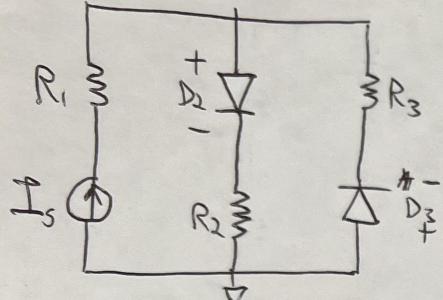


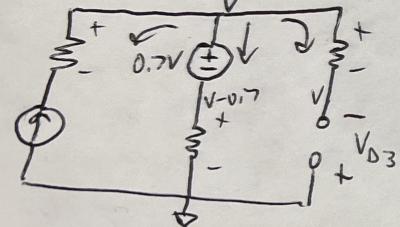
## Multiple Diodes



$$I_s = 1mA$$

$$R_1 = R_2 = R_3 = 1k\Omega$$

### Guess D<sub>2</sub>=on, D<sub>3</sub>=off



$$-I_s + \frac{(V-0.7)-0}{R_2} + 0 = 0$$

$$V\left(\frac{1}{R_2}\right) = \frac{0.7}{R_2} + I_s$$

$$V = 1.7V$$

#### D<sub>2</sub> check

$$I > 0?$$

$$\frac{V-0.7}{R_2} > 0?$$

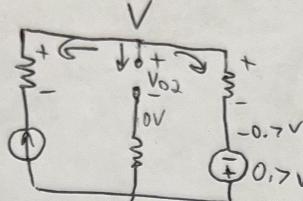
#### D<sub>3</sub> check

$$V_{D_3} < 0.7?$$

$$0 - V < 0.7$$

✓

### Guess D<sub>2</sub>=off, D<sub>3</sub>=on



$$-I_s + 0 + \frac{V-(-0.7)}{R_3} = 0$$

$$V\left(\frac{1}{R_3}\right) = I_s - \frac{0.7}{R_3}$$

$$V = 0.3V$$

#### D<sub>2</sub> check

$$V_{D_2} < 0.7?$$

$$0.3 - 0 < 0.7$$

✓

#### D<sub>3</sub> check

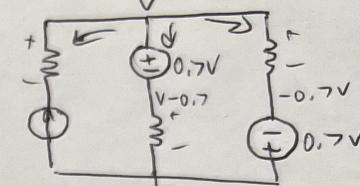
$$I > 0?$$

$$-\frac{V-(-0.7)}{R_3} > 0?$$

$$-1mA > 0$$

✗

### Guess D<sub>2</sub>=on, D<sub>3</sub>=on



$$-I_s + \frac{(V-0.7)-0}{R_2} + \frac{V-(-0.7)}{R_3} = 0$$

$$V\left(\frac{1}{R_2} + \frac{1}{R_3}\right) = I_s + \frac{0.7}{R_2} - \frac{0.7}{R_3}$$

$$V = 0.5V$$

#### D<sub>2</sub> check

$$I > 0?$$

$$\frac{V-0.7}{R_2} > 0?$$

$$-0.2mA > 0$$

✗

#### D<sub>3</sub> check

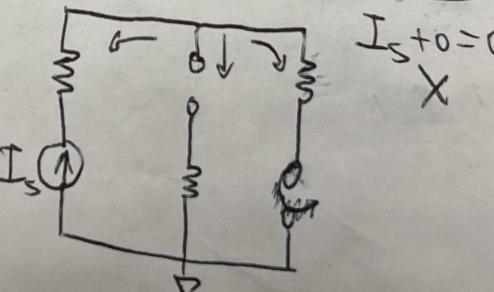
$$I > 0?$$

$$-\frac{V-(-0.7)}{R_3} > 0?$$

$$-1.2mA > 0$$

✗

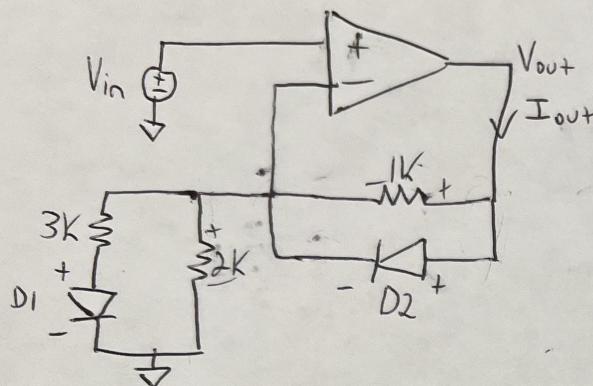
### Guess D<sub>2</sub>=off, D<sub>3</sub>=off



