Consistent Model for Drain Current Mismatch in MOSFETs Using the Carrier Number Fluctuation Theory

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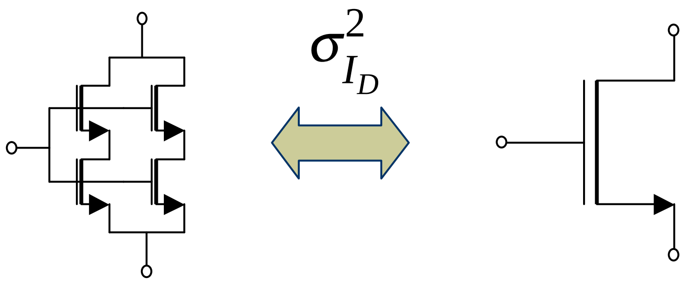
OUTLINE

- Introduction
- Mismatch Channel Model
- Fluctuation of Charge Density
- Number Fluctuation Model
- Mismatch vs. Inversion Level
- Experimental Results
- Conclusions

INTRODUCTION

- Desirable properties of mismatch models: consistency, accuracy, simplicity.
- Consistency :

series-parallel association



- Consistency : contributions of the randomly varying technological, e. g. V_T, C'_{ox} and geometric (W, L) parameters.
- Consistency: local fluctuations in V_T rather than total fluctuation (lumped parameter).
- Accuracy/consistency: model valid for any bias condition.
- Simplicity: simple models, easy-to-extract parameters

INTRODUCTION

Purpose: A simple one-equation mismatch model for hand analysis & design and circuit simulation.

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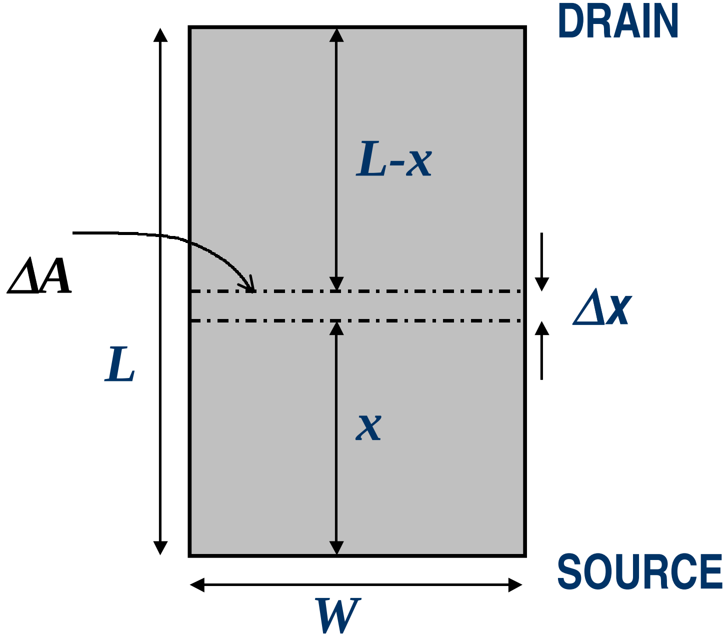
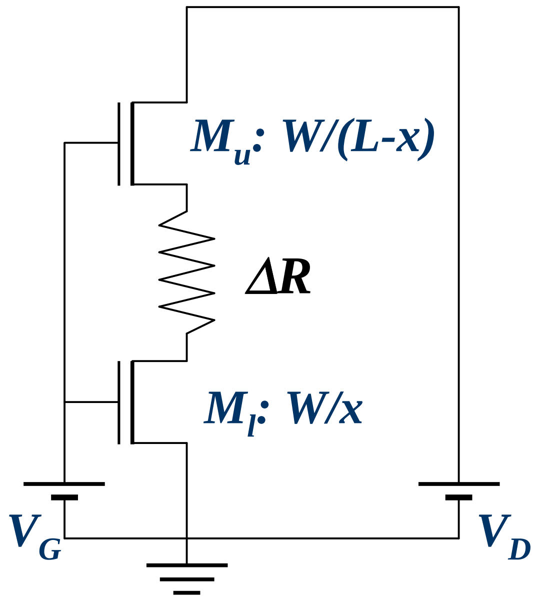
MISMATCH CHANNEL MODEL

