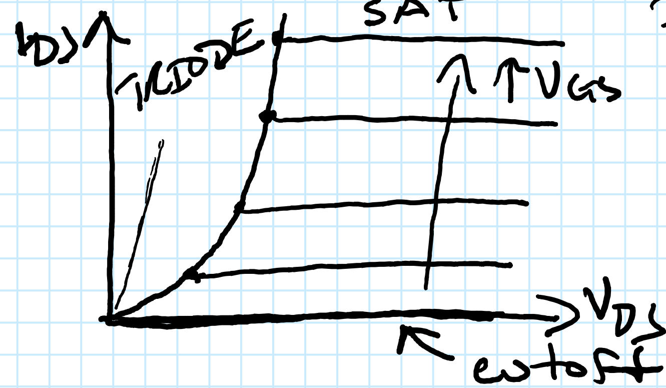
SCS MODEL SWITCH CURRENT SOURCE (ANALOG)

SATURATION



IDEAL CURRENT SOURCE

- Constant i_{DS} over a range of V_{DS}

$$i_{DS} = \begin{cases} 0 & V_{GS} < V_T \\ \frac{K}{2}(V_{GS}-V_T)^2 & V_{GS} \geq V_T;\ V_{DS} \geq V_{GS}-V_T \end{cases}$$

$f(V_{GS})$

Edge of Saturation

$$V_{DS} = V_{GS} - V_T \Rightarrow i_{DS} = \frac{K}{2}(V_{GS}-V_T)^2 = \frac{K}{2}V_{DS}^2$$

$$K = \boxed{\mu C_{ox}}\left(\frac{W}{L}\right) \Rightarrow K = K'\left(\frac{W}{L}\right)$$

W — width

L — length

C_{ox} — Capacitance / area of gate oxide

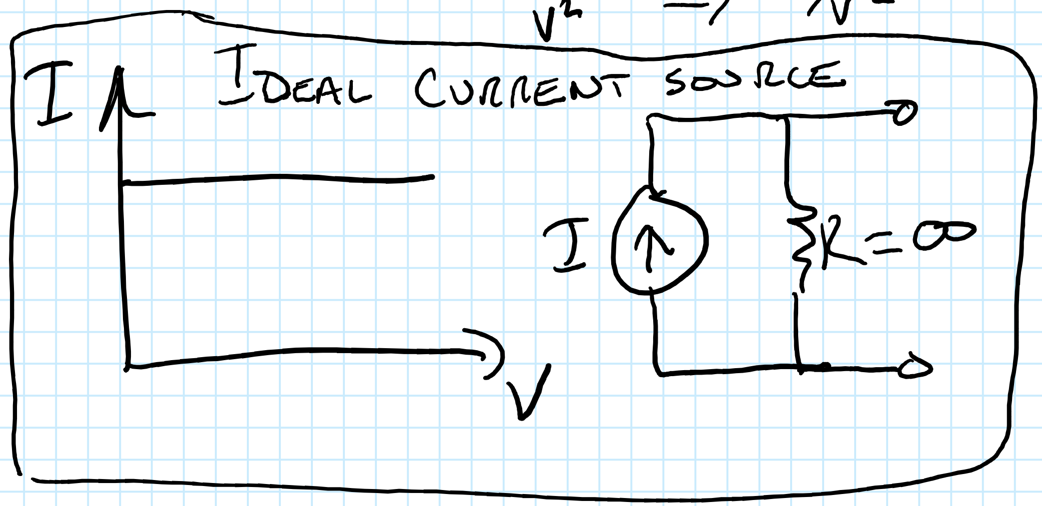
μ — mobility

Technology Constants

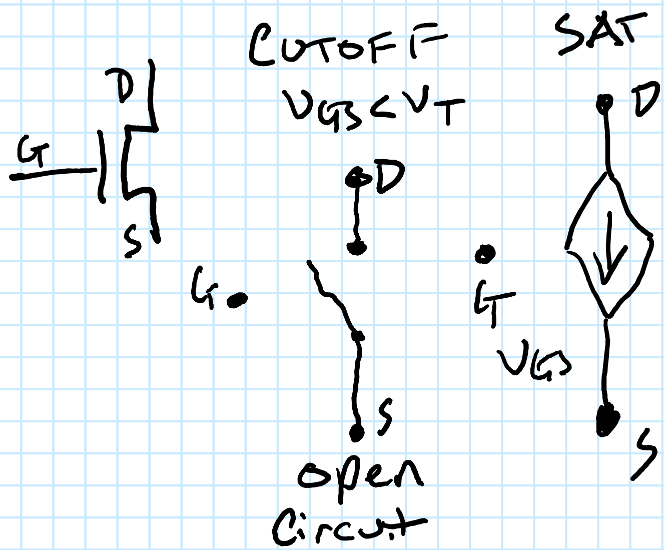
Design parameters

$$\mu\left[\frac{cm^2}{V\cdot s}\right] C_{ox}\left[\frac{C}{V\,cm^2}\right]\left(\frac{W}{L}\right)$$

