Short-Channel Current Model: Analysis

Instructor – Dr. Madhav Rao

Finding Vds_{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 $V_{ds} = V_{ds\,sat}$

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

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

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

NPTEL

If $\boxed{V_{gs} - V_t << V_c}$ → $V_{ds\,sat}$ due to pinch-off effect

$$I_{ds\,sat\,short\text{-}channel} = W C_{ox} \frac{(V_{gs} - V_t)^2}{V_c} v_{sat}$$

→ Square Law

If $\boxed{V_{gs} - V_t >> V_c}$

$$I_{ds\,sat\,short\text{-}channel} = W C_{ox} (V_{gs} - V_t) v_{sat}$$

→ Linear Law

→ $V_{ds\,sat}$ is achieved due to velocity saturation

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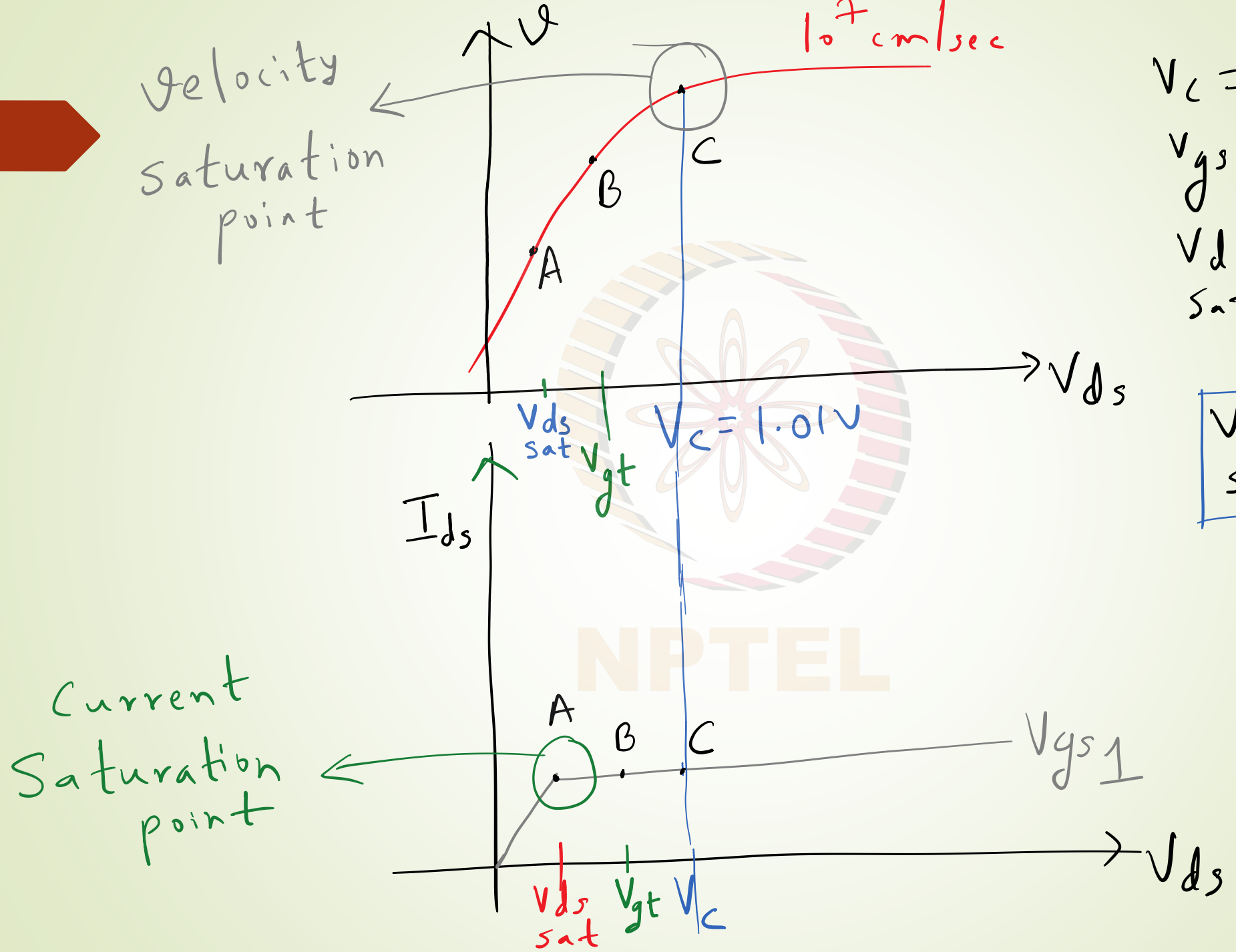


