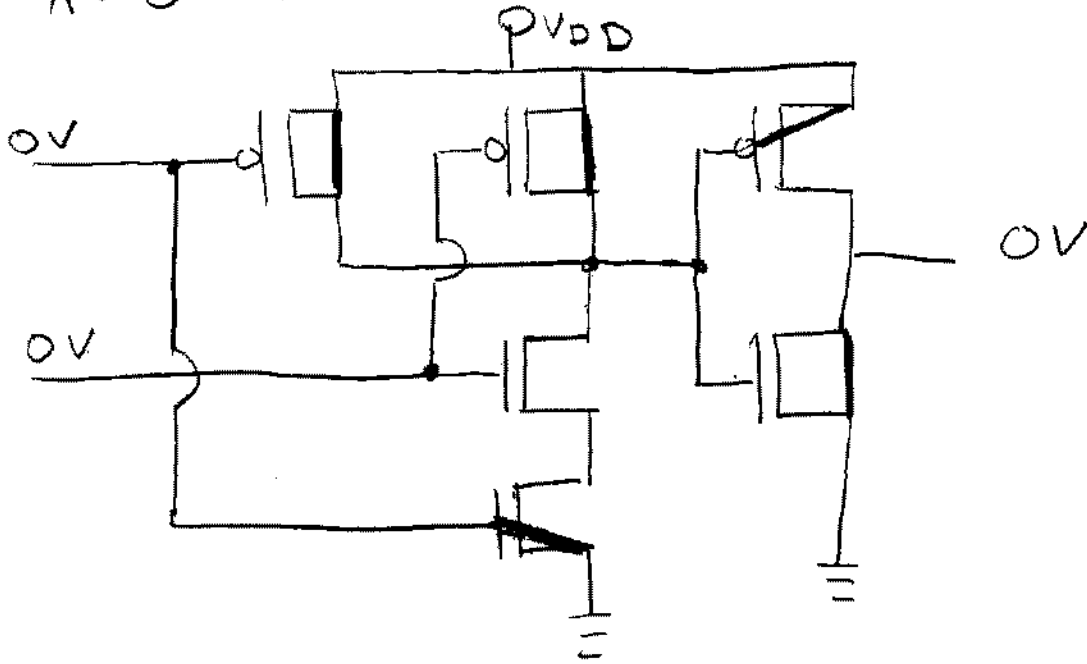


EE 40

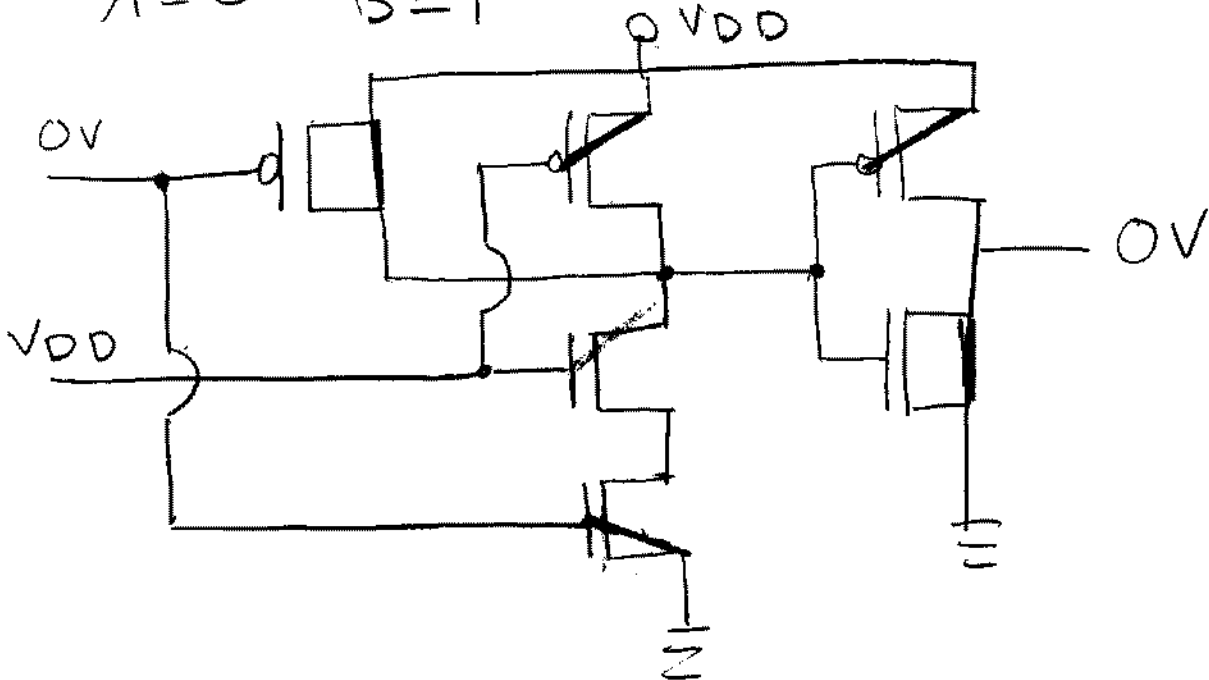
Homework 7 Solutions

Problem 1:

$A = 0$   $B = 0$

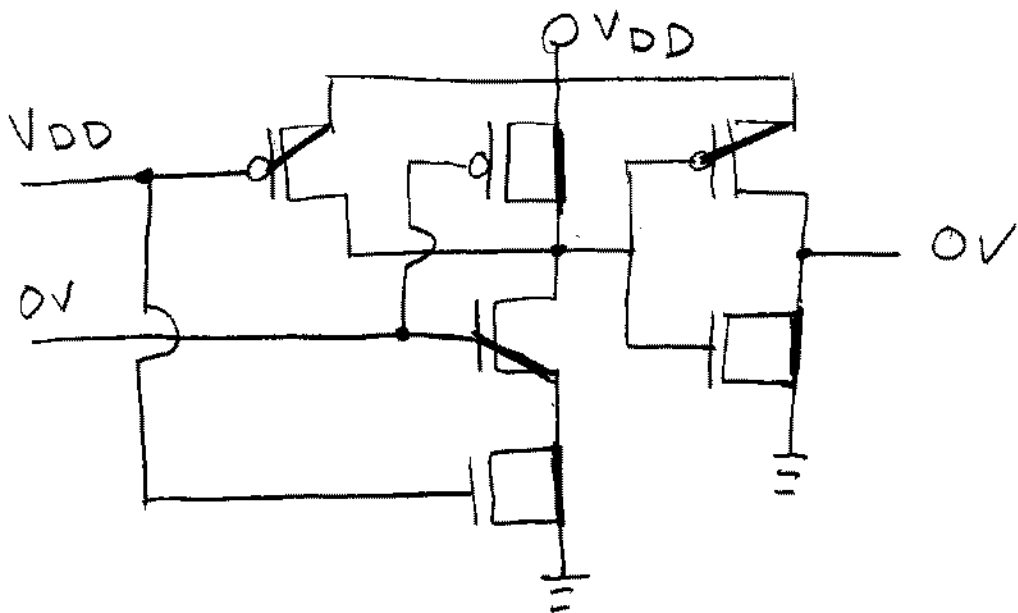


$A = 0$   $B = 1$

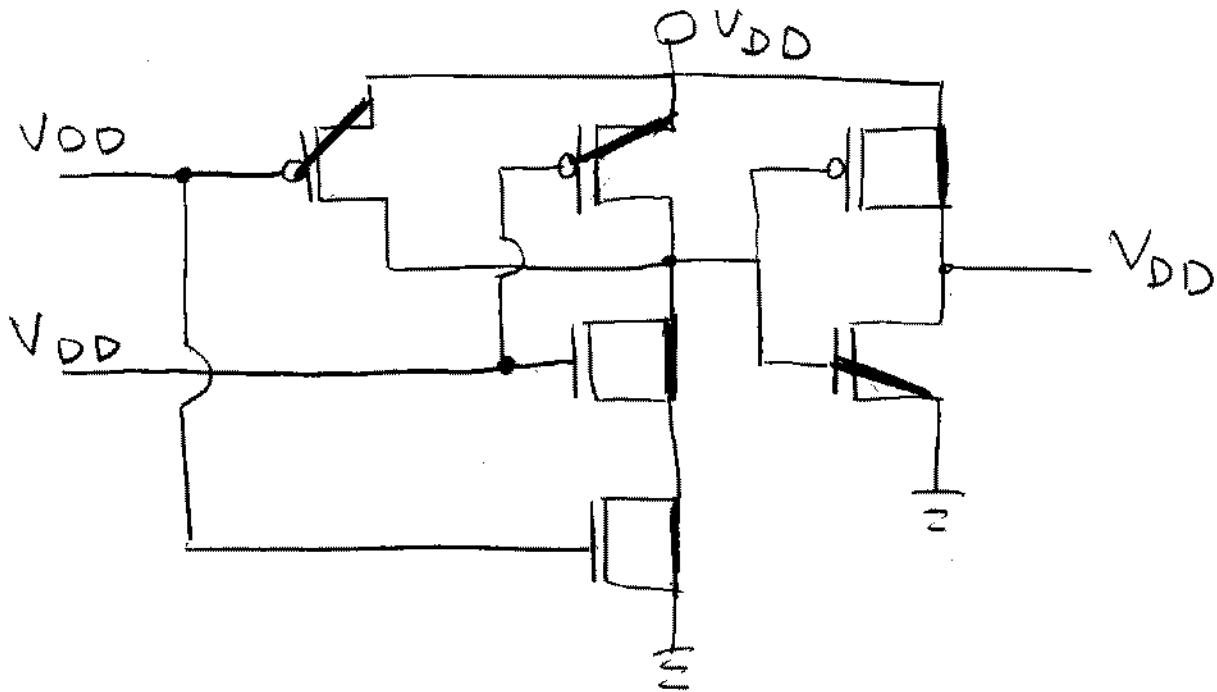


2

A=1 B=0



A=1 B=1

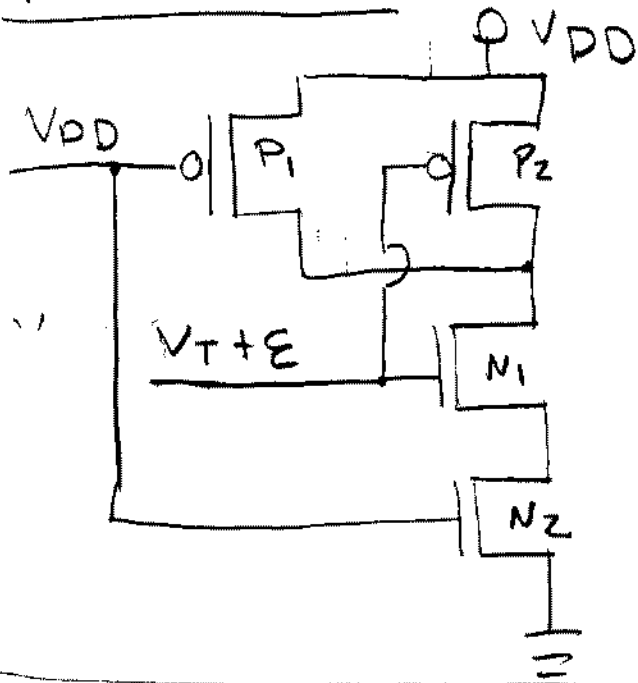


A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

AND

# Problem 2<sub>6</sub>

(3)



$P_1: V_{GS_{P1}} = 0$  cutoff  $I_{DP1} = 0$

