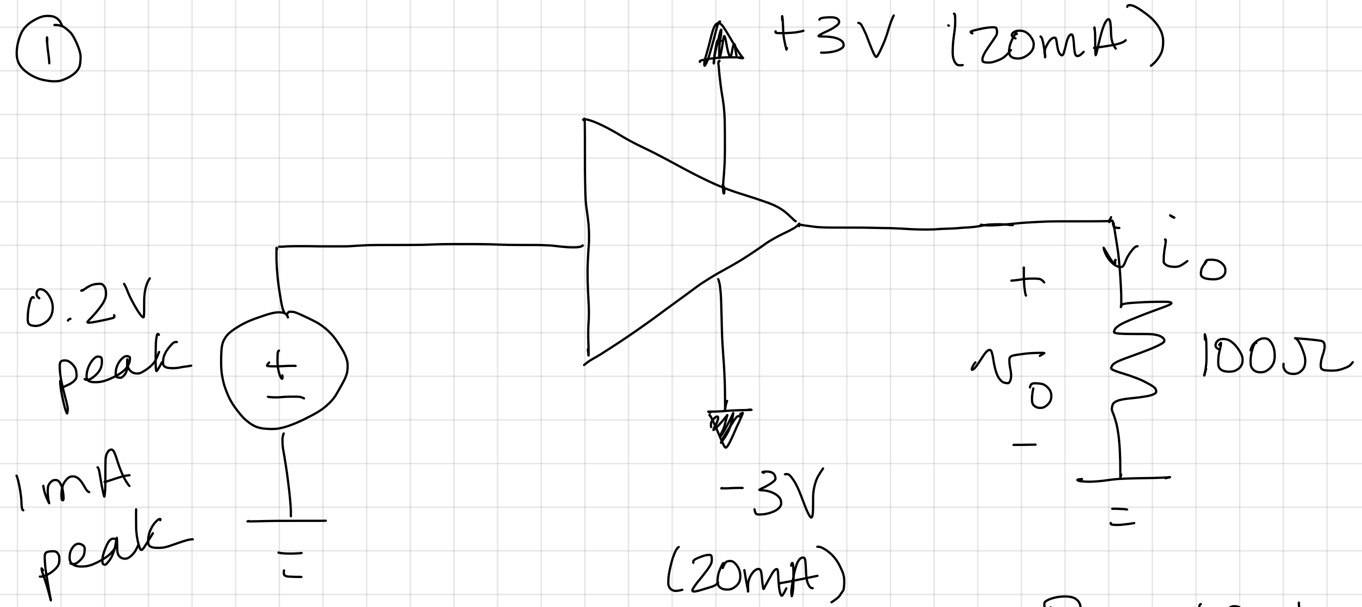
EE 315 HW #1 Solutions

1



$P_o = 48.4\,mW$

$$P_o = \frac{v_o^2}{100}$$

$$v_o^2 = 100(48.4\times10^{-3})$$

$$v_o = 2.2\,V$$

$$i_o = \frac{v_o}{100} = 22.0\,mA$$

a) $$A_v = \frac{v_o}{v_i} = \frac{2.2}{0.2} = 11\,\frac{V}{V} \text{ or } 20.83\,dB$$

$$A_i = \frac{i_o}{i_i} = \frac{22\times10^{-3}}{1\times10^{-3}} = 22\,\frac{A}{A}$$

or 26.85 dB

$$A_p = \frac{P_o}{P_i} = \frac{v_o i_o}{v_i i_i} = \frac{(2.2)(22\times10^{-3})}{(.2)(1\times10^{-3})}$$

$$A_p = 242 \ \frac{W}{W} \ \text{or} \ 23.84\,dB$$

b) * now we have to deal w/ rms units or remember that <u>average</u> power is $\frac{1}{2}VI$.

$$P_{dc} + P_i = P_L + P_{diss}$$

same as P_o

$$P_{dc} = 3(20\times10^{-3})(2)$$

there are 2 supplies

assume <u>average values</u>

$$P_{dc} = 120\,mW$$

$$P_o = \frac{1}{2}\left(\frac{v_o^2}{100}\right) = 24.2\,mW$$

$$P_i = \frac{P_o}{A_p} = \frac{24.2}{242} = 0.1\,mW$$

$$\eta = \frac{P_o}{P_{dc}} \times 100 = \frac{24.2}{120} \times 100$$

$\eta = 20.17\%$

c) $P_{diss} = P_{dc} + P_i - P_o$

$$\boxed{P_{diss} = 95.9\ mW}$$

(2)

$v_o = A v_I$
$A = 200\ V/V$

DC supplies	input at clipping	output at clipping
$\pm 2V$	$\pm 8.5mV$	$v_o = \pm 200(8.5 \times 10^{-3})$ $\boxed{v_o = \pm 1.7\ V}$
$\pm 5V$	$\pm 21.5mV$	$v_o = \pm 200(21.5 \times 10^{-3})$ $\boxed{v_o = \pm 4.3V}$
$\pm 10V$	$\pm 42.5mV$	$v_o = \pm 200(42.5 \times 10^{-3})$ $\boxed{v_o = \pm 8.5V}$

so: for $\pm 2V$, $-1.7\ V \leq v_o \leq 1.7\ V$

$\pm 5V$, $-4.3\ V \leq v_o \leq 4.3\ V$

$\pm 10V$, $-8.5\ V \leq v_o \leq 8.5\ V$

clipping occurs at : ~ 85% of DC supply

$$\frac{1.7}{2} = 0.85 \;;\; \frac{4.3}{5} = 0.86$$

$$\frac{8.5}{10} = 0.85$$

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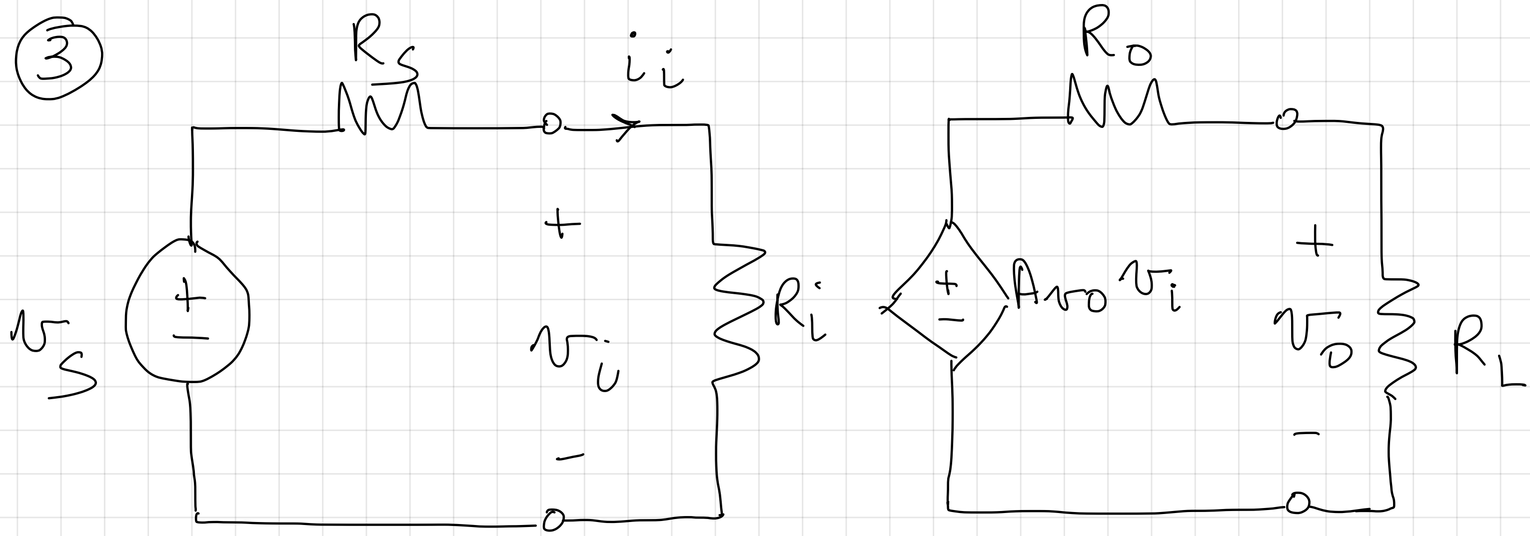
(3)



