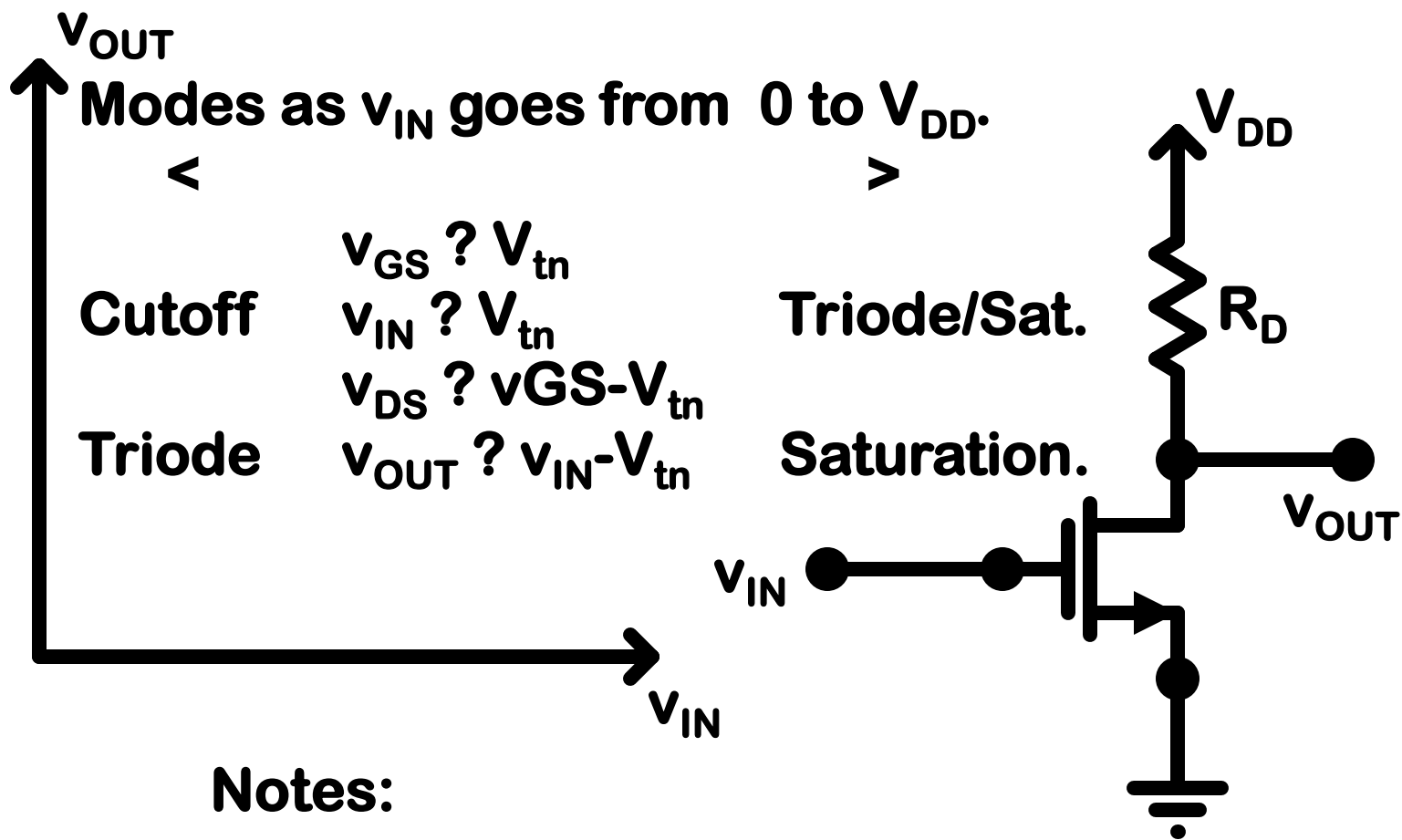


Notes:

$$V_{IN} = V_{GS}$$

$$V_{OUT} = V_{DS} = V_{DD} - R_D i_D$$

As v_{IN} (or v_{GS}) increases from zero to V_{DD} .