- MOSFET channel splitting

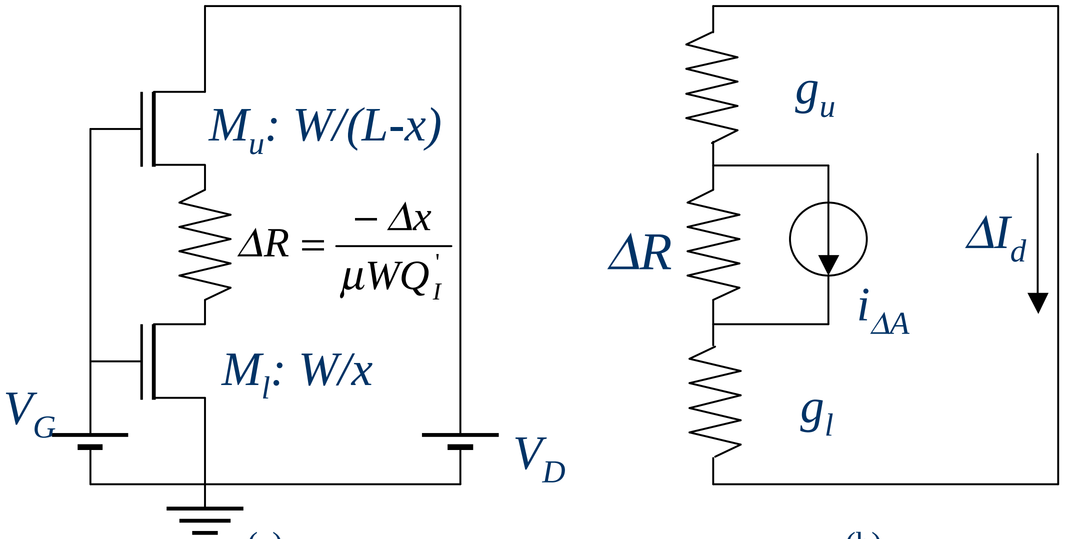


- Transistor equivalent circuit



Basic formulation: $$I_D = -\mu \frac{W}{dx} Q_I^{'} . dV_X$$

MISMATCH CHANNEL MODEL



(a) (b)

small-signal equivalent circuit

$$\Delta R = -\frac{\Delta x}{\mu W Q_I'}$$

$$g_l = -\mu \frac{W}{x} Q_{IX}'$$

$$g_u = -\mu \frac{W}{L-x} Q_{IX}'$$

- Mismatch results from local current fluctuation ($i_{\Delta A}$) in the small channel element.

MISMATCH CHANNEL MODEL

- Contribution of local current fluctuation ($i_{\Delta A}$) to drain current (ΔI_d):

$$\Delta I_d = (\Delta x / L) . i_{\Delta A}$$

- The fluctuation of the local charge is the main contribution to mismatch

$$i_{\Delta A} = I_D \frac{\Delta Q_I^{'}}{Q_I^{'}}$$

- Total drain current variance is the sum of (uncorrelated) individual contributions

$$(\Delta I_D)^2 = \frac{1}{L^2} \int_0^L \left[\Delta x (i_{\Delta A})^2 \right] dx$$

⇑

contribution of the channel element to total current

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FLUCTUATION OF CHARGE DENSITY

- From UCCM

$$\frac{\Delta Q_I'}{Q_I'} = \frac{-C_{ox}'\Delta V_T}{Q_I' - nC_{ox}'\phi_t}$$

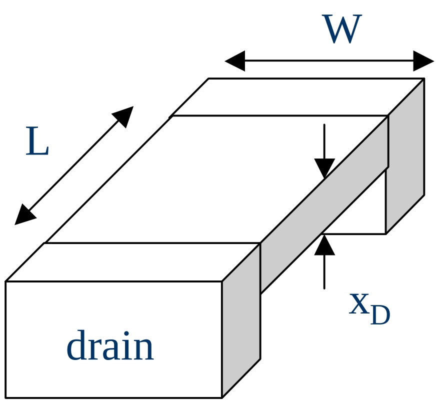
- Local fluctuation of V_T from Pelgrom's expression

$$\sigma_{VT}^2 = \frac{A_{VT}^2}{LW} \Rightarrow \overline{\Delta V_T^2} = \frac{A_{VT}^2}{\Delta x W}$$

lumped *distributed*

- Poisson statistics for depletion charge fluctuations

$$A_{VT}^2 = \frac{q^2}{C_{ox}'^2}(N.x_D) = \frac{q^2}{C_{ox}'^2} N_{oi}$$



N_{oi}: effective number of impurities per unit area of gate

NUMBER FLUCTUATION MODEL

The previous considerations result for the current mismatch in any operating region

$$\frac{\sigma_{I_D}^2}{I_D^2} = \frac{q^2 N_{oi} \mu}{L^2 n C'_{ox} I_D} \ln\left(\frac{Q'_{IP} + Q'_{IS}}{Q'_{IP} + Q'_{ID}} \right)$$

