Simplified All-Region Models

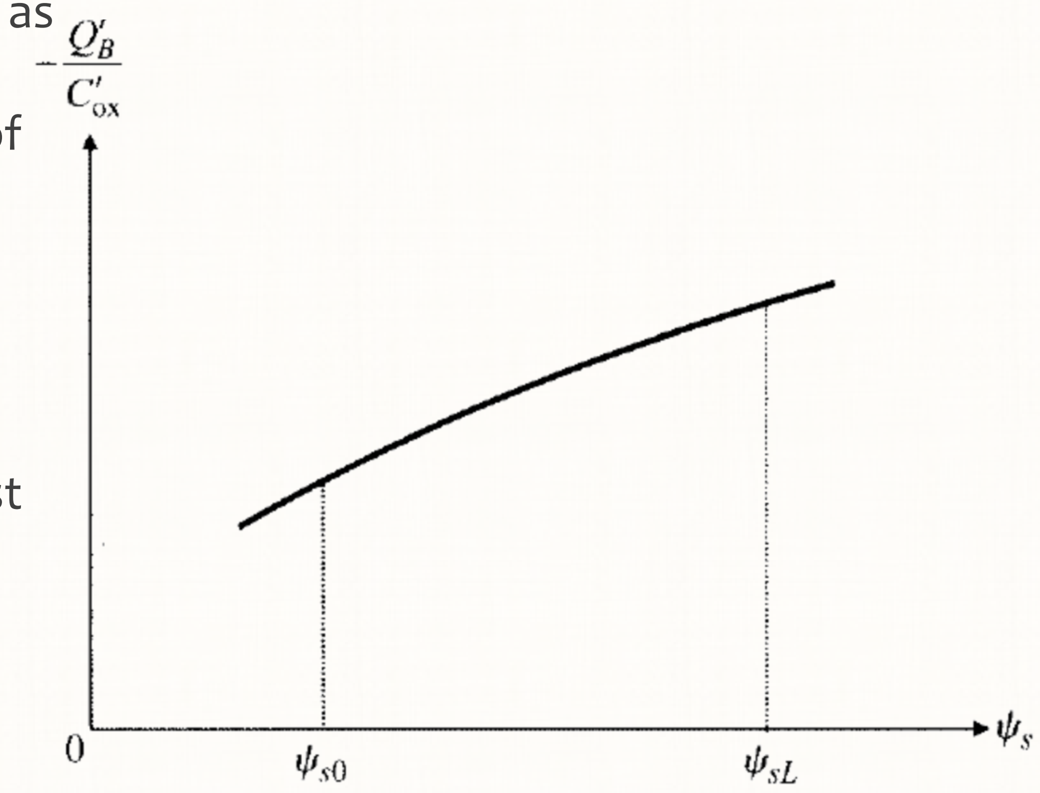
Linearizing the Depletion Region Charge

- The "complete" all-region model of 4 terminal MOS is very accurate, but is too complicated for some applications such as transient response calculation.
- It is clear from the development presented that the origin of these terms is the square root in the expression for Q'_B in following equation:

$$Q'_B = -\gamma C'_{ox}\sqrt{\psi_s}$$

- This equation is plotted in following figure
- Since the slope of the plot in following figure does not vary much, it is reasonable to attempt to approximate it with first two terms of Taylor expansion around a convenient expansion point such as ψ_{se}

$$-\frac{Q'_B}{C'_{ox}} = \gamma\sqrt{\psi_{se}} + \frac{\gamma}{2\sqrt{\psi_{se}}}(\psi_s - \psi_{se})$$



Linearizing …

- Defining α

$$\alpha = 1 + \frac{\gamma}{2\sqrt{\psi_{se}}}$$

$$-\frac{Q'_B}{C'_{ox}} = \gamma\sqrt{\psi_{se}} + (\alpha - 1)(\psi_s - \psi_{se})$$

- Now from our past equations

$$\int_{\psi_{s0}}^{\psi_{sL}} (Q'_B) d\psi_S(x) = -C'_{ox}\left[\gamma\sqrt{\psi_{se}} + (\alpha - 1)(\psi_{se} - \frac{\psi_{s0} + \psi_{sL}}{2})\right](\psi_{sL} - \psi_{s0})$$

$$Q'_B(\psi_{SL}) - Q'_B(\psi_{S0}) = -C'_{ox}(\alpha - 1)(\psi_{sL} - \psi_{s0})$$