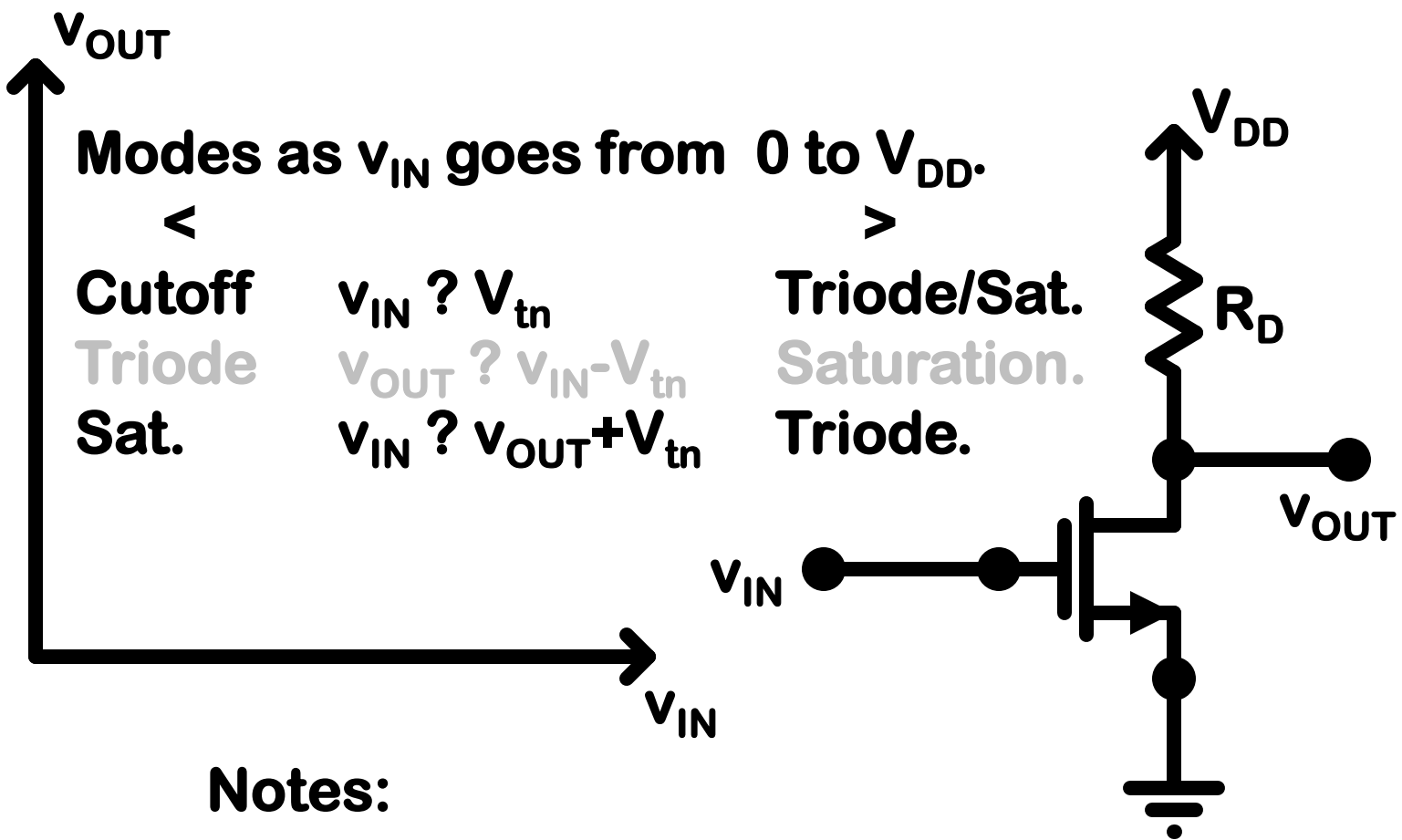


Notes:

$v_{IN} = v_{GS}$

$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$

As v_{IN} (or v_{GS}) increases from zero to V_{DD} .

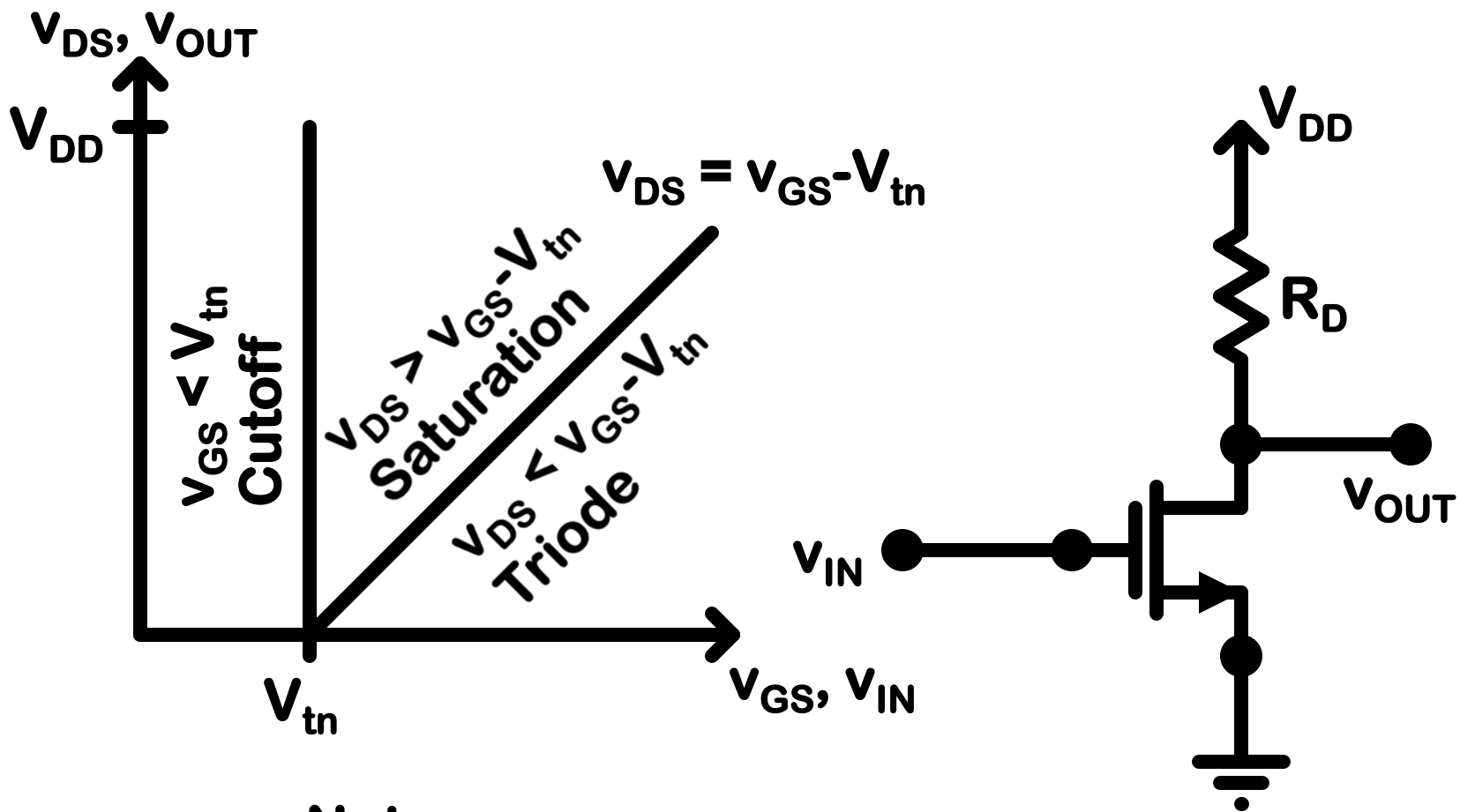


Notes:

$v_{IN} = v_{GS}$

$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$

As v_{IN} (or v_{GS}) increases from zero to V_{DD} .

