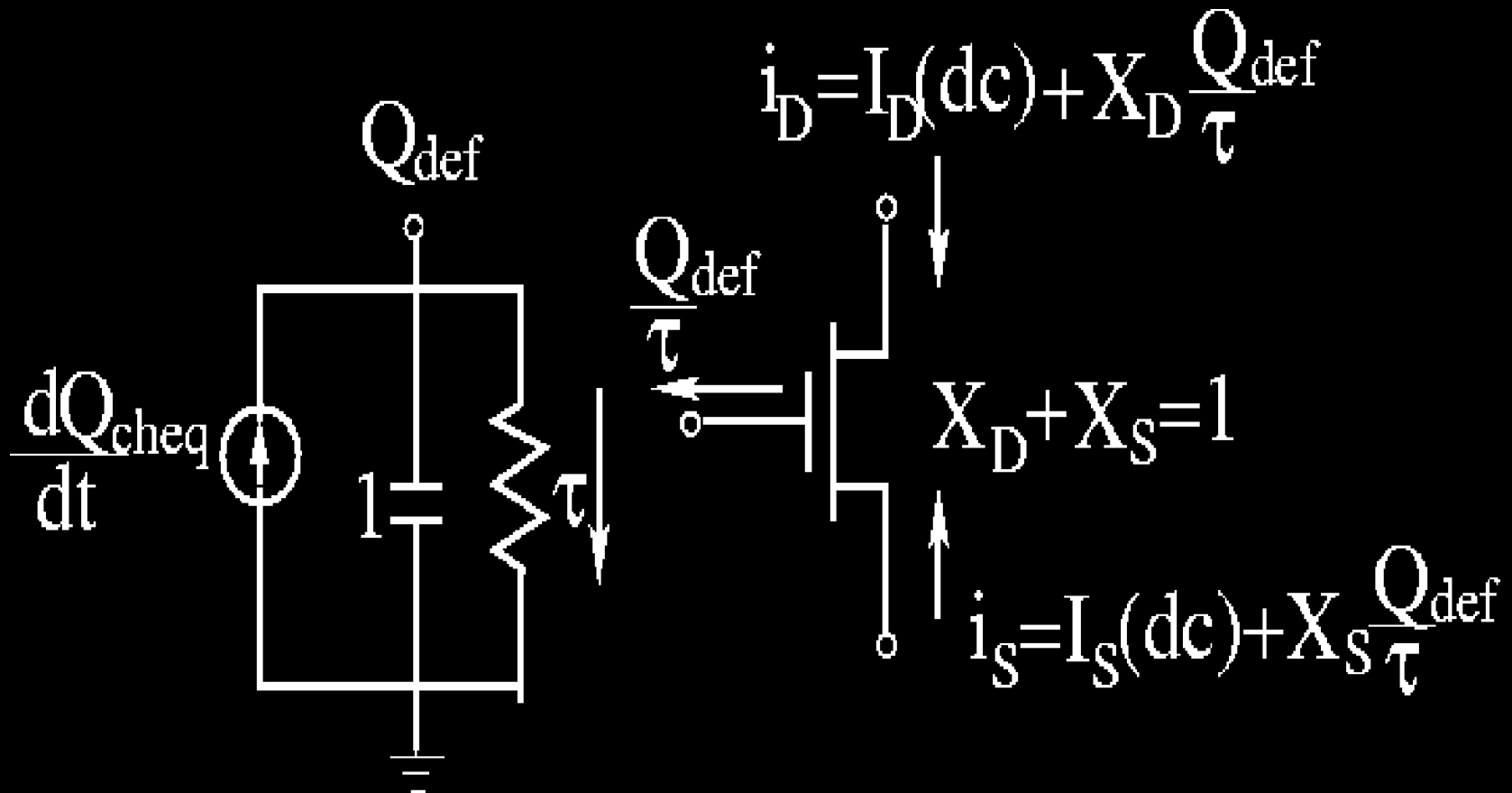
$$Q_{def} = Q_{cheq} - Q_{ch}$$

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

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

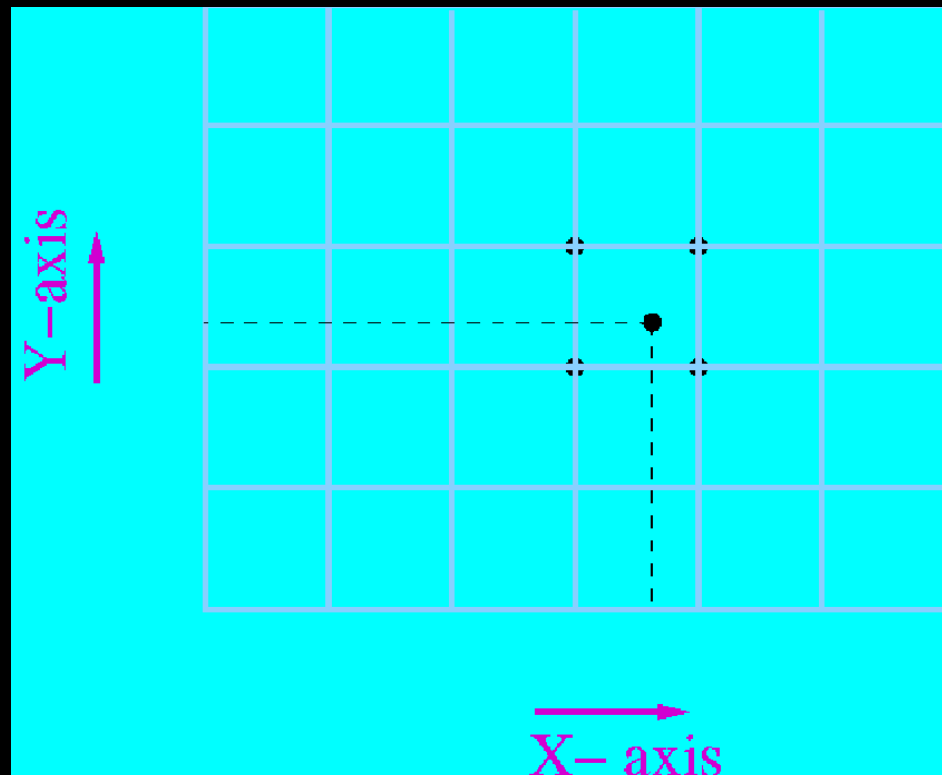
$$\frac{dQ_{def}}{dt} = \frac{dQ_{cheq}}{dt} - \frac{Q_{def}}{\tau}$$

