Weak Inversion

Special Conditions in Weak Inversion

- For a transistor operating in weak inversion *no* part of the channel is moderately or strongly inverted.
- For a weakly inverted point in the channel, the surface potential satisfies:

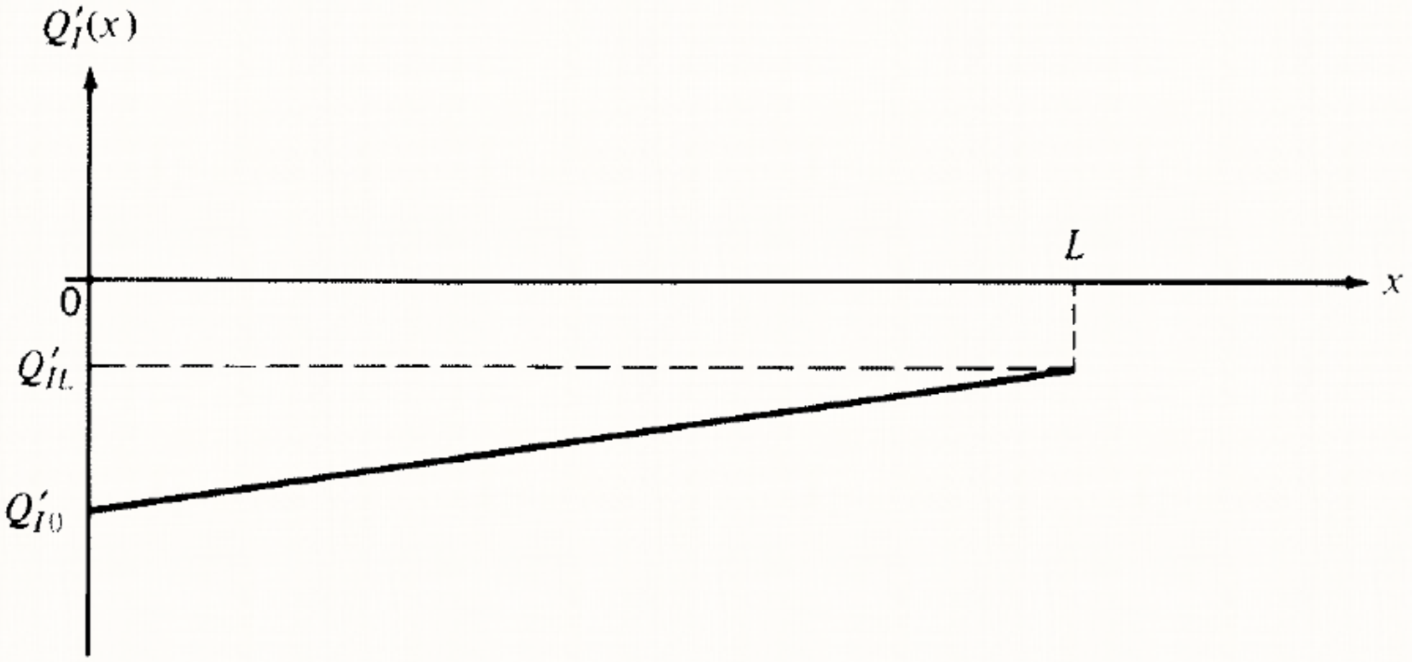
$$\psi_s \approx \psi_{sa}(V_{GB}) = \left(-\frac{\gamma}{2} + \sqrt{\frac{\gamma^2}{4} + V_{GB} - V_{FB}}\right)^2$$

- Since the surface potential depends only on V_{GB} it is independent of the position along the channel. This implies two important facts:
  1. Q_I' will be independent of position along the channel, as seen before. This means that the depletion region depth does not change along the channel.
  2. Since all points at the surface are assumed at the same potential with respect to the substrate, the potential difference between such points is zero. Therefore, the electric field has a zero horizontal component. If there is current through the channel, then, it cannot be caused by drift; thus, all current must be caused by diffusion.