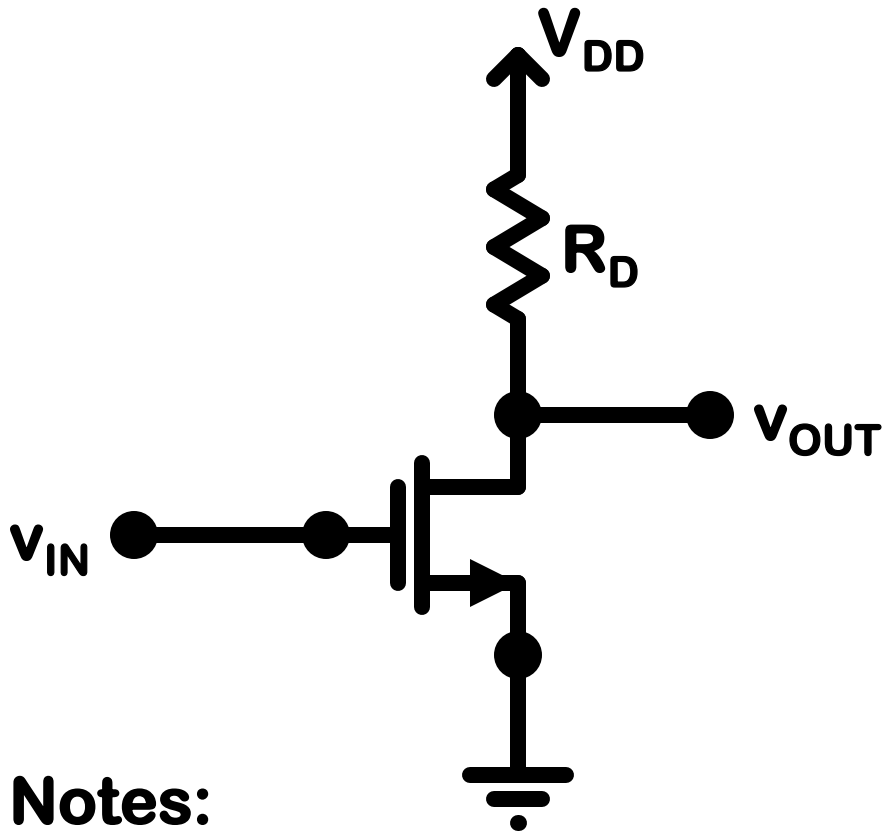


Notes:

$$V_{IN} = V_{GS}$$

$$V_{OUT} = V_{DS} = V_{DD} - R_D i_D$$

As v_{IN} (or v_{GS}) increases from zero to V_{DD} .
Modes: cutoff, saturation, triode



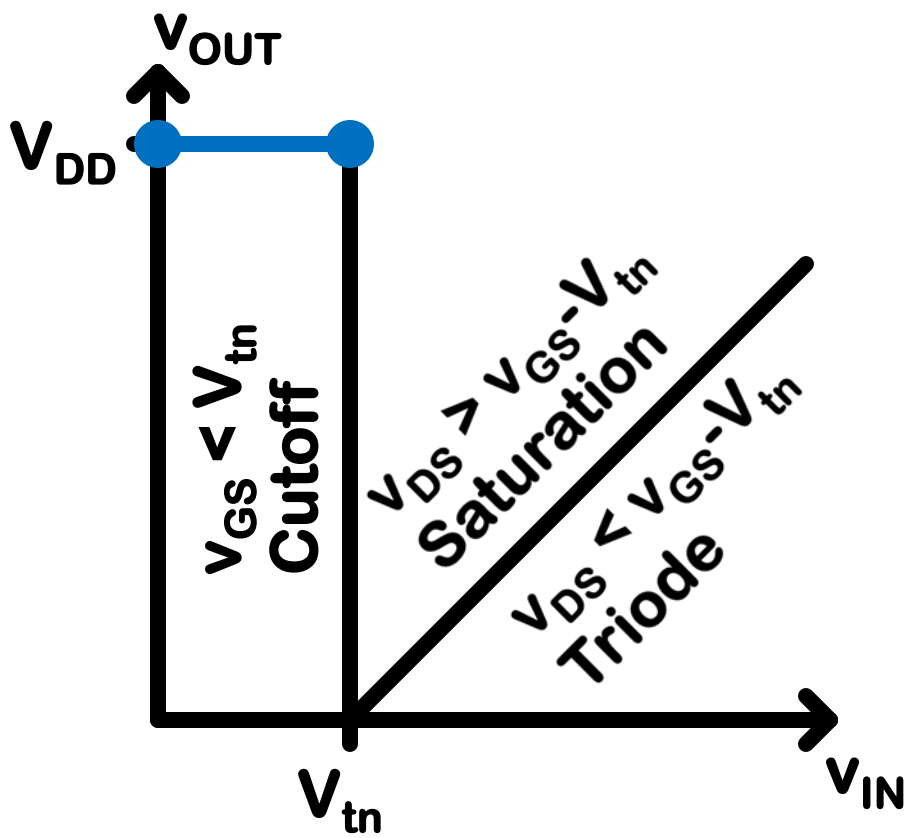
Notes:

$$V_{IN} = V_{GS}$$

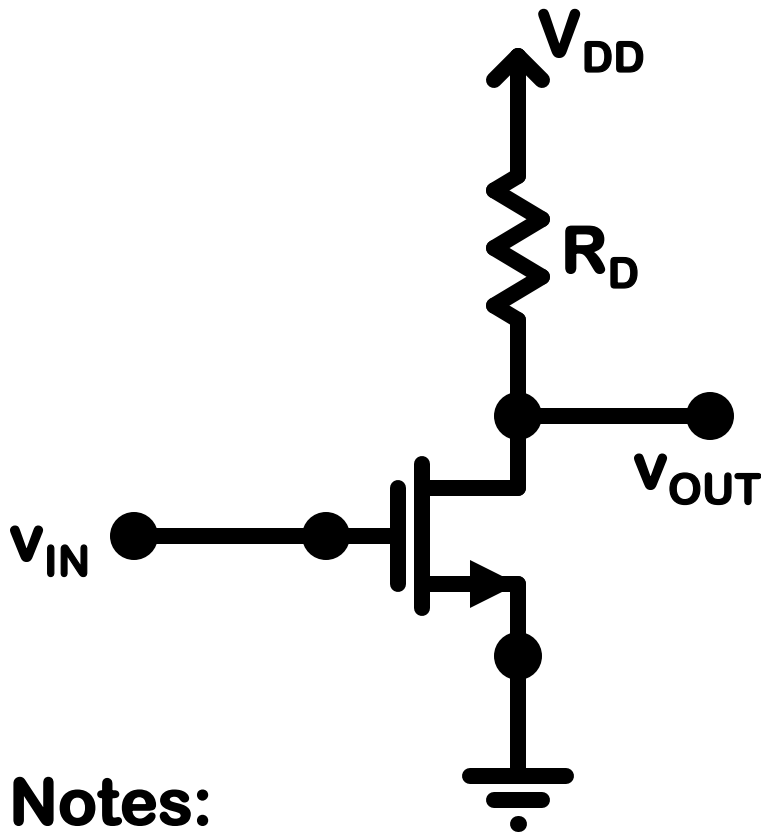
$$V_{OUT} = V_{DS} = V_{DD} - R_D i_D$$

1. Cutoff Mode:
2. $i_D = 0$
3. $v_{OUT}(v_{IN}) = V_{DD}$
4. $v_{GS} - V_{tn} < 0$
 $v_{IN} < V_{tn}$

$$v_{OUT}(v_{IN}) = V_{DD} \text{ for } v_{IN} < V_{tn}$$



$$v_{OUT}(v_{IN}) = V_{DD} \text{ for } v_{IN} < V_{tn}$$



Saturation Mode:
Device Parameter:

$$k_n = k_n' (W/L)$$

$$i_D = 0.5k_n(v_{GS} - V_{tn})^2$$

$$v_{OUT}(v_{IN}) = V_{DD} - R_D 0.5k_n(v_{IN} - V_{tn})^2$$

$$v_{GS} - V_{tn} > 0$$

$$v_{IN} > V_{tn}$$

$$v_{DS} > v_{GS} - V_{tn}$$

$$V_{DD} - R_D 0.5k_n(v_{IN} - V_{tn})^2 > v_{IN} - V_{tn}$$

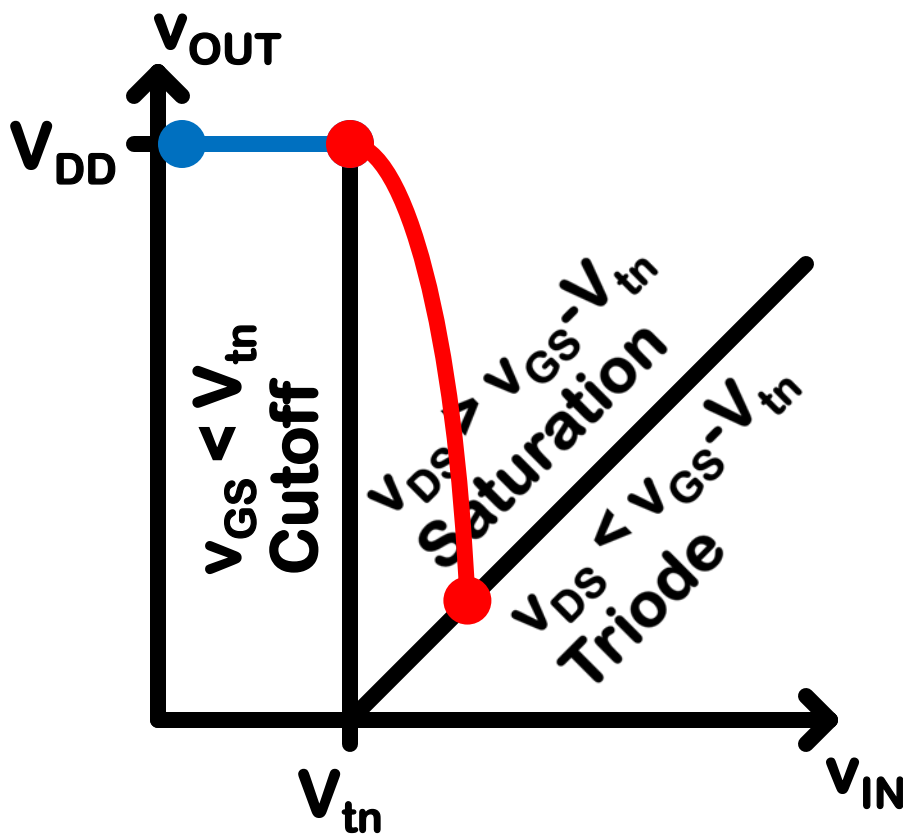
$$v_{IN} < V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$$

Notes:

$$v_{IN} = v_{GS}$$

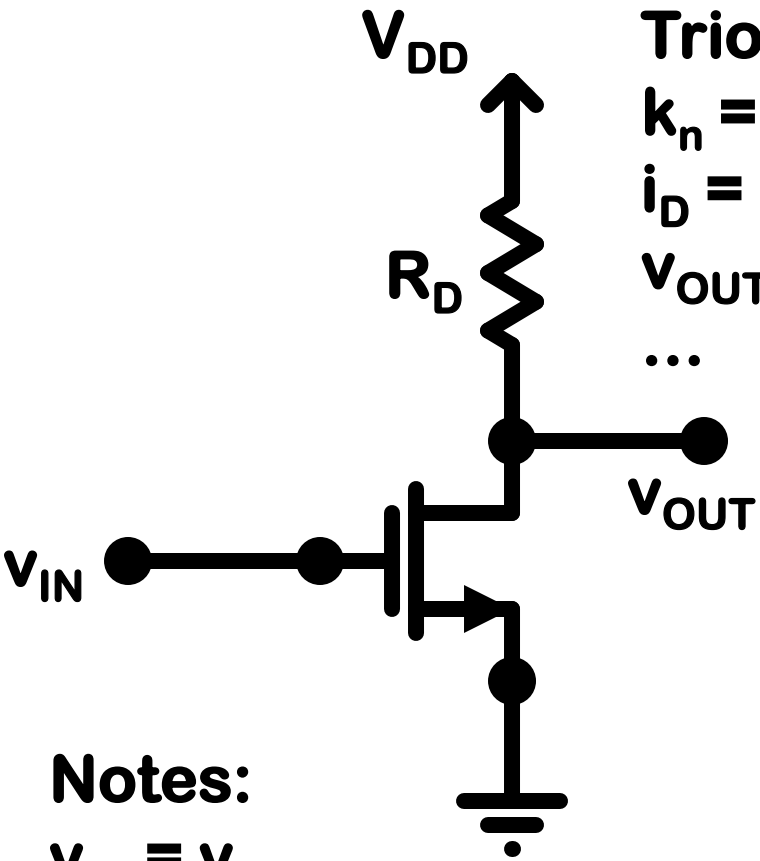
$$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$$