$P_2: V_{GS_{P2}} = V_T + E - V_{DD}$  steep curve

$N_1: V_{GS_{N1}} \leq V_T + E$   
(since  $V_{DS_{N2}} \geq 0$ )

cutoff not possible

since  $I_{DN1} = 0 \Rightarrow I_{DN2} = 0$

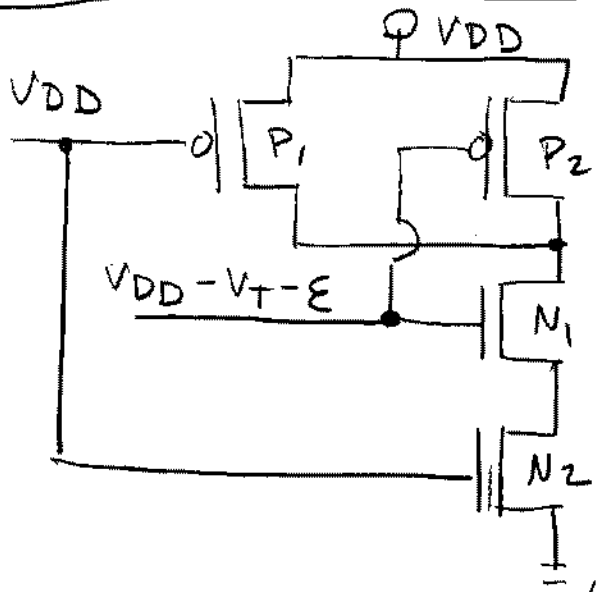
$\Rightarrow V_{DS_{N2}} = 0$ ; this would make  $V_{GS_{N1}} = V_T + E$  (not cutoff!)