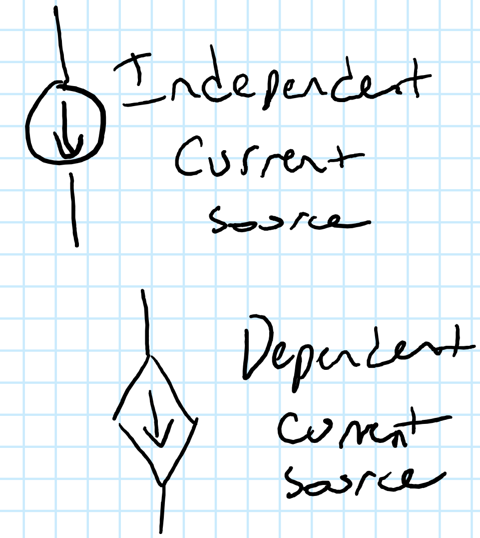
$$\frac{C/s}{V^2} \Rightarrow A/V^2$$



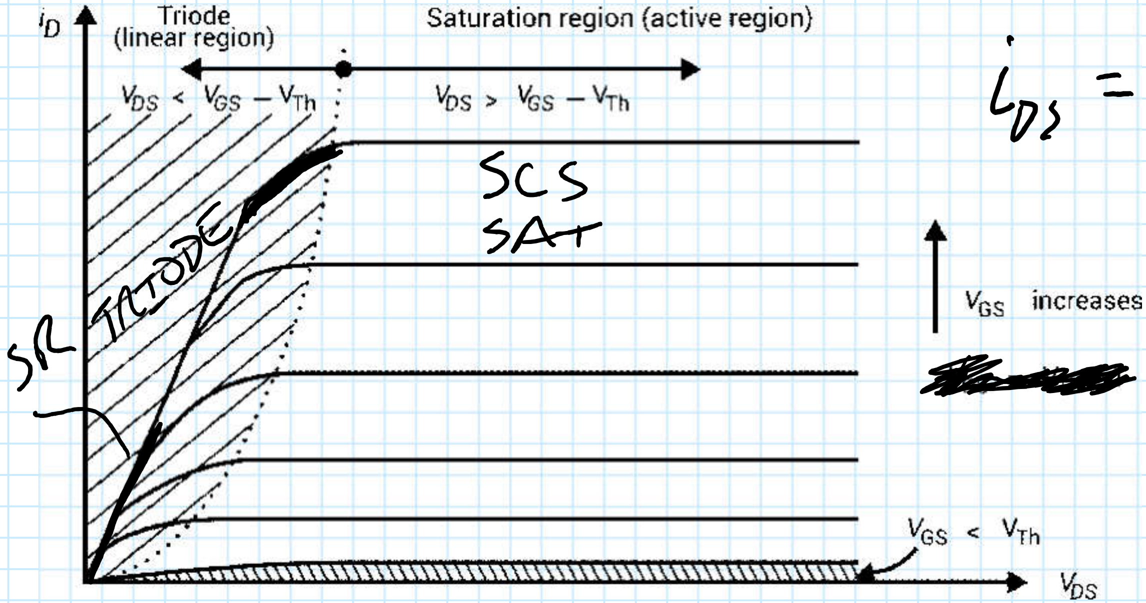
SCS CIRCUIT MODEL



$$i_{DS} = \frac{K}{2}(V_{GS} - V_T)^2$$



UNIFIED MODEL



$$i_{DS} = \begin{cases} 0 & V_{GS} < V_T \text{ CUTOFF} \\ K\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right] & \text{TRIODE } V_{GS} \geq V_T,\ V_{DS} < V_{GS}-V_T \\ \frac{K}{2}(V_{GS}-V_T)^2 & \text{SAT } V_{GS} \geq V_T,\ V_{DS} \geq V_{GS}-V_T \end{cases}$$

