Design and Analysis of VLSI Subsystems
Dr. Madhav Rao
Department of Electronics and Communication Engineering
Indian Institute of Technology, Bangalore

Lecture - 07
Short channel current model

Long channel transistor has the channel length above 1 micron and can be used in long channel current model. The channel length less than 1 micron can be used in short channel current model. Based on the performance parameter or estimation, short channel gives very close to measured value and long channel do not provide very close value, but it's easy to estimate the current. Thereby its easy in processing the performance, power and delay.

The long channel current equation is

$$I_{ds,long-channel} = \frac{\mu C_{ox} W}{L}(V_{gs} - V_t - \frac{V_{ds}}{2})V_{ds}$$

(7.1)

Substitute $V_{ds} = \frac{E_{ds}}{L}$

$$I_{ds,long-channel} = \mu C_{ox} W(V_{gs} - V_t - \frac{V_{ds}}{2})E_{ds}$$

$$I_{ds,long-channel} = \mu C_{ox} W(V_{gs} - V_t - \frac{V_{ds}}{2})v$$

For $E < E_c$,

$$v = \frac{\mu_{eff} E}{1+\frac{E}{E_c}}$$

The short channel current equation is

$$I_{ds,short-channel} = \frac{\mu_{eff} C_{ox} W \frac{V_{ds}}{L}}{1+\frac{V_{ds}}{V_{c-n}}}(V_{gs} - V_t - \frac{V_{ds}}{2})$$

(7.2)

Where, $E = \frac{V_{ds}}{L}$ and $V_{c-n} = E_c x L$

From sodini reference paper, the derivation for short channel model;

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

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

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

$$E(x) = \frac{I_{ds}}{\mu_{eff}C_{ox}W\left(V_g - V_t - V(x)\right) - \frac{I_{ds}}{E_c}} \tag{7.3}$$

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

Consider integral on both sides,

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

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

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

Where,

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

Add and subtract $\frac{V_s}{2}$,

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

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

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

Therefore,

$$I_{ds,short-channel} = \frac{\mu_{eff}C_{ox}W\frac{V_{ds}}{L}}{1+\frac{V_{ds}}{V_{c-n}}}(V_{gs} - V_t - \frac{V_{ds}}{2})$$

At velocity saturation,

$$V(x) = V_{sat},\ V(x) = V_{ds,sat}$$

$$I_{ds,sat\ shortchannel} = C_{ox}W(V_{gs} - V_t - V_{ds,sat})V_{sat}$$

(7.4)

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

To find $V_{ds,sat}$ for short channel,

$$I_{ds,linear\ shortchannel} = I_{ds,sat\ shortchannel}$$

$$\frac{\frac{\mu C_{ox}W}{L}(V_{gs} - V_t - \frac{V_{ds}}{2})V_{ds}}{1+\frac{E}{E_c}} = C_{ox}W(V_{gs} - V_t - V_{ds,sat})V_{sat}$$

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

$$V_{ds,sat} = \frac{V_c(V_{gs} - V_t)}{(V_{gs} - V_t + V_c)}$$

(7.5)

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

$$I_{ds,sat} = C_{ox}W\frac{V_{gt}^2}{V_c + V_{gt}}V_{sat} \qquad (7.6)$$

Where, $V_{gt} = V_{gs} - V_t$