Assignment 10
E3225
Art of Compact Modeling

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1 Problem 1

Calculate Drain Current (ID) and plot, using EKV, PSP and Surface Potential Based Model, and compare:

1.1

$I_D - V_G$ characteristics, for one low and high V_D, semilog (left yaxis) and linear (right y-axis).

Solution:
In this entire report , will call Surface potential based model as Ψ based model.

Ψ based:

$$f(\psi_s) = \mu C_{ox}^{'}[(V_{GB} - V_{FB} + \phi_t)\psi_s - \frac{1}{2}\psi_s^2 - \frac{2}{3}\gamma\psi_s^{3/2} + \phi_t\gamma\psi_s^{1/2}] \tag{1}$$

$$I_{DS} = \frac{W}{L}[f(\psi_{sL}) - f(\psi_{s0})] \tag{2}$$

EKV:

$$I_{DS} = 2n\beta\phi_t^2[(q_s^2 + q_s) - (q_d^2 - q_d)] \tag{3}$$

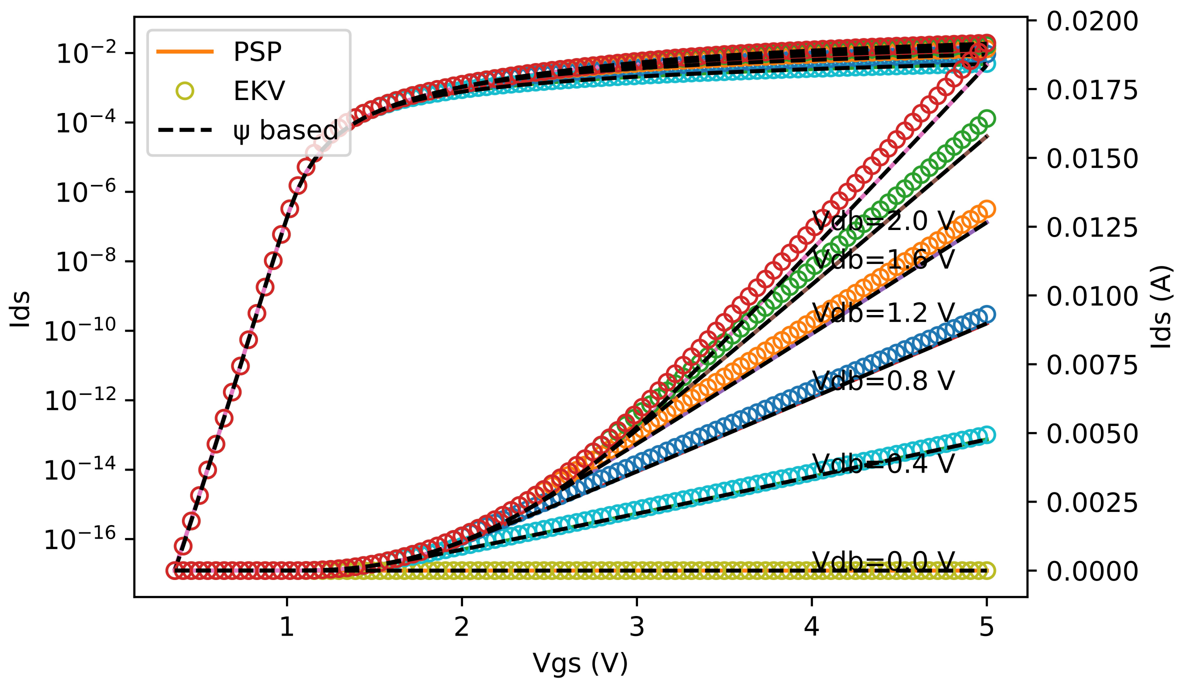
where,
* $\beta = \mu C_{ox}\frac{W}{L}$

* $n \triangleq 1 + \frac{\gamma}{2\sqrt{\psi_p}}$

PSP:

$$I_D = -\mu(\frac{W}{L})C_{ox}(q_{im} - \alpha_m\phi_t)\phi \tag{4}$$

Where,
* $\phi = \phi_{sd} - \phi_{ss}$
* $\alpha_m = 1 + \frac{\gamma}{2\sqrt{\phi_m - \phi_t}}$
* $q_{im} = -\frac{\gamma\phi_t\Delta(\phi_m,\zeta_m)}{\sqrt{\phi_m - \phi_t + \phi_t\Delta(\phi_m,\zeta_m)} + \sqrt{(\phi_m - \phi_t)}}$
* $\phi_m = \frac{(\phi_{ss} + \phi_{sd})}{2}$
* $\Delta(\phi_m,\zeta_m) = \frac{1}{2}[\Delta(\phi_{ss},V_{sb}) + \Delta(\phi_{sd},V_{sb} + V_{ds})] - \frac{\phi^2}{4\gamma^2\phi_t}$
* $\Delta(\phi_s,\zeta) = e^{\frac{(\phi_s - 2\phi_f - \zeta)}{\phi_t}}$