$R_s = 200\,k\Omega$ $\quad R_i = 1\,M\Omega$ $\quad R_L = 150\,\Omega$

$v_s = 2\,V$ peak $\quad R_o = 40\,\Omega$ $\quad A_{vo} = 1\,V/V$

$$v_o = \frac{R_L}{R_L + R_o}\left(A_{vo} v_i\right)$$

$$v_i = \frac{R_i}{R_i + R_s} v_s$$

$$v_o = \left(\frac{R_L}{R_L+R_o}\right)(A_{vo})\left(\frac{R_i}{R_i+R_s}\right)v_s$$

$$\frac{v_o}{v_s} = \left(\frac{150}{150+40}\right)(1)\left(\frac{1\times10^6}{1\times10^6+200\times10^3}\right)$$

$$\frac{v_o}{v_s} = (0.789)(1)(0.833)$$

means attenuation

$$\boxed{A_v = \frac{v_o}{v_s} = 0.6575 \text{ V/V or } -3.64\,\text{dB}}$$

$$v_o = 0.6575\cdot(2) = 1.315$$

$$i_o = \frac{v_o}{R_L} = \frac{1.315}{150} = 8.77\,\text{mA}$$

$$i_i = \frac{v_s}{R_i+R_s} = \frac{2}{1.2\times10^6} = 1.67\,\mu\text{A}$$

$$\boxed{A_i = \frac{i_o}{i_i} = 5.25\times10^3 \text{ A/A or } 74.4\,\text{dB}}$$

$$A_p = \frac{P_o}{P_s} = \frac{v_o i_o}{v_s i_s} = \frac{(1.315)(8.77 \times 10^{-3})}{(2)(1.67 \times 10^{-6})}$$

$$A_p = 3.45 \times 10^{3} \ \frac{W}{W}$$

or 35.38 dB

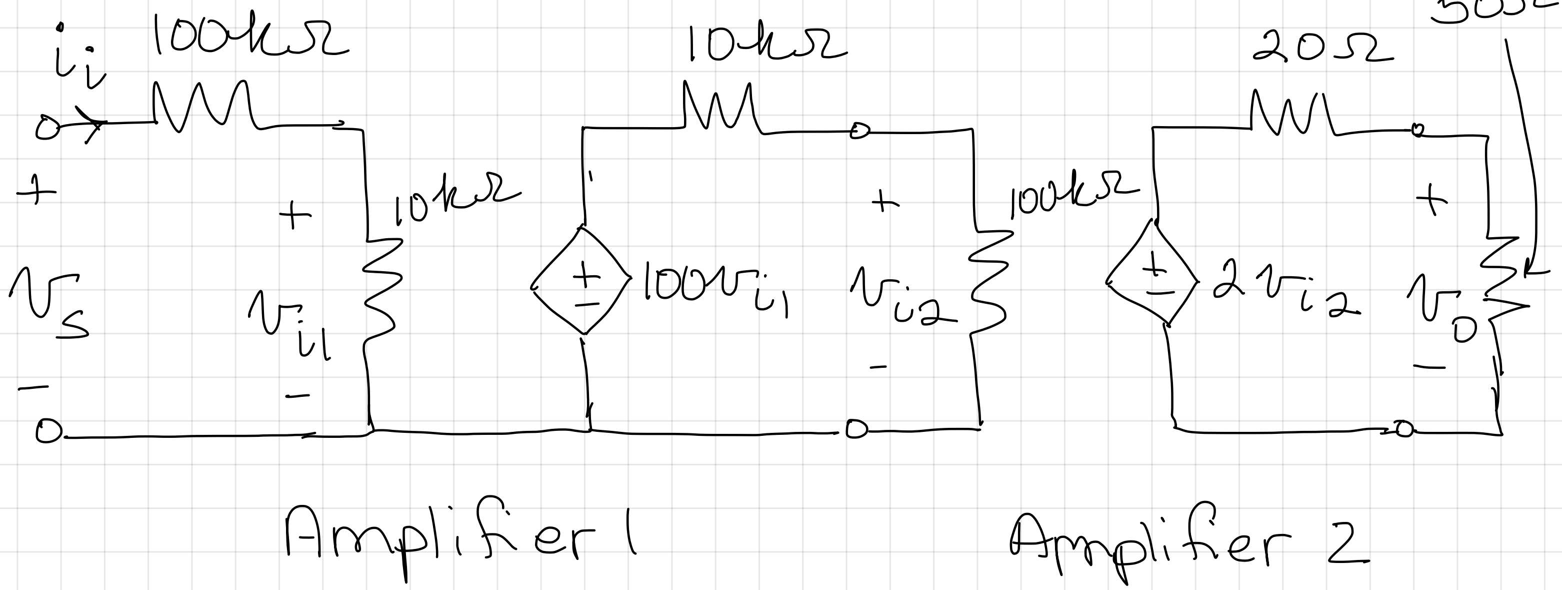
I would also except:

$$A_p = \frac{P_o}{P_i} = \frac{v_o i_o}{i_i^2 (R_i)} = \frac{(1.315)(8.77 \times 10^{-3})}{(1.67 \times 10^{-6})^2 (1 \times 10^{6})}$$

$$A_p = 4.14 \times 10^{3} \ \frac{W}{W} \text{ or } 36.16 \text{ dB}$$

does not take into account the source resistance - it is pretty minimal.

(4) $v_s = 10\text{mV}$ $40\text{dB} = 100\text{V/V}$ $6\text{dB} = 2\text{V/V}$



solve for A_v, A_i, A_p

$$\frac{v_o}{v_s} = \left(\frac{50}{50+20}\right)(2)\left(\frac{100\times10^3}{110\times10^3}\right)(100)\left(\frac{10\times10^3}{110\times10^3}\right)$$

$$= (0.714)(2)(0.909)(100)(0.0909)$$

$$\frac{v_o}{v_s} = 23.14\ \frac{V}{V}$$

A_v

$$v_o = 23.14(10\times10^{-3})$$
$$= 231.47\text{mV}$$

$$i_o = \frac{v_o}{50} = 4.63\text{mA}$$

$$i_i = \frac{v_s}{110\times10^3} = \frac{10\times10^{-3}}{110\times10^3}$$

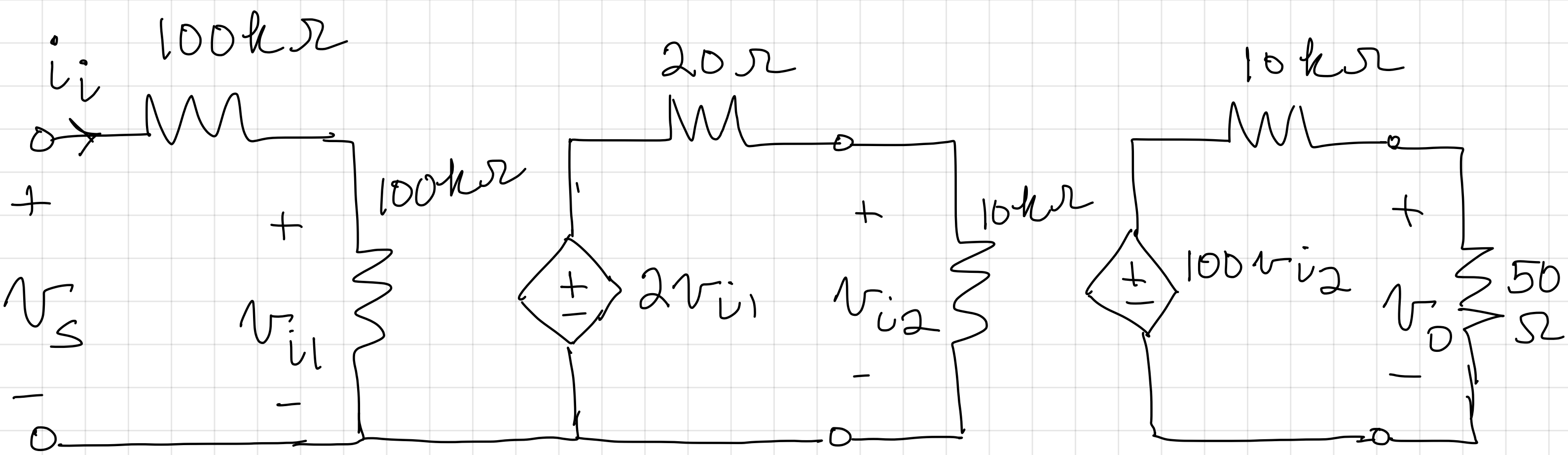
$$i_i = 9.09\times10^{-8}\ A$$

$$A_i = \frac{i_o}{i_i} = \frac{4.63\times10^{-3}}{9.09\times10^{-8}}$$

$$= 5.09\times10^{4}\ A/A$$

$$A_p = \frac{P_o}{P_s} = \frac{v_o i_o}{v_s i_i} = 1.18\times10^{6}\ \frac{W}{W}$$