# BSIM3 NQS model equivalent circuit



# LUT approach

$F(x,y)$



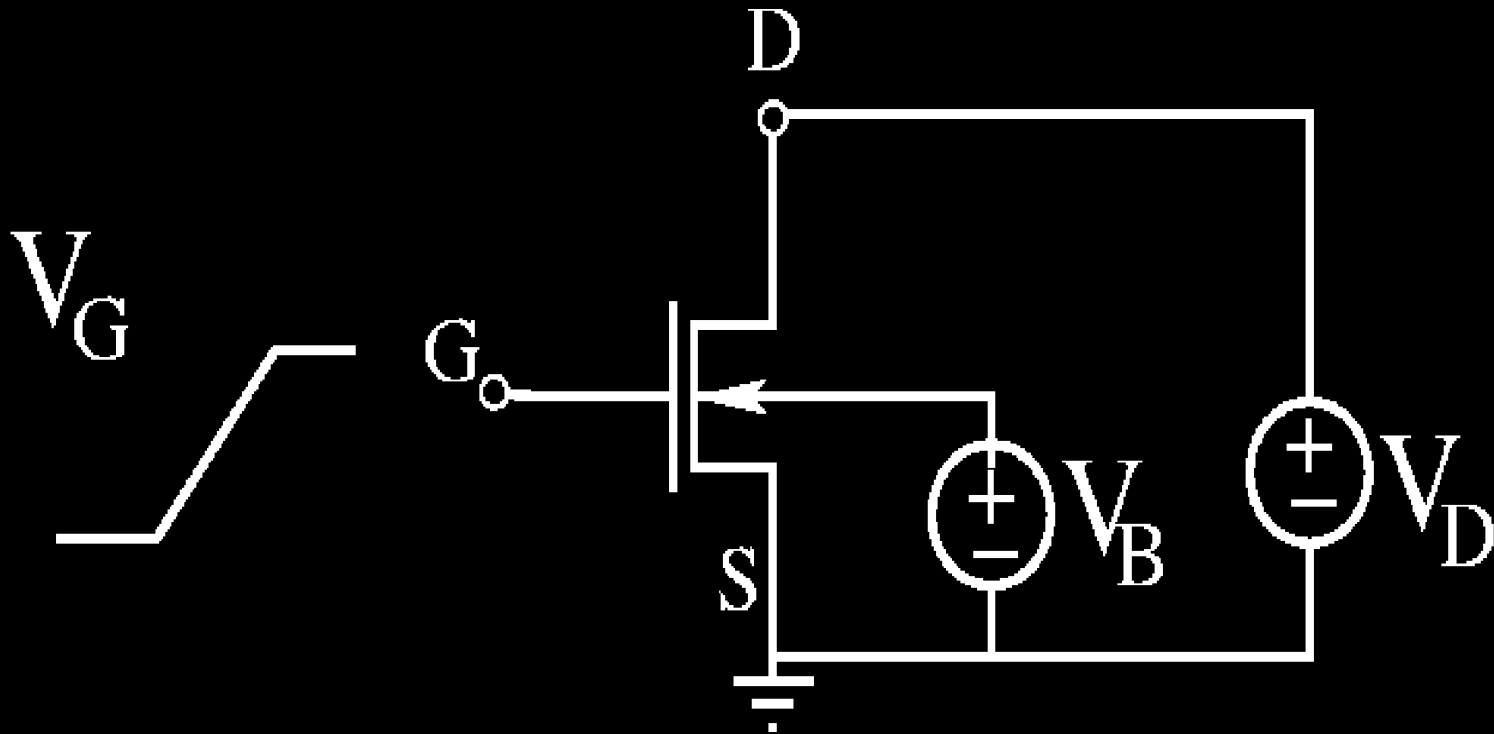
2-D LUT

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

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

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

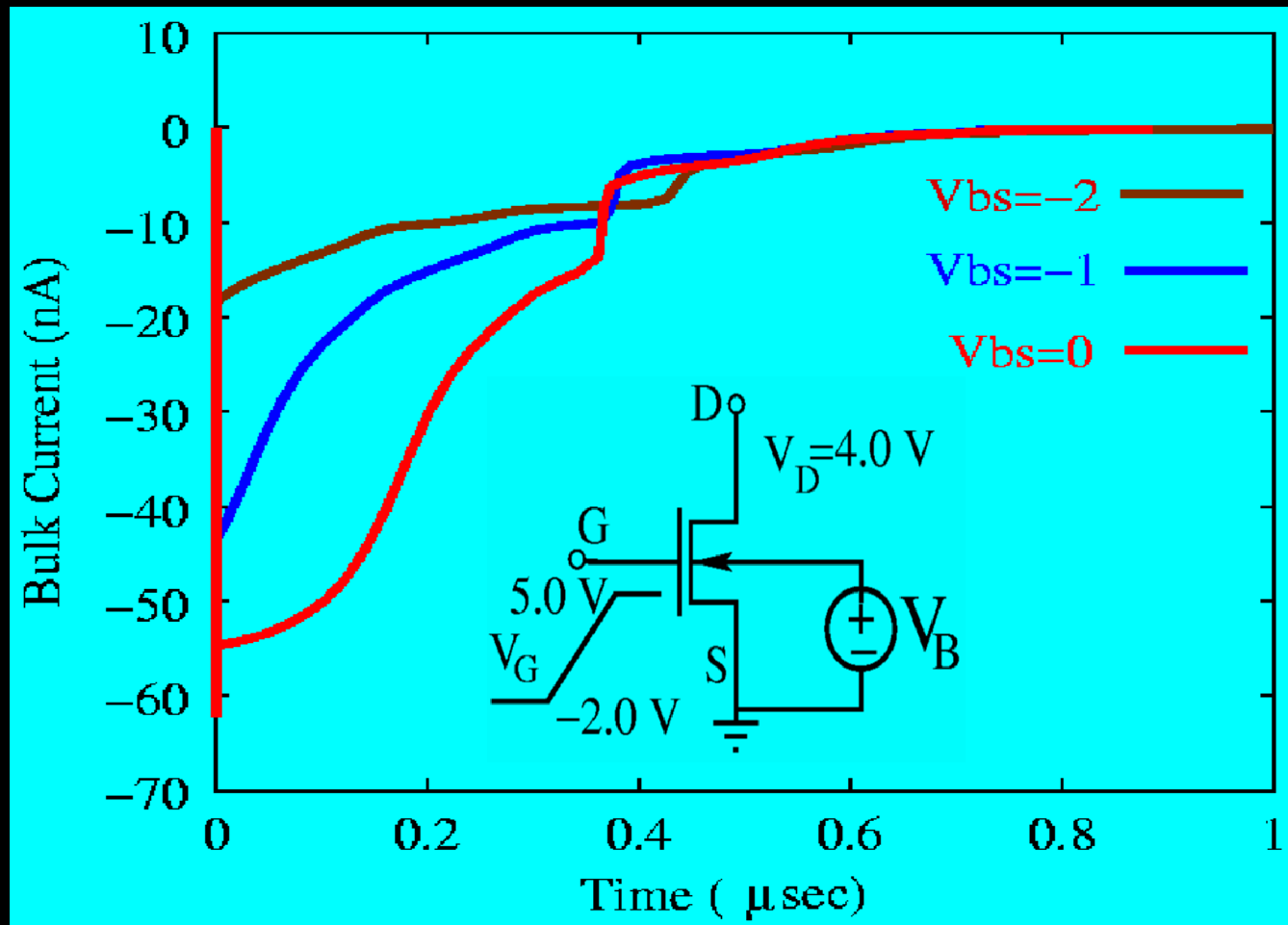
$$I_B(V_B^0, V_G(t), V_D^0)$$

# Bulk charge extraction

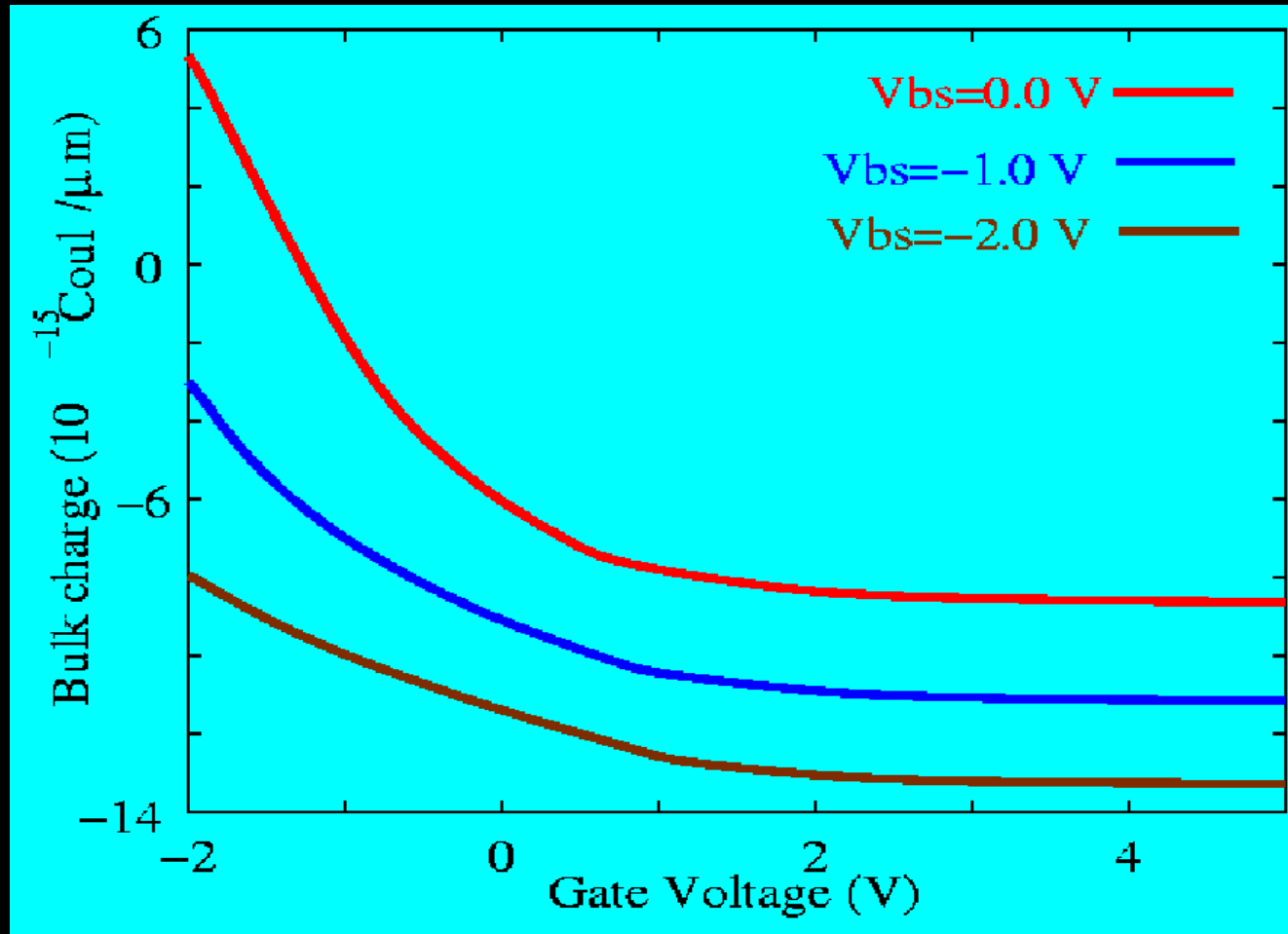
$$\frac{dQ_B}{dt} = \frac{\partial Q_B}{\partial V_G} \frac{dV_G}{dt} = \frac{\partial