Advanced MOSFETs and Novel Devices

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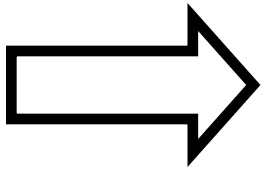
4. Tutorial & Exercise

Shrinking

Constant Field scaling (ideal):

Factor $S > 1$

- Lateral dimensions (L, W) 1/S
- Vertical dimensions (d_{OX}, r_j) 1/S
- Channel doping (N_A, N_D) *S
- Supply voltage (V_{DD}) 1/S



electric field in transistor remains constant

Constant Voltage scaling:

- Lateral dimensions 1/S
- Vertical dimensions 1/S
- Channel doping *S

Shrinking - Exercise

Determine the influence of constant field scaling on a *p*-channel MOSFET of the 180 nm technology node ($S = \sqrt{2}$). Calculate the threshold voltage V_T and draw the output characteristics for different gate-source voltages ($|V_{GS}|=V_{DD}$, $0.75*V_{DD}$, $0.5*V_{DD}$ and $0.25*V_{DD}$) for the original and the scaled device. Use the gradual channel approximation. Neglect fixed and trapped oxide charges.

Technology parameters:

V_{DD}	d_{OX}	N_D	L	W	ϕ_M-χ_{Si}	μ_p
1.8 V	3 nm	1e18 cm^{-3}	140 nm	3*L	1.12 V	500 cm^2/ Vs

Shrink – Solution

Threshold voltage:

$$V_T = \Phi_{MS} - |\frac{Q''_{Depl}}{C''_{Ox}}| - |2\Psi_B| - \frac{Q''_{Ox}}{C''_{Ox}}$$

Workfunction difference:

$$\Phi_{MS} = \Phi_M - \left(\chi_{Si} + \frac{E_g}{2q} - |\Psi_B|\right)$$

Electrostatic bulk potential:

$$\Psi_B = \frac{k_B T}{q} \cdot \ln(\frac{N_{dop}}{n_i})$$

Normalized Capacitor:

$$C''_{Ox} = \frac{C_{Ox}}{A} = \frac{\epsilon_0 \epsilon_{SiO_2}}{d_{Ox}}$$

Space charge:

$$Q''_{Depl} = \int_0^{w_{max}} \rho_S(x)dx = w_{max} e N_D$$

Depletion region:

$$w_{max} = \sqrt{\frac{4\epsilon_o \epsilon_{Si} |\Psi_B|}{eN_D}}$$

Shrinking - Results

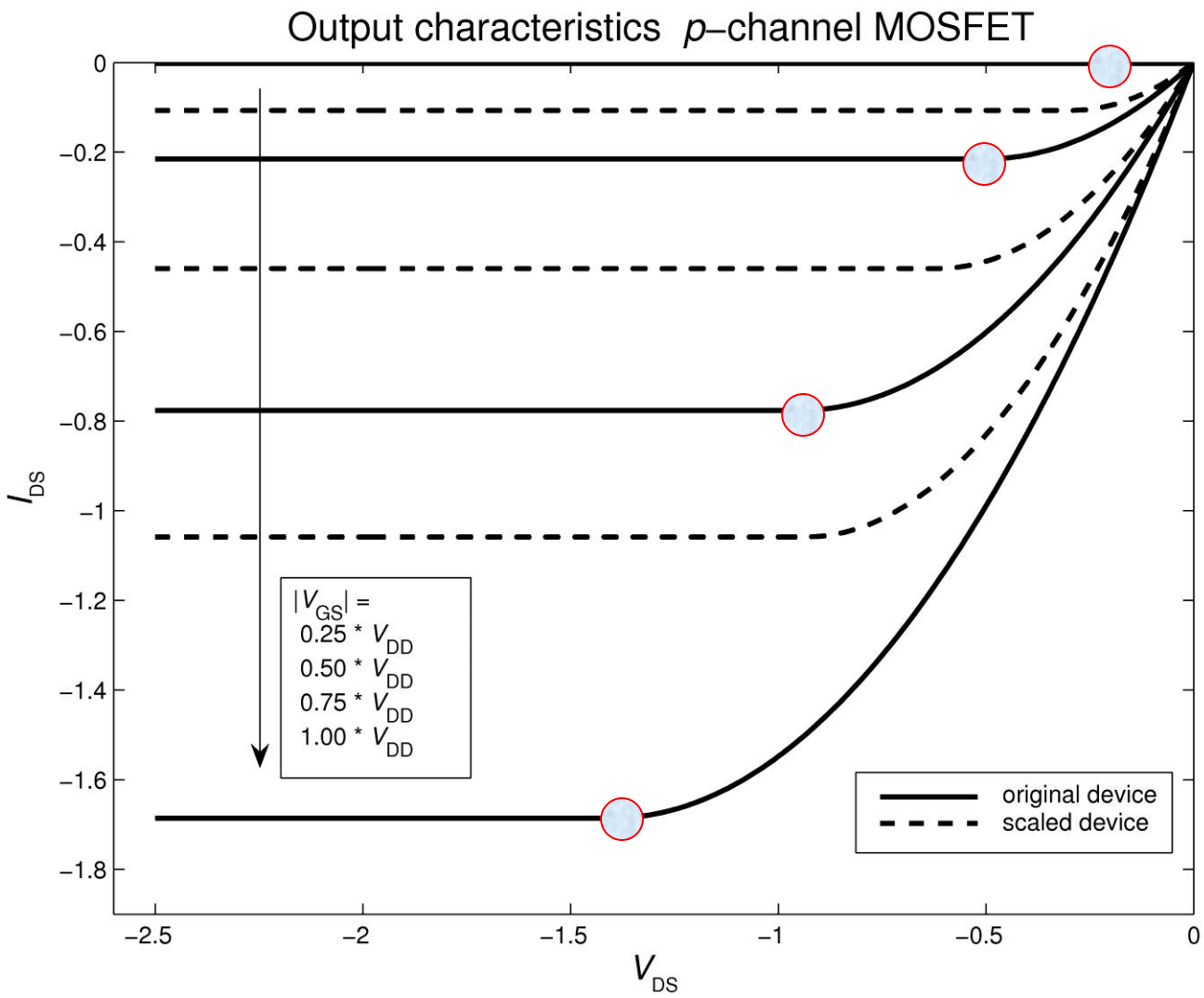
Selected points of the output characteristic

$V_{DD1} = V_{DD} = 1.8V$

$V_{DD2} = V_{DD1} / S = 1.27V$

V_{GS}	- ¼ V_{DD}	- ½ V_{DD}	- ¾ V_{DD}	- V_{DD}
$V_{GS1} - V_{T1}$				
I_{Dsat1}				
$V_{GS2} - V_{T2}$				
I_{Dsat2}				

Shrink – Solution



$V_{DD\ orig}$ = 1.8 V

$V_{DD\ scaled}$ = 1.8 / S V

= 1.27 V

Result:
Shrinked device shows lower I, but because following C_{gate} is shrinked as well, the lower I can charge the next gate faster ?