with $Q'_{IP} = -nC'_{ox}\phi_t$

MISMATCH vs. INVERSION LEVEL

In terms of inversion level†

$$\frac{\sigma_{I_D}^2}{I_D^2} = \frac{N_{oi}}{WLN^{*2}} \frac{1}{i_f - i_r} \ln\left(\frac{1+i_f}{1+i_r}\right)$$

where $$N^* = \frac{-Q_{IP}^{'}}{q} = \frac{nC_{ox}^{'}\phi_t}{q}$$

† for long channel MOSFET, from ACM model

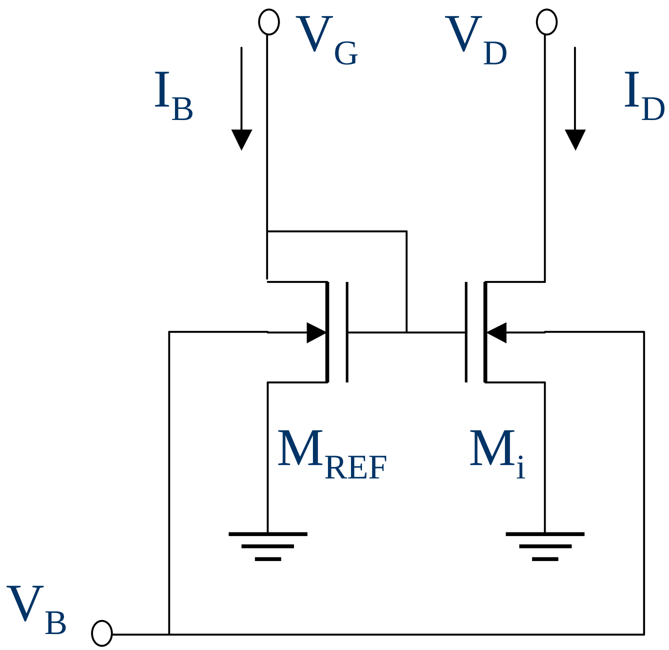
$$I_D = I_F - I_R = I_S(i_f - i_r) \qquad I_S = \tfrac{1}{2}\mu C_{ox}^{'} n\phi_t^2 (W/L)$$

SUMMARY

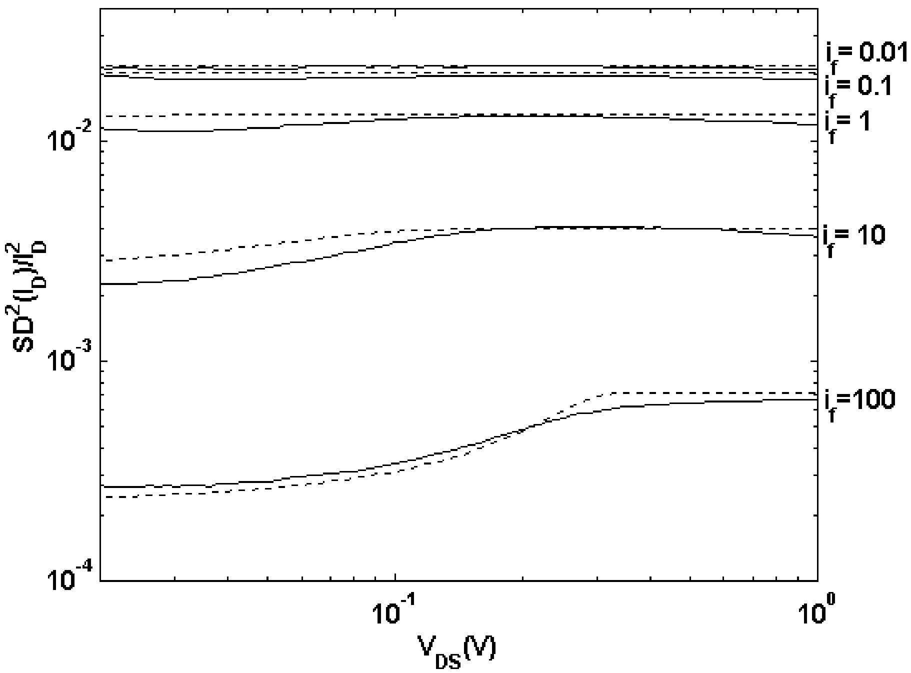
$\dfrac{\sigma^2_{I_D}}{I_D^2}$	weak inversion ($i_f<1$)	strong inversion ($i_f>>1$)
linear region ($i_f \approx i_r$)	$\dfrac{N_{oi}}{WLN^{*2}}$	$\dfrac{N_{oi}}{WLN^{*2}} \dfrac{1}{1+i_f}$
saturation region ($i_f>>i_r$)	$\dfrac{N_{oi}}{WLN^{*2}}$	$\dfrac{N_{oi}}{WLN^{*2}} \dfrac{\ln(1+i_f)}{i_f}$