Q_B}{\partial V_G} \left( \frac{V_{G2} - V_{G1}}{t_2 - t_1} \right)$$

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

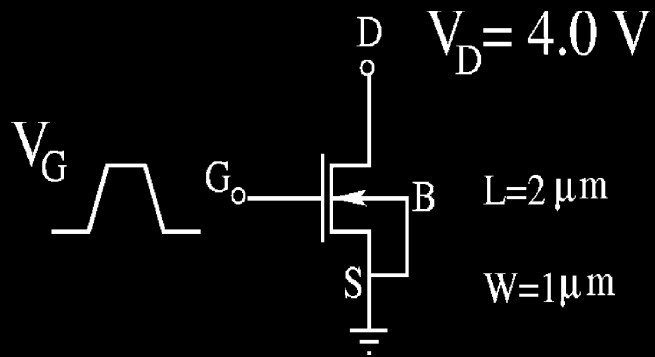
# Transient bulk current



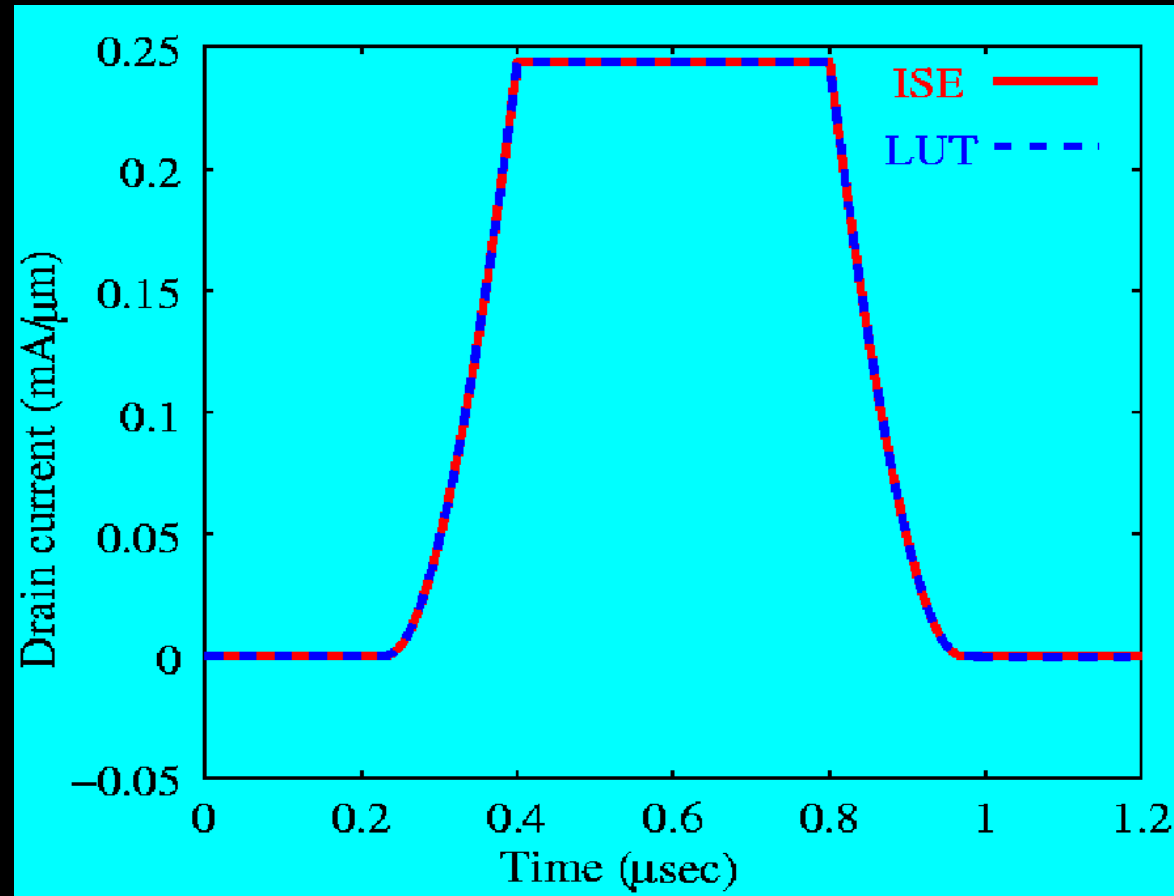
# Extracted bulk charge



# Validation of LUT model



Rise and fall  
time=0.2 usec



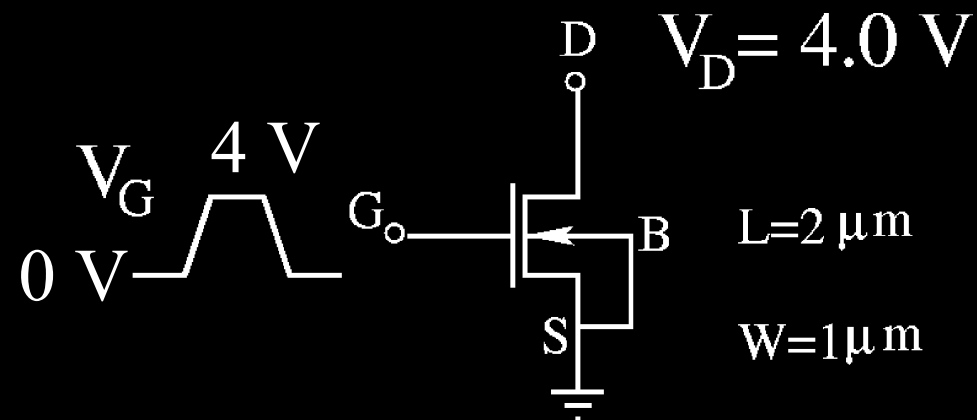
## Use of LUT simulator in evaluation of QS/NQS models e.g., BSIM3

- 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:

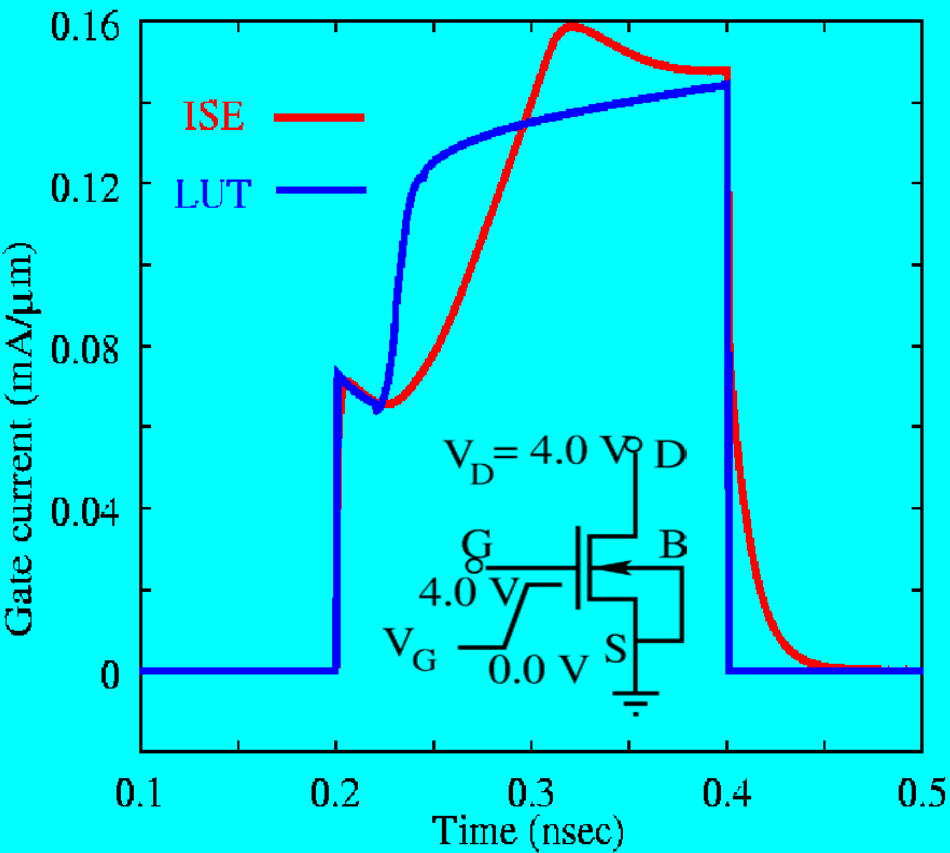
- Extract tables of terminal currents and charges using a 2-D device simulator (ISE-TCAD) => The LUT model or the “exact” QS model.
- Study terminal currents versus time for two cases
  - (i)  $V_g$  transient,
  - (ii)  $V_d$  transient.
- Compare the results with BSIM3 QS and NQS models.