So  $N_1$  turned on, barely shallow curve;  $I_{DN1}$  small

$N_2: V_{GS_{N2}} = V_{DD}$  steep curve

$-I_{DP2} = I_{DN1} = I_{DN2}$  (since  $I_{DP1} = 0$ )

$P_1$  cutoff  $P_2$  triode (steep curve, small  $I_{DP2}$ )  
 $N_1$  saturation  $N_2$  triode (steep curve, small  $I_{DN2}$ )  
 $V_{DS_{N1}} > V_{GS_{N1}} - V_T = E$



$P_1: \text{cutoff}$  ( $V_{GS_{P1}} = 0 \Rightarrow I_{DP1} = 0$ )

$P_2: V_{GS_{P2}} = -V_T - E$  shallow curve small  $I_{DP2}$

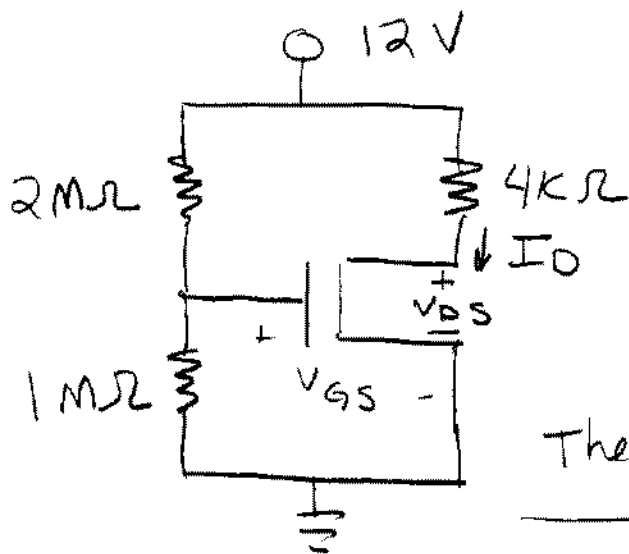
$N_2: V_{GS_{N2}} = V_{DD}$  steep curve small  $I_{DN2} = -I_{DP1} \Rightarrow V_{DS_{N2}}$  small

$N_1: V_{GS_{N1}} = V_{DD} - V_T - E - V_{DS_{N2}}$  large steep curve & small  $I_{DN1} = -I_{DP1}$

( $N_1$  triode  $N_2$  triode  $P_2$  saturation)

### Problem 3:

(4)



$$V_{GS} = 12 \cdot \frac{1M\Omega}{1M\Omega + 2M\Omega} = 4V$$

(using voltage division since no gate current)

$$12V = 4k\Omega I_D + V_{DS}$$

These facts do not change!

Now guess saturation mode.

$$\begin{aligned} I_D &= I_{D_{SAT}} (1 + \lambda V_{DS}) = 2 \cdot 10^{-3} (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \\ &= 2 \cdot 10^{-3} (4 - 1)^2 (1 + 0.01 V_{DS}) = 1.8 \cdot 10^{-2} (1 + 0.01 V_{DS}) \end{aligned}$$

Use above KVL equation

$$I_D = \frac{1}{4k} (12 - V_{DS}) \text{ and substitute in: } \uparrow$$

$$0 = 1.8 \cdot 10^{-2} (1 + 0.01 V_{DS}) + 2.5 \cdot 10^{-4} (V_{DS} - 12)$$

$$4.3 \cdot 10^{-4} V_{DS} = -1.5 \cdot 10^{-2} \Rightarrow V_{DS} = -35V \text{ impossible!}$$

Guess triode mode:

$$I_D = \frac{2 I_{D_{SAT}}}{(V_{GS} - V_T)^2} \left( V_{GS} - V_T - \frac{V_{DS}}{2} \right) V_{DS}$$

$$= 2 \cdot 2 \cdot 10^{-3} \left( 4 - 1 - \frac{V_{DS}}{2} \right) V_{DS}$$

5

Substitute  $I_D = \frac{1}{4k} (12 - V_{DS})$

$$0 = 4 \cdot 10^{-3} \left( 3 - \frac{V_{DS}}{2} \right) V_{DS} + \frac{1}{4k} (V_{DS} - 12)$$