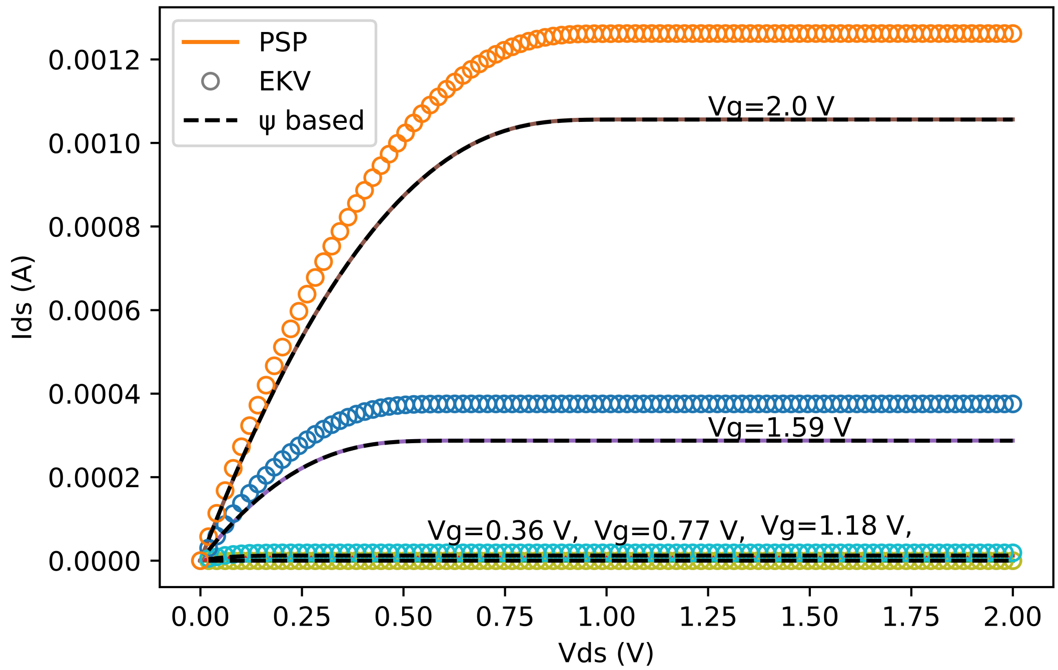


As can be seen clearly fronm the linear part of figure, that PSP and ψ based model almost overlap but EKV model have very little deviation, which increases with increase in V_d.

1.2

$I_D - V_{DS}$ characteristic, for different V_G.
Solution:

using equations (1), (2), (3) and (4) for V_{DS} :



ψ based model and PSP model are in good agreement with each other, but for EKV model error increases for higher V_g, for $V_g = 2V$ it is as high as 8 % .

2 Problem 2

Plot Inversion Charge along the channel (Fig.2(b) in PSP_Core.pdf) using EKV, PSP and Surface Potential Based model approach and compare.

Solution:

ψ based:

$\psi(x)$ **vs x:**

$$\frac{x}{L} = \frac{f(\psi_s(x)) - f(\psi_{s0})}{f(\psi_{sL}) - f(\psi_{s0})} \tag{5}$$

equation (1) is used in equation (5) for calculating $f(\psi_s(x))$ using Newton Raphson method, have solved for $\psi_s(x)$.

$$Q_B^{'} = -\sqrt{2q\epsilon_s N_A}\sqrt{\psi_s(x)} \tag{6}$$

$$Q_G^{'} = C_{ox}^{'}(V_{GB} - V_{FB} - \psi_s(x)) - Q_o^{'} = C_{ox}^{'}\gamma\sqrt{\psi_s(x) + \phi_t e^{\frac{\psi_s(x)\ -\ (2\phi_f + V_{cb})}{\phi_t}}} - Q_o^{'} \tag{7}$$

$$Q_I^{'} = -\ Q_B^{'}\ -\ Q_G^{'} \tag{8}$$

expression of $\psi_s(x)$ is used in equation (8) to get Inversion charge along channel length.