Special Conditions in Weak Inversion

- From our previous discussion (and here) about diffusion current we have:

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



Body-Referenced Model

- The two values of Q_I' can be found from previous equation, which is valid in weak inversion and even in depletion:

$$Q_{I0}' = \frac{-\sqrt{2q\epsilon_s N_A}}{2\sqrt{\psi_{sa}}}\phi_T e^{(\psi_{sa}-2\phi_F)/\phi_T} e^{-(V_{SB})/\phi_T}$$

$$Q_{IL}' = \frac{-\sqrt{2q\epsilon_s N_A}}{2\sqrt{\psi_{sa}}}\phi_T e^{(\psi_{sa}-2\phi_F)/\phi_T} e^{-(V_{DB})/\phi_T}$$

- With substitution we have:

$$\boldsymbol{I_{DS}} = \frac{W}{L}\hat{\boldsymbol{I}}(V_{GB})\left(e^{-(V_{SB})/\phi_T} - e^{-(V_{DB})/\phi_T}\right)$$

Where

$$\hat{\boldsymbol{I}}(V_{GB}) = \mu\frac{\sqrt{2q\epsilon_s N_A}}{2\sqrt{\psi_{sa}}}\phi_T^2 e^{(\psi_{sa}-2\phi_F)/\phi_T}$$

- Note: this equation is very similar to Ebers-Moll equations. Because similar mechanisms are responsible for current flow in the bipolar transistor (under common assumptions) and the weakly inverted MOS transistor

Source-Referenced Model

- I_{DS} Equation (4.8.3) can be rewritten as follows:

$$I_{DS} = -\frac{W}{L}\mu\phi_T Q'_{I0}(1 - \frac{Q'_{IL}}{Q'_{I0}})$$

$$\frac{Q'_{IL}}{Q'_{I0}} = e^{-(V_{DB}-V_{SB})/\phi_T} = e^{-V_{DS}/\phi_T}$$

Thus we have:

$$I_{DS} = -\frac{W}{L}\mu\phi_T Q'_{I0}(1 - e^{-V_{DS}/\phi_T})$$

Again based on what we have found for three terminal MOS:

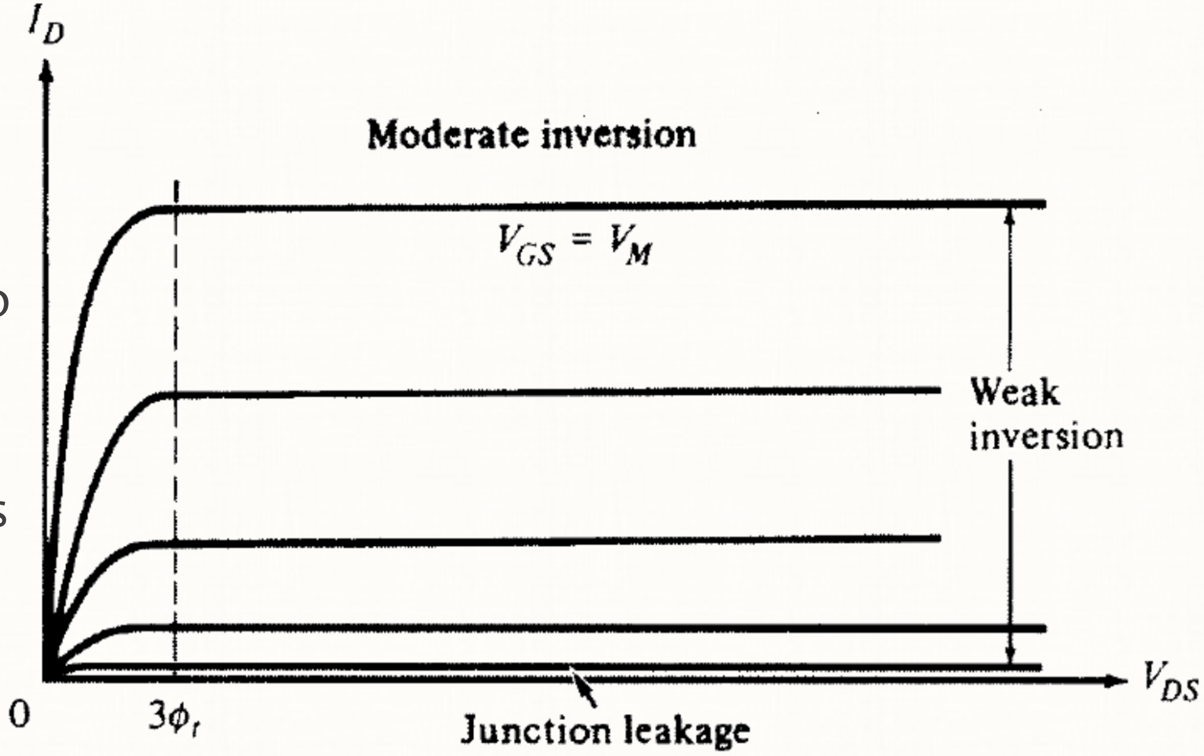
$$I_{DS} = \frac{W}{L} I'_M e^{\frac{(V_{GS}-V_M)}{n\phi_T}}(1 - e^{-V_{DS}/\phi_T})$$

