Short Channel Current

Instructor – Dr. Madhav Rao

$$I_{ds}\text{ Long-ch} = \frac{\mu C_{ox} W}{L}\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right) V_{ds}$$

$$I_{ds}\text{ Long-ch} = \mu C_{ox} W \left(V_{gs} - V_t - \frac{V_{ds}}{2}\right) E_{ds}$$

$$I_{ds} = C_{ox} W \left(V_{gs} - V_t - \frac{V_{ds}}{2}\right) v$$

For $E < E_c$, $v = \dfrac{\mu_{eff} E}{1 + E/E_c}$

$$\boxed{I_{ds}\text{ short-ch Linear} = \frac{C_{ox} W \mu_{eff} \frac{V_{ds}}{L}}{1 + \frac{V_{ds}}{V_{c-N}}}\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)}$$

Sodini paper derivation on Short Channel Current model

$$I_{ds} = W C_{ox} \left(V_g - V_t - V(x) \right) v(x)$$

$$I_{ds} = W C_{ox} \left(V_g - V_t - V(x) \right) \frac{\mu_{eff} E(x)}{1 + \frac{E(x)}{E_c}}$$

$$I_{ds} + I_{ds} \frac{E(x)}{E_c} = W C_{ox} \left(V_g - V_t - V(x) \right) \mu_{eff} E(x)$$

$$E(x) = \frac{I_{ds}}{W C_{ox} \left(V_g - V_t - V(x) \right) - \frac{I_{ds}}{E_c}}$$

$$\frac{dV(x)}{dx} = \frac{I_{ds}}{(\text{———})}$$

$$\int_{V_s}^{V_d} dV(x)\left(\mu_{eff} W C_{ox}\left(V_g - V_t - V(x)\right) - \frac{I_{ds}}{E_c}\right) = \int_0^L I_{ds}\, dx$$

$$\frac{\mu_{eff} W C_{ox}}{-2}\left[\left(V_g - V_t - V_d\right)^2 - \left(V_g - V_t - V_s\right)^2\right] = \frac{I_{ds}}{E_c} V_{ds} + I_{ds} L$$

$$\frac{\mu_{eff} W C_{ox}}{2}\left(V_{ds}\right)\left(2V_{gt} - V_d - V_s\right) = I_{ds}\left(L + \frac{V_{ds}}{E_c}\right)$$

$$2V_{gt} - V_d - V_s = 2\left(V_{gt} - \frac{V_d}{2} - \frac{V_s}{2}\right)$$

$$= 2\left(V_{gs} - V_t - \frac{V_d}{2} - \frac{V_s}{2} + V_s\right)$$

$$= 2\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)$$

$$\mu_{eff} W C_{ox} V_{ds}\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right) = I_{ds}\left(1 + \frac{V_{ds}}{E_c}\right)$$

$$I_{ds} = \frac{\mu_{eff} \frac{W}{L} C_{ox} V_{ds}}{\left(1 + \frac{E}{E_c}\right)}\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)$$

Short-channel
Linear

At velocity saturation

$$v(x) = v_{sat}, \quad V(x) = V_{ds_{sat}}$$

$$\boxed{I_{ds_{\text{short-channel sat}}} = W C_{ox}\left(V_{gs} - V_t - V_{ds_{sat}}\right) v_{sat}}$$

$$I_{ds} = W C_{ox}\left(V_{gs} - V_t - V(x)\right) v(x)$$

Finding $V_{ds_{sat}}$ for Short-Channel

$$I_{ds_{\text{short-channel Linear}}} = I_{ds_{\text{short-channel sat}}}$$

$$\frac{\mu_{eff} C_{ox} \frac{W}{L} \left(V_{gs} - V_t - \frac{V_{ds}}{2} \right) V_{ds}}{\left(1 + E/E_c \right)} = W C_{ox} v_{sat} \left(V_{gs} - V_t - V_{ds_{sat}} \right)$$

When $V_{ds} = V_{ds_{sat}}$

$$\boxed{V_{ds_{sat}} = \frac{V_c \left(V_{gs} - V_t \right)}{V_{gs} - V_t + V_c}}$$

$$V_{gt} - V_{ds_{sat}} = \frac{V_{gt}^2}{V_c + V_{gt}}$$

$$\boxed{I_{ds_{sat}} = w C_{ox} \frac{V_{gt}^2}{V_c + V_{gt}} v_{sat}}$$

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