- Subsequently:

$$\boldsymbol{I_{DS1}} = \frac{W}{L}\mu C'_{ox}\left[\left(V_{GB} - V_{FB} - \psi_{se} - \gamma\sqrt{\psi_{se}}\right) + \alpha\left(\psi_{se} - \frac{\psi_{s0}+\psi_{sL}}{2}\right)\right](\psi_{sL} - \psi_{s0})$$

$$\boldsymbol{I_{DS2}} = \frac{W}{L}\mu C'_{ox}\alpha\phi_T(\psi_{sL} - \psi_{s0})$$

Linearizing …

- Channel end potentials are calculated before.
- In this situation the inversion layer charge become:

$$Q_I' = -C_{ox}'(V_{GB} - V_{FB} - \psi_s) - Q_B' = -C_{ox}'(V_{GB} - V_{FB} - \psi_{se} - \gamma\sqrt{\psi_{se}} - \alpha(\psi_s - \psi_{se}))$$

- Our discussion so far has been in terms of an arbitrary expansion point ψ_{se}.
- Several choices for ψ_{se} have been proposed in the literature.
- Next discussion in about choosing ψ_{se}.

Body-Referenced Simplified All-Region Models

- First choice :

$$\psi_{se} = \psi_{sm} = \frac{\psi_{s0} + \psi_{sL}}{2}$$

- Note that ψ_{sm} is the midpoint of the *potential*, not the physical midpoint of the channel.

- The resulting value of α:

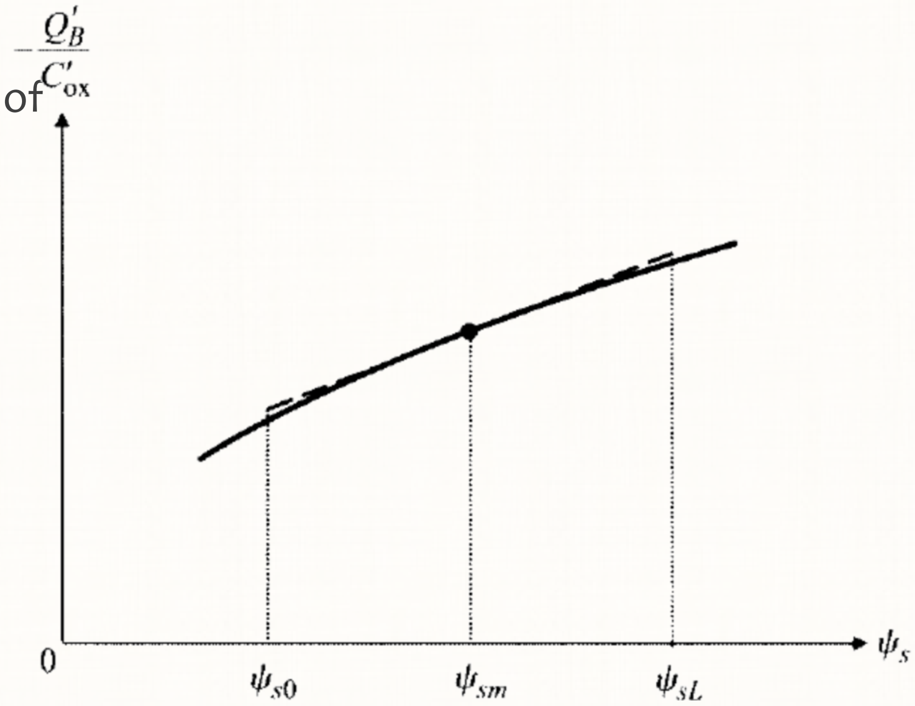
$$\alpha = \alpha_m = 1 + \frac{\gamma}{2\sqrt{\psi_{sm}}}$$

- The corresponding equations for Q'_B, $\boldsymbol{I_{DS1}}$ *and* $\boldsymbol{I_{DS2}}$ become:

$$-Q'_B = C'_{ox}\left[\gamma\sqrt{\psi_{sm}} + (\alpha_m - 1)(\psi_s - \psi_{sm})\right]$$

$$\boldsymbol{I_{DS1}} = \frac{W}{L}\mu C'_{ox}\left[\left(V_{GB} - V_{FB} - \psi_{sm} - \gamma\sqrt{\psi_{sm}}\right)\right](\psi_{sL} - \psi_{s0})$$

$$\boldsymbol{I_{DS2}} = \frac{W}{L}\mu C'_{ox}\alpha_m\phi_T(\psi_{sL} - \psi_{s0})$$