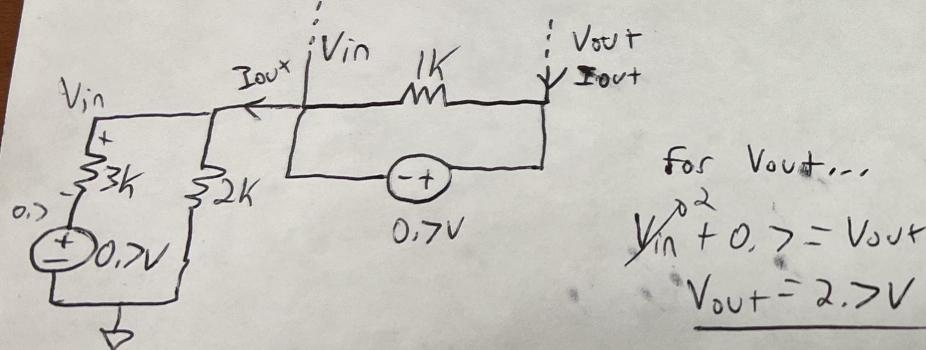
$$I_s + 0 = 0$$

✗

## Multiple diodes + op-amp



③ Guess  $D_1 = \text{on}$ ,  $D_2 = \text{on}$



$$\cdot I_{1K} = 0.7 \text{ mA}$$

$$\cdot I_{2K} = \frac{2}{2K} = 1 \text{ mA}$$

$$\cdot I_{3K} = \frac{2 - 0.7}{3K} = 0.43 \text{ mA}$$

Plug into B

$$\underline{I_{out} = 1.43 \text{ mA}}$$

$$V_{in} = 2V \rightarrow V_{out+} ? \quad I_{out} ?$$

① Op-amp rules

$$\rightarrow V^+ = V_{in} = V^-$$

$$\rightarrow i^+ = i^- = 0A$$

② Observations

A  $I_{out} = I_{1K} + I_{D2}$

B  $I_{out} = I_{2K} + I_{3K}$

$\bullet V_{D2} = V_{1K}$

$\hookrightarrow$  If  $D_2$  on,  $I_{1K} = \frac{0.7}{1K} = 0.7 \text{ mA}$

and

$$V_{in} + 0.7 = V_{out}$$

$\bullet I_{2K} = \frac{V_{in} - 0}{2K}$  — always true, independent of  $D_2, D_3$  modes!

D1 check

$I > 0?$   
 $I_{3K} = 0.43 \text{ mA}$



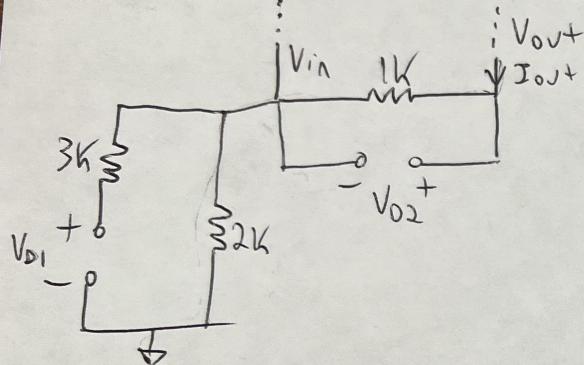
D2 check

$I > 0?$   
 $I_{D2} = \text{use } \boxed{A}$   
 $= 0.73 \text{ mA}$



$V_{in} = 0.5V \rightarrow V_{out}?$   $I_{out}?$

OFF, off



$$\cdot I_{out} = I_{1K} = I_{2K}$$

$$\cdot I_{2K} = \frac{V_{in}}{2K} = 0.25mA = I_{out}$$

$$\cdot V_{out} = V_{in} + I_{1K} \cdot 1K$$

$$V_{out} = 0.5 + 0.25mA \cdot 1K \approx$$

$$\underline{V_{out} = 0.75V}$$

$V_{in} = 0.5V$   
still

Change the value of the 2K  
→ what value causes D2 to turn on?

