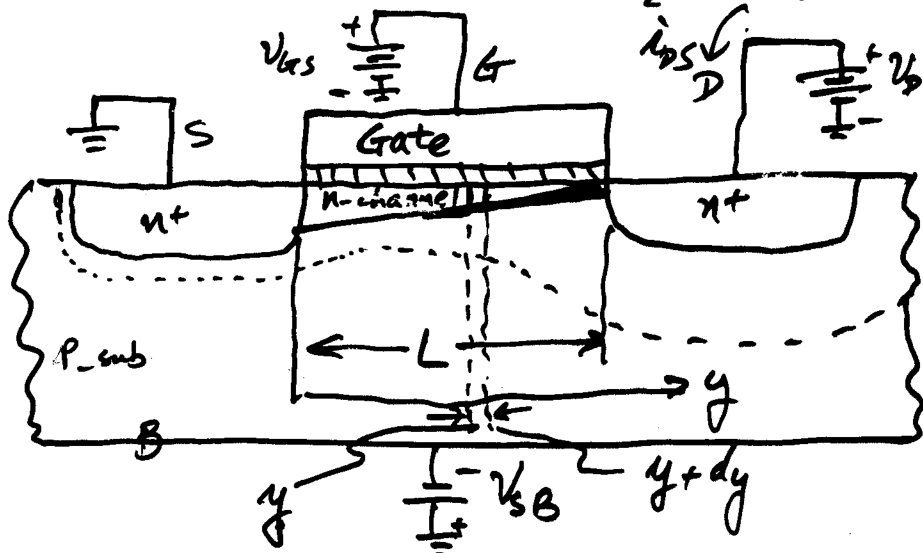
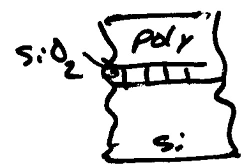
DEVELOPMENT OF LARGE-SIGNAL MODEL FOR MOSFET FOR SHA EQ. AND FOR DSM TECHNOLOGY

SAH MODEL

$$i_D = \frac{k'}{2}\frac{W}{L}(V_{GS}-V_{TN})^2 \quad , V_{DS} \geq V_{GS}-V_T$$

$$i_D = \frac{k'}{2}\frac{W}{L}\left[2(V_{GS}-V_{TN})V_{DS}-V_{DS}^2\right], \quad V_{DS} < V_{GS}-V_T$$





note:
$v(y=0) = 0$
$v(y=L) = V_{DS}$

1) charge per unit area at point y in the channel is $q = CV \rightarrow Q_n(y) = C_{ox}\left[V_{GS}-V_T-v(y)\right]$

2) $i_{DS} = Q_n \times v \times W$ where v = carrier velocity

3) Assume $v = \mu E_y = \mu \frac{dv(y)}{dy}$

4) $i_{DS} = i_D = \underline{C_{ox}\left(V_{GS}-v(y)-V_T\right]}\,\underline{\mu E_y}\,\underline{W}$

$\Rightarrow i_D\,dy = \underbrace{\mu C_{ox}}_{k'} W \left[V_{GS}-v(y)-V_T\right] dv(y)$

5) $\int_0^L i_D\,dy = k'W \int_0^{V_{DS}} \left[V_{GS}-v(y)-V_T\right] dv(y)$

$i_D L = k'W\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$

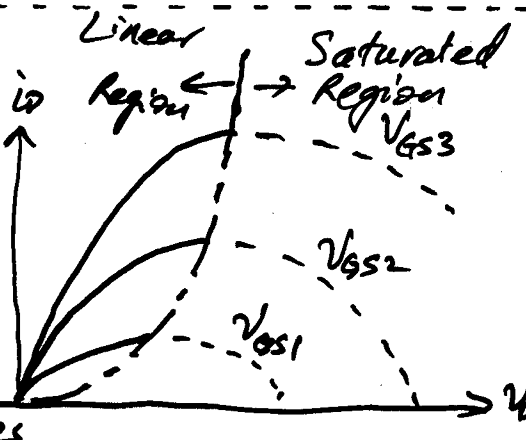
$$\Rightarrow \quad i_D = k'\frac{W}{L}\left[(V_{GS}-V_T)V_{DS}-\frac{V_{DS}^2}{2}\right], \quad V_{DS} < V_{GS}-V_T$$

Linear Region or Triode Region

Saturation Region

No channel length modulation:

$i_{DS} = K'\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right] \rightarrow$



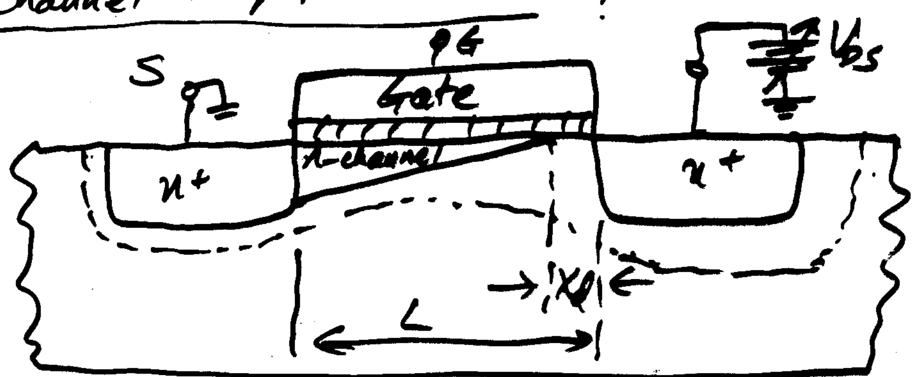
Peaks occur at $V_{DS} = V_{GS} - V_T$

$$V_{Dsat} \equiv V_{GS} - V_T$$

When $V_{DS} \geq V_{Dsat}$ the drain-source current becomes independent of V_{DS}