Now, let's switch the order:



Amplifier 2 Amplifier 1

$$\frac{v_o}{v_s} = \left(\frac{50}{50+10\times10^3}\right)(100)\left(\frac{10\times10^3}{10\times10^3+20}\right)(2)\left(\frac{100\times10^3}{200\times10^3}\right)$$

$$= (0.005)(100)(0.998)(2)(0.5)$$

$$\boxed{\frac{v_o}{v_s} = 0.5 \ \frac{V}{V}} \quad A_v$$

$$v_o = 0.5(10 \times 10^{-3})$$

$$v_o = 5 \ mV$$

$$i_o = \frac{v_o}{50} = 0.1 mA$$

$$i_i = \frac{v_s}{200 \times 10^3} = 5 \times 10^{-8} A$$

$$A_i = \frac{i_o}{i_i} = 2{,}000 \ A/A$$

$$A_p = \frac{v_o i_o}{v_s i_i} = 1{,}000 \ W/W$$

Compare

order	A_v	A_i	A_p
Amp1, Amp2	23.14 V/V	5.09×10^4 A/A	1.18×10^6 W/W
Amp2, Amp1	0.5 V/V	2000 A/A	1000 W/W

which is better?

It depends, I could make an argument for both.

Amp1, Amp2 : good A_v but very high A_i & A_p - can the load handle it?

Amp2, Amp1 : A_v is small - maybe too small depending on the application but A_i + A_p are pretty good.

My point here is that there is no "right" answer - it depends on the application and what is needed at the load.

And - don't simply pick a stage based on one factor. Based on lectures, you might have been tempted to just go w/ the high R_i as Amp stage 1 and low R_o as Amp stage 2, that design plan is never a good one!

Get used to this!

We are not in EE 213 land anymore!

EE 315 Module 2A Practical Problem Solutions

(1)

$R_i = 80\,k\Omega$

$$G = \frac{200}{80} = 2.5\ V/V$$

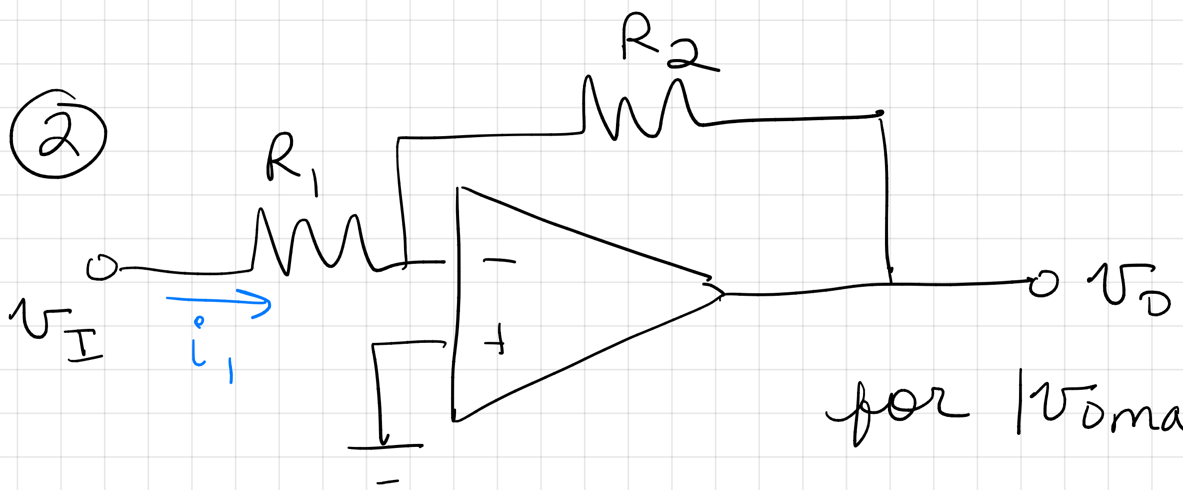
$R_i = 15\,k\Omega$

$$G = \frac{30}{15} = 2\ V/V$$

$R_i = 40\,k\Omega$

$$G = \frac{90}{40} = 2.25\ V/V$$

(2)



for $|v_{O\,max}| = 10V$

$$|v_{I\,max}| = \frac{10}{5} = 2V$$

$i_{max} = 50 \times 10^{-6} A$

$-10V \leq v_O \leq 10V$

$$G = -5\frac{V}{V}$$

$$i_{max} = \frac{v_I}{R_1} = \frac{2}{R_1} = 50 \times 10^{-6}$$

$$\boxed{R_1 = 40\,k\Omega}$$

$$-5 = \frac{-R_2}{R_1}$$

$R_2 = 5R_1$

$$\boxed{R_2 = 200\,k\Omega}$$

check R_2 current

$$\left|\frac{0 - v_{o\,max}}{200\times10^3}\right| \le 50\,\mu A$$

$$\left|\frac{-10}{200\times10^3}\right| = 50\,\mu A$$

okay!

③ for standard inverting configuration

$$G = \frac{-R_2}{R_1}$$

max $R = 100\,k\Omega$

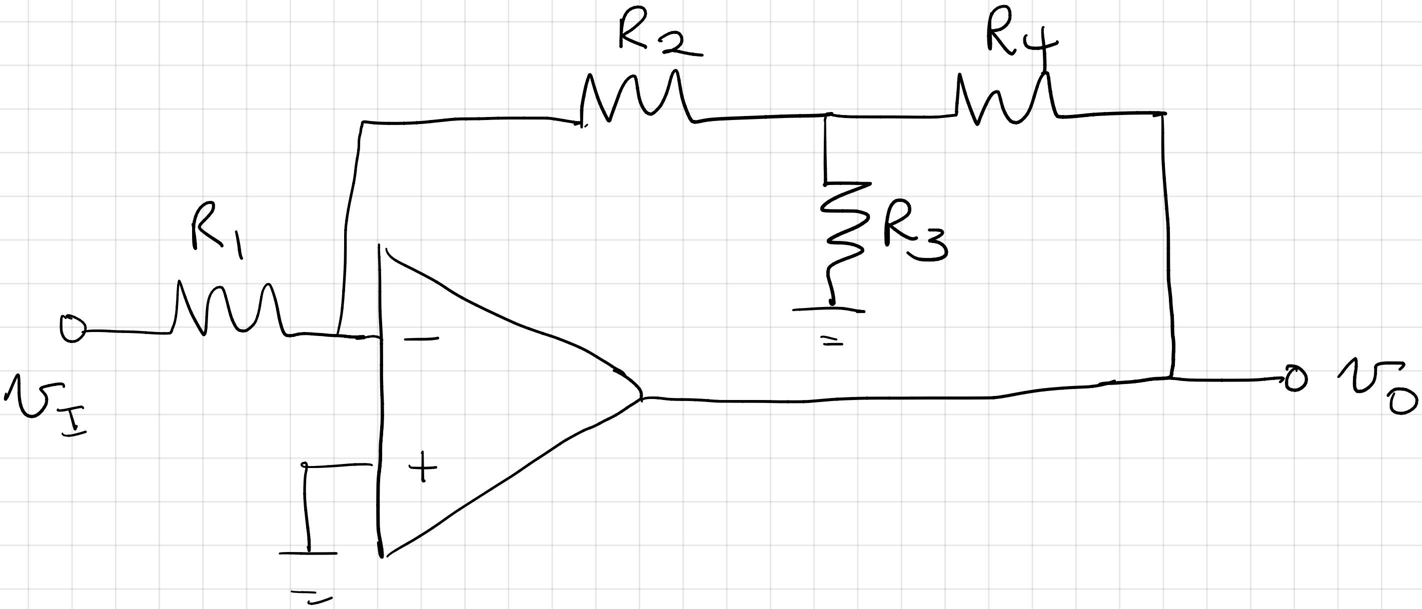
$G = -1000$ V/V

$$R_i = R_1$$

$$1000 = \frac{\cancel{R_2}\ 100\,k\Omega}{R_1}$$

$$\boxed{R_i = 10\,k\Omega}$$

$$\boxed{\begin{aligned} R_1 &= 10\,k\Omega \\ R_2 &= 100\,k\Omega \end{aligned}}$$



$$\frac{v_O}{v_I} = -\frac{R_2}{R_1}\left(\frac{R_4}{R_2} + \frac{R_4}{R_3} + 1\right)$$

let $R_1 = R_2 = R_4 = 100\ k\Omega$

$$\frac{v_O}{v_I} = \frac{-\cancel{100}^{1}}{\cancel{100}}\left(\frac{\cancel{100}^{1}}{\cancel{100}} + \frac{100 \times 10^3}{R_3} + 1\right) = -1000$$