— how does 2K relate to D2?

$$\cdot I_{2K} = \frac{V_{in}}{2K} = I_{1K} \quad (2K \text{ affects } 1K \text{ current})$$

$$\cdot I_{1K} = \frac{V_{D2}}{1K} \quad \text{and for } D2 \text{ to turn on, need}$$

$$I_{1K} = I_{2K} \quad V_{D2} = 0.7V$$

$$\text{so, } \frac{V_{D2}}{1K} = \frac{V_{in}}{2K}$$

$$\frac{0.7}{1K} = \frac{0.5}{R}$$

$$\underline{R = 714\Omega} \quad \text{to switch mode}$$

Check D2

$$V_{D2} < 0.7$$

$$V_{out} - V_{in} < 0.7$$

$$0.75 - 0.5 < 0.7$$



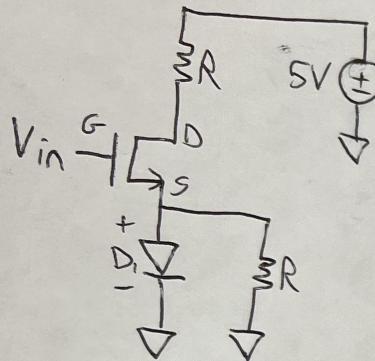
Check D1

$$V_{D1} < 0.7$$

$$V_{in} - 0 < 0.7$$



## Diode + MOSFET



$$V_T = 1.3V$$

$$k = 0.6 \text{ mA/V}^2$$

$$R = 1\text{ k}\Omega$$

$V_{in} = 4V$ , find modes

$$V_G = V_{in}$$

$$V_D = ? = 5 - I_{DS} \cdot R$$

$$V_s = ?$$

assuming  $D_1$  on...

$$V_{G-S} > V_T \Rightarrow$$

$$4 - 0.7 > 1.3$$

✓

$$\text{Check: } V_{DS} > V_{G-S} - V_T$$

$$3.1 > 2$$

✓

check DI

$I > 0?$

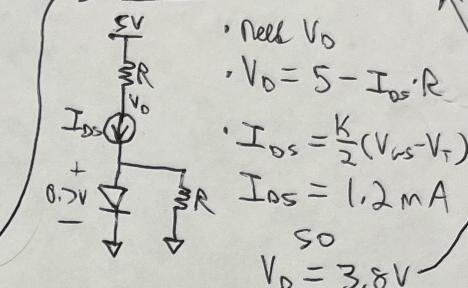
$$I_{DS} = I + I_R$$

$$1.2 \text{ mA} = I + \frac{0.7}{R}$$

$$I = 0.5 \text{ mA}$$

✓

Guess Sat



• Need  $V_D$

$$V_D = 5 - I_{DS} \cdot R$$

$$I_{DS} = \frac{k}{2}(V_{GS} - V_T)^2$$

$$I_{DS} = 1.2 \text{ mA}$$

$$\text{so } V_D = 3.8 \text{ V}$$

$V_{in} = 1V$ , find modes

$$V_G = V_{in}$$

$$V_D = ? = 5 - I_{DS} \cdot R$$

$$V_s = ? = 0.7V \text{ IF } D_1 \text{ on}$$

→ Let's guess  $D_1$  on...

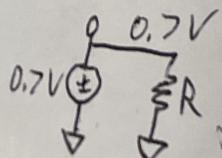
①  $V_{G-S} > V_T \Rightarrow$

$$1 - 0.7 > 1.3$$

X → transistor off

5V

$\frac{5V}{R}$



transistor off  
diode off

② Check DI

$I > 0?$

$$I = -\frac{0.7}{R}$$

X

Check DI off

(transistor still off)

5V

$\frac{5V}{R}$

$$V_{D1} < 0.7 \Rightarrow$$

$$0 - 0 < 0.7$$

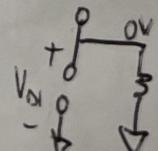
✓

③  $V_s$  changes since diode mode changed, recheck trans.