Where

$$I'_M = \mu\frac{-\sqrt{2q\epsilon_s N_A}}{2\sqrt{2\phi_F + V_{SB}}}\phi_T^2 \text{ and } \psi_{sa} = 2\phi_F + V_{SB}$$

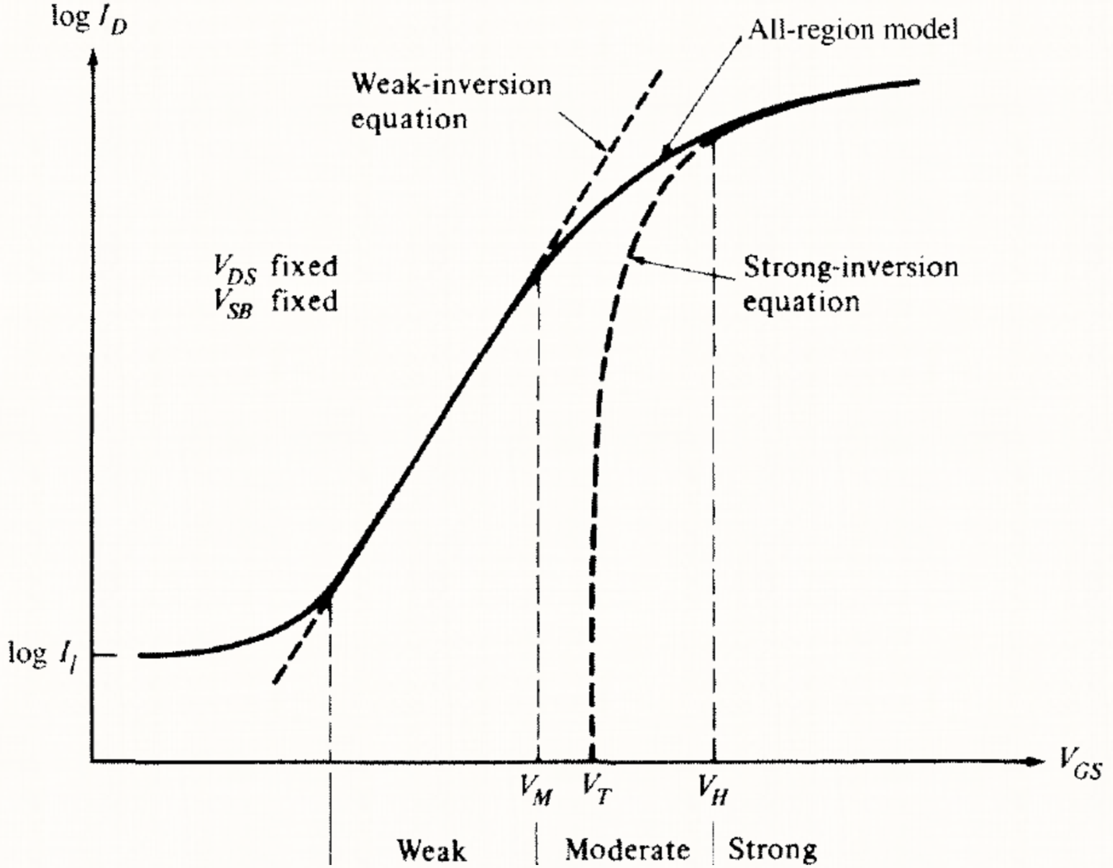
Source-Referenced Model

- I_{DS} is plotted vs. V_{DS} by using past equation in Fig., with V_{GS} as a parameter, for a fixed V_{SB}.
- As seen, the curves become horizontal for V_{DS} larger than a few ϕ_T since the last exponential in the equation becomes negligible compared to 1.
- Using equal V_{GS} steps, the vertical spacing of successive curves in Fig for a given V_{DS} increases nearly exponentially. This exponential behavior is brought out clearly by plotting log I_{DS} vs. V_{GS} with V_{DS} fixed, as shown in next Fig.



Source-Referenced Model

- log I_{DS} vs. V_{GS} with V_{DS} fixed



Moderate-Inversion and Single-Piece Models

Moderate-Inversion and Single-Piece Models

- The I_{DS}-V_{DS} characteristics of the transistor in this region have a shape roughly similar to that in strong inversion, but are not described accurately by strong inversion equations since, as shown before.
- In moderate inversion, both drift *and* diffusion contribute significantly to the value of the drain current.
- Convenient simplifications are not known for this region.
- One can use the all-region models described before.
- Due to the difficulties mentioned previously in developing moderate inversion expressions, and the need for continuity of I_{DS} and its derivatives, several semiempirical "single-piece" expressions have been proposed