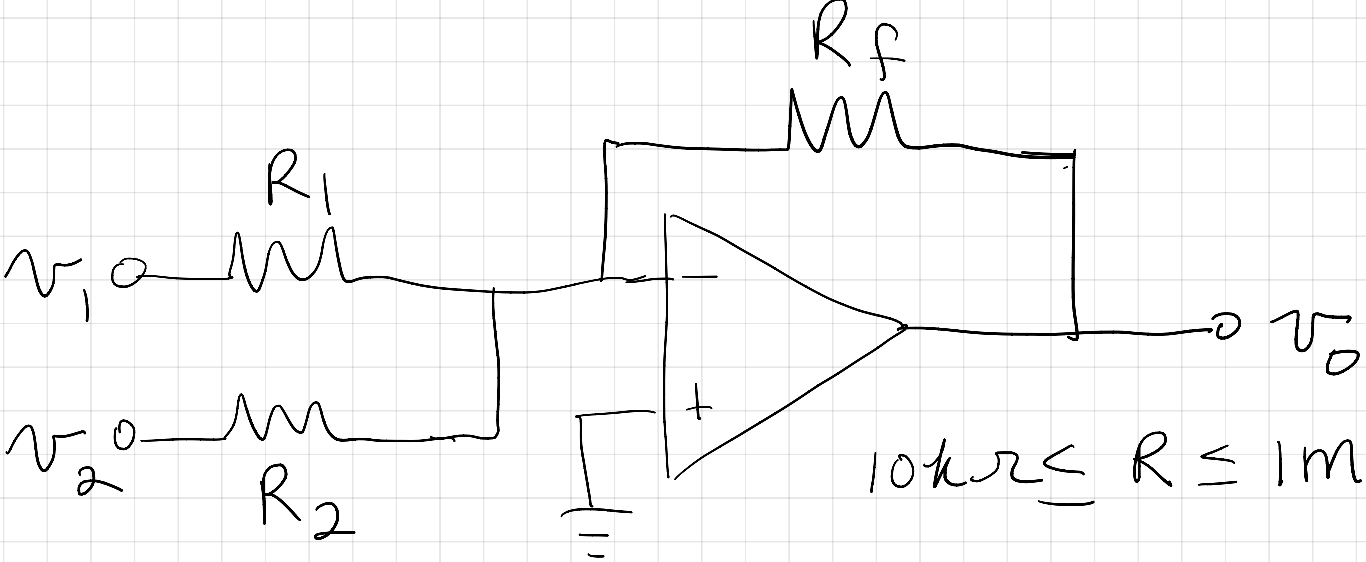
$$2 + \frac{100 \times 10^3}{R_3} = 1000$$

$$\boxed{R_i = 100 k\Omega}$$

$$\frac{100 \times 10^3}{R_3} = 998$$

$$\boxed{R_3 = 100.20\ \Omega}$$

④ $\boxed{v_o = -2v_1 - 8v_2}$



$10k\Omega \leq R \leq 1M\Omega$

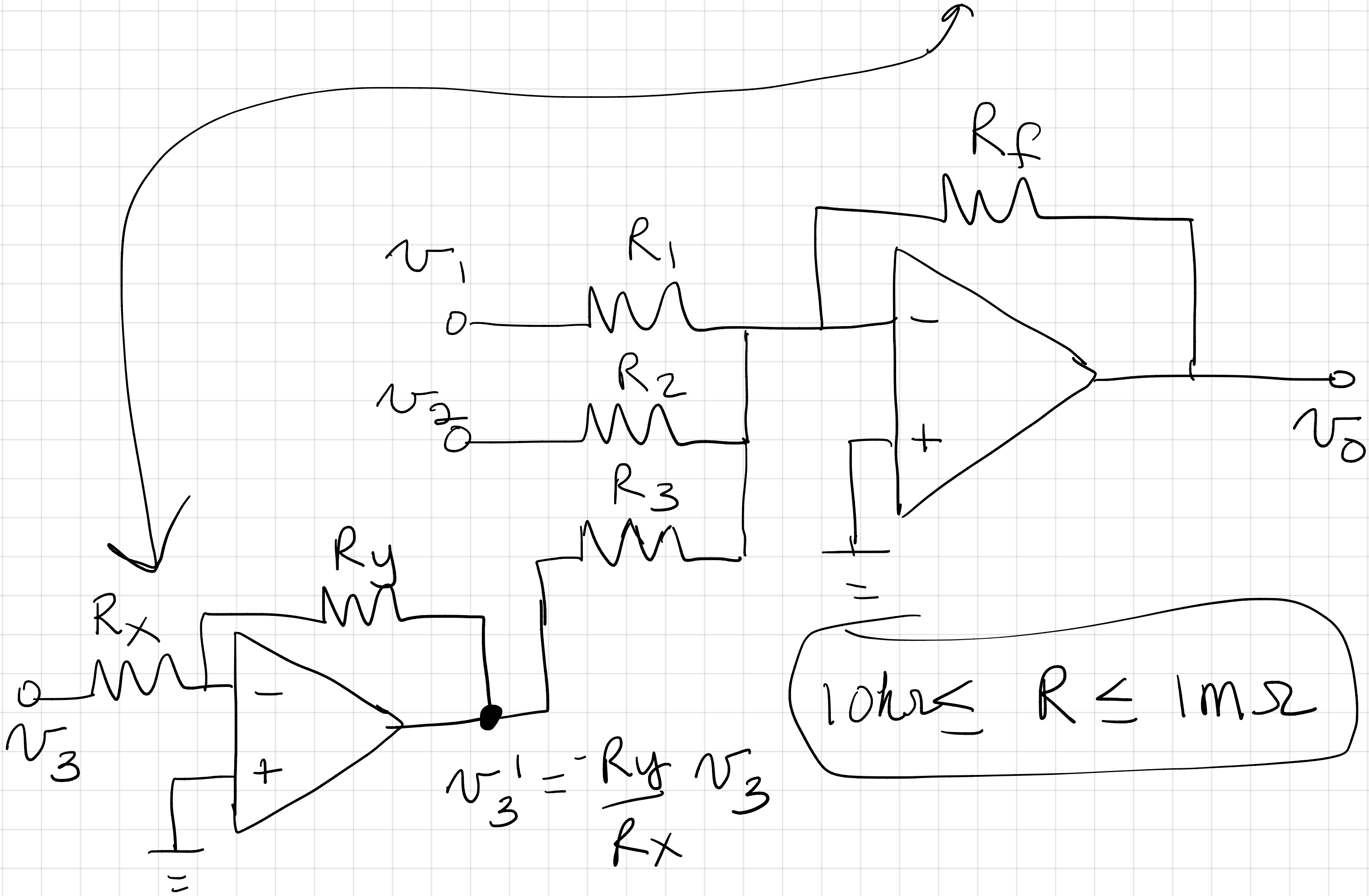
$$v_o = -\frac{R_f}{R_1} v_1 - \frac{R_f}{R_2} v_2$$

$$\frac{R_f}{R_1} = 2 \qquad \frac{R_f}{R_2} = 8$$

let

$$\boxed{\begin{aligned} R_f &= 400k\Omega \\ R_1 &= \frac{R_f}{2} = 200k\Omega \\ R_2 &= \frac{R_f}{8} = 50k\Omega \end{aligned}}$$