$$v_{OUT}(v_{IN}) = V_{DD} - R_D 0.5k_n(v_{IN} - V_{tn})^2 \text{ for } V_{tn} < v_{IN} < V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$$



$$v_{\text{OUT}}(v_{\text{IN}}) = V_{\text{DD}} \text{ for } v_{\text{IN}} < V_{\text{tn}}$$

$$v_{\text{OUT}}(v_{\text{IN}}) = V_{\text{DD}} - R_{\text{D}} 0.5 k_{\text{n}} (v_{\text{IN}} - V_{\text{tn}})^2 \text{ for } V_{\text{tn}} < v_{\text{IN}} < V_{\text{tn}} + ((1 + 2R_{\text{D}} k_{\text{n}} V_{\text{DD}})^{1/2} - 1) / R_{\text{D}} k_{\text{n}}$$



Triode Mode:

$$k_n = k_n' (W/L)$$

$$i_D = k_n (v_{GS} - V_{tn} - 0.5v_{DS})v_{DS}$$

$$v_{OUT} = V_{DD} - R_D k_n (v_{IN} - V_{tn} - 0.5v_{OUT})v_{OUT}$$

...

Notes:

$$v_{IN} = v_{GS}$$

$$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$$

$v_{OUT}(v_{IN}) = \text{SEE NEXT PAGE for}$
 $v_{IN} > V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$

Triode Mode:

$$k_n = k_n' (W/L)$$

$$i_D = k_n (v_{GS} - V_{tn} - 0.5v_{DS})v_{DS}$$

$$v_{OUT} = V_{DD} - R_D k_n (v_{IN} - V_{tn} - 0.5v_{OUT})v_{OUT}$$

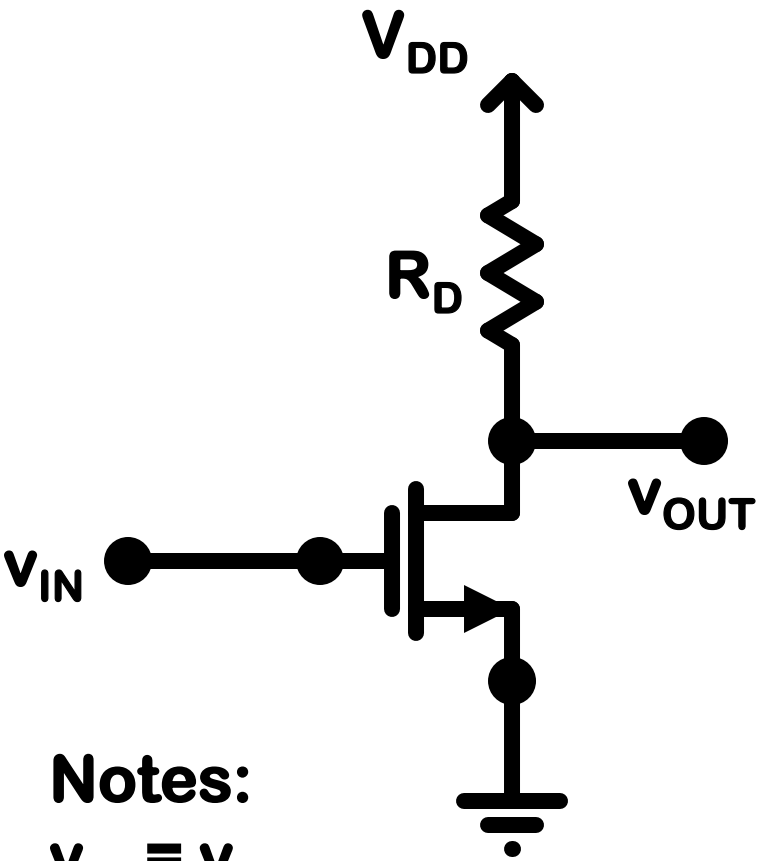
$$R_D 0.5k_n v_{OUT}^2 - (R_D k_n (v_{IN} - V_{tn}) + 1)v_{OUT} + V_{DD} = 0$$

$$a = 0.5R_D k_n$$

$$b = -(R_D k_n (v_{IN} - V_{tn}) + 1)$$

$$c = V_{DD}$$

$$v_{OUT} = (-b - \text{sqrt}(b^2 - 4ac))/(2a)$$



Triode (small v_{DS}) Mode:

$$k_n = k_n' (W/L)$$

$$i_D = k_n (v_{GS} - V_{tn}) v_{DS}$$

$$V_{OUT} = V_{DD} - R_D k_n (v_{IN} - V_{tn}) v_{OUT}$$

$$V_{OUT} = V_{DD} / (1 + R_D k_n (v_{IN} - V_{tn}))$$

$$v_{DS} \ll v_{GS} - V_{tn}$$

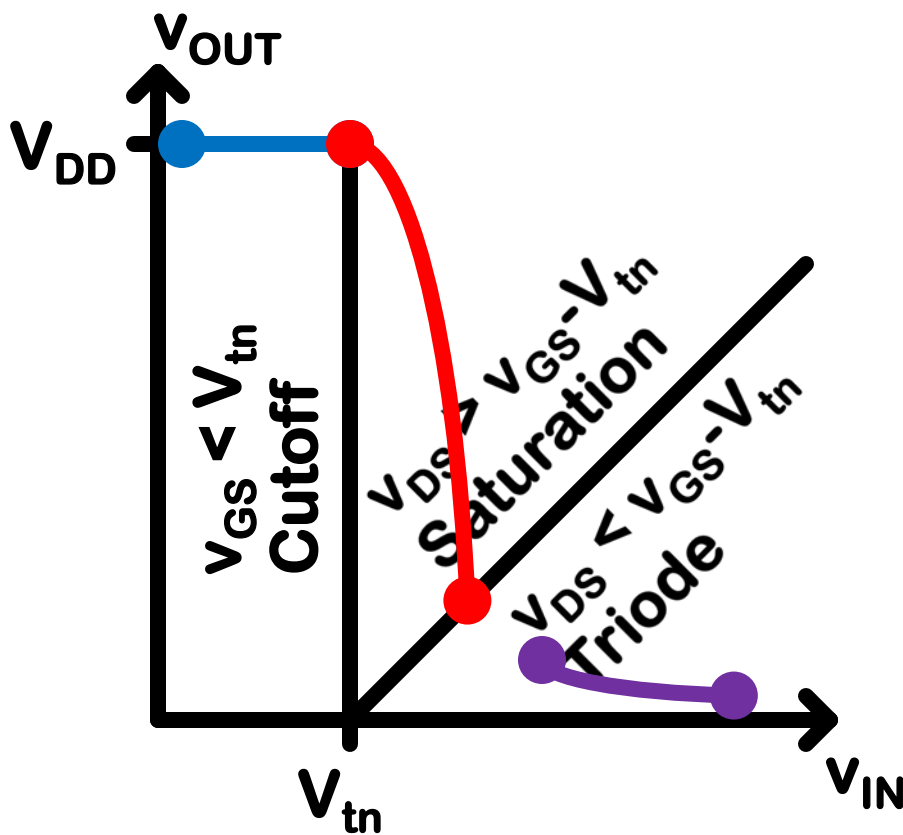
$$V_{DD} / (1 + R_D k_n (v_{IN} - V_{tn})) \ll (v_{IN} - V_{tn})$$

Notes:

$$V_{IN} = v_{GS}$$

$$V_{OUT} = v_{DS} = V_{DD} - R_D i_D$$

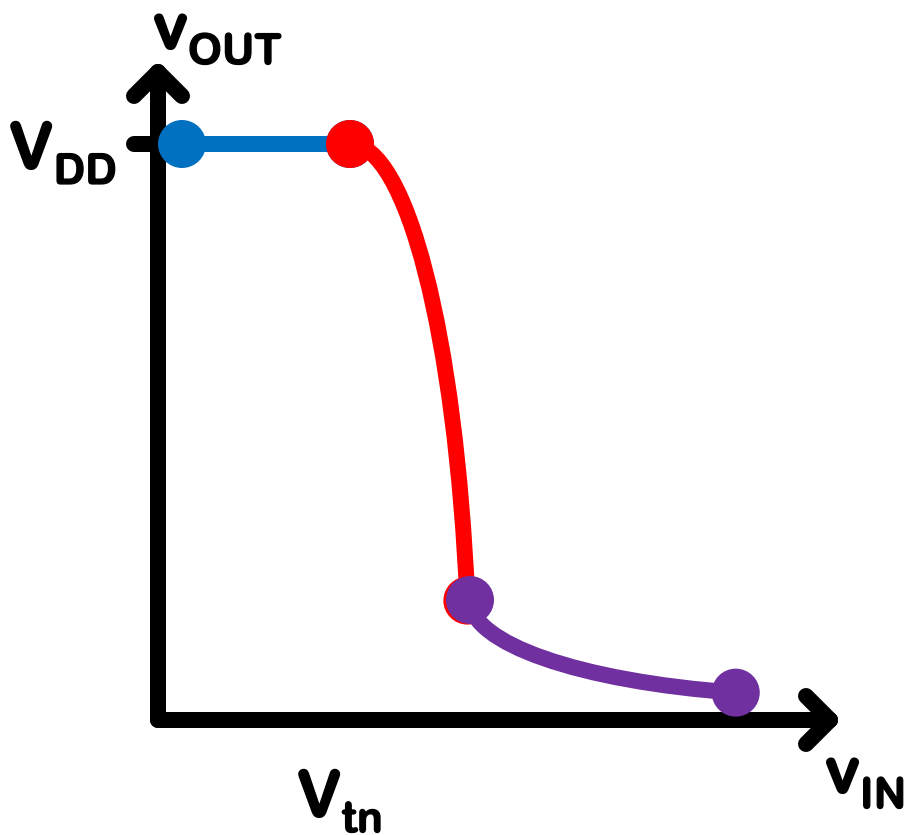
$$v_{OUT}(v_{IN}) = V_{DD} / (1 + R_D k_n (v_{IN} - V_{tn})) \text{ for } v_{IN} \gg V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$$



$$v_{OUT}(v_{IN}) = V_{DD} \text{ for } v_{IN} < V_{tn}$$

$$v_{OUT}(v_{IN}) = V_{DD} - R_D 0.5k_n (v_{IN} - V_{tn})^2 \text{ for } V_{tn} < v_{IN} < V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$$

$$v_{OUT}(v_{IN}) = V_{DD} / (1 + R_D k_n (v_{IN} - V_{tn})) \text{ for } v_{IN} \gg V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$$