VS. $\underline{S\text{-}R}$

TRIODE $\rightarrow i_D = \frac{V_{DS}}{R_{ON}}$

AT TRIODE-SAT BOUNDARY

$$V_{DS} = V_{GS} - V_T$$

$$K\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right] = \frac{K}{2}(V_{GS}-V_T)^2$$

$$K\left[V_{DS}\cdot V_{DS} - \frac{V_{DS}^2}{2}\right] \stackrel{\checkmark}{=} \frac{K}{2}V_{DS}^2$$

$$\frac{di_{DS}}{dV_{DS}} = K\left[(V_{GS}-V_T) - \frac{\cancel{2}V_{DS}}{\cancel{2}}\right]$$

at boundary

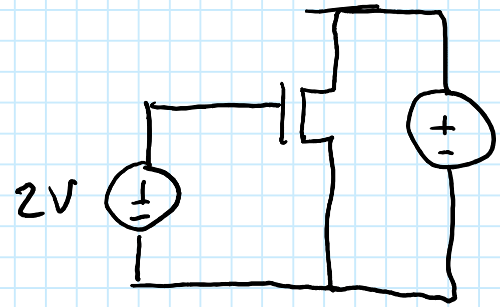
$$V_{DS} = V_{GS} - V_T$$

$$= K\left[V_{DS} - V_{DS}\right] = 0$$

at $V_{DS} = 0^+ \Rightarrow$ small

S-R TRIODE $\Rightarrow R = \frac{1}{K(V_{GS}-V_T)} = R_{ON}$

SATURATION EXAMPLES



$K = 1\,mA/V^2$

$V_T = 1V$

What mode of operation?

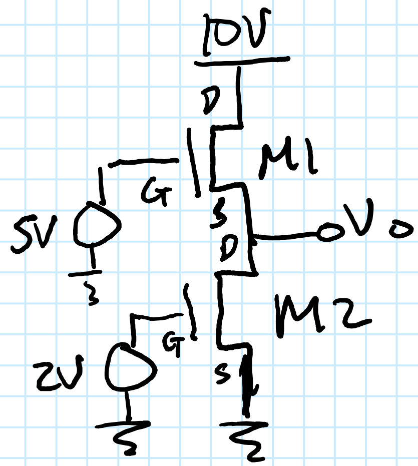
$V_{DS} \geq V_{GS} - V_T$

$5V \geq 2V - 1V \Rightarrow \underline{SAT}$

What is I_{DS}?

$i_{DS} = \frac{K}{2}(V_{GS} - V_T)^2 = 0.5\,mA$

7.6



What is V_o

Given that M1, M2 are in SAT ⟹ SCS

$K = 4\,mA/V^2$; $V_T = 1V$

M1 M2

$\frac{\cancel{K}}{\cancel{2}}(V_{GS1} - V_T)^{\cancel{2}} = \frac{\cancel{K}}{\cancel{2}}(V_{GS2} - V_T)^{\cancel{2}}$

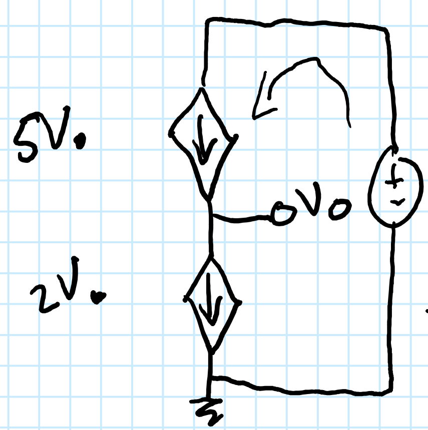
$V_{GS1} - V_T = 2 - 1 = 1$

$V_{GS1} = 2V \Rightarrow V_o = 3V$

$V_{G1} - V_{S1}$

$V_{G1} - V_{GS1}$

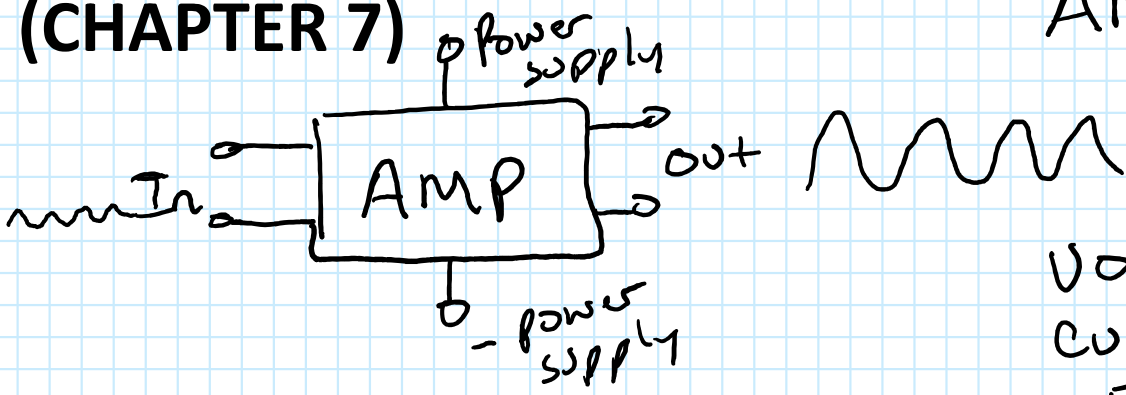
$5 - 2 = 3V$



CHECK

$V_{DS} \geq V_{GS} - V_T$ ✓ FOR M1 & M2

MOSFET AMPLIFIERS (CHAPTER 7)