④ b. $v_0 = -12v_1 - 3v_2 + 2v_3$



$$v_0 = -\frac{R_f}{R_1} v_1 - \frac{R_f}{R_2} v_2 - \frac{R_f}{R_3} v_3'$$

$$v_0 = -\frac{R_f}{R_1} v_1 - \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} \cdot \frac{R_y}{R_x} v_3$$

$$\frac{R_f}{R_1} = 12 \qquad \frac{R_f}{R_2} = 3 \qquad \frac{R_y}{R_x} \frac{R_f}{R_3} = 2$$

let $R_f = 600\,k\Omega$

$R_y = 10\,k\Omega$

$R_x = 10\,k\Omega$

$R_3 = \frac{R_y}{R_x} \cdot \frac{R_f}{2}$

$\boxed{R_3 = 300\,k\Omega}$

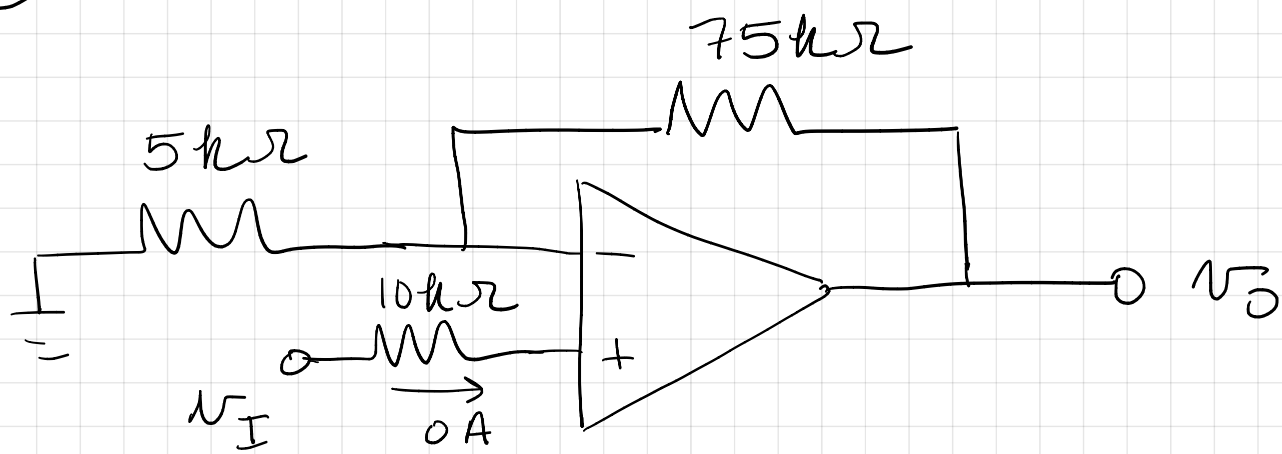
$R_1 = \frac{R_f}{12}$

$\boxed{R_1 = 50\,k\Omega}$

$R_2 = \frac{R_f}{3}$

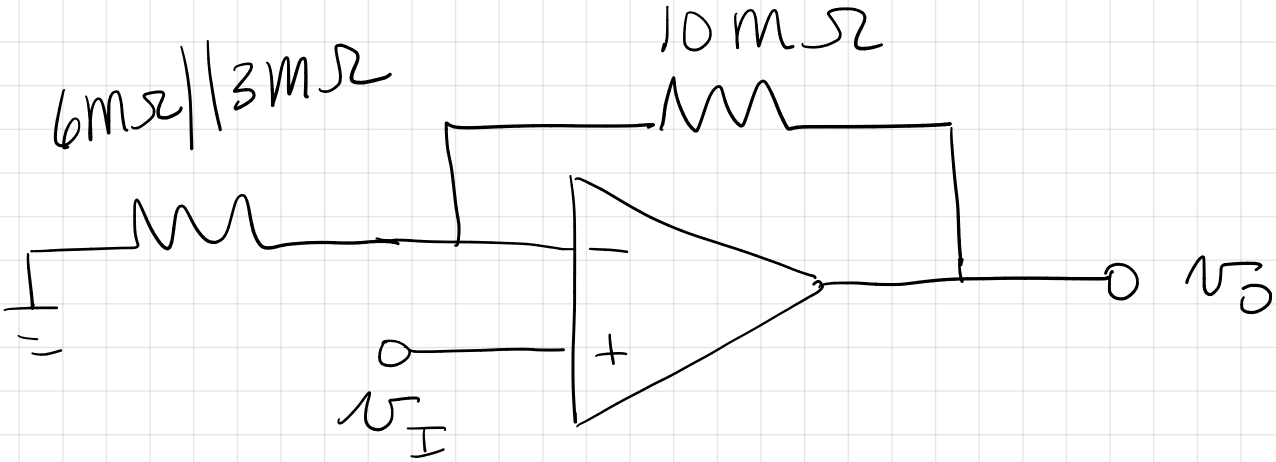
$\boxed{R_2 = 200\,k\Omega}$

5



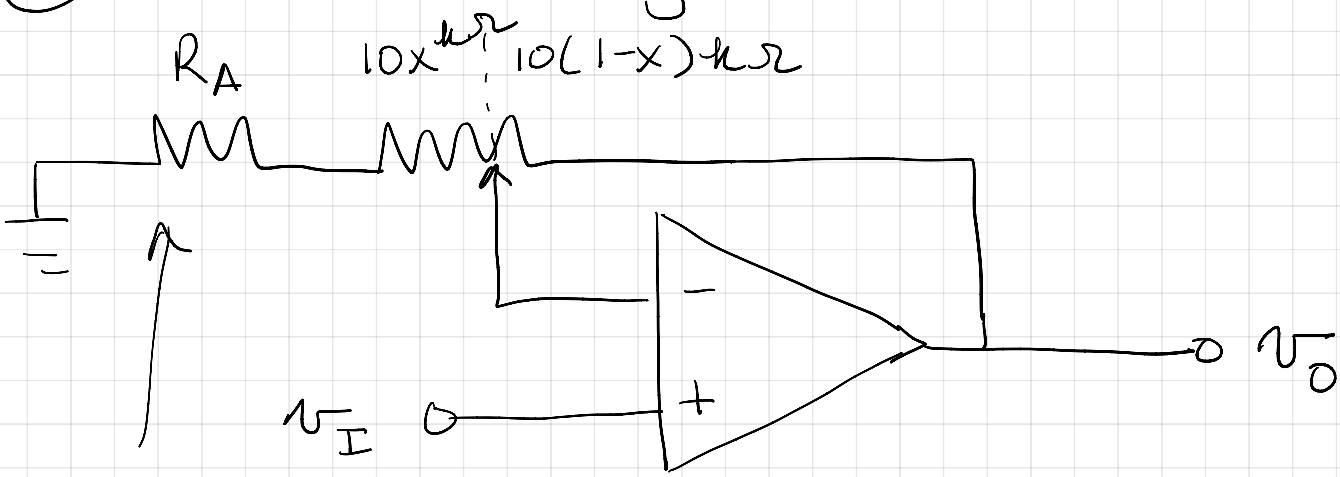
$R_i = \infty$

$G = 1 + \frac{75}{5} = 16\,V/V$



$R_i = \infty$ $\qquad G = 1 + \frac{10}{2} = 6 \frac{V}{V}$

(6) (to control gain



add a fixed resistor that prevents the gain from going to infinity

when $x = 0$ (max gain)

$R_1 = R_A$

$R_2 = 10\,k\Omega$

$G = 11$ V/V

$x = 1$ (min gain)

$R_2 = 0$

$R_1 = R_A + 10\,k\Omega$

$G = 1$

$$G = 1 + \frac{R_2}{R_1} = 11$$

$$\frac{R_2}{R_1} = 10$$

$$\frac{10k\Omega}{R_A} = 10$$

$$\boxed{R_A = 1k\Omega}$$

7. inverting amp

$$\left.\begin{aligned} R_2 &= 100k\Omega \\ R_1 &= 5k\Omega \end{aligned}\right\}$$ chose these at random

ideal : $G = -\frac{R_2}{R_1} = -20V/V$

finite : $$G = \frac{-R_2/R_1}{1 + \frac{1}{A}\left(1 + \frac{R_2}{R_1}\right)}$$