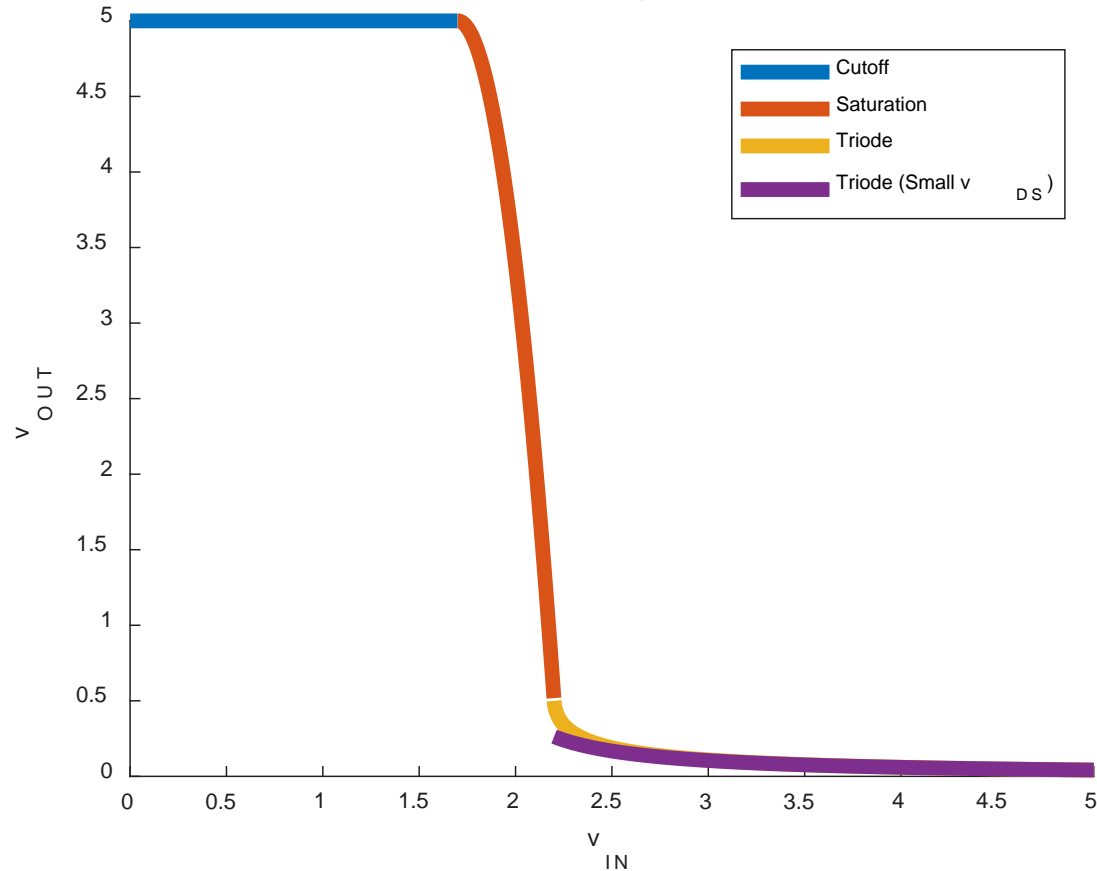


$$v_{\text{OUT}}(v_{\text{IN}}) = V_{\text{DD}} \text{ for } v_{\text{IN}} < V_{\text{tn}}$$

$$v_{\text{OUT}}(v_{\text{IN}}) = V_{\text{DD}} - R_{\text{D}} 0.5 k_{\text{n}} (v_{\text{IN}} - V_{\text{tn}})^2 \text{ for } V_{\text{tn}} < v_{\text{IN}} < V_{\text{tn}} + ((1 + 2R_{\text{D}} k_{\text{n}} V_{\text{DD}})^{1/2} - 1) / R_{\text{D}} k_{\text{n}}$$

$$v_{\text{OUT}}(v_{\text{IN}}) \approx V_{\text{DD}} / (1 + R_{\text{D}} k_{\text{n}} (v_{\text{IN}} - V_{\text{tn}})) \text{ for } v_{\text{IN}} \gg V_{\text{tn}} + ((1 + 2R_{\text{D}} k_{\text{n}} V_{\text{DD}})^{1/2} - 1) / R_{\text{D}} k_{\text{n}}$$

NMOS Inverter/Amplifier



Cutoff:

$$V_{OUT}(V_{IN}) = V_{DD}$$

for $V_{IN} < V_{tn}$

Saturation:

$$V_{OUT}(V_{IN}) = V_{DD} - R_D 0.5 k_n (V_{IN} - V_{tn})^2$$

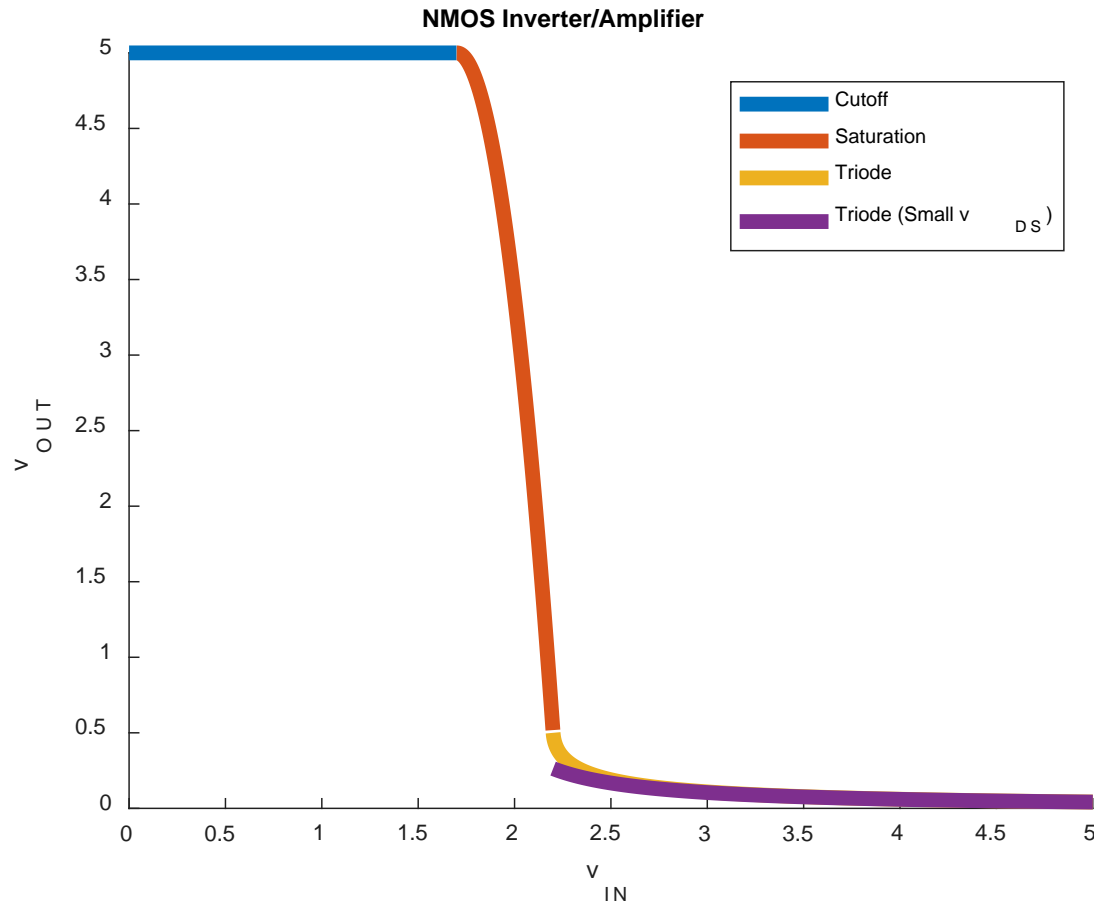
for $V_{tn} < V_{IN} < V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$

