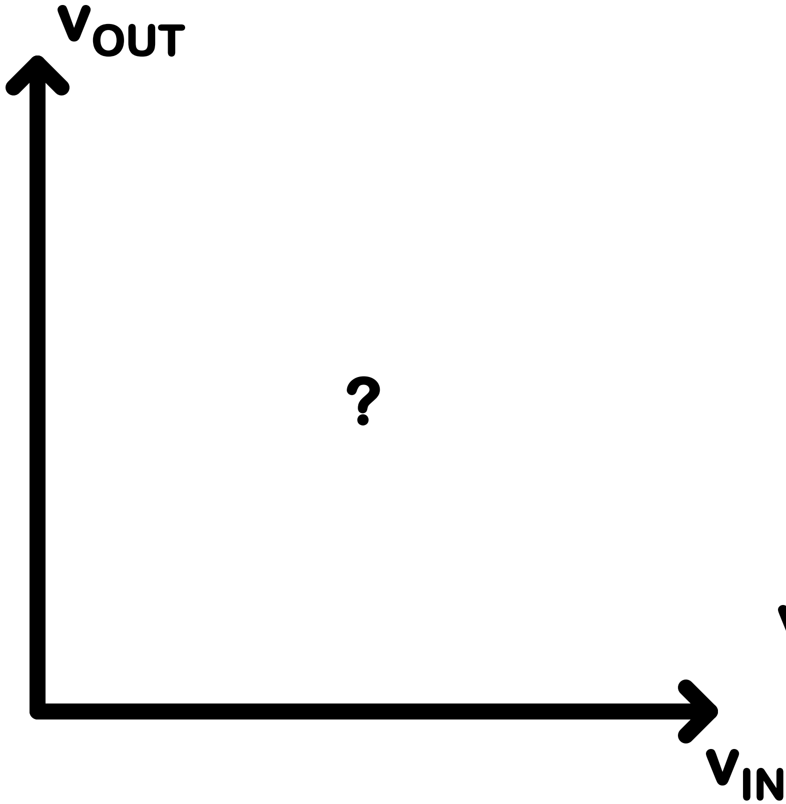
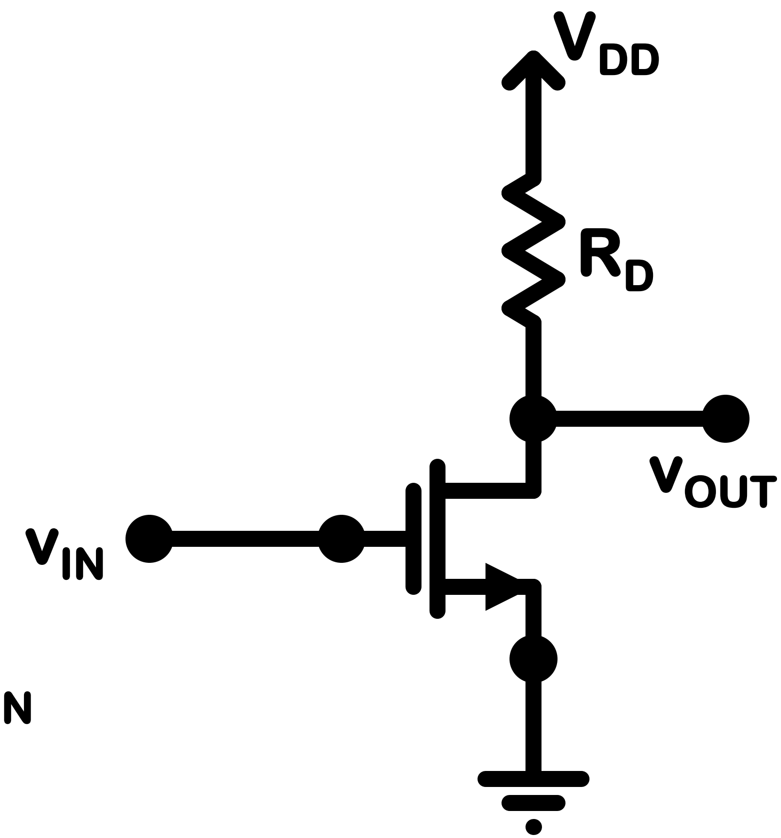




Notes:

$v_{IN} = v_{GS}$

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

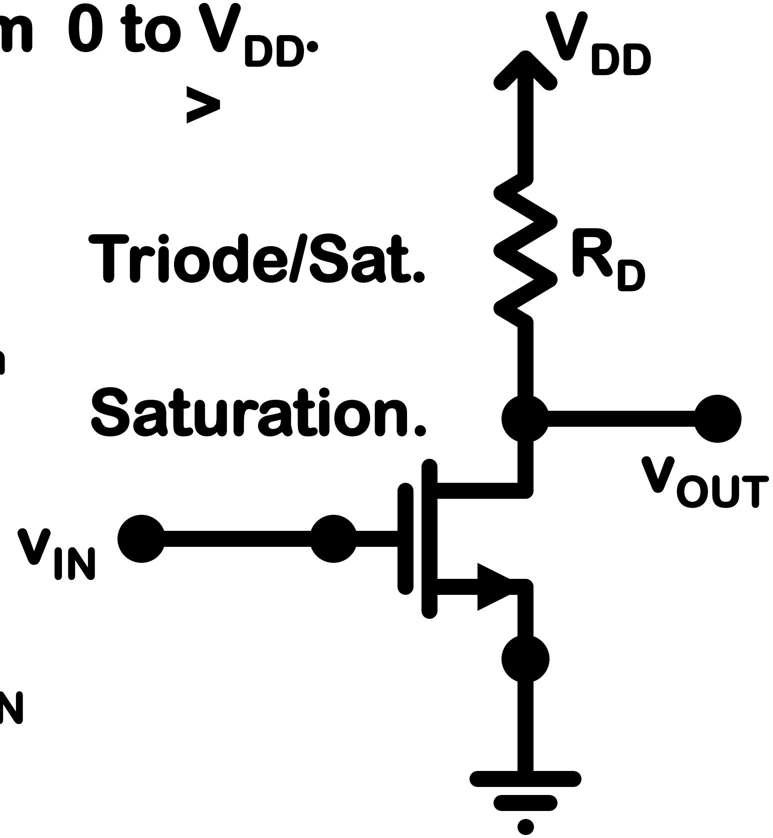
As v_{IN} (or v_{GS})increases from zero to V_{DD}.

v_{OUT}

Modes as v_{IN} goes from 0 to V_{DD}.