A (V/V)	G (V/V)
100	-16.53
1,000	-19.59
10,000	-19.96
100,000	-19.996
1,000,000	-19.9996

looking at this range
A changes by a factor of 1000
G changes by a factor of 1.02

pretty stable yay!

cont non-inverting

ideal $R_2 = 100k\Omega$, $R_1 = 5k\Omega$ } again chose random

$$\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1} = 21 \text{ V/V}$$

non ideal
$$G = \frac{1 + R_2/R_1}{1 + \frac{1 + R_2/R_1}{A}}$$

A (V/V)	G (V/V)
100	17.35
1,000	20.57
10,000	20.956
100,000	20.9956
1,000 000	20.9996

a

looking at this range
A changes by a factor of 1000
G changes by a factor of 1.02

pretty stable yah!

module 2B practice problem solutions

(1) Difference Amp (assume ideal & matched resistors)

$R_{id} = 2R_1 = 50\,k\Omega$

$\boxed{R_1 = 25\,k\Omega}$

$A_d = 50 = \frac{R_2}{R_1}$ $\boxed{R_2 = 1.25\,M\Omega}$

for $A_{cm} = 0$ $\boxed{R_4 = R_2 = 1.25\,M\Omega}$

$\boxed{R_1 = R_3 = 25\,k\Omega}$

(2) since $R_1 \neq R_3$
$R_2 \neq R_4$

$$\boxed{\begin{aligned} R_1 &= 10k\Omega \\ R_2 &= 55k\Omega \\ R_3 &= 6k\Omega \\ R_4 &= 58k\Omega \end{aligned}}$$

$$A_{cm} = -\frac{R_2}{R_1} + \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)$$

$$A_d = \frac{1}{2}\left(\frac{R_2}{R_1} + \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)\right)$$

$$A_{cm} = \frac{-55}{10} + \left(1 + \frac{55}{10}\right)\left(\frac{58}{6+58}\right)$$

$$\boxed{A_{cm} = 0.39 \ V/V}$$

$$A_d = \frac{1}{2}\left(\frac{55}{10} + \left(1 + \frac{55}{10}\right)\left(\frac{58}{6+58}\right)\right)$$

$$\boxed{A_d = 5.70 \ V/V}$$

$$CMRR = 20 \log \left| \frac{A_d}{A_{cm}} \right| = 23.29 \ dB$$

③ $$A_d = \left(1 + \frac{2R_2}{2R_1}\right)\underbrace{\left(\frac{R_4}{R_3}\right)}_{\text{second gain stage}}$$

I didn't specify the size of the pot. I chose $100k\Omega$

lots of possible designs!

$$\frac{R_4}{R_3} = 2\frac{V}{V} \qquad \text{let } \boxed{\begin{aligned} R_4 &= 200k\Omega \\ R_3 &= 100k\Omega \end{aligned}}$$

$$2R_1 = R_f + 100k\Omega \begin{cases} \text{max}: R_f + 100k\Omega \\ \text{min}: R_f \end{cases}$$

$$A_d = \left(1 + \frac{2R_2}{2R_1}\right)(2)$$

$A_d = 5$ for $2R_1$ at max value

$A_d = 500$ for $2R_1$ at min value

$$\left(1 + \frac{2R_2}{R_f + 100k}\right)(2) = 5$$

$$\boxed{2R_2 = 1.5\left(R_f + 100 \times 10^3\right)}$$

$$\left(1 + \frac{2R_2}{R_f}\right)(2) = 500$$

$$\boxed{2R_2 = 249 R_f}$$

$$249 R_f = 1.5R_f + 150\times10^3$$

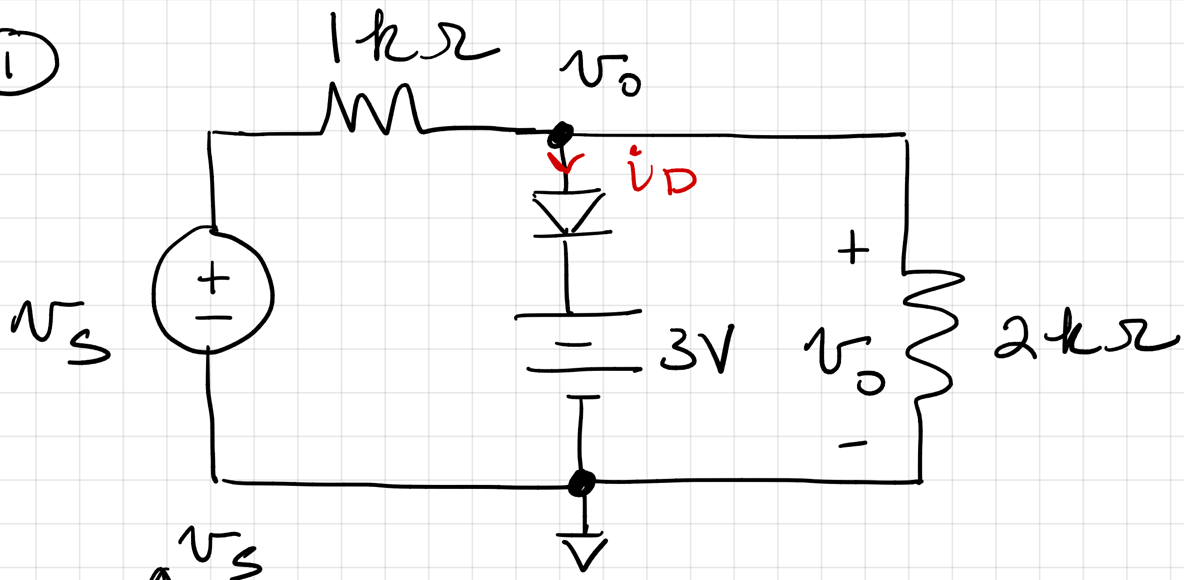
$$247.5R_f = 150\times10^3$$

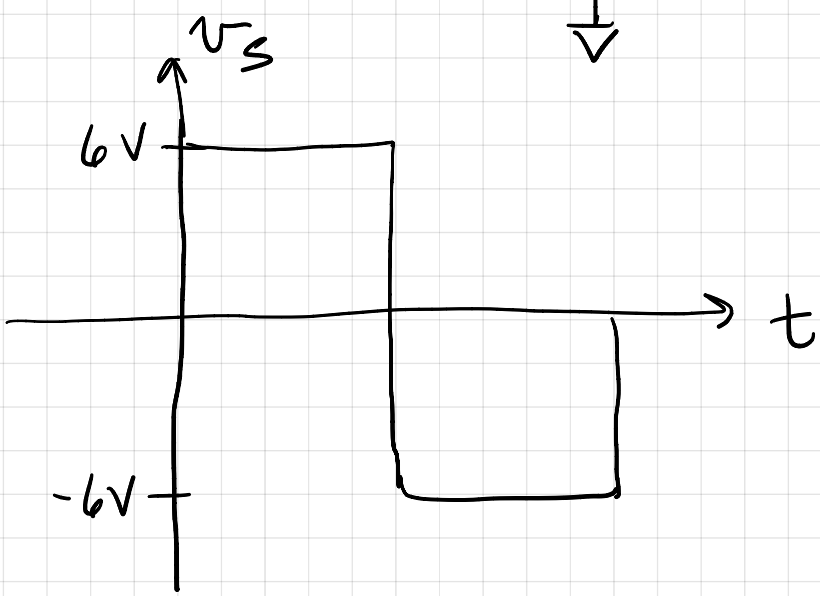
$$\boxed{\begin{aligned} R_f &= 606.06\,\Omega \\ R_2 &= 75.45\,k\Omega \end{aligned}}$$

EE 315

Homework #3 – Solutions

1





by nodal analysis:

$$\frac{v_o - v_s}{1000} + i_D + \frac{v_o}{2000} = 0$$

$$i_D = \frac{v_s}{1000} - \left(\frac{v_o}{1000} + \frac{v_o}{2000}\right)$$

$$i_D = \frac{v_s}{1000} - \frac{v_o(1.5)}{1000}$$

$$i_D = v_S - 1.5\, v_O \quad (mA)$$

if diode is on : $i_D > 0$

$v_O = 3V$

there are two values of v_S :