EKV:

$$I_f = q_s^2 + q_s \tag{9}$$

$$I_r = q_d^2 - q_d \tag{10}$$

$$q^2 + q = I_f - \frac{x}{L}(I_f - I_r) \tag{11}$$

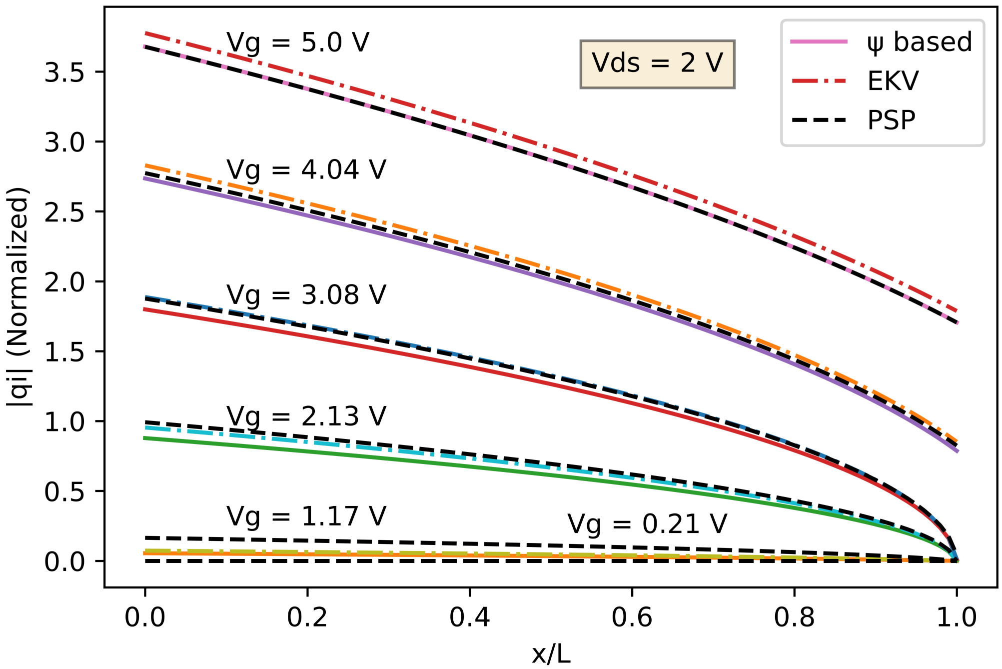
equation (11) is solved using Newton Raphson method to get Inversion charge as a function of distance along channel length.

PSP:

$$q_i = q_{im}\ +\ \alpha_m(\phi_s\ -\ \phi_m) \tag{12}$$

where,
* $\phi_s = \phi_m\ +\ H[1\ -\ \sqrt{1\ -\ (\frac{2\phi}{HL})(y\ -\ y_m)}]$
* $H = \phi_t\ -\ \frac{q_{im}}{\alpha_m}$
* $y_m = (\frac{L}{2})(1\ +\ \frac{\phi}{4H})$

rest other parameters are same as in equation (4) .



Here distance is normalized with channel length and charge is normalized with C_{ox}.

For low V_g compared to ψ based approach, EKV model is accurate within few percent. But as V_g increases PSP model come up with better match to ψ based approach than EKV model.

3 Problem 3

Plot Transcapacitances (C_{gg}, C_{dg}, C_{sg}, C_{bg}) as function of V_G, at high and low V_{DS} (Fig.3 in PSP_Core.pdf), using EKV, PSP and Surface Potential Based Model and compare.

Solution:

ψ based:

Charges:

* $Q_B^{'} = -\sqrt{2q\epsilon_s N_A}\sqrt{\psi_s(x)}$

* $Q_B = W\int_0^L Q_B^{'}\,dx$

* $Q_G^{'} = C_{ox}^{'}(V_{GB} - V_{FB} - \psi_s(x)) - Q_o^{'} = C_{ox}^{'}\gamma\sqrt{\psi_s(x) + \phi_t e^{\frac{\psi_s(x)\ -\ (2\phi_f + V_{cb})}{\phi_t}}} - Q_o^{'}$

* $Q_G = W\int_0^L Q_G^{'}\,dx$

* $Q_I^{'} = -Q_G^{'} - Q_B^{'} = -\sqrt{2q\epsilon_s N_A}[\sqrt{\psi_s(x) + \phi_t e^{\frac{\psi_s(x)\ -\ (2\phi_f + V_{cb})}{\phi_t}}} - \sqrt{\psi_s(x)}]$

- From $Q_I^{'}$, Q_S and Q_D can be calculated as follows:

* $Q_D = W \int_0^L \frac{x}{L} Q_I^{'} \, dx$

* $Q_S = W \int_0^L (1 - \frac{x}{L}) Q_I^{'} \, dx$

Transcapacitance Calculation:

$C_{gg} = \frac{dQ_G}{dV_G}$

$C_{bg} = \frac{dQ_B}{dV_G}$

$C_{dg} = \frac{dQ_D}{dV_G}$

$C_{sg} = \frac{dQ_S}{dV_G}$

EKV:

Charges:

* $Q_I = -Q_0 WL(\frac{2}{3}\frac{\chi_f^2 \ + \ \chi_f \chi_r \ + \ \chi_r^2}{\chi_f \ + \ \chi_r} - \frac{1}{2})$

* $Q_B \cong -\gamma C_{ox}^{'} WL\sqrt{\Psi_p} - \frac{n-1}{n} Q_I$ where, $\Psi_p = \Psi_0 + V_P$

* $Q_G = -Q_I \ - \ Q_B \ - \ Q_{ox}$

* $Q_D = -\frac{Q_0}{2} WL(\frac{4}{15}\frac{2\chi_f^3 \ + \ 4\chi_f^2 \chi_r \ + \ 6\chi_f \chi_r^2 \ + \ 3\chi_r^3}{(\chi_f \ + \ \chi_r)^2} \ - \ \frac{1}{2})$

* $Q_S = Q_I \ - \ Q_D$

* where, $\chi_{f/r} = \frac{1}{2} + q_{if/r}$, q_i is calculated from input voltage equation of EKV model.

Transcapacitance Calculation:

$C_{gg} = \frac{dQ_G}{dV_G}$

$C_{bg} = \frac{dQ_B}{dV_G}$

$C_{dg} = \frac{dQ_D}{dV_G}$

$C_{sg} = \frac{dQ_S}{dV_G}$

PSP:

Charges and Transcapacitances:

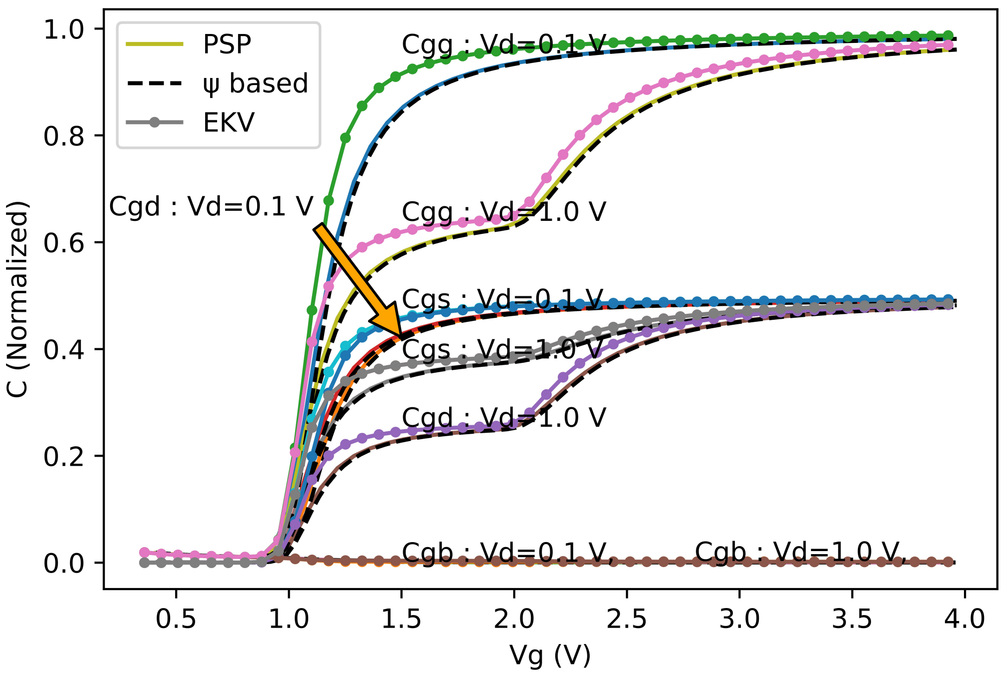
* $Q_G = -q_{im} \ + \ \gamma\sqrt{(\phi_m \ - \ \phi_t)} \ + \ (\frac{\phi^2}{12H})$

* $Q_D = \frac{1}{2}[q_{im} \ + \ \frac{\alpha_m \phi}{6}(1 \ - \ \frac{\phi}{2H} \ - \ \frac{\phi^2}{20H^2})]$

* $Q_B = -\gamma\sqrt{\phi_m \ - \ \phi_t} \ - \ \frac{(1 \ - \ \alpha_m)\phi^2}{12H}$

* $Q_S = -Q_G \ - \ Q_D \ - \ Q_B$

$C_{ij} = (2\delta_{ij}\ -\ 1)(\frac{\partial Q_i}{\partial V_j})\ ,\ where\ i,\ j\ =\ G,\ S,\ D,\ B$



All the capacitances are normalized with respect to C_{ox}.

PSP model is in well accordance with ψ based model in all the regims, while EKV model deviates a bit in the weak to moderate inversion regime for low V_d, for high V_d the mismatch span is larger.