# Simulation set-up for $V_g$ transient

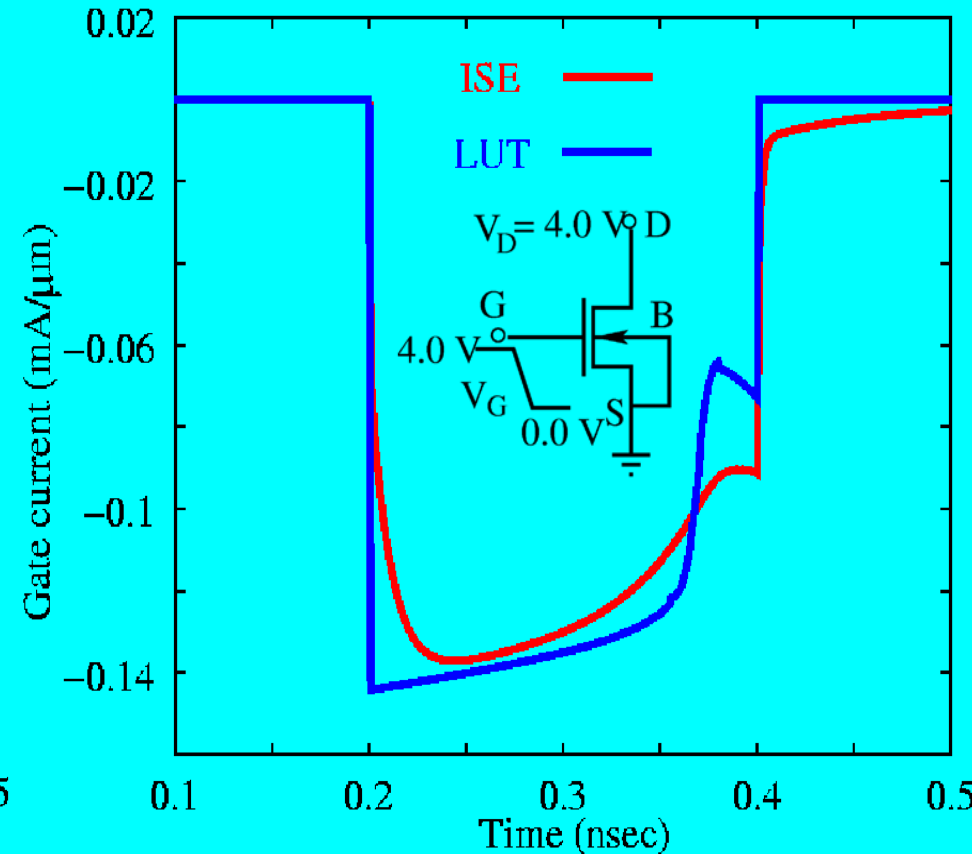


Rise and fall time = 0.2 nsec

# Gate current for the $V_G$ transient

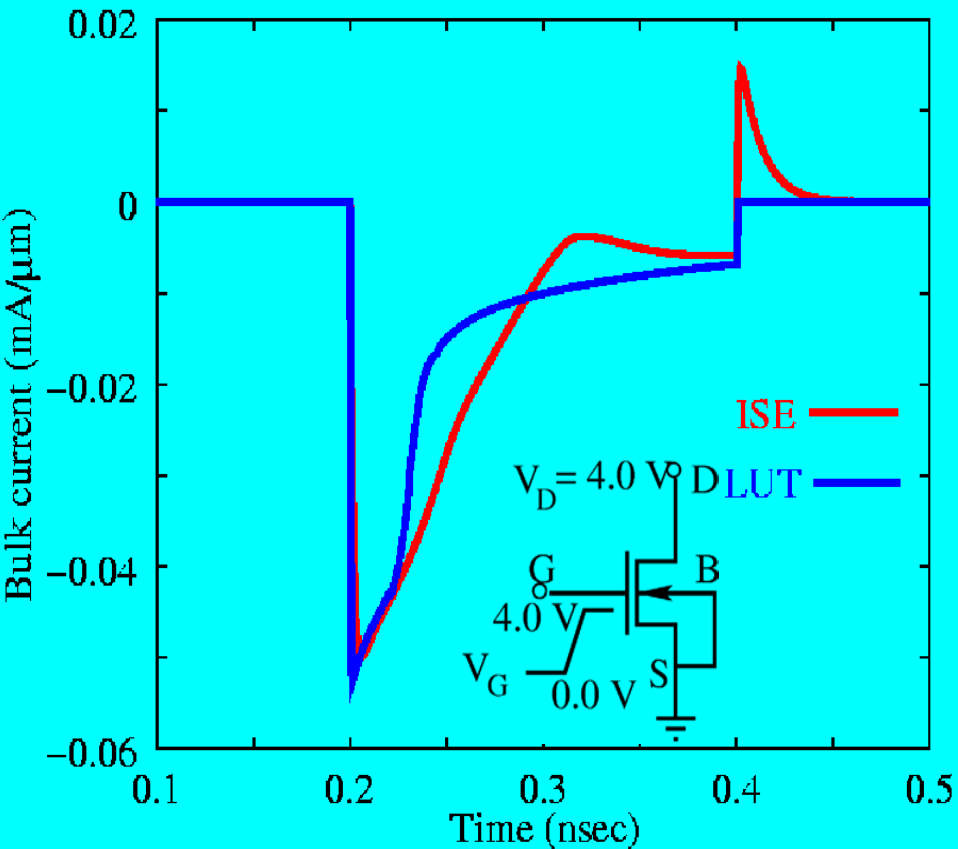


Input rising

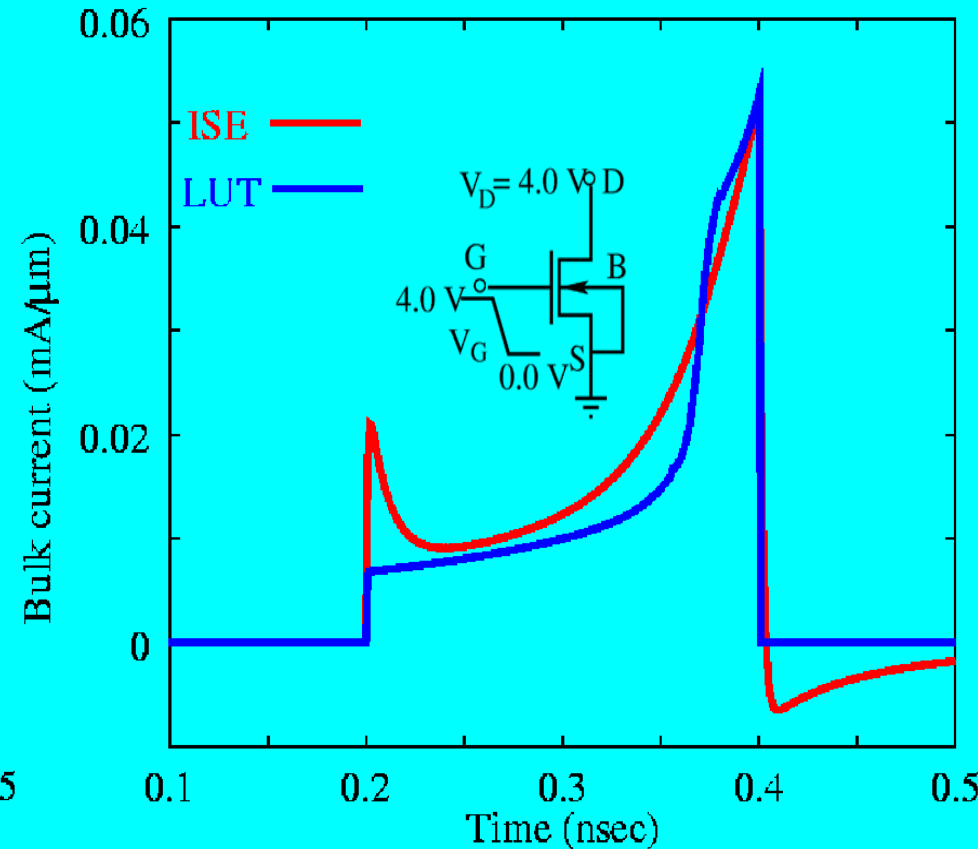


Input falling

# Bulk current for the $V_g$ transient

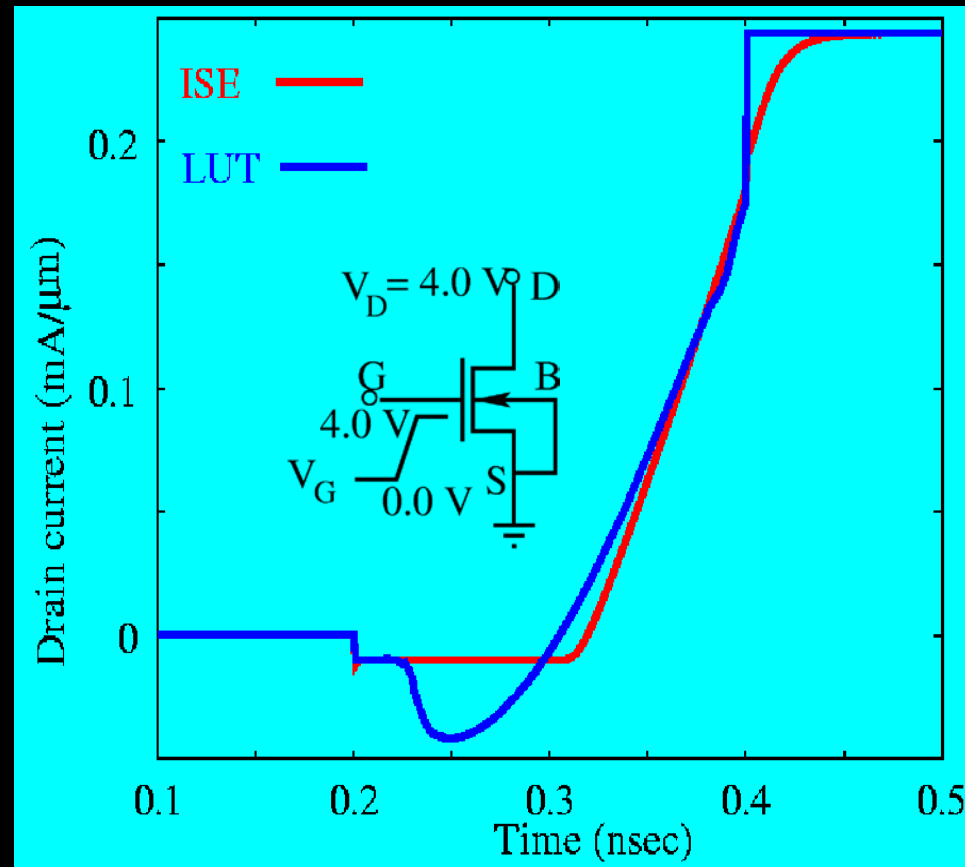


