ECEN4827/5827 Short-Channel Effects


- Short-channel effects become visible for channel lengths \( L < 1 \mu m \)
- Particularly important for high-frequency designs in deep sub-micron processes
- Physical origins: velocity saturation of the carrier in the channel

At low electric field values, carrier drift velocity is directly proportional to the field strength

\[
v_d = \mu_n E
\]

At high electric field values, carrier drift velocity curves and eventually saturates at a maximum ("scattering-limited") velocity

\[
v_d = \frac{\mu_n E}{1 + E / E_c}
\]

Example:

\( L = 0.5 \mu m, \ V_{DS} = 0.75 \ V \) results in \( E = E_c \)
Effect on ID in active/saturation region

Simple model, no short-channel effects:

\[ I_d = \frac{\mu_n C_{\text{ox}}}{2} \frac{W}{L} (V_{GS} - V_{tn})^2 = \frac{\mu_n C_{\text{ox}}}{2} \frac{W}{L} V_{ov}^2 = \frac{\mu_n C_{\text{ox}}}{2} \frac{W}{L} V_{DS,\text{act}}^2 \]

Including short-channel effects:

\[ I_d = \frac{\mu_n C_{\text{ox}}}{2} \frac{W}{L} V_{DS,\text{act}}^2 \]

\[ V_{DS,\text{act}} = E_c L \left( \sqrt{1 + \frac{2(V_{GS} - V_{tn})}{E_c L}} - 1 \right) \]

In the limit:

\[ I_d = \mu_n C_{\text{ox}} W (V_{GS} - V_{tn}) E_c \]
Transconductance and $f_T$

Simple model, no short-channel effects:

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{tn})$$

$$f_T = \frac{g_m}{2\pi C_{gs}} = \frac{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{tn})}{4\pi \frac{W}{3} W L C_{ox}} = \frac{3}{4\pi} \frac{\mu_n (V_{GS} - V_{tn})}{L^2}$$

With short-channel effects, in the limit ($E_c L << (V_{GS} - V_{tn})$):

$$g_m = \mu_n C_{ox} W E_c$$

$$f_T = \frac{g_m}{2\pi C_{gs}} = \frac{\mu_n C_{ox} W E_c}{4\pi \frac{W}{3} W L C_{ox}} = \frac{3}{4\pi} \frac{\mu_n E_c}{L}$$
CMOS Technology Evolution versus Time

\[ f_t \text{ [GHz]} \]

\[ f_t \text{ for NMOS @ } (V_{GS} - V_{th} = 0.5V) \]

*Ref: Paul R. Gray UCB EE290 course ’95