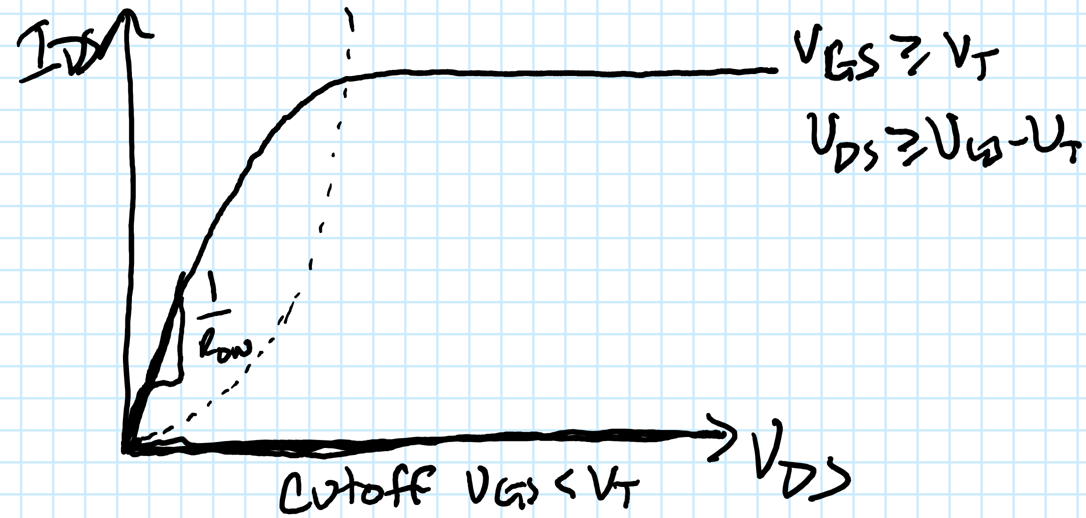
AMPLIFICATION = GAIN

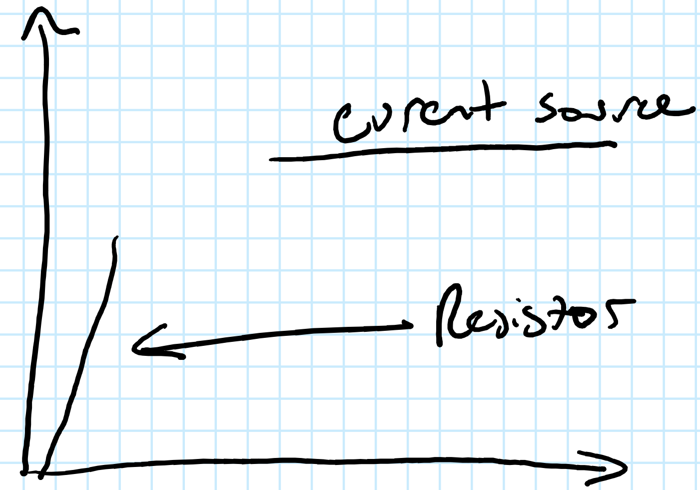
VOLTAGE
CURRENT
BOTH

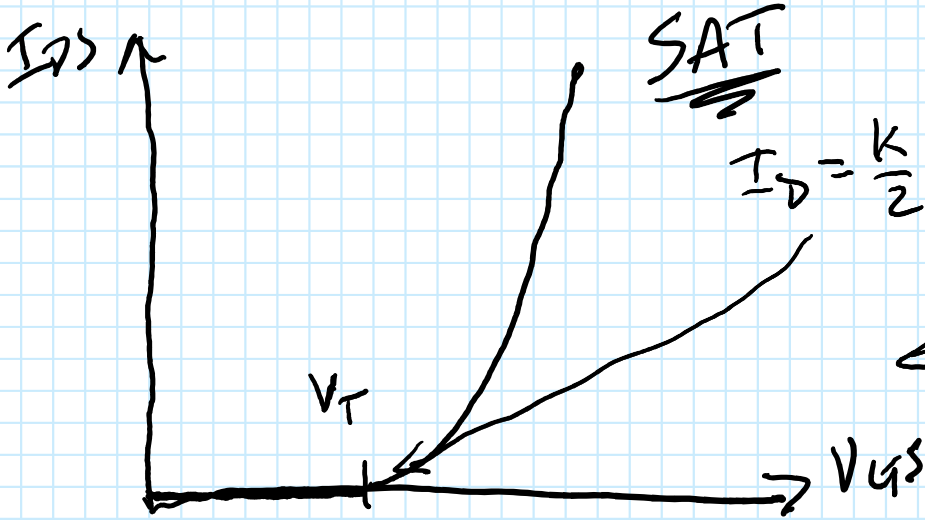
POWER AMP

$V_{OUT} \times I_{OUT} > V_{IN} \cdot I_{IN}$ → Power Gain

MOSFET REVIEW







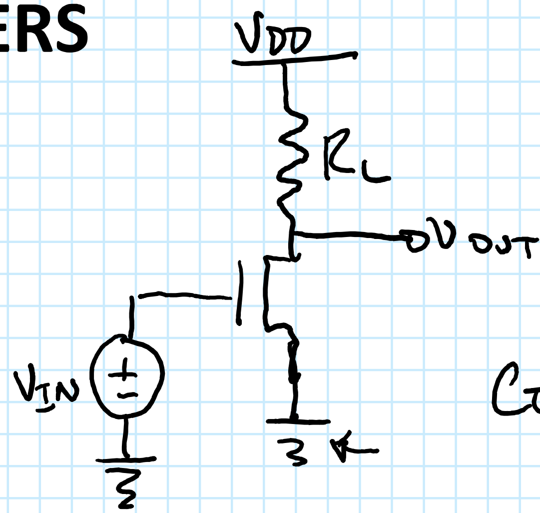
SAT

$$I_D = \frac{K}{2}(V_{GS} - V_T)^2$$

$V_{GS} = V_{DS}$

$\Rightarrow$ SAT

COMMON SOURCE AMPLIFIERS



looks like NMOS INVERTER

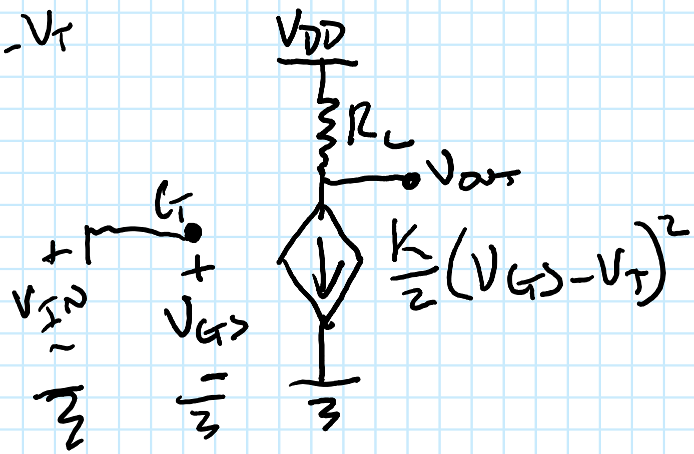
(DNMOS) INVERTERS OPERATE IN TRIODE $\Rightarrow$ SR