	<		>
		v_{GS} ? V_{tn}	
Cutoff		v_{IN} ? V_{tn}	**Triode/Sat.**
		v_{DS} ? vGS-V_{tn}	
Triode		v_{OUT} ? v_{IN}-V_{tn}	**Saturation.**

v_{IN}

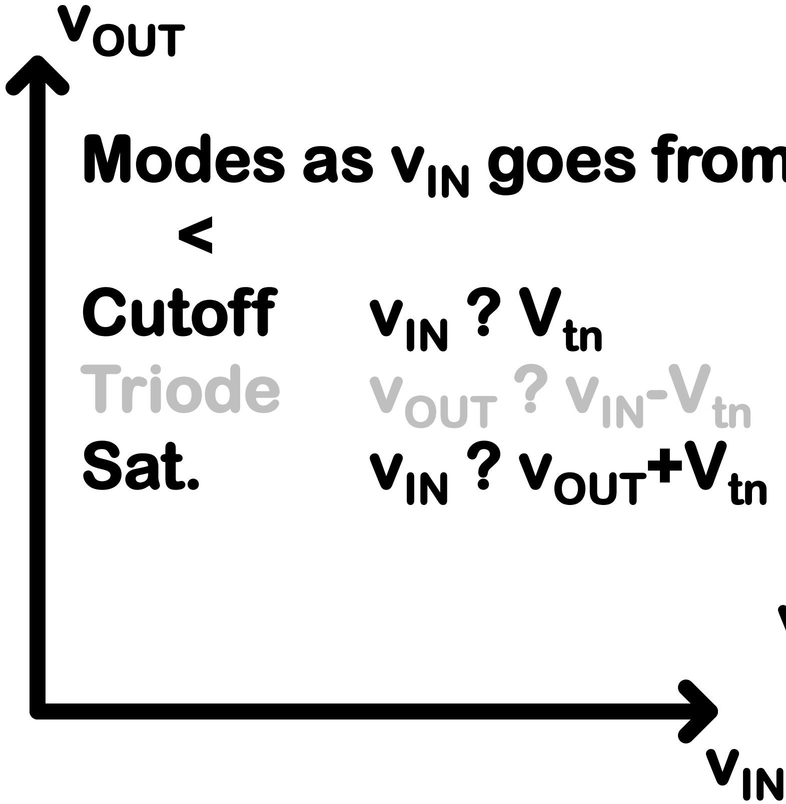


Notes:

$v_{IN} = v_{GS}$

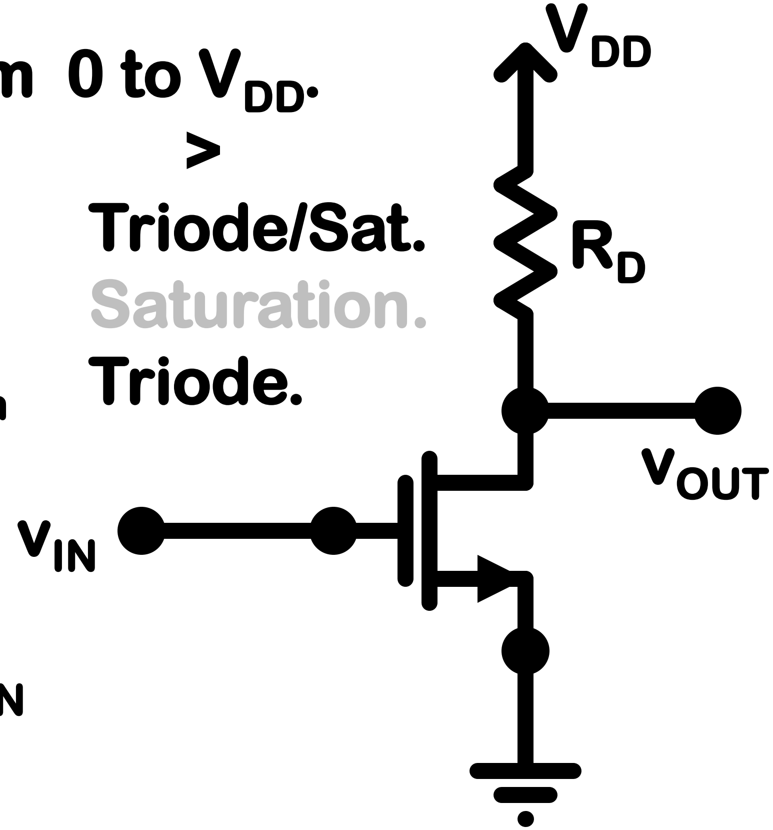
$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$

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



Modes as v_{IN} goes from 0 to V_{DD}.

	<		>
Cutoff	v_{IN} ? V_{tn}		Triode/Sat.
Triode	v_{OUT} ? $v_{IN}-V_{tn}$		Saturation.
Sat.	v_{IN} ? $v_{OUT}+V_{tn}$		Triode.