Triode:

$$V_{OUT} = ((R_D k_n (V_{IN} - V_{tn}) + 1) - ((R_D k_n (V_{IN} - V_{tn}) + 1)^2 - 2R_D k_n V_{DD})^{1/2}) / (R_D k_n)$$

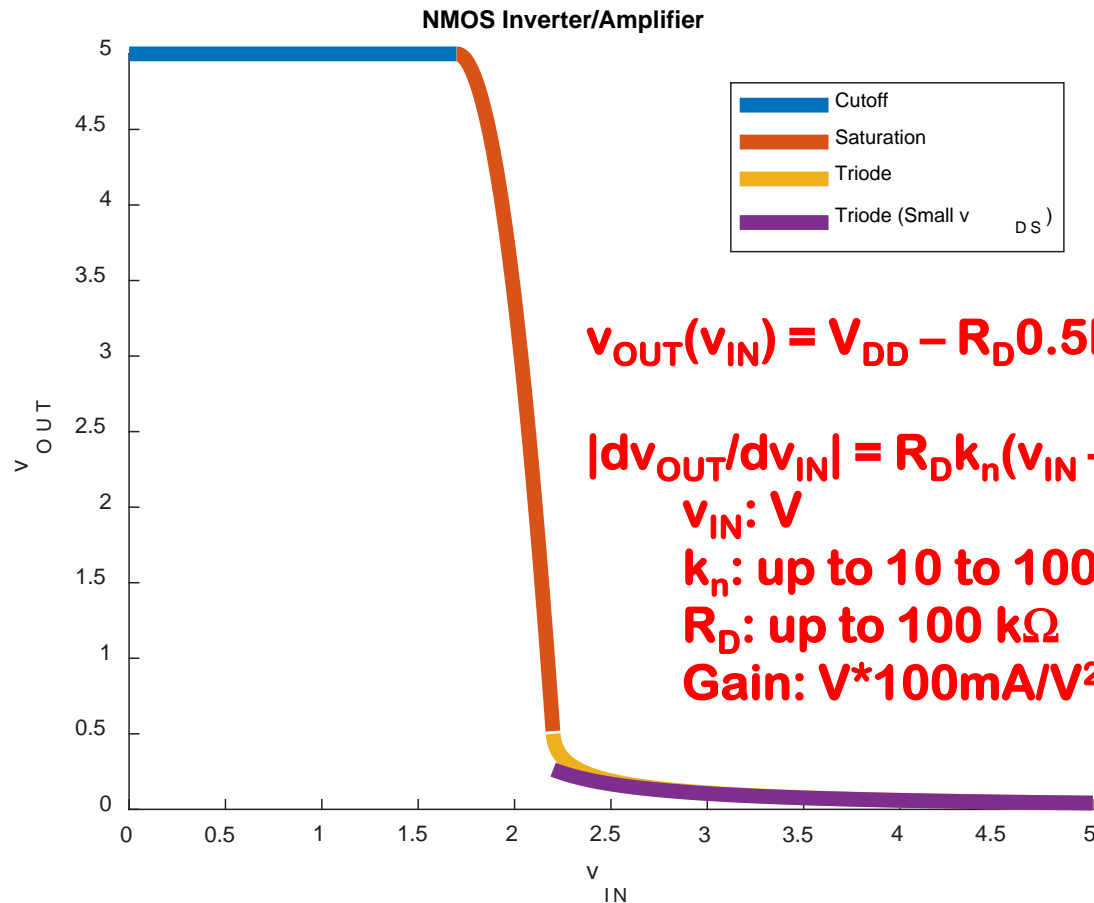
for $V_{IN} > V_{tn} + ((1 + 2R_D k_n V_{DD})^{1/2} - 1) / R_D k_n$

MOSFETs can be used in Digital Logic Applications.



The Cutoff and Triode Regions exhibit a definite digital high or low output. Saturation region is more ambiguous and is not good for logic application.

MOSFETs can be used Amplifier (Analog Applications).



$$V_{OUT}(V_{IN}) = V_{DD} - R_D 0.5k_n(v_{IN} - V_{tn})^2$$

$$\left| \frac{dv_{OUT}}{dv_{IN}} \right| = R_D k_n (v_{IN} - V_{tn})$$

$$v_{IN}: V$$

$$k_n: \text{up to } 10 \text{ to } 100+ \text{ mA/V}^2$$

$$R_D: \text{up to } 100 \text{ k}\Omega$$

$$\text{Gain: } V * 100 \text{ mA/V}^2 * 100 \text{ k(V/A)} = \text{very large}$$

The Saturation region exhibits a slope with a large absolute value, $\left| \frac{dv_{OUT}}{dv_{IN}} \right| \gg 1$ (can't be done with passive components). In this region, small variations in the input will result in large variations in the output.

MOSFETs can be used Amplifier (Analog Applications).