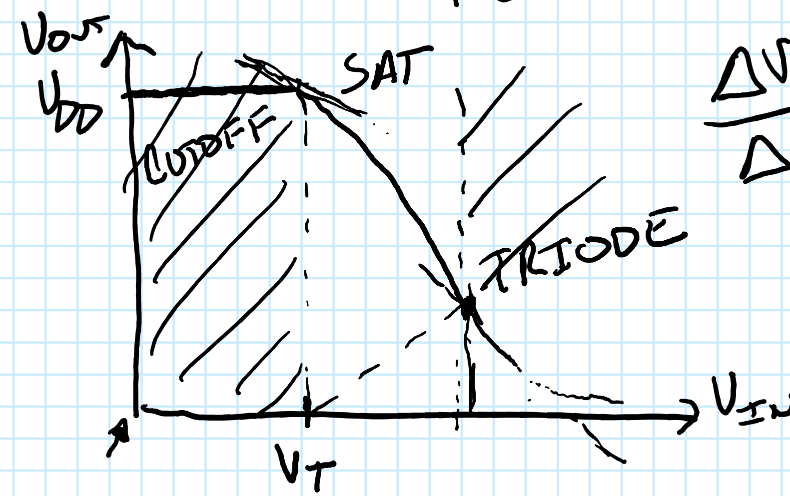
C.S AMP $\Rightarrow$ SAT

MOSFET $\rightarrow$ Current source

COMMON SOURCE $\rightarrow$ SOURCE IS REFERENCE

$V_{DS} \geq V_{GS} - V_T$

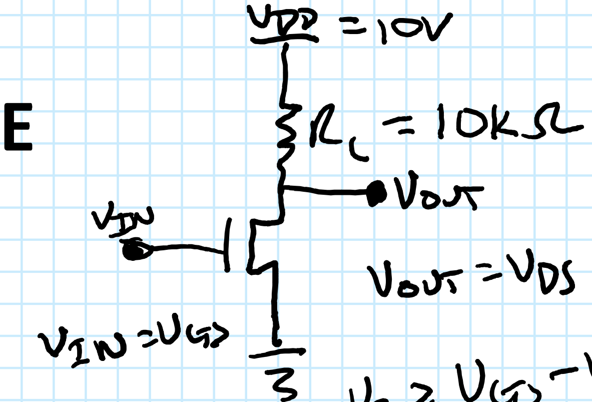




$$\frac{\Delta V_{OUT}}{\Delta V_{IN}} = \text{GAIN}$$

$$V_{OUT} = V_{DD} - \frac{k}{2}(V_{IN} - V_T)^2 R_L$$

COMMON SOURCE AMPLIFIERS 2



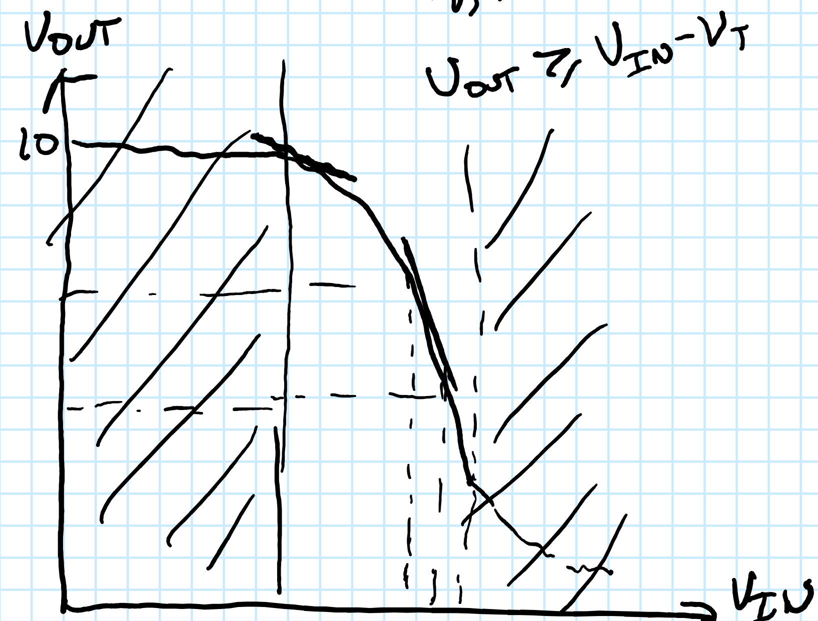
$K = 1mA/V^2$

$V_T = 1V$

$V_{DS} \geq V_{GS} - V_T$

$V_{OUT} \geq V_{IN} - V_T$

V_{IN}	V_{OUT}	
0.5	10	CUTOFF
1.0	10	
1.4	9.2	①
1.5	8.8	
1.8	6.8	
1.9	6	
2.0	5	SAT ②
2.1	4	
2.2	2.8	
2.3	1.6	
2.32	1.3	TRIODE
2.35	0.9	
2.4	0	