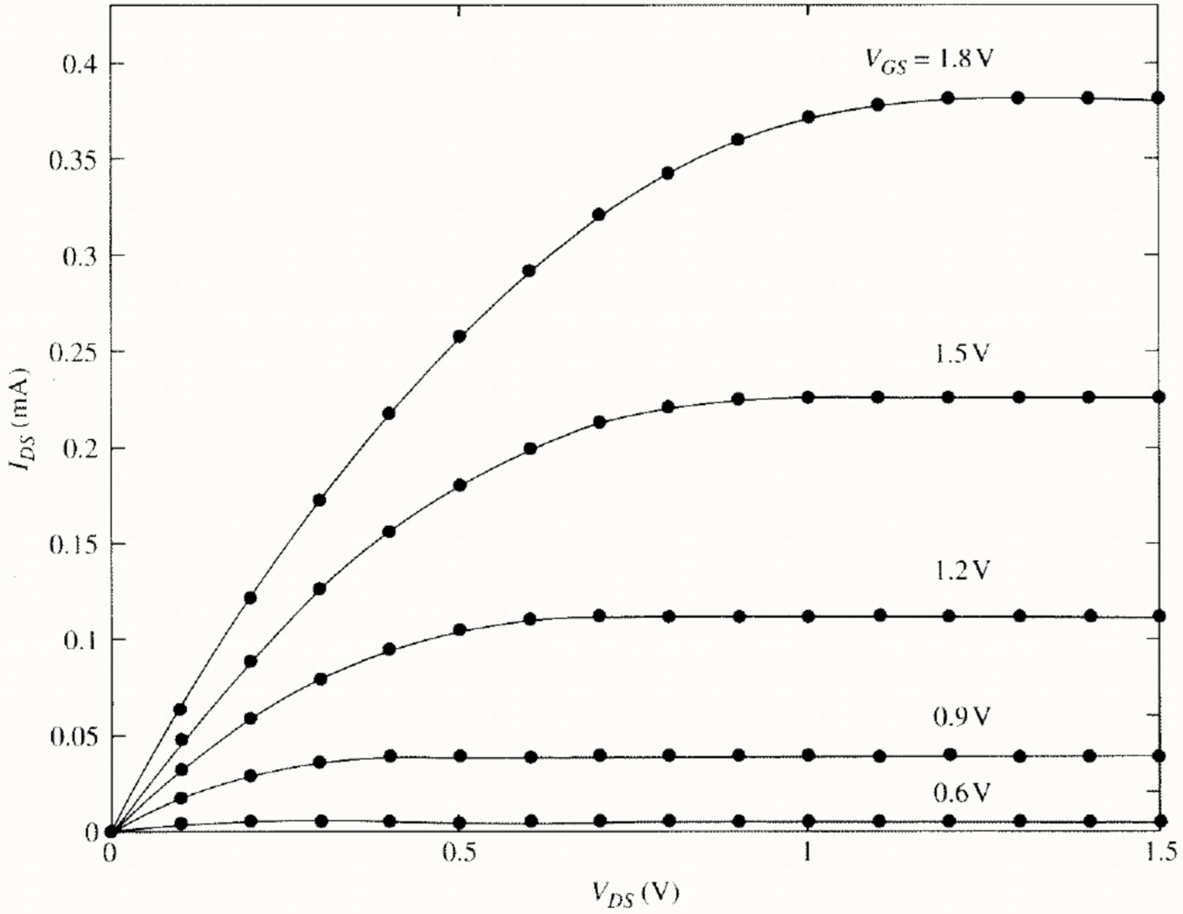


Body-Referenced Simplified …

- Note that ψ_{sm} and α_m change when ψ_{sL} changes.
- As introduced before, the quantity $C'_{ox}\left(V_{GB} - V_{FB} - \psi_{sm} - \gamma\sqrt{\psi_{sm}}\right)$ is the magnitude of the inversion charge (per unit area).
- Thus, $\boldsymbol{I_{DS1}}$ (drift current) can be interpreted as follows: the "vertical" field caused by the applied voltage *VGB* induces a conducting channel to form underneath the gate, with an "effective" charge as above, and the "lateral" field caused by $\psi_{sL} - \psi_{s0}$ causes current to flow through this conducting channel.