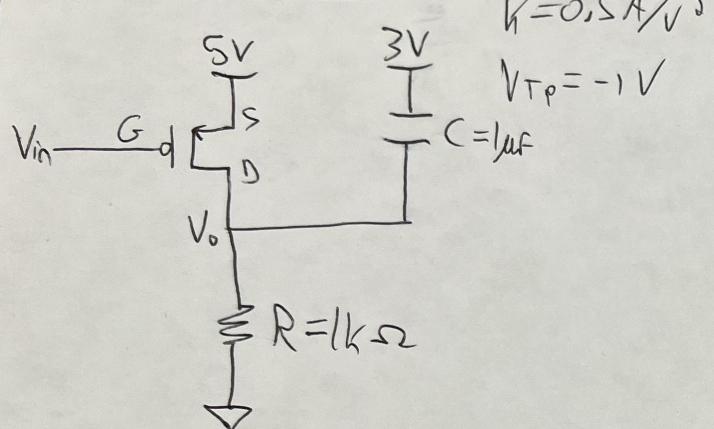
$$V_{G-S} < V_T \Rightarrow$$

$$1 - 0 < 1.3 \Rightarrow$$

✓



### RC + MOSFET



①  $t < 0$

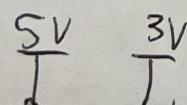
$$V_{SG} > V_T \quad ?$$

$$5-5 > |-1|$$

X off

$$V_T = |V_{Tn}|$$

$$V_T = V_{Tn}$$



$$V_c(0^-) = V_c(0^+) = 3 - 0 = \underline{\underline{3V}}$$

$$V_{in} = 5V, \text{ long time} \longrightarrow V_{in} = 0V @ t=0$$

Find  $V_o(t)$ ,  $t > 0$

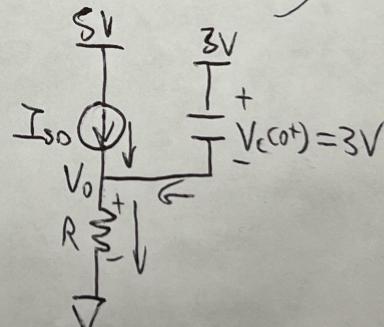
②  $t > 0$

$$V_{SG} > V_T \quad ?$$

$$5-0 > |-1|$$

✓ on

Guess Sat



@ check mode at  $0^+$

$$V_o(0^+) = 3 - V_c(0^+) = 0V = V_D(0^+)$$

~~$V_{SG} > V_{Tn}$~~

$$5-0 > 5-0-|-1|$$

✓ Saturation

③ Find  $V_o(t)$

$$I_{SD} + i_c = i_R$$

$$\frac{k}{2}(V_{SG}-V_T)^2 + C \frac{d}{dt} V_c(t) = \frac{V_o(t)-0}{R}$$

$$4 + C \frac{d}{dt} (3 - V_o(t)) = \frac{V_o(t)}{R}$$

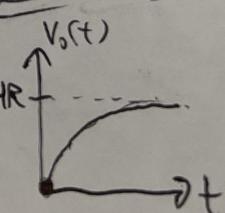
$$\frac{d}{dt} V_o(t) + \frac{1}{RC} V_o(t) = \frac{4}{C}$$

$$V_o(t) = \frac{B}{A} + K e^{-At}$$

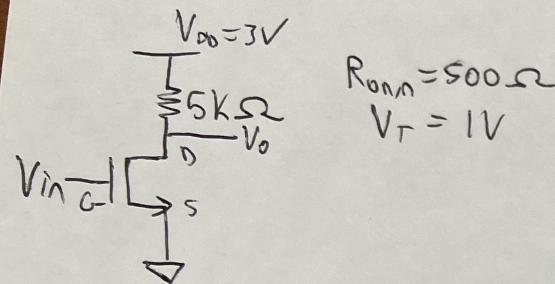
$$V_o(t) = 4R + K e^{-t/RC}$$

$$V_o(0^+) = 0 = 4R + K e^{0/RC}$$

$$K = -4R$$



## SR Model (from lecture)

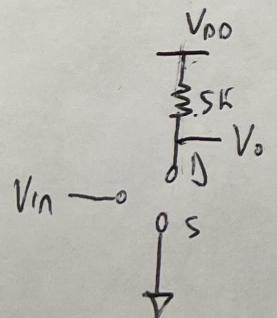


$$\underline{V_{in} = 0V}$$

$$V_{GS} > V_T ?$$

$$0 - 0 > 1 \quad X$$

off



$$V_o = \cancel{V_{DD}} - \cancel{5K} \cdot 0A$$

$$\boxed{V_o = V_{DD}}$$

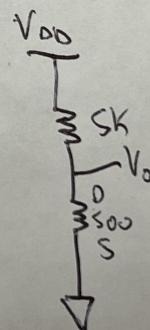
$$\boxed{P_m = V_{DS} I_{DS} = 0W}$$

$$\underline{V_{in} = 5V}$$

$$V_{FS} > V_T ?$$

$$5 - 0 > 1 \quad \checkmark$$

on



$$V_o = V_{DD} \frac{R_{on}}{R_{on,n} + R} = 0.273V$$

$$P_m = V_{DS} I_{DS} = \frac{V_{DS}^2}{R_{on,n}} = \frac{V_o^2}{R_{on,n}}$$

$$P_{VDD} = V_{DD} I_{DS} = \frac{V_{DD}^2}{R + R_{on,n}}$$