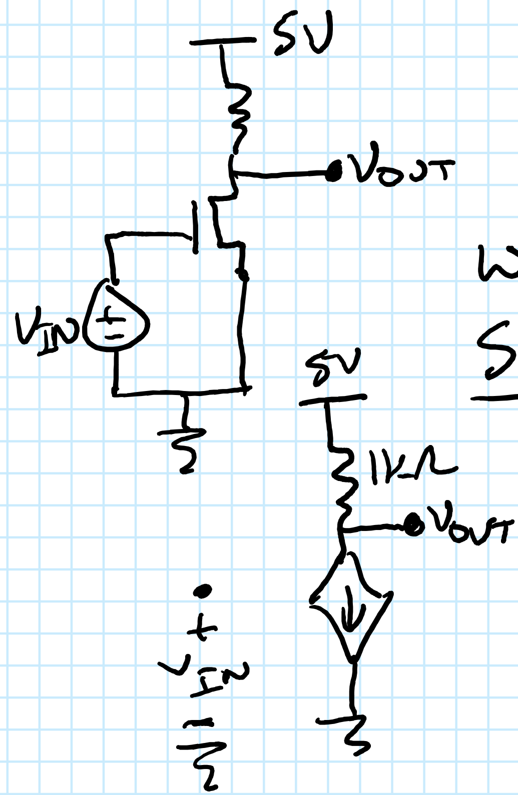


① $GAIN = \frac{-0.4}{0.1} = -4$

② $GAIN = \frac{-1}{0.1} = -10$

COMMON SOURCE AMPLIFIER EXAMPLE

EX 7.7



$k = 0.5\,mA/V^2$

$V_T = 0.8V$

What is V_{OUT} if $V_{IN} = 2.5V$?

