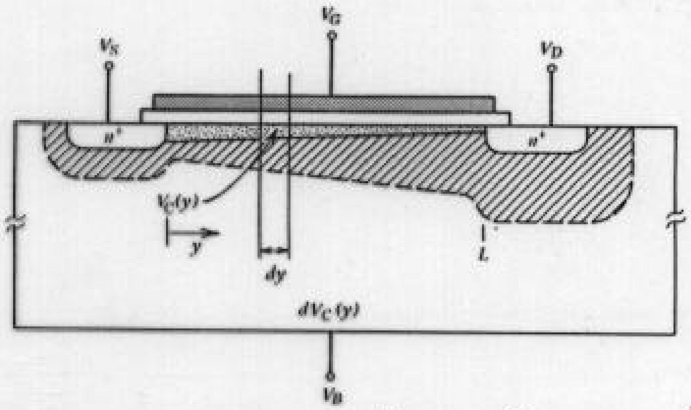
I-V CHARACTERISTICS : DISTRIBUTED ANALYSIS



$V_D \leq V_G - V_T$: GRADUAL CHANNEL APPROXIMATION

$I_D(y) = -Q_n(y)\, v(y)\, W$

TO GET A POSITIVE CURRENT

$$\begin{cases} v(y) = -\mu_n \mathcal{E}_y \\ \mathcal{E}_y = -\dfrac{dV_c(y)}{dy} \\ Q_n(y) = Q_n[V_c(y)] \quad \text{G.C.A.} \end{cases}$$

$I_D = -\mu_n W\, Q_n[V_c(y)] \dfrac{dV_c(y)}{dy}$ = CONSTANT IN STEADY STATE

$$I_D \int_S^D dy = -\mu_n W \int_{V_S}^{V_D} dV_c\, Q_n(V_c)$$

$$\boxed{I_D = -\mu_n \frac{W}{L} \int_{V_S}^{V_D} dV_c\, Q_n(V_c)}$$

$$Q_n = -C_{ox}\left[V_G - V_{FB} - 2|\phi_p| - V_c\right] + \sqrt{2\epsilon_0\epsilon_s q N_a(2|\phi_p| + V_c - V_B)} \qquad (8.3.16)$$

a. CHARGE CONTROL MODEL : $\begin{cases} Q_d(V_c) = Q_d(V_s) \\ Q_d = -\sqrt{2\epsilon_0\epsilon_s q N_a[2|\phi_p| + V_s - V_B]} \end{cases}$

$Q_{n_1}(V_c) = -C_{ox}[V_G - V_T(V_s) - (V_c - V_s)]$

$$\boxed{I_{D_1} = +\mu_n C_{ox} \frac{W}{L}\left[(V_G - V_T^s)V_{DS} - \frac{V_{DS}^2}{2}\right]} \qquad V_{DS} \leq V_{GT}$$

GRADUAL CHANNEL APPROX. (GCA)

$V_{DS} < V_{GT}$

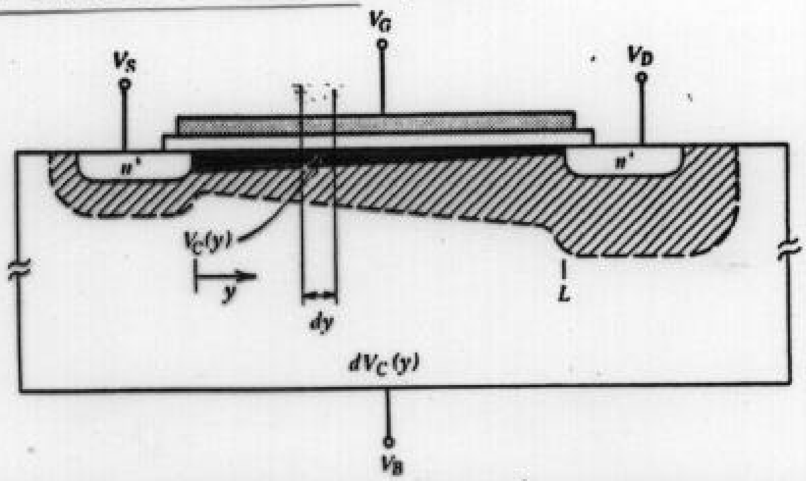


Figure 9.4 MOSFET cross section indicating the differential length dy along the channel. An ohmic voltage drop $dV_C = I_D dR$ is sustained across dy. The channel is W units wide.