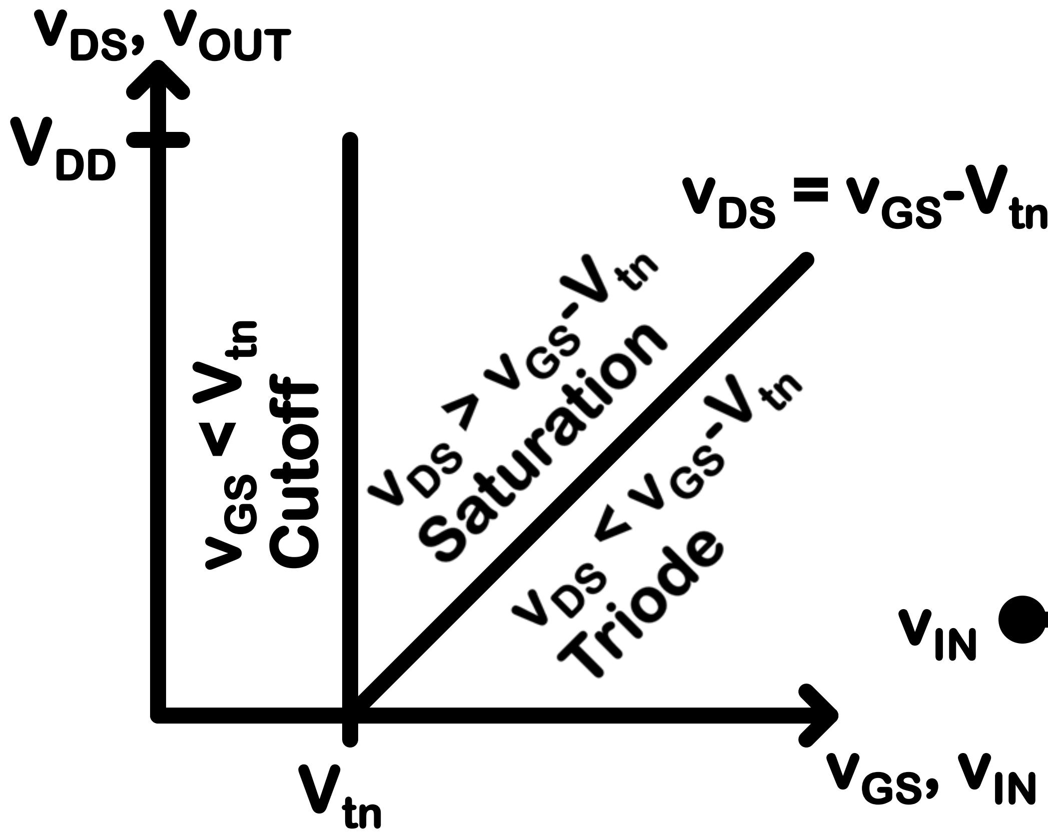


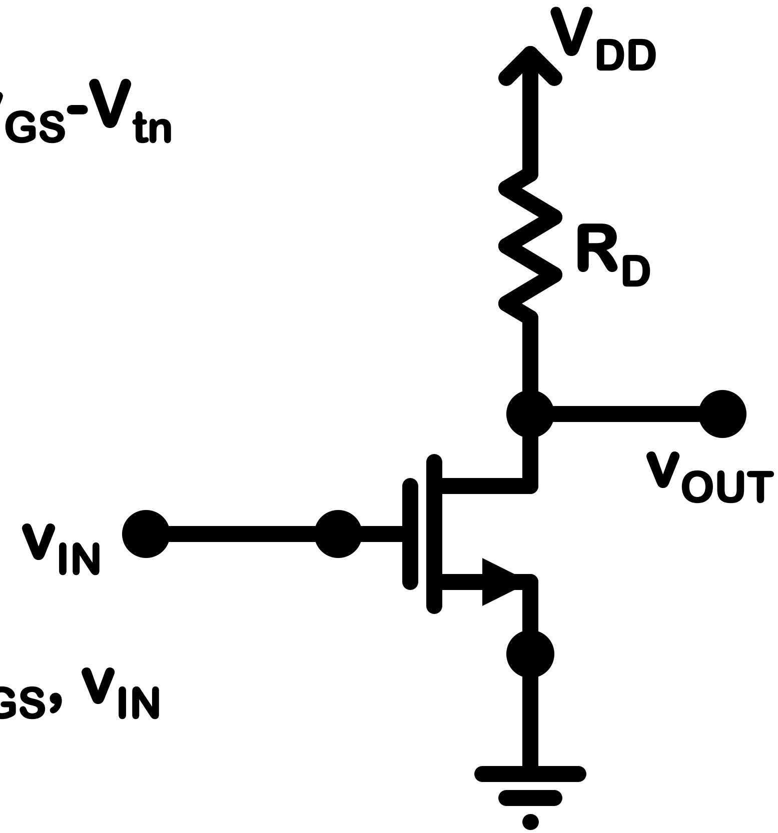
Notes:

$v_{IN} = v_{GS}$

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

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



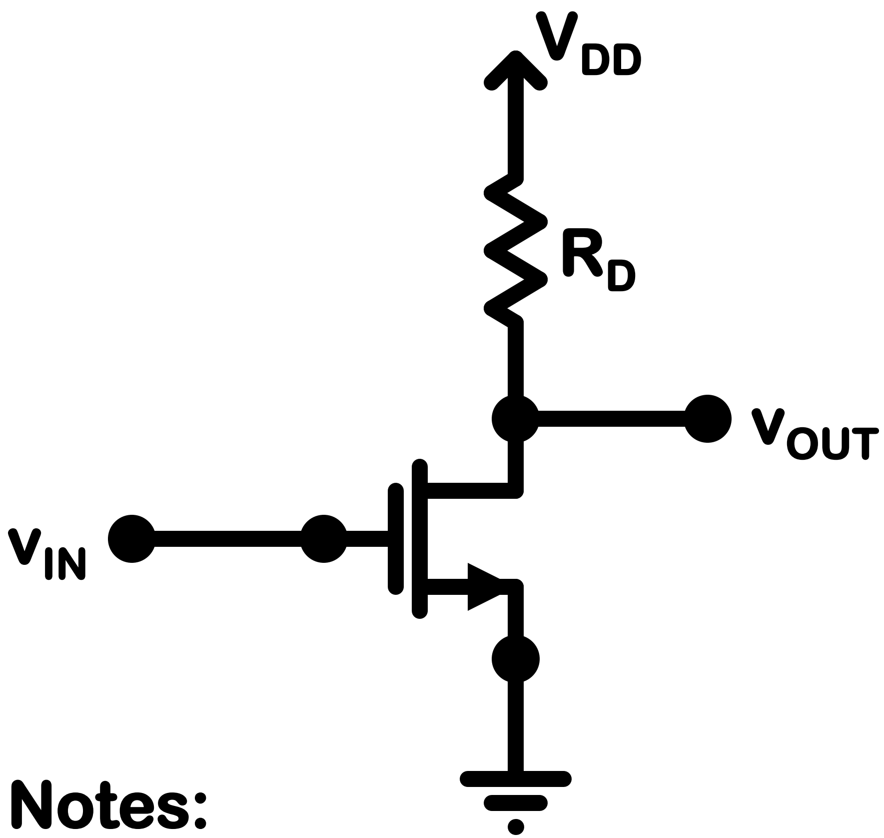


Notes:

$v_{IN} = v_{GS}$

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

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



1. **Cutoff Mode:**
2. $i_D = 0$
3. $v_{OUT}(v_{IN}) = V_{DD}$

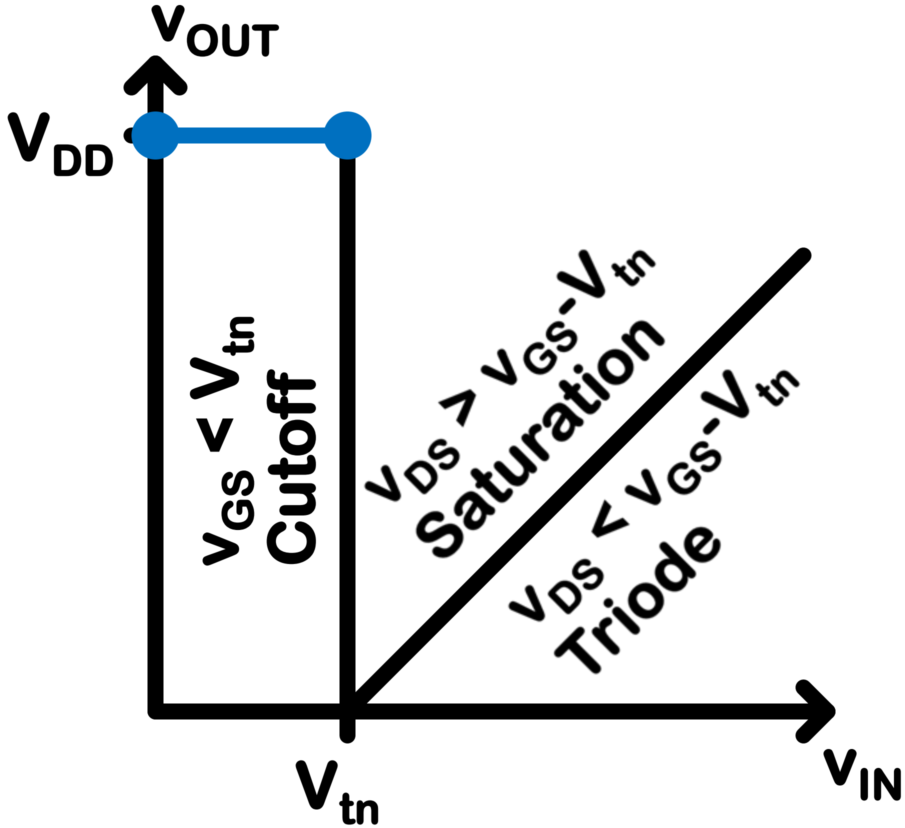
4. $v_{GS} - V_{tn} < 0$
   $v_{IN} < V_{tn}$

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

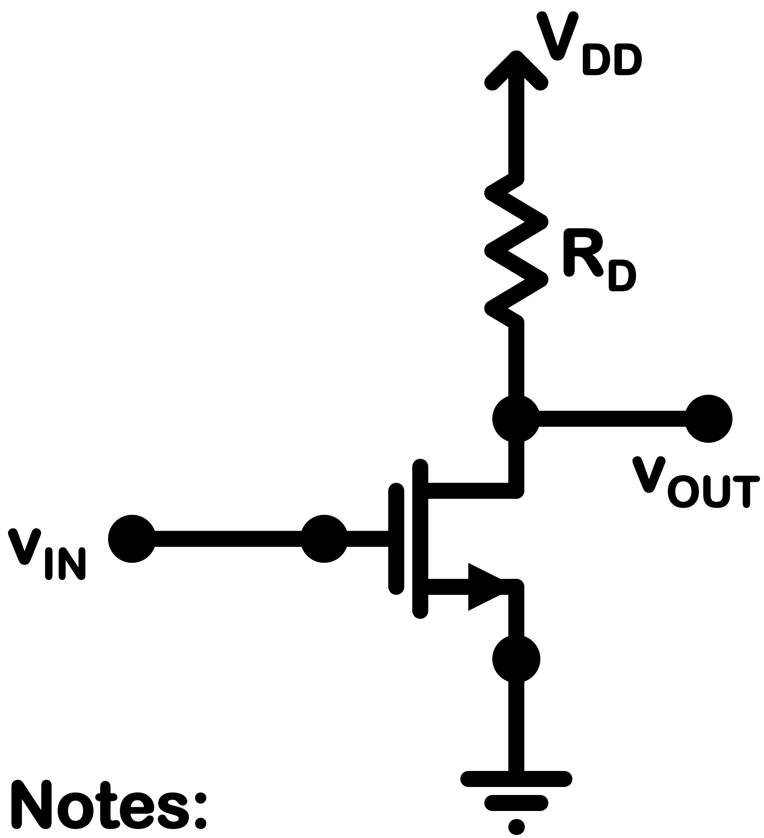
Notes:

$v_{IN} = v_{GS}$

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



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



Saturation Mode:

Device Parameter:

$k_n = k_n' (W/L)$

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

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

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

$v_{IN} > V_{tn}$

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

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

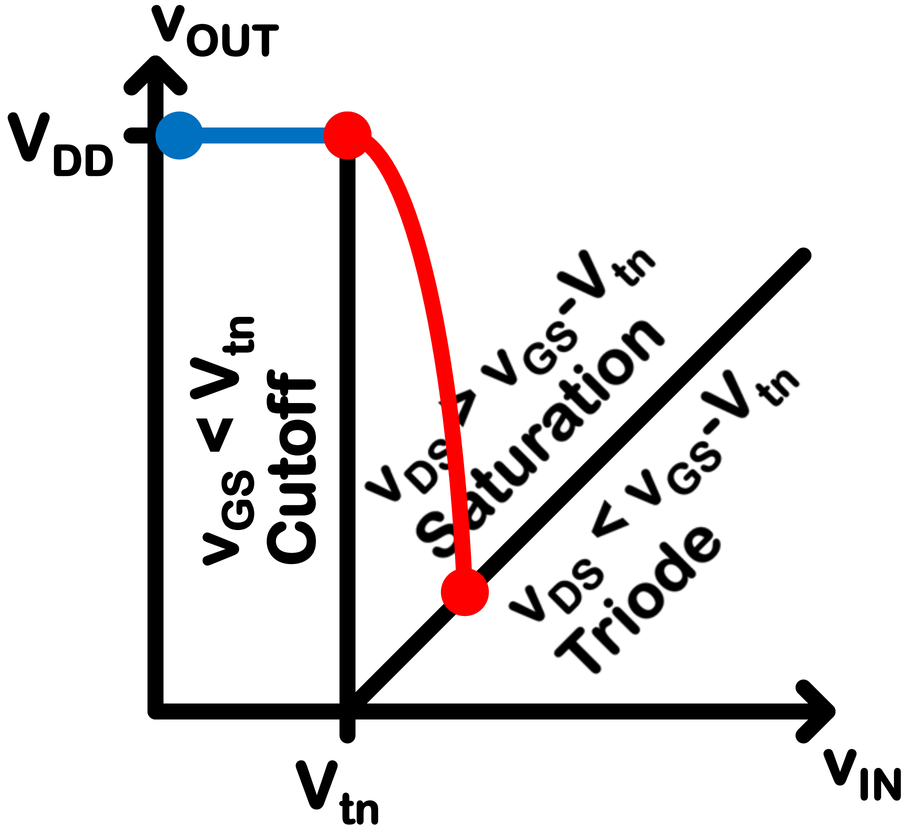
$v_{IN} < V_{tn} + ((1+2R_D k_n V_{DD})^{1/2} - 1)/R_D k_n$

Notes:

$v_{IN} = v_{GS}$

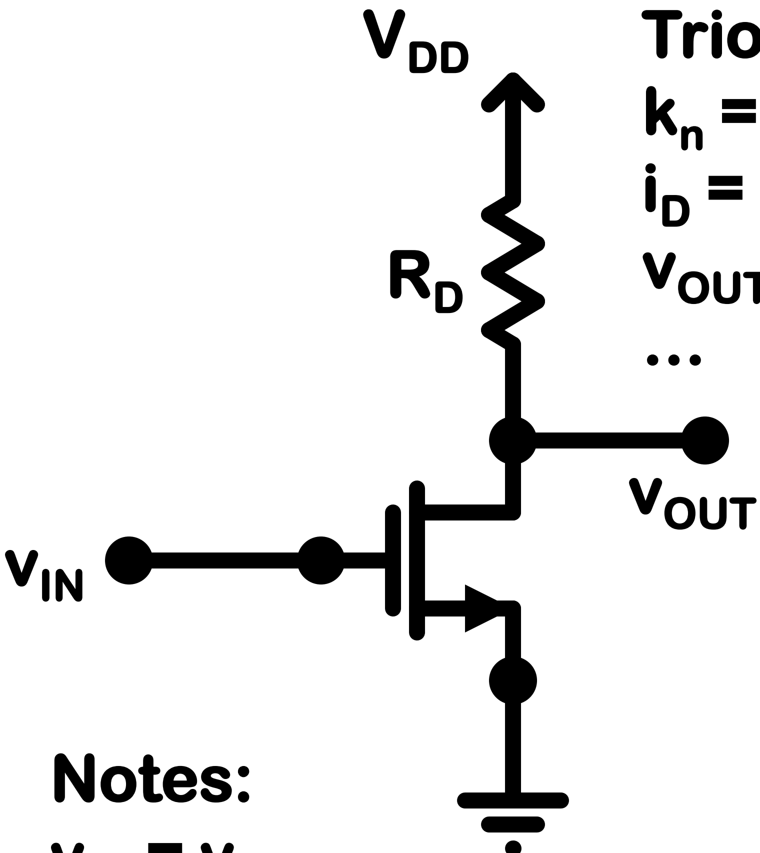
$v_{OUT} = v_{DS} = V_{DD} - R_D i_D$

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



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

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



Triode Mode:

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

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

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

…

Notes:

$v_{IN} = v_{GS}$

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

$v_{OUT}(v_{IN})$ = SEE NEXT PAGE for

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

Triode Mode:

$k_n = k_n' (W/L)$

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

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

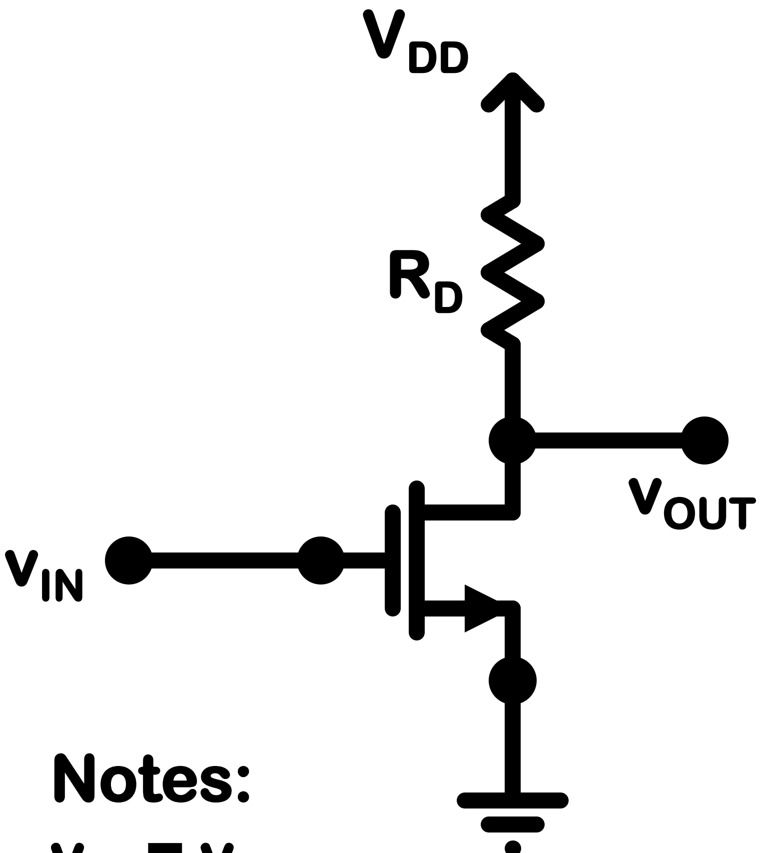
$R_D 0.5 k_n v_{OUT}^2 - (R_D k_n(v_{IN} - V_{tn})+1)v_{OUT} + V_{DD} = 0$

$a = 0.5R_D k_n$

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

$c = V_{DD}$

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



Triode (small v_{DS}) Mode:

$k_n = k_n' (W/L)$

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

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

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

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

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

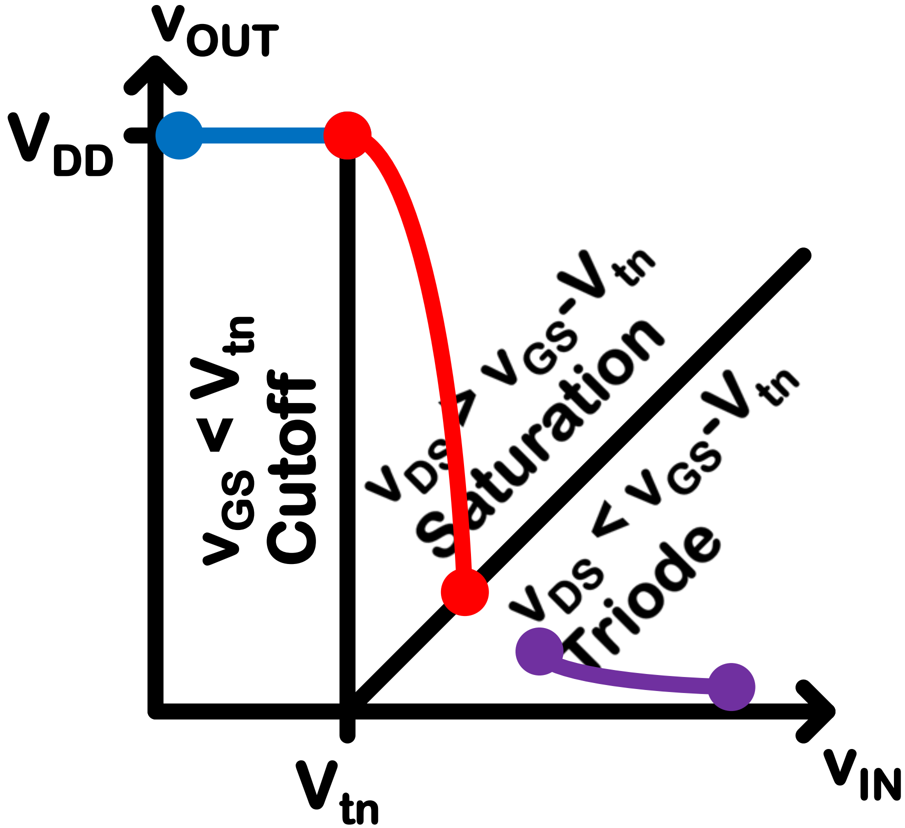
Notes:

$v_{IN} = v_{GS}$

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

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

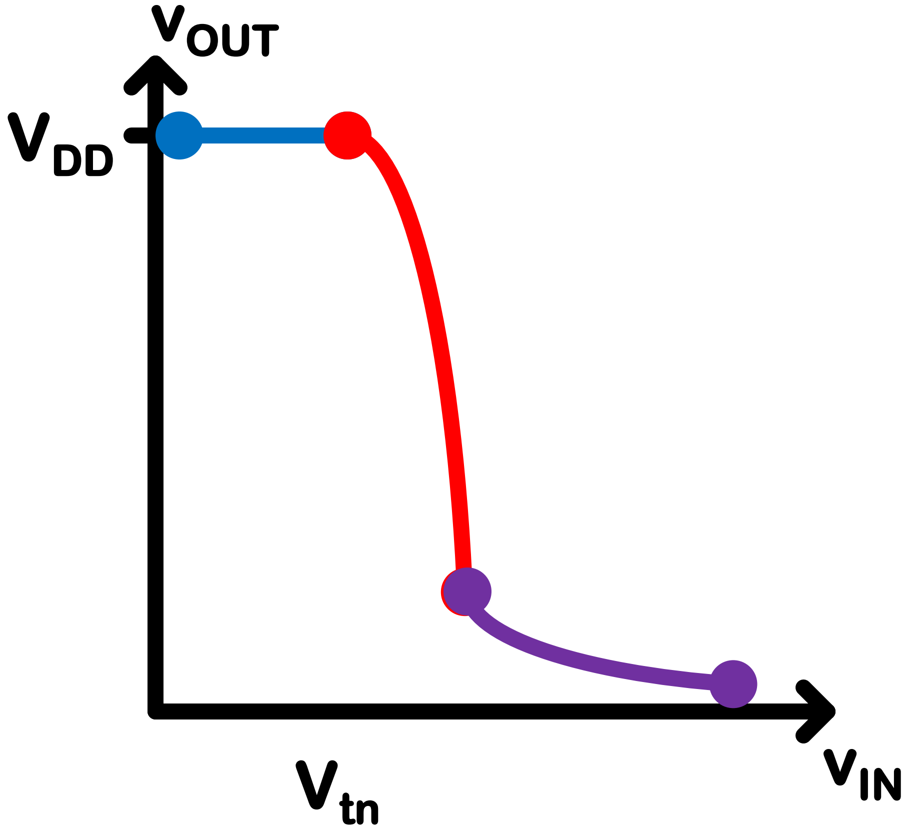
$v_{IN} >> V_{tn} + ((1+2R_D k_n V_{DD})^{1/2} - 1)/R_D k_n$