<u>SAT</u>

$$V_{OUT} = V_{DD} - \frac{k}{2}(V_{IN} - V_T)^2 R_L$$

$$= 5V - \frac{0.5\cancel{m}}{2}(2.5V - 0.8)^2\, 1\cancel{k}\Omega$$

$$= 4.28V$$

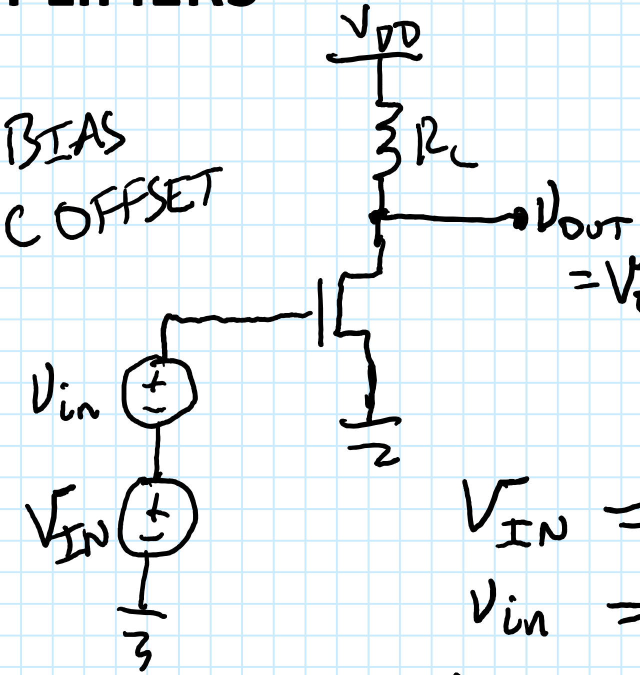
$V_{DS} \geq V_{GS} - V_T$

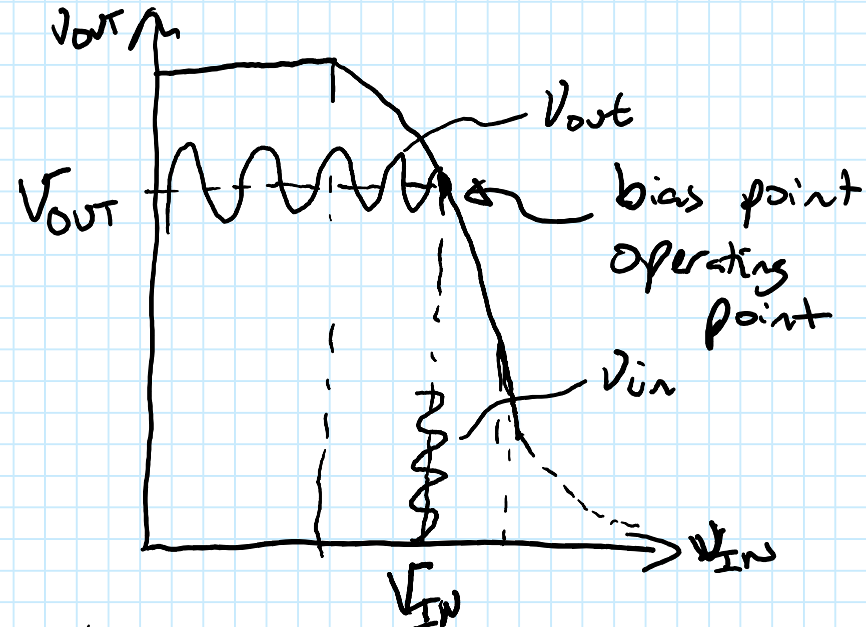
$4.28 \geq 2.5 - 0.8$ ✓ SAT

BIASING MOSFET AMPLIFIERS

KEEP MOSFET IN SAT MODE

DC BIAS
DC OFFSET

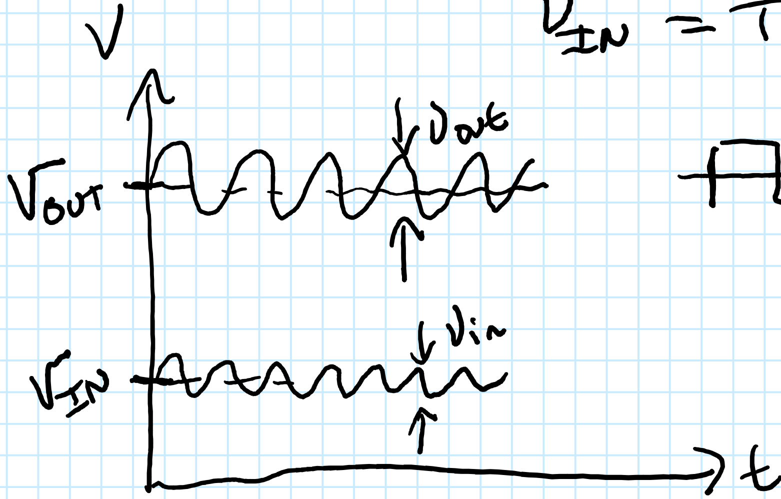


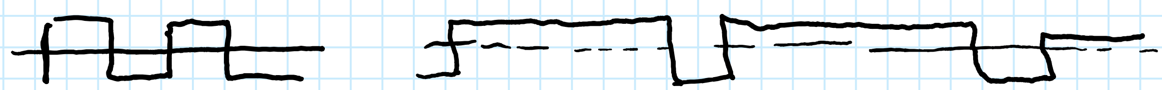


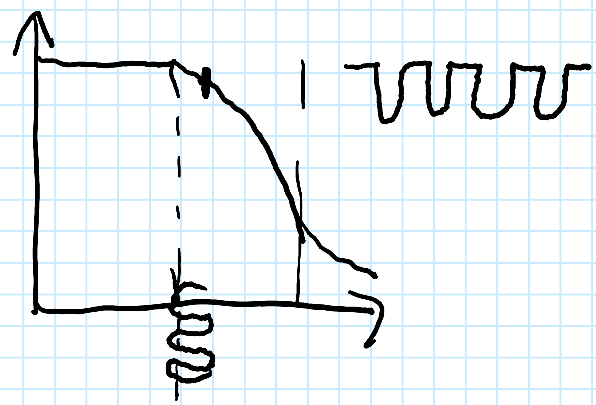
V_{IN} = DC bias