$$= 2 \cdot 10^{-3} V_{DS}^2 + 1.225 \cdot 10^{-2} V_{DS} - 3 \cdot 10^{-3}$$

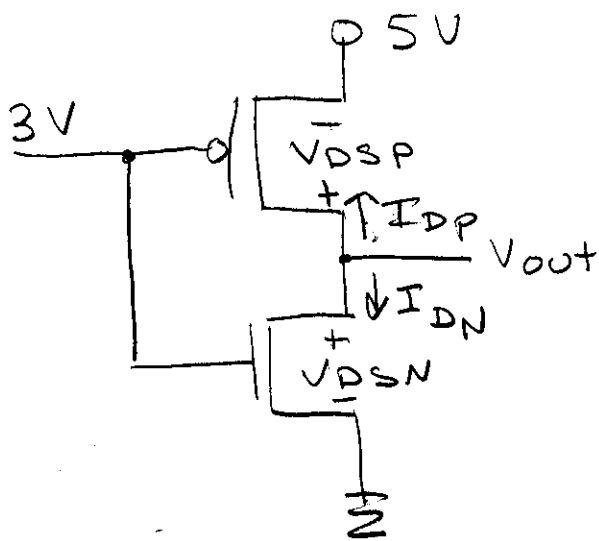
$V_{DS} = 5.87 \text{ V}$  or  $0.256 \text{ V}$

$V_{DS} = 5.87 \text{ V}$  is impossible for triode

$V_{DS} = 0.256 \quad I_D = \frac{1}{4k} (12 - V_{DS}) = 2.94 \text{ mA}$

$P = V_{DS} I_D = 750 \mu \text{ W}$

Problem 4:



$5 \text{ V} = V_{DSN} - V_{DSP}$

$I_{DN} + I_{DP} = 0$

Guess: PMOS saturation, NMOS triode.

$$I_{DP} = I_{DSATP} (1 + \lambda V_{DSP}) = -2 \cdot 10^{-5} (V_{GSP} - V_{TP})^2$$

$$= -2 \cdot 10^{-5} (-3 - 5 - -1)^2 = -2 \cdot 10^{-5} \text{ A}$$

$$I_{DN} = \frac{2 I_{DSATN} (V_{GSN} - V_{TN} - \frac{V_{DSN}}{2}) V_{DSN}}{(V_{GSN} - V_{TN})^2}$$

$$I_{DN} = 2.2 \cdot 10^{-5} \left( 3 - 1 - \frac{V_{DSN}}{2} \right) V_{DSN}$$

$$= 4 \cdot 10^{-5} \left( 2 - \frac{V_{DSN}}{2} \right) V_{DSN}$$

$$= -I_{Dp} = 2 \cdot 10^{-5}$$

$$0 = -2 \cdot 10^{-5} V_{DSN}^2 + 8 \cdot 10^{-5} V_{DSN} - 2 \cdot 10^{-5}$$

$$V_{DSN} = 0.268 \text{ V or } 3.73 \text{ V} \rightarrow \text{impossible for triode}$$

$$\Rightarrow V_{DSP} = V_{DSN} - 5 = -4.7 \text{ agrees with saturation}$$

$$V_{OUT} = V_{DSN} = \boxed{0.268 \text{ V}}$$

Grading:

Each problem 25 points

Problem 1: 5 points for each of 4 correct cases & 5 points for final answer  
Give full credit for correct final answer

Problem 2: 1 "free" points

3 points for each correct transistor mode  
(there were 4 transistors in each of the 2 circuits)

Problem 3° \* if alternate version was solved, please give to Prof Ross to grade. 7

Correct  $V_{SS} \rightarrow 5$  points

Problem was changed 12 hours after initial posting.

Correct KVL relating  $I_D$  to  $V_{DS} \rightarrow 5$  points

Correct mode eventually found  $\rightarrow 5$  points

Correct triode or saturation equation  $\rightarrow 5$  points

Correct substitution & solution  $\rightarrow 5$  points

When the error is small, give 3 out of 5 pts.

Problem 4°

Correct  $V_{SSN} + V_{BSP} \rightarrow 4$  points

Correct KCL relating  $I_{DN} + I_{DP} \rightarrow 3$  points

Correct KVL relating  $V_{DSN} + V_{DSP} \rightarrow 3$  points

Correct mode eventually found  $\rightarrow 4$  points

Correct triode equation  $\rightarrow 3$  points

Correct saturation equation  $\rightarrow 3$  points

Correct substitution & solution  $\rightarrow 5$  points

Deduct 1-2 points for minor errors.