VELOCITY SATURATION (CONTINUATION)

$$I_D = I_S \frac{i_f - i_r}{1 + \xi\left(\sqrt{1+i_f} - \sqrt{1+i_r}\right)}$$

$$\xi = \frac{V_T}{L E_{SAT}}, \quad E_{SAT} = \frac{v_{SAT}}{\mu_n}$$

$$v_{drift} = \frac{\mu_n E}{1 + \frac{E}{E_{SAT}}}$$

- STRONG INVERSION: $q(i_f) \approx \sqrt{i_f}$

$$\frac{V_G - V_{th}}{n V_T} = \sqrt{i_f} \quad \text{(ASSUME } V_S = 0\text{)}$$

IF TRANSISTOR IS ACTIVE:

$$I_D \simeq \frac{n \mu_n C_{ox} V_T^2}{2} \frac{W}{L} \frac{i_f}{1 + \frac{V_T}{L E_{SAT}}\left(\sqrt{i_f} - 1\right)}$$

($i_f = \left(\frac{V_G - V_{th}}{n V_T}\right)^2$)

$$I_D \simeq \frac{\cancel{n} \mu_n C_{ox} \cancel{V_T^2}}{2} \frac{W}{L} \cdot \left(\frac{V_G - V_{th}}{n \cancel{V_T}}\right)^2 \frac{1}{1 + \frac{V_T}{L E_{SAT}}\left(\sqrt{i_f} - 1\right)}$$

(n) REMAINS

- IF $\sqrt{i_f}$ LARGE ENOUGH:

$$I_D \approx \frac{\mu_n C_{ox}}{2} \frac{W}{\cancel{L}} \frac{(V_G - V_{th})^2}{n} \frac{1}{\frac{\cancel{V_T}}{\cancel{L} E_{SAT}} \cancel{\left(\frac{V_G - V_{th}}{n V_T}\right)}}$$

$$\approx \frac{\mu_n C_{ox}}{2} W (V_G - V_{th}) E_{SAT}$$

- LINEAR DEPENDENCE OF $(V_G - V_{th})$
- INDEPENDENT OF L
- ONLY FOR VERY STRONG INVERSION / VERY SHORT L

- WEAK INVERSION : $\sqrt{1+i_f} \approx 1 + \frac{i_f}{2}$

$$I_D \simeq \frac{I_S \; i_f}{1 + \underbrace{\frac{V_T}{LE_{SAT}} \frac{i_f}{2}}_{\text{IF } i_f \text{ SMALL THIS TERM NEGLIGIBLE}}} \quad \text{(ACTIVE)}$$

$$\therefore \; I_D \simeq I_S \, i_f \quad \text{SAME AS LONG-CHANNEL}$$

EXAMPLE : $E_{SAT} = 2 \times 10^6 \frac{V}{m}$

$L_{eff} = 140 \, nm$

$$\frac{V_T}{LE_{SAT}} = 0.093$$

$i_f = 100 \Rightarrow \frac{V_T}{LE_{SAT}} \left(\sqrt{1+i_f} - 1 \right) = 0.84$ IMPORTANT COMPARED TO 1

$i_f = 0.1 \Rightarrow \frac{V_T}{LE_{SAT}} \left(\sqrt{1+i_f} - 1 \right) = 0.005$ NEGLIGIBLE