CHARGE CONTROL MODEL

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_G - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right] \qquad V_{DS} \le V_{GT}$$

$$\boxed{I_{D_{SAT}} = \frac{\mu_n W C_{ox}}{2L}(V_G - V_T)^2} \qquad V_{DS} \ge V_{GT}$$

$$V_T = V_{FB} + 2|\phi_p| + \sqrt{2\epsilon_0\epsilon_s q N_a (2|\phi_p| + V_S - V_B)}/C_{ox} + V_S$$

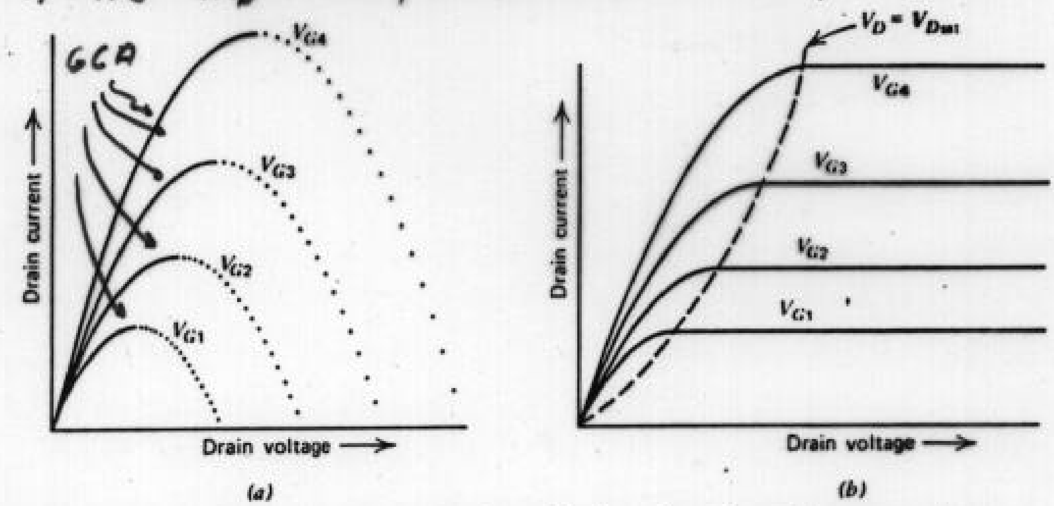


Figure 9.5 (*a*) Drain current as a function of drain voltage for various gate voltages as predicted by Equation 9.1.9. The dotted portions of the curve are unreasonable on physical grounds. (*b*) Overall $I_D - V_D$ curves as predicted by Equations 9.1.9 and 9.1.11. The dashed curve represents values of V_{Dsat} from Equation 9.1.10. The gate voltage increases from bottom to top in both curve families, and V_S has been taken to be zero.

b. VARIABLE DEPLETION-CHARGE ANALYSIS : $Q_d(V_c)$

$$I_{DZ} = \mu_m \frac{W}{L} \int_{V_S}^{V_D} dV_c \left\{ C_{ox}(V_G - V_{FB} - 2|\phi_p| - V_c) - \sqrt{2\epsilon_0\epsilon_s q N_a (2|\phi_p| + V_c - V_B)} \right\}$$

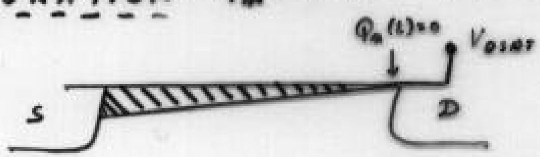
KEEP V_c INSIDE $\sqrt{\ }$

$$\boxed{I_{DZ} = \mu_m \frac{W}{L} \left\{ C_{ox}\left(V_G - V_{FB} + 2|\phi_p| - \tfrac{1}{2}(V_D + V_S)\right) V_{DS} - \frac{2}{3}\sqrt{2\epsilon_0\epsilon_s q N_a}\left[(2|\phi_p| + V_D - V_B)^{3/2} - (2|\phi_p| + V_S - V_B)^{3/2} \right] \right\}} \qquad V_{DS} \le V_{GT}$$

$$V_T^D = V_{FB} + 2|\phi_p| + V_D + \sqrt{2\epsilon_0\epsilon_s q N_a (2|\phi_p| + V_D - V_B)} \Big/ C_{ox}$$

NOT POSSIBLE TO EXPRESS I_{DZ} AS A FUNCTION OF V_T^D !!

SATURATION: $Q_m(L) = 0$ FOR V_{DSAT}



$$Q_m(L) = -C_{ox}[V_G - V_{FB} - 2|\phi_p| - V_{DSAT}] + \sqrt{2\epsilon_0\epsilon_s q N_a (2|\phi_p| + V_{DSAT} - V_B)} = 0$$

$$V_{DSAT} = V_G - V_{FB} - 2|\phi_p| - \frac{\epsilon_0\epsilon_s q N_a}{C_{ox}^2}\left[\sqrt{1 + \frac{2C_{ox}^2}{\epsilon_0\epsilon_s q N_a}(V_G - V_{FB} - V_B)} - 1\right]$$