$\therefore\ i_{DS} = K'\frac{W}{L}\left[(V_{GS}-V_T)V_{Dsat} - \frac{1}{2}V_{Dsat}^2\right] = \frac{K'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2$

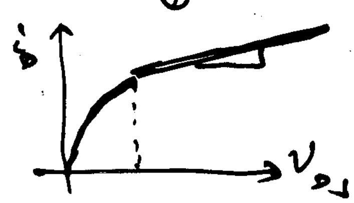
Channel length modulation:



$L_{eff} = L - X_d$

$\therefore\ i_D = \frac{K'}{2}\left(\frac{W}{L_{eff}}\right)(V_{GS}-V_T)^2 \Rightarrow \frac{di_D}{dV_{DS}} = -\frac{K'}{2}\left(\frac{W}{L_{eff}^2}\right)(V_{GS}-V_T)^2\frac{dL_{eff}}{dV_{DS}}$

or $\frac{di_D}{dV_{DS}} = -\frac{i_D}{L_{eff}}\frac{dL_{eff}}{dV_{DS}} = \frac{i_D}{L_{eff}}\frac{dX_d}{dV_{DS}} = \lambda i_D$



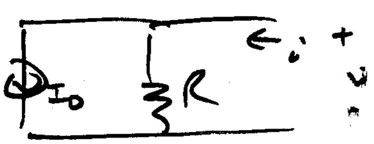
thus

$i_D(V_{DS}) = i_D(\lambda = 0) + \left(\frac{di_D}{dV_{DS}}\right)V_{DS}$

$= i_D + \lambda i_D = i_D(1 + \lambda V_{DS})$

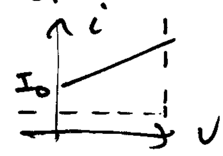
$\Rightarrow i_D = \underbrace{\frac{K'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2}(1+\lambda V_{DS})$, $V_{DS} \geq V_{GS} - V_T$

Recall non-ideal current source:



$i = I_0 + \frac{v}{R} = I_0 + I_0\frac{v}{I_0 R}$

$= I_0\left(1 + \frac{1}{RI_0}v\right)$



DSM ? DSM effects:

1) strong vertical field ($t_{ox} \downarrow$)

2) Saturation of drift current velocity ($L \downarrow$)

$v = \mu_e E_y / (1 + \frac{E_y}{E_c})$ $E_y < E_c$ = critical field

$v = v_{sat} = \frac{\mu_e}{2} E_c$ $E_y \geq E_c$

A Redevelopment of Previous eq. given,

Linear Region: $i_{DS} = \left(\frac{W}{L}\right)\left(\frac{\mu_e}{1+\frac{V_{DS}}{E_c L}} C_{ox}\right)\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right) V_{DS} \cancel{(1+\lambda V_{DS})}$

sat. $i_{DS} = W \times Q_{ox} \times v_{sat} = W C_{ox} (V_{GS} - V_T - V_{DS}) v_{sat}$

$= \frac{\mu_e E_c}{2} C_{ox} W (V_{GS} - V_T - V_{DS})$

Equate the above two current to find the intercept point, where V_{Dsat} is defined.

$$\left(\frac{W}{L}\right)\left(\frac{\mu_e C_{ox}}{1+\frac{V_{DS}}{E_c L}}\right)\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right) V_{DS} = \frac{\mu_e E_c}{2} C_{ox} W (V_{GS} - V_T - V_{DS})$$

$$\Rightarrow V_{DS}[(V_{GS} - V_T) + E_c L] = E_c L (V_{GS} - V_T)$$

$$\Rightarrow V_{Dsat} = \frac{(E_c L)(V_{GS} - V_T)}{(V_{GS} - V_T) + (E_c L)} = (E_c L) \,//\, (V_{GS} - V_T)$$

If $E_c L \ll V_{GS} - V_T$ short channel $\Rightarrow V_{Dsat} \approx E_c L$

$$\Rightarrow I_{DS} = W C_{ox} (V_{GS} - V_T - V_{Dsat}) v_{sat}$$

$$\approx W C_{ox} \underline{(V_{GS} - V_T)} v_{sat}$$

Linear

If $E_c L \gg V_{GS} - V_T$ Long channel $\Rightarrow V_{Dsat} = V_{GS} - V_T$

$$\Rightarrow I_{DS} = \frac{\mu_e C_{ox}}{2}\left(\frac{W}{L}\right)(V_{GS} - V_T)^2$$ square-law

$$\boxed{\text{At sat.: } I_{DS} = W v_{sat} C_{ox} \frac{(V_{GS} - V_T)^2}{(V_{GS} - V_T) + E_c L} = \frac{\mu_e C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T) V_{Dsat}}$$