$V_c = 1.01V$

$V_{gs} = 1V, \; V_t = 0.3V$

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

$$\boxed{V_{ds\,sat} = 0.41V}$$

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

Short-channel

$$\left(I_{ds\,\text{short-channel}}\right)_A = W C_{ox}\left(V_{gs} - V_t - V_{ds\,sat}\right) v_c(x)$$

$$\left(I_{ds\,\text{short-channel}}\right)_B = W C_{ox}\left(V_{gs} - V_t - V_{ds\,sat}\right) v_c(x)$$

$$\left(I_{ds\,\text{short-channel}}\right)_C = W C_{ox}\left(V_{gs} - V_t - V_{ds\,sat}\right) v_c(x)$$

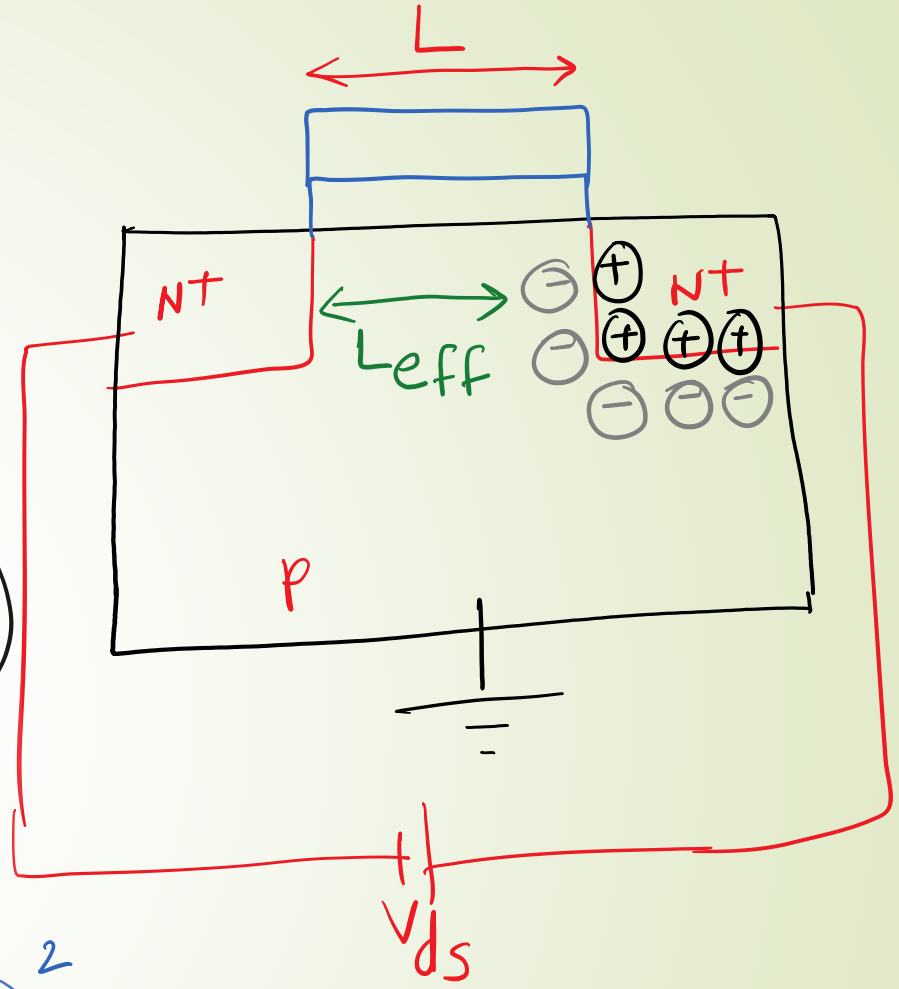
In Short-Channel, once the Vds reaches closer to Vds_{sat}, then majority carrier velocity shoots up to maximum, due to high electric field, and then Current remains constant even after increase in Vds.