EXPERIMENTAL RESULTS

Test circuit



Saturation level dependence



Measured: —; Model: ---

Test chip contains 24 NMOS 30µm x 1.2µm transistors in the ES2 1.2µm CMOS DLM process

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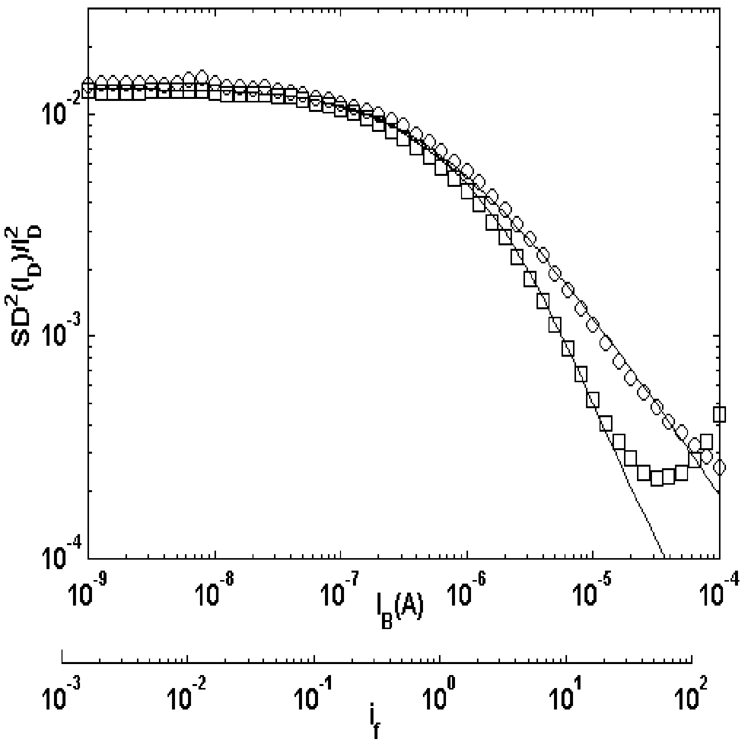
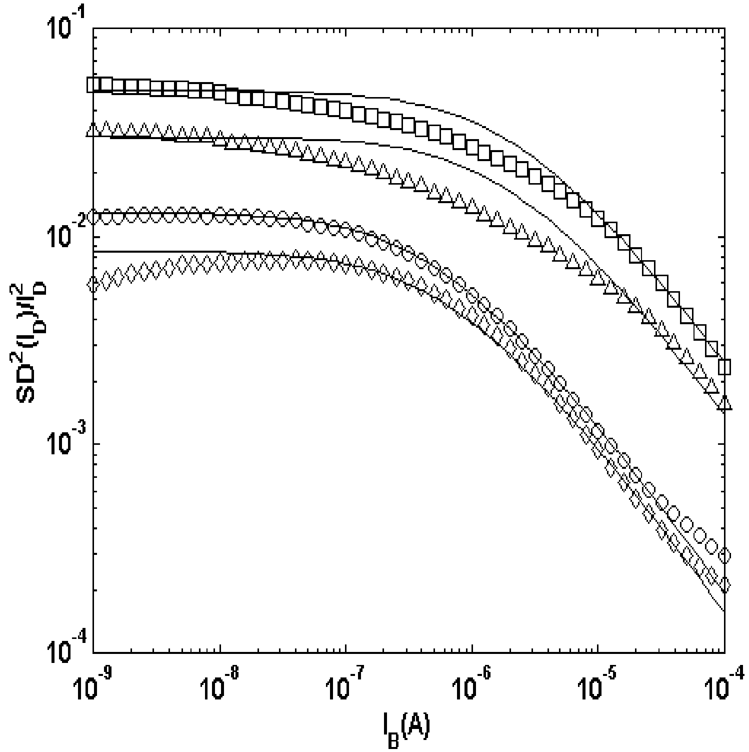
EXPERIMENTAL RESULTS

Dependence on inversion level



Linear: □ (V_{DS}=50mV); Saturation: ○ (V_{DS}=1V) regions. —; Model

Dependence on bulk-source voltage



V_{BS} : □= -1.8V; △= -1.2V; ○= 0V; ◇=+0.3V. (Saturation: V_{DS}=*1V*).

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CONCLUSIONS

- Physics-based approach (fluctuation in the number of carriers) used for derivation of mismatch.
- Use of ACM model resulted in a compact easy-to-use formula that is continuous in any operating region.
- Experimental results confirmed the accuracy of our model under various bias conditions.
- Useful tool for designers to predict transistor mismatch in an accurate and easy way.
- Single parameter model (N_{oi}) to interface foundries and designers.