$v_S = +6V$ and $v_S = -6V$

for $v_S = 6V \Rightarrow$ assume diode on

$v_O = 3V$, $i_D = 6 - 1.5(3)$

$i_D = 1.5mA$

yay! diode is on

for $v_S = -6V \Rightarrow$ assume diode on

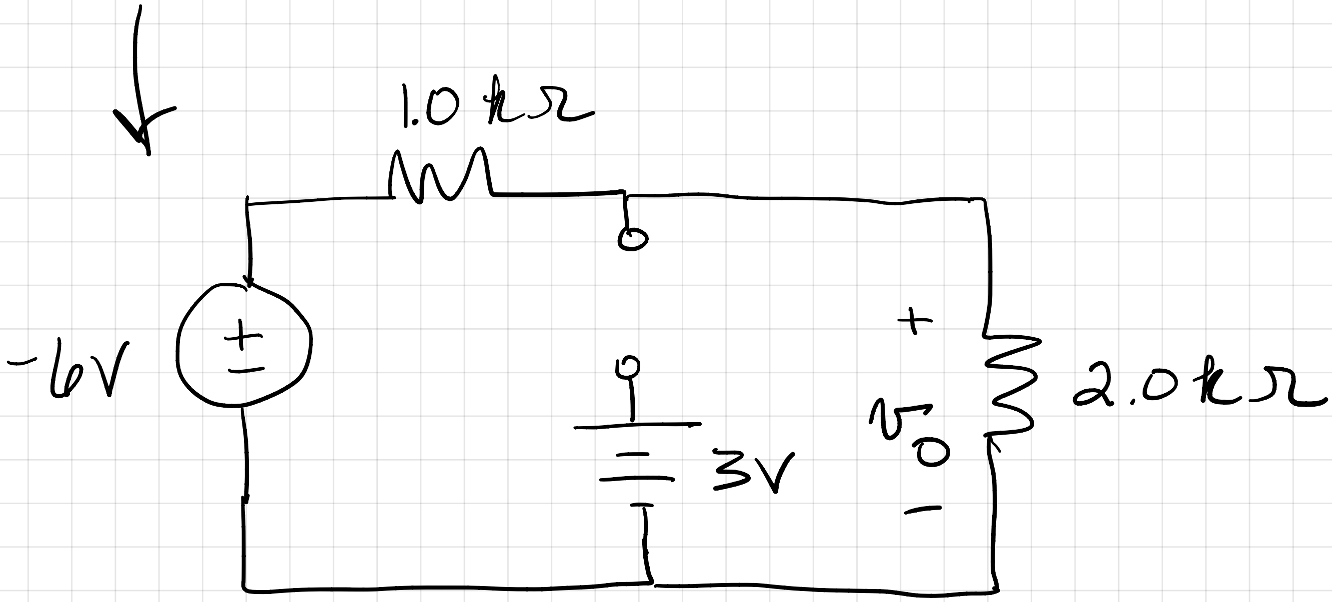
$v_O = 3V$, $i_D = -6 - 1.5(3)$

$= -10.5mA$

$i_D < 0$

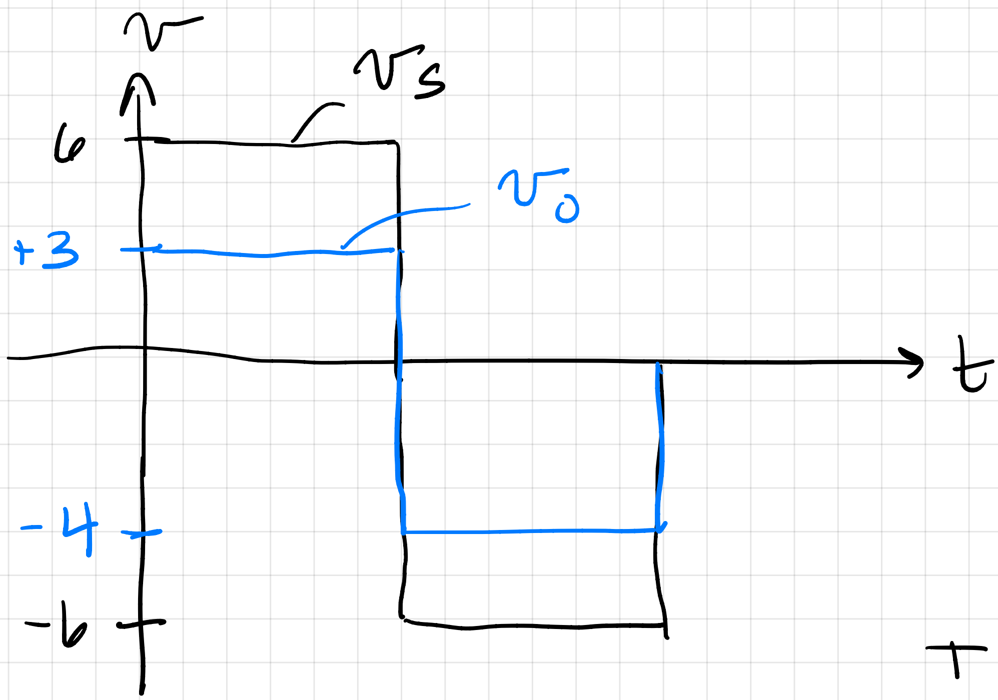
Diode is off!

when the diode is off



by voltage division

$$v_o = -6\left(\frac{2}{3}\right) = -4V$$



$$\text{Average value} = \frac{1}{T}\int_0^T v_o(t)\,dt$$

$$V_0 = \frac{1}{T}\left[\int_0^{T/2} 3\,dt + \int_{T/2}^{T} -4\,dt\right]$$

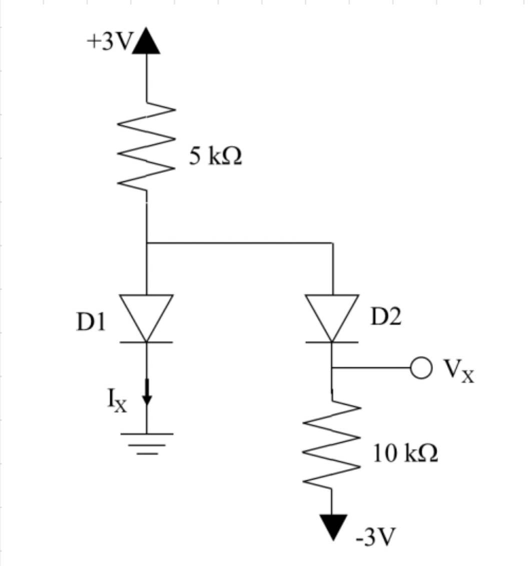
$$= \frac{1}{T}\left[\left. 3t \right|_0^{T/2} + \left. (-4t) \right|_{T/2}^{T}\right]$$

$$= \frac{1}{T}\left(\frac{3T}{2} + \left(-4T + 2T\right)\right)$$

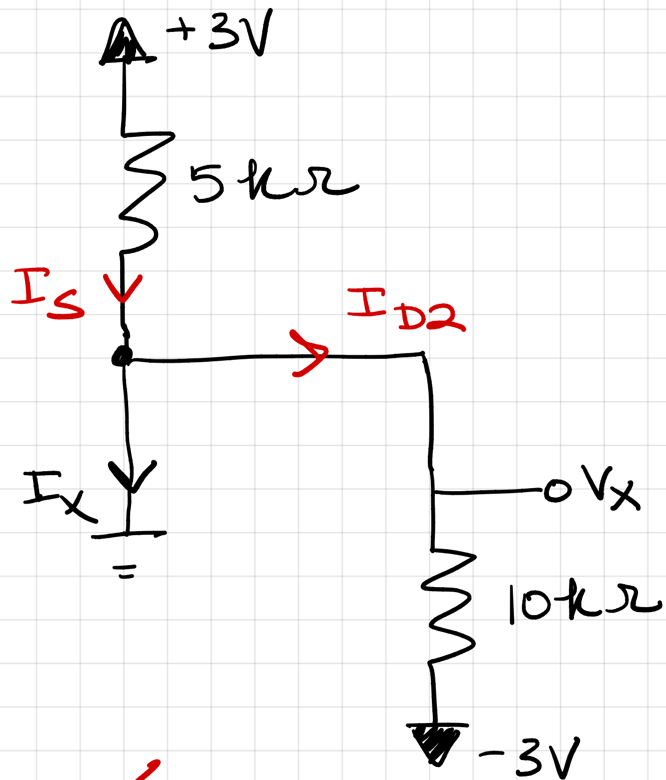
$$= \frac{1}{T}\left(-\frac{T}{2}\right)$$

$$\boxed{V_0 = -0.5\ V}$$

(2)



Assume both diodes are on.