Channel Length modulation

$$L_{eff} = L - L_d$$

$$I_{ds}\uparrow \propto \frac{1}{L\downarrow}$$

$$I_{ds\,\text{short-channel sat}} = W C_{ox} \frac{\mu_{eff} V_c}{2 L_{eff}} \left(\frac{V_{gt}^2}{V_{gt} + V_c} \right)$$



$$I_{ds\,\text{Long-channel sat}} = \mu C_{ox} \frac{W}{2 L_{eff}} (V_{gs} - V_t)^2$$

Ld is a function of Vds, hence Ld varies with Vds now, hence Ids_{sat} varies now and does not remain constant post saturation in short-channel

$$\frac{\partial I_{ds\,sat\,Long\text{-}channel}}{\partial V_{ds}} = -\frac{\mu W C_{ox}}{2 L_{eff}^2}\left(V_{gs}-V_t\right)^2 \frac{\partial L_{eff}}{\partial V_{ds}} \quad \text{— (1)}$$

$$L_{eff} = L - L_d$$

$$\frac{\partial L_{eff}}{\partial V_{ds}} = -\frac{\partial L_d}{\partial V_{ds}} \quad \text{— (2)}$$

$$\frac{\partial I_{ds\,sat\,Long\text{-}channel}}{\partial V_{ds}} = \frac{I_{ds\,sat}}{L_{eff}} \frac{\partial L_d}{\partial V_{ds}}$$

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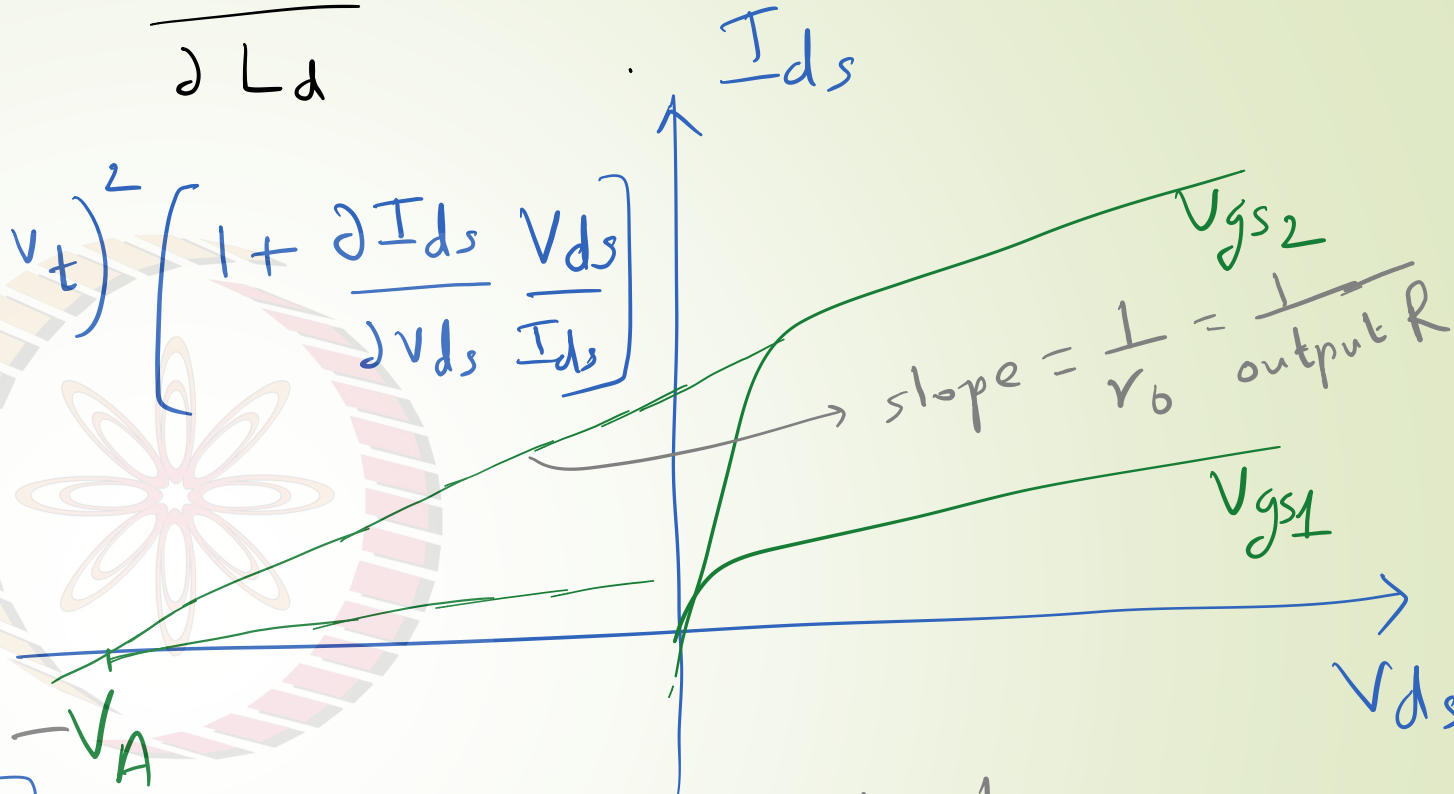
$$V_A = L_{eff} \frac{\partial V_{ds}}{\partial L_d}$$