Input rising

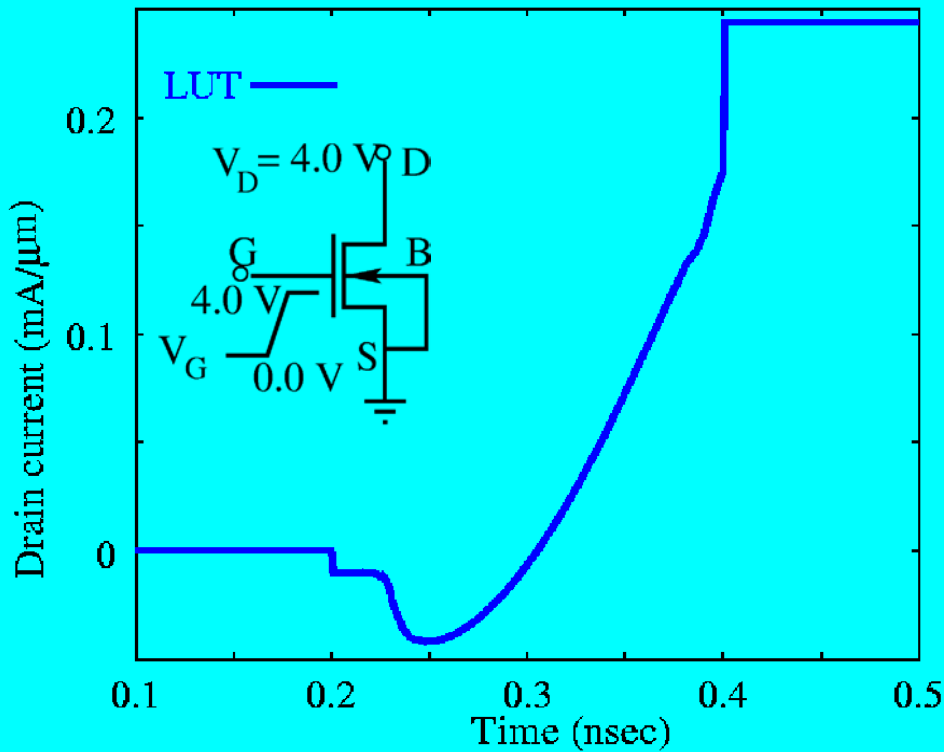


Input falling

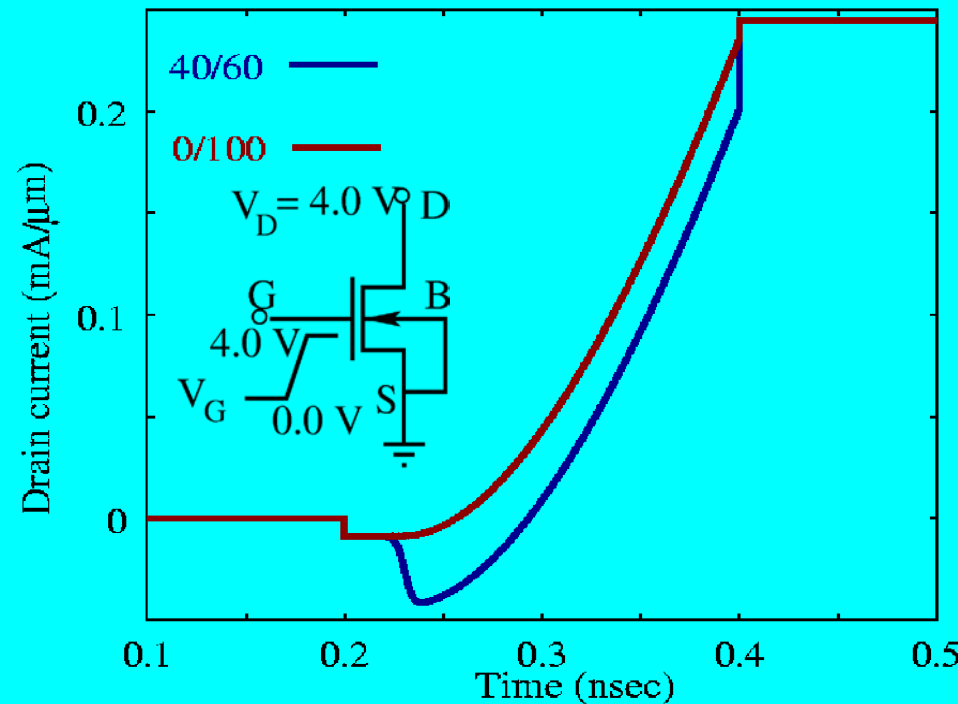
# Drain current with ISE/LUT



# Drain current with LUT and BSIM3 QS

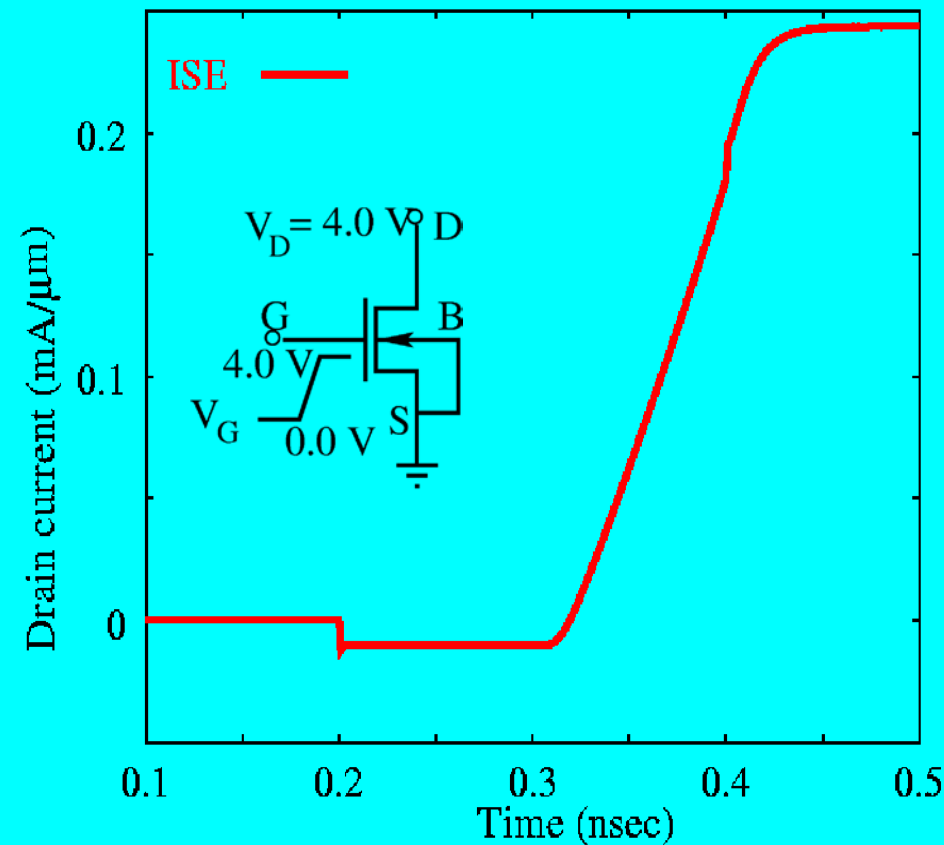


LUT (Rising input)

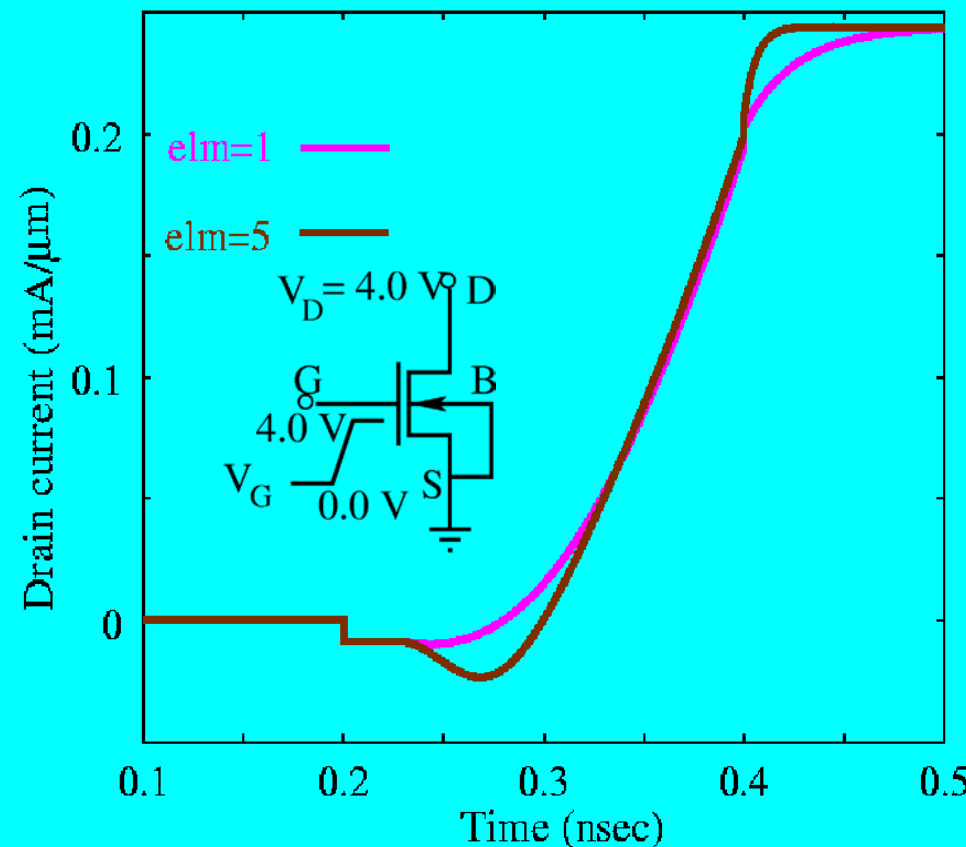


BSIM3 QS (Rising input)