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

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

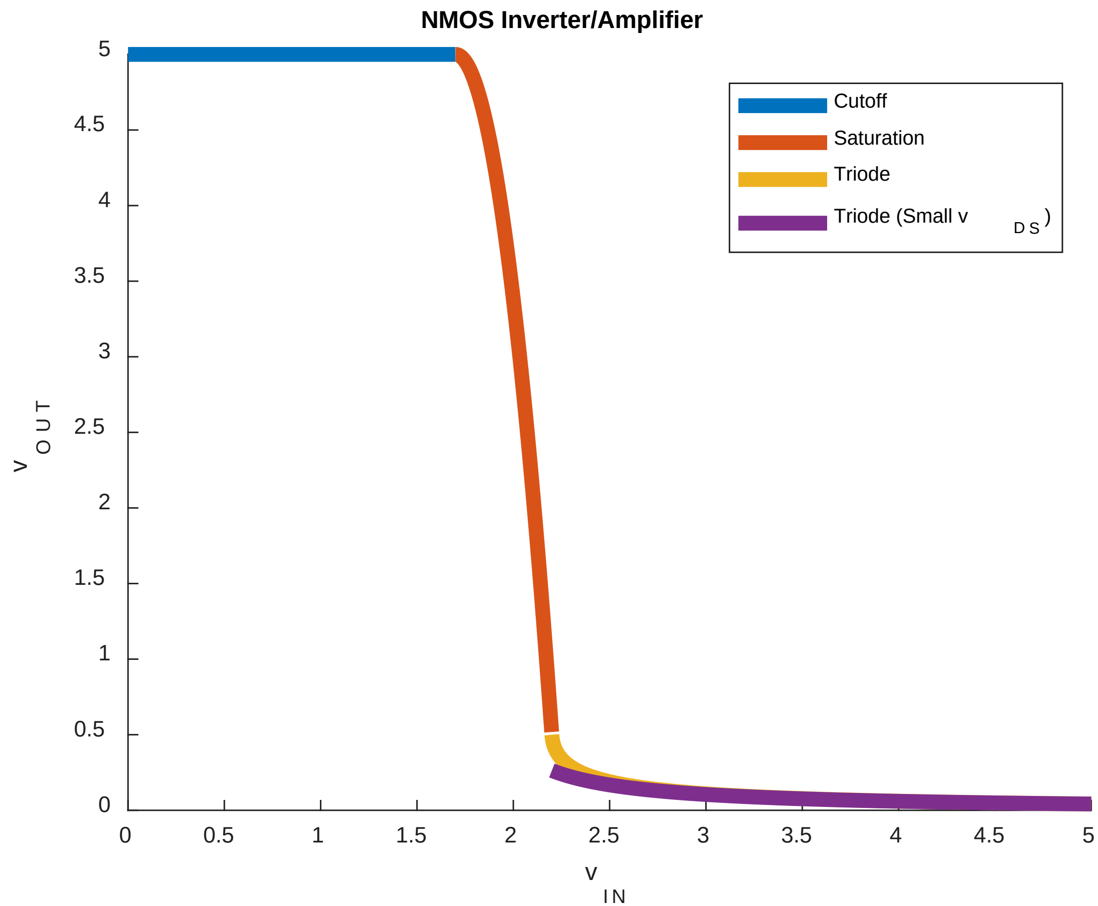
$$v_{OUT}(v_{IN}) = V_{DD}/(1+R_D k_n(v_{IN} - V_{tn})) \quad \text{for}$$
$$v_{IN} >> V_{tn} + ((1+2R_D k_n V_{DD})^{1/2} - 1)/R_D k_n$$



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

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

$$v_{OUT}(v_{IN}) \approx V_{DD}/(1+R_Dk_n(v_{IN} - V_{tn})) \quad \text{for}$$
$$v_{IN} >> V_{tn} + ((1+2R_Dk_nV_{DD})^{1/2} - 1)/R_Dk_n$$



Cutoff:

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

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

Saturation:

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

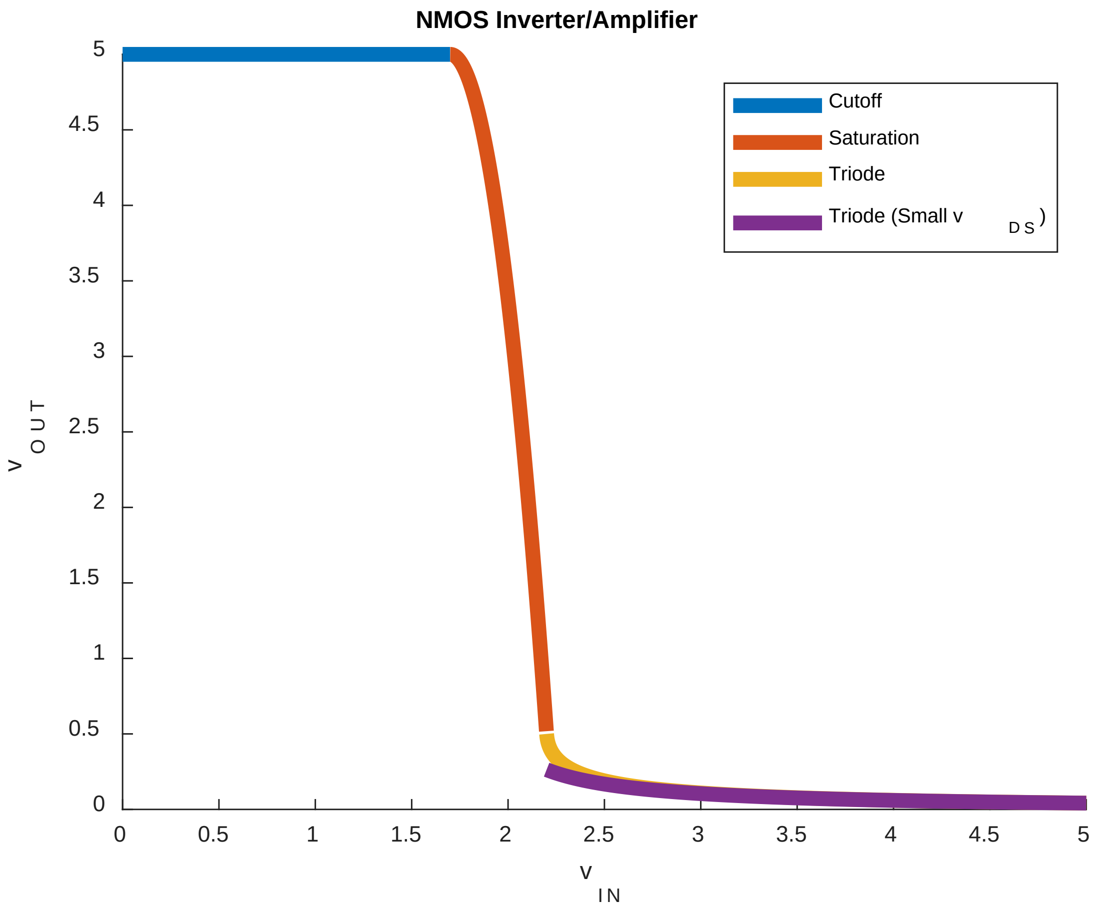
for $V_{tn} < v_{IN} < V_{tn} + ((1+2R_D k_n V_{DD})^{1/2} - 1)/R_D k_n$

Triode:

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

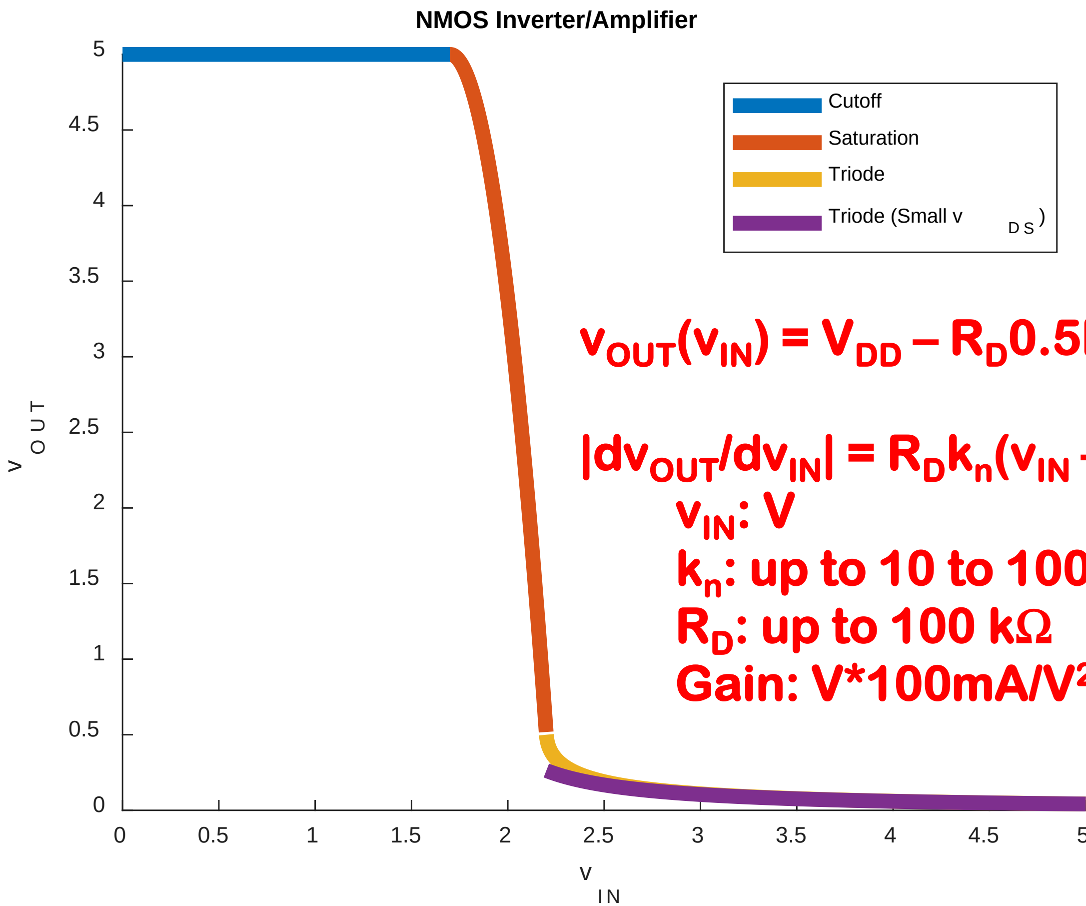
for $v_{IN} > V_{tn} + ((1+2R_D k_n V_{DD})^{1/2} - 1)/R_D k_n$

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).



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

$|dv_{OUT}/dv_{IN}| = R_D k_n (v_{IN} - V_{tn})$

v_{IN}: V

k_n: up to 10 to 100+ mA/V^2

R_D: up to 100 kΩ

Gain: V*100mA/V^2*100k(V/A) = very large

The Saturation region exhibits a slope with a large absolute value, $|dv_{OUT}/dv_{IN}|$>>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).