v_{in} = small signal

v_{IN} = TOTAL VARIABLE = $V_{IN} + v_{in}$



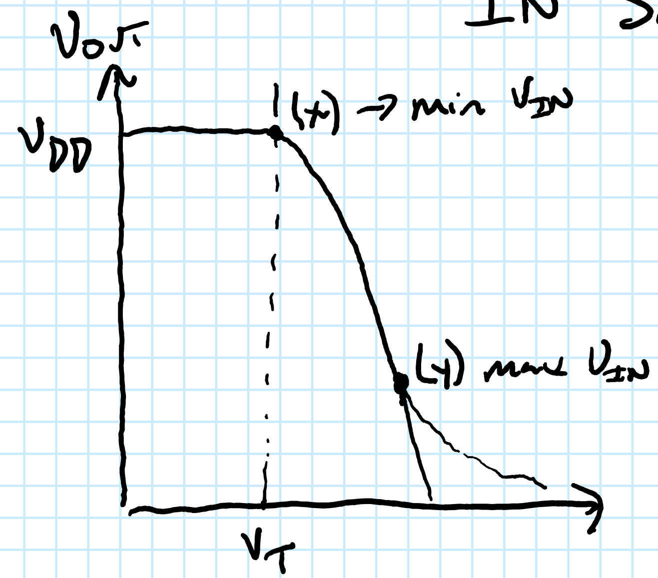




LARGE-SIGNAL ANALYSIS

LARGE SIGNAL ANALYSIS → behavior under large changes in input voltage
- same magnitude as operating parameters

- ① FIND TRANFER FUNCTION – V_{OUT} vs V_{IN}
  ② RANGE OF VALID INPUTS TO REMAIN IN SAT & CORRESPONDING OUTPUTS



LOWEST VALID INPUT → MAX OUTPUT

(x) $V_{IN} > V_T$ $\quad V_{OUT} = V_{DD}$

(y) $V_{OUT} = V_{IN} - V_T$ → BORDER OF TRIODE