# Drain current with ISE and BSIM3 NQS



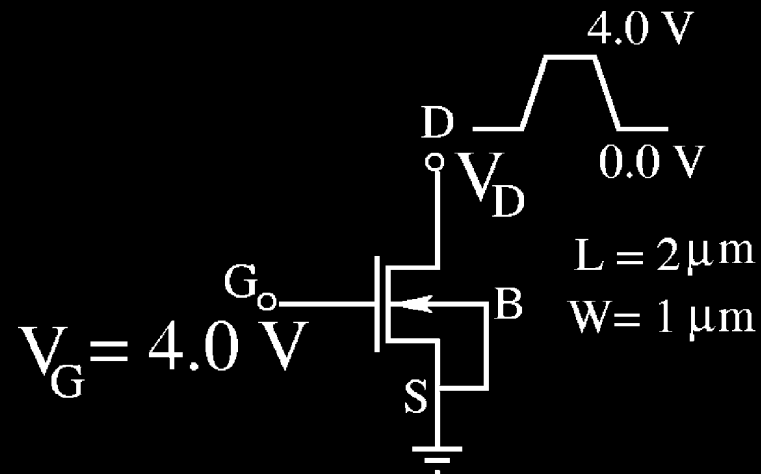
ISE (Rising input)



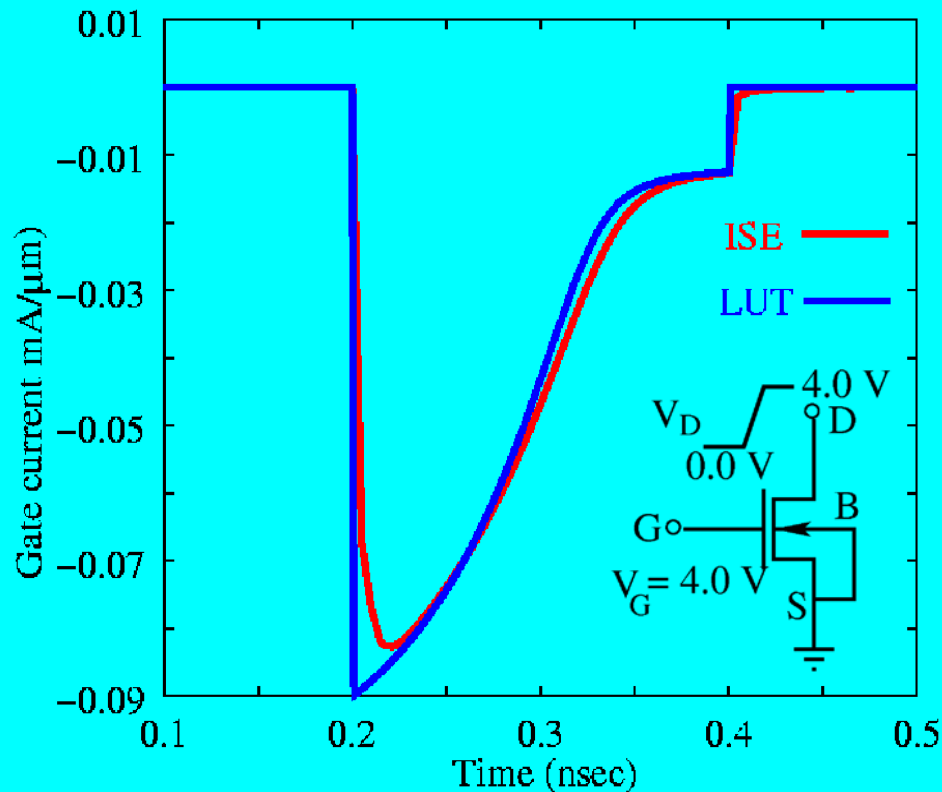
BSIM3 NQS (Rising input)

