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Level 3 Spice from Depletion-Region Approximation Referred to Source

Taylor Series Expansion Parameter

$$\alpha_s = 1 + \frac{\gamma}{2\sqrt{\psi_{sS}}} \quad (1)$$

$$V_T = V_{FB} + \psi_{sS} + \gamma\sqrt{\psi_{sS}} \quad (2)$$

$$V_P = \frac{V_G - V_T}{\alpha_s} \quad (3)$$

$$V_{IS} = \alpha_s V_{Ps} \quad (4)$$

$$V_{ID} = \alpha_s\left[V_P - \left(\psi_{sD} - \psi_{sD}\right)\right] \quad (5)$$

With depletion-region approximation, general.

$$i_{Ddrift} = \frac{1}{2\alpha_s}\left(V_{IS}{}^2 - V_{ID}{}^2\right) \quad (6)$$

Source-reference case.

$$i_{Ddrift} = \frac{\alpha_s}{2}\left[V_P{}^2 - \left(V_P - \left(\psi_{sD} - \psi_{sS}\right)\right)^2\right] \quad (7)$$

$$i_{Ddrift} = \alpha_s\left[V_P\left(\psi_{sD} - \psi_{sS}\right) - \frac{\left(\psi_{sD} - \psi_{sS}\right)^2}{2}\right] \quad (8)$$

Strong Inversion – Level 3

$$V_{GS} = V_G - V_S \quad (9)$$

$$\psi_{sD} - \psi_{sS} = V_D - V_S = V_{DS} \quad (10)$$

Threshold Voltage Referred to Source

$$V_P = \frac{V_G - \left(V_{FB} + PHI + V_S + \gamma\sqrt{PHI + V_S}\right)}{\alpha_s} = \frac{V_{GS} - \left(V_{FB} + PHI + \gamma\sqrt{PHI + V_S}\right)}{\alpha_s} \quad 11$$

$$V_{TO} = V_{FB} + PHI + \gamma\sqrt{PHI} \quad 12$$

$$V_T = V_{FB} + PHI + \gamma\sqrt{PHI + V_S} = V_{TO} + \gamma\left(\sqrt{PHI + V_S} - \sqrt{PHI}\right) \quad 13$$

$$\alpha_s = 1 + \frac{\gamma}{2\sqrt{PHI + V_S}} \quad 14$$

$$i_D = \alpha_s\left(V_P V_{DS} - \frac{{V_{DS}}^2}{2}\right) \quad 15$$

$$i_D = \left(V_G - V_{Ts}\right)V_{DS} - \alpha_s\frac{{V_{DS}}^2}{2} \quad 16$$

At Saturation

$$i_D = \frac{\alpha_s}{2}{V_P}^2 \quad 17$$

$$I_{Dsat} = UO \cdot COX\frac{W}{L_{eff}}i_D \quad 18$$

Channel-Length Modulation

$$z = \sqrt{\frac{2\varepsilon_s}{qN_{sub}}} \quad 19$$

$V_{DS} = V_{DS} > V_{dsat}\, ?\, V_{DS} : V_{dsat}$ ($l_p = 0$ in Pre-Sat, $L = L_{eff}$)

$$l_p = z\sqrt{KAPPA\left(V_{DS} - V_{Dsat}\right)} \quad 20$$

$$L = L_{eff} - l_p \qquad (21)$$

$$I_D = UO \cdot COX \frac{W}{L} i_D \qquad (22)$$

$VMAX \neq 0$, Include Mobility Reduction Effects in General

$$UCRIT = \frac{VMAX}{UO} \qquad (23)$$

$$V_C = UCRIT \cdot L_{eff} \qquad (24)$$

Mobility Reduction due to Vertical Electric Field

$$U_b = \frac{UO}{1 + THETA\left(V_{GS} - V_T\right)} \qquad (25)$$

$$V_b = \left[1 + \left(V_{GS} - V_T\right) THETA\right] V_C \qquad (26)$$

Reduced Saturation Voltage

$$V_{dsat} = V_{Dsat} + V_b - \sqrt{V_{Dsat}{}^2 + V_b{}^2} \qquad (27)$$

Channel-Length Modulation with $VMAX \neq 0$

$$V_{ds} = V_{DS} > V_{dsat} \; ? V_{dsat} : V_{DS} \qquad (28)$$

$$E_P = \frac{KAPPA}{L_{eff}} \left[\frac{i_{Dx}}{\left(V_{Dsat} - V_{ds}\right) - \frac{i_{Dx}}{V_b + V_{ds}}} \right] \qquad (29)$$

$$i_{Dx} = \left[V_{Dsat} V_{ds} - \frac{1}{2} V_{ds}{}^2 \right] \qquad (30)$$

$$l_c = \frac{z^2 E_p}{2} \qquad (31)$$

$$V_{DS} = V_{DS} > V_{dsat} \; ? V_{DS} : V_{dsat} \qquad (32)$$

$$l_p = z\sqrt{KAPPA\left(V_{DS} - V_{Dsat}\right)} \quad \text{Eq. 20}$$

$$L_p = \sqrt{l_c^{\,2} + l_p^{\,2}} - l_c^{\,2} \qquad 33$$

$$L = L_{eff} - L_p \qquad 34$$

$$I_D = U_{eff} \cdot COX \frac{W}{L} i_D \qquad 35$$

$$V_{ds} = V_{DS} > V_{dsat}\, ?\, V_{dsat} : V_{DS} \qquad 36$$

$$U_{eff} = \frac{U_b}{1 + \frac{V_{ds}}{V_b}} \qquad 37$$

$$COX = \frac{\varepsilon_i}{t_{ox}} \qquad 38$$

V_{dsat0} Based on Slope of ID = Zero. $V_{dsat0} > V_{dsat}$

$$V_{dsat0} = \left[\sqrt{\frac{2V_{Dsat}}{V_b} + 1} - 1\right] V_b \qquad 39$$

Alternate Form - $V_{dsat} \rightarrow V_{dsat0}$ for large V_b or $KAPPA \rightarrow \infty$ for finite slope.

$$V_{dsat0} = V_{Dsat0} + V_b\left(1 + \frac{V_{dsat0}}{V_b}\right) - \sqrt{V_{Dsat}^{\,2} + \left[V_b\left(1 + \frac{V_{dsat0}}{V_b}\right)\right]^2} \qquad 40$$

Drain and Source Series Resistance RS and RD

V_{GS}, V_{DS}, V_S measured, externally applied.

$$V_{GS}' = V_{GS} - I_D R_S \qquad 41$$

$$V_S' = V_S + I_D R_S \qquad 42$$

$$V_{DS}' = V_{DS} - I_D R_S - I_D R_D \qquad 43$$

Static Feedback - $V_{DS}' = V_{DS} - I_D R_S - I_D R$

$$V_{DS}' = V_{DS} - I_D R_S - I_D R_D \qquad 44$$

DIBL - ETA

$$V_T = V_T - ETA \cdot \sigma \cdot V_{DS} \qquad 45$$

$$\sigma = \frac{8.15 \cdot 10^{-22}}{C_{ox} L_{eff}^{\ 3}} \qquad 46$$