Body-Referenced Simplified …

- Although square-root terms are still present in equations, the expressions are analytically and computationally simpler than before and numerically more stable to evaluate; yet, they are essentially indistinguishable in terms of accuracy.
- One can choose another point of ψ_{se} such as ψ_{s0}



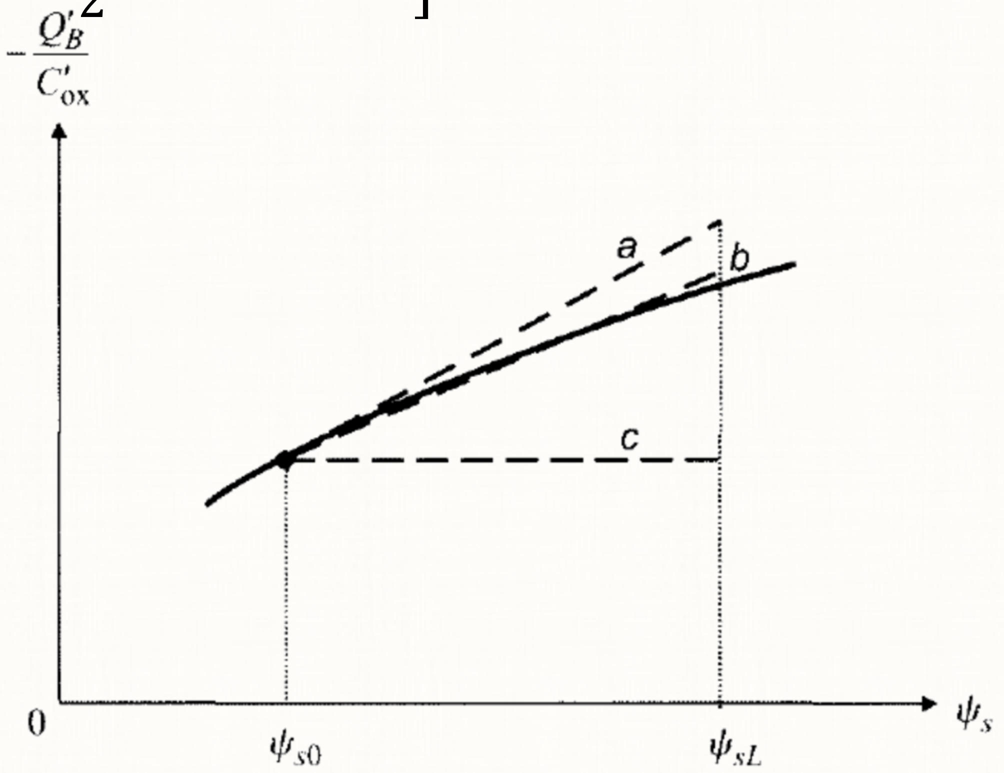
Source-Referenced Simplified All-Region Models

- If $\psi_{se} = \psi_{s0}$ by substituting to our general equation

$$I_{DSN} = \frac{W}{L}\mu C'_{ox}\left[\left(V_{GB} - V_{FB} - \psi_{s0} - \gamma\sqrt{\psi_{s0}}\right)(\psi_{sL} - \psi_{s0}) - \frac{\alpha}{2}(\psi_{sL} - \psi_{s0})^2\right]$$

$$I_{DS2} = \frac{W}{L}\mu C'_{ox}\alpha\phi_T(\psi_{sL} - \psi_{s0})$$

$$\alpha = \alpha_I = 1 + \frac{\gamma}{2\sqrt{\psi_{s0}}}$$



Charge Formulation of Simplified All-Region Models

- As it is shown Q'_B is change linearly → Q'_I can be also assumed to change linearly as:

$$Q'_I = -C'_{ox}(V_{GB} - V_{FB} - \psi_s) - Q'_B = -C'_{ox}(V_{GB} - V_{FB} - \psi_{se} - \gamma\sqrt{\psi_{se}} - \alpha(\psi_s - \psi_{se}))$$

- For such approximations, the corresponding inversion charge Q'_I for a fixed V_{GB} also varies linearly with ψ_s.
- This approximation for Q'_I is more accurate than the one for Q'_B, as Q'_I already contained a dominant linear term to begin with.

$$\frac{dQ'_I}{d\psi_s} = \alpha C'_{ox}$$

- Based on past driven equation now we have:

$$I_{DS1} = \frac{W}{L}\mu\left(\int_{\psi_{s0}}^{\psi_{sL}}(-Q'_I)d\psi_s(x)\right) = \frac{W}{L}\mu\left(\int_{Q'_{I0}}^{Q'_{IL}}(-Q'_I)\frac{1}{\alpha C'_{ox}}dQ'_I\right) = \frac{W}{L}\mu\frac{1}{\alpha C'_{ox}}(Q'^2_{I0} - Q'^2_{IL})$$

$$I_{DS2} = \frac{W}{L}\mu\phi_T\,(Q'_{IL} - Q'_{I0})$$

$$\psi_{se} = \psi_{sa}$$