# Simulation set-up for $V_d$ transient

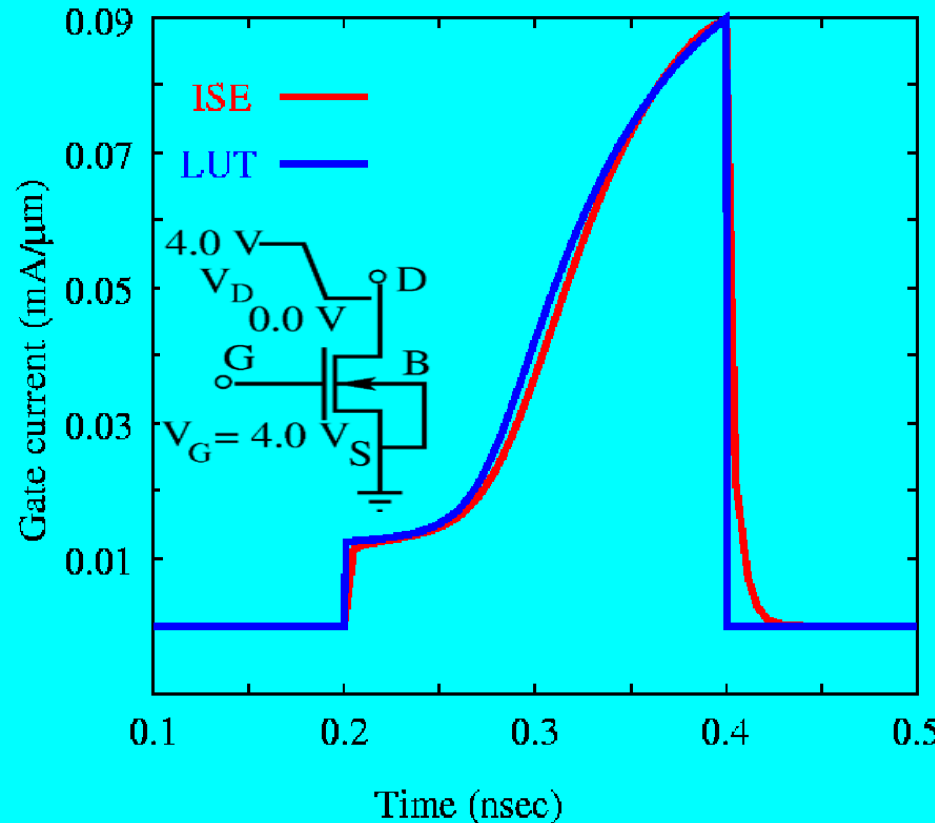
Rise and fall time=0.2 nsec



# Gate current for the $V_d$ transient

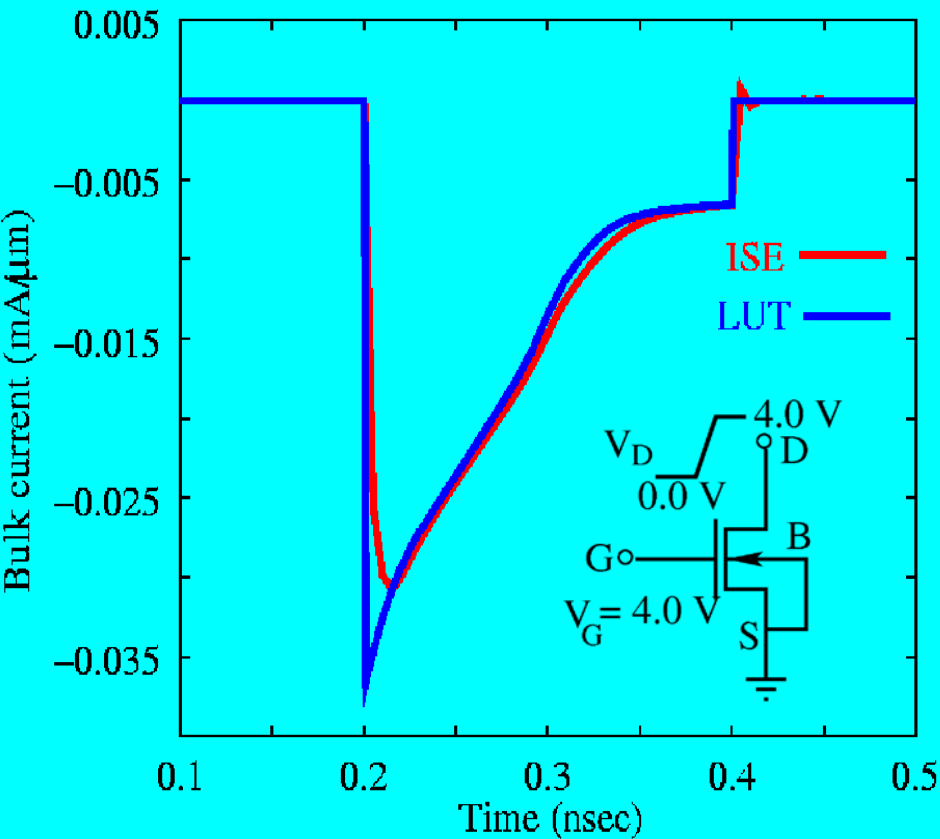


Input rising

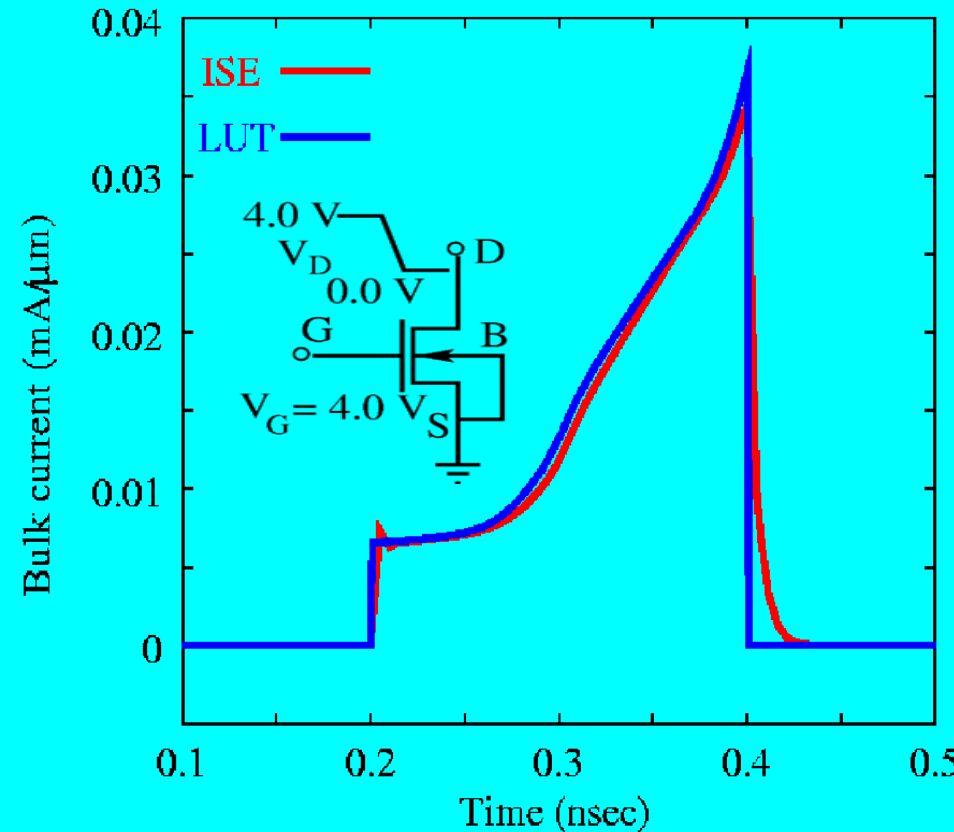


Input falling

# Bulk current for the $V_D$ transient

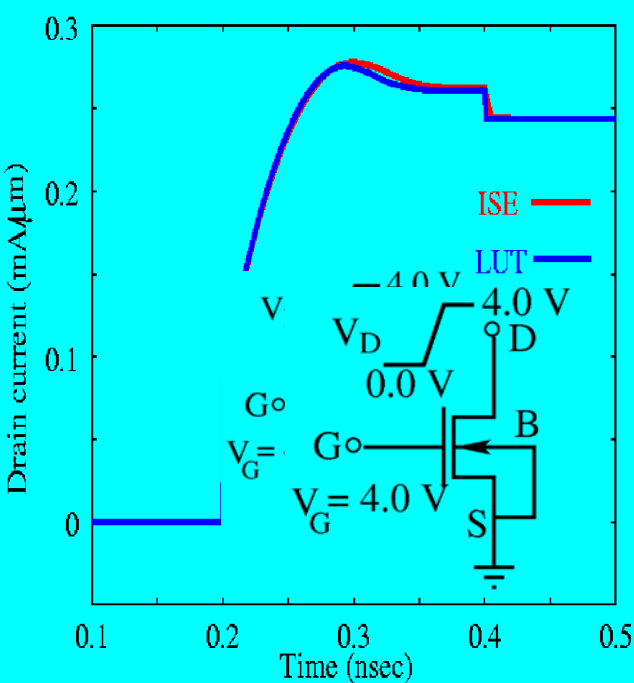


Input rising

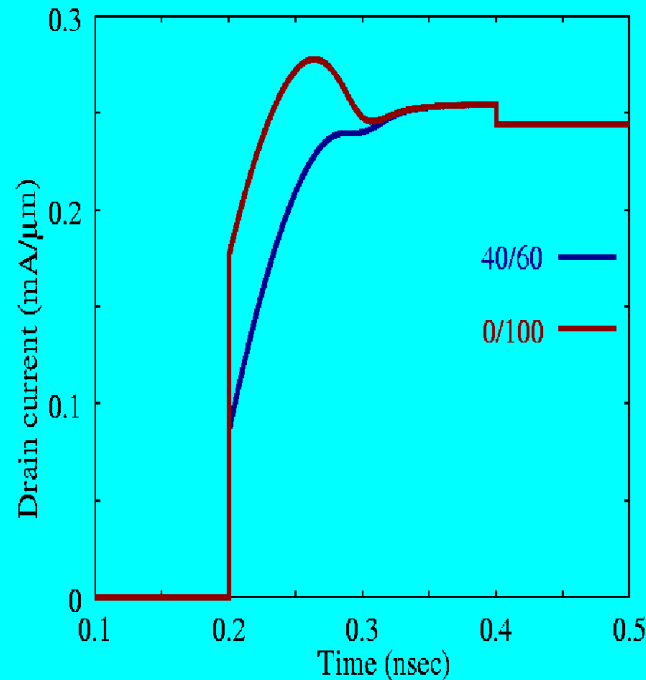


Input falling

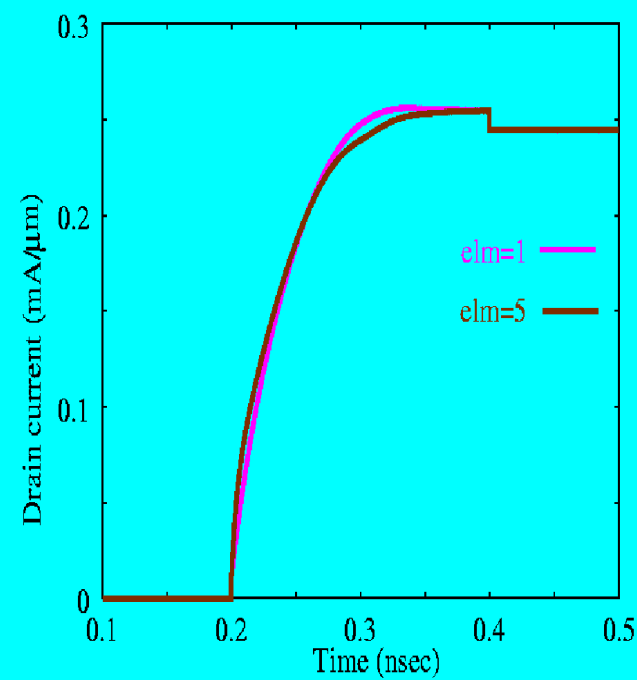
# Drain current with ISE/LUT and BSIM3



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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