$$I_{ds_{sat}} = \frac{\mu W C_{ox}}{2 L_{eff}} (V_{gs} - V_t)^2 \left[1 + \frac{\partial I_{ds}}{\partial V_{ds}} \frac{V_{ds}}{I_{ds}} \right]$$

Long-channel



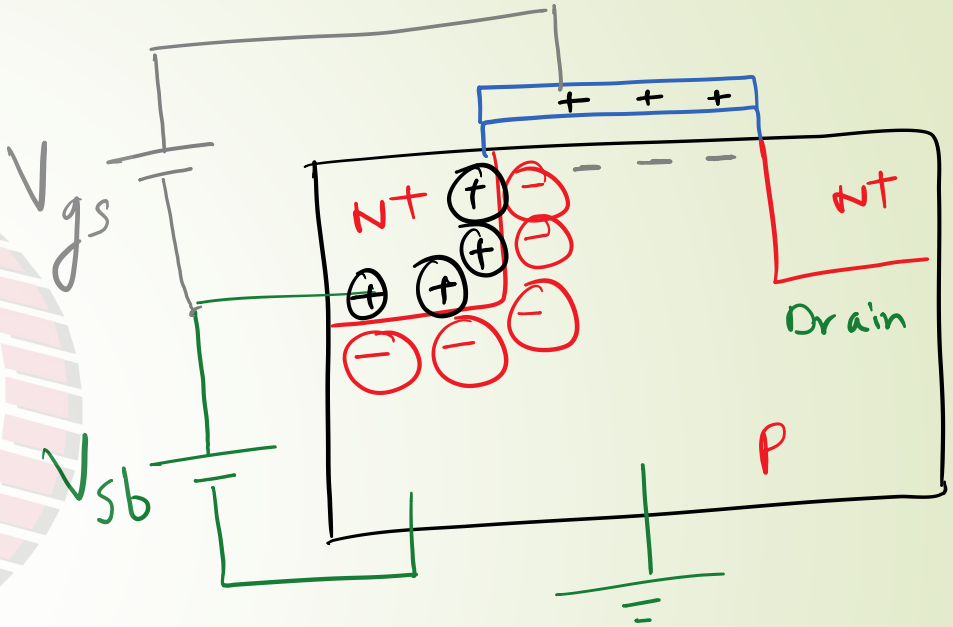
→ process dependent

$$\boxed{I_{ds} = \frac{\mu W C_{ox}}{2 L_{eff}} (V_{gs} - V_t)^2 \left(1 + \frac{V_{ds}}{V_A} \right)}$$

Hence Ids_{sat} increases linearly post saturation.

Threshold Voltage effects with respect to source-body potential

Applying more Vsb creates more depletion region near source and requires more Vgs to create channel between source and drain as shown in the diagram to the right.



Read Threshold Voltage effects with respect to source-body potential expression from Weste-Harris Textbook on your own !!