I_X & $I_{D2} > 0$

$$\boxed{V_X = 0\,V}$$

$$I_{D2} = \frac{0-(-3)}{10} = 0.3\,mA$$ ✓

$$I_S = \frac{3-0}{5} = 0.6\,mA$$

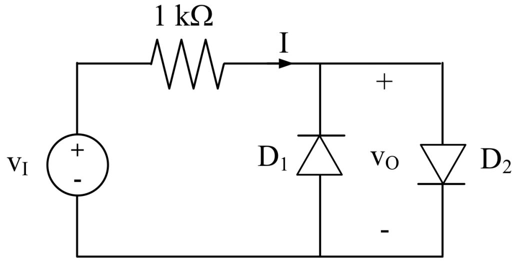
by KCL :

$$I_X = I_S - I_{D2}$$
$$= 0.6 - 0.3$$
$$\boxed{I_X = 0.3\,mA}$$ ✓

③

▼ -3V

3. For the following circuit, $v_I = 10\cos(t)$ volts. Assume ideal diodes.
   a. For what values of v_I is diode 1 on?
   b. For what values of v_I is diode 2 on?
   c. What is the peak current value, I (magnitude only required).
   d. Plot the voltages, v_I and v_O.



a) D1 is on when $v_I < 0$

$I < 0$

$I = -10\,mA$

$v_o = 0V$

b) D2 is on when $v_I > 0$

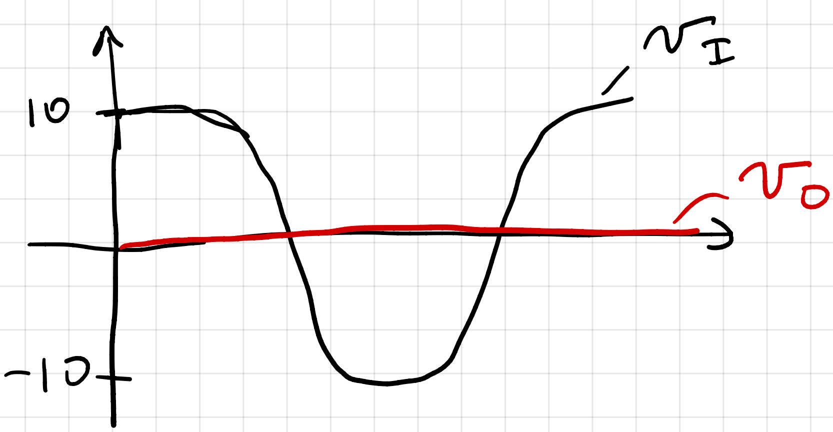
$I > 0$

$I = +10\,mA$

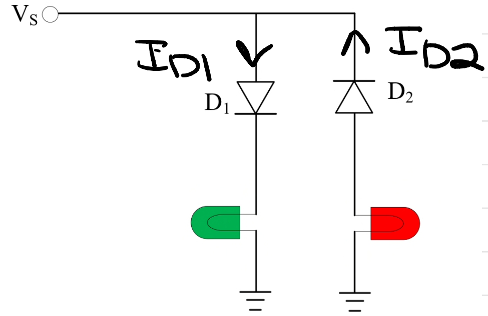
$v_o = 0V$

c) peak current is $\frac{10}{1000} = 10mA$

d)



4. Consider the following circuit. The voltage, V_S, can be either +3V, 0V, or -3V. The LED lights require +3 volts dropped across them in order to light up. Assume ideal diodes.



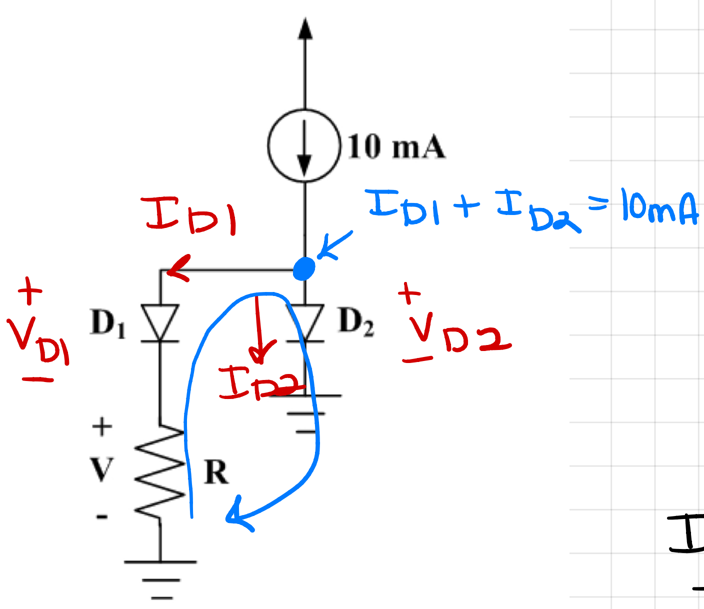
   a. What does V_S need to be for the green light (only) to be on?
   b. What does V_S need to be for the red light (only) to be on?
   c. Can both lights be on simultaneously?

a) $V_s = 3V$

b) $V_s = -3V$

c) no if $V_s = 0$, no current will flow.

(5)



by KVL

$$V + V_{D1} - V_{D2} = 0$$

$$V_{D2} - V_{D1} = V$$
$$= 80mV$$

$V = 80mV$

$$R = \frac{V}{I_{D1}}$$

$$\frac{I_{D2}}{I_{D1}} = \exp\left(\frac{V_{D2} - V_{D1}}{nV_T}\right)$$

$$\frac{I_{D2}}{I_{D1}} = \exp\left(\frac{80}{25}\right)$$

$$\frac{I_{D2}}{I_{D1}} = 24.53$$

$$I_{D2} = 24.53\, I_{D1}$$

$$I_{D1} + I_{D2} = 10$$

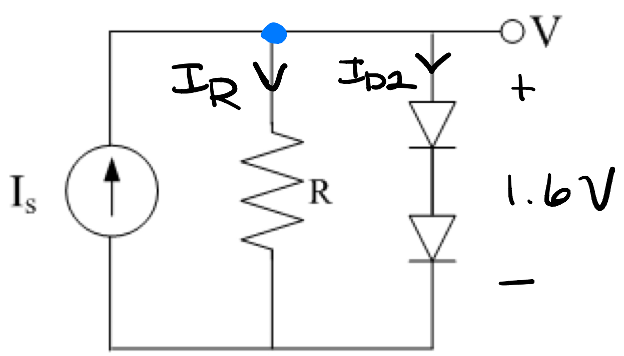
$$25.53\, I_{D1} = 10$$

$$I_{D1} = 0.392\,mA$$

$$R = \frac{80}{0.392}$$

$$\boxed{R = 204.24\ \Omega}$$

⑥ $I_R = I_S - I_{D2}$



$V = 1.6V$

$I_S = 100mA$

for $V_D = 0.7V$

$I_D = 1mA$

diodes are identical, so each diode will provide $\frac{1.6}{2} = 0.8V$

$$I_{D2} = I_{D1} \exp\left(\frac{V_{D2} - V_{D1}}{V_T}\right)$$

$$= (1) \exp\left(\frac{0.8 - 0.7}{25 \times 10^{-3}}\right) (mA)$$

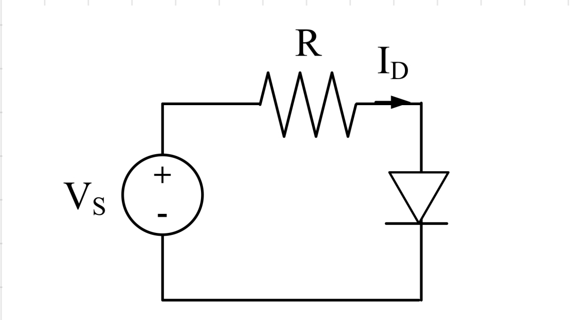
$$I_{D2} = 54.6\,mA$$

$$I_R = (100 - 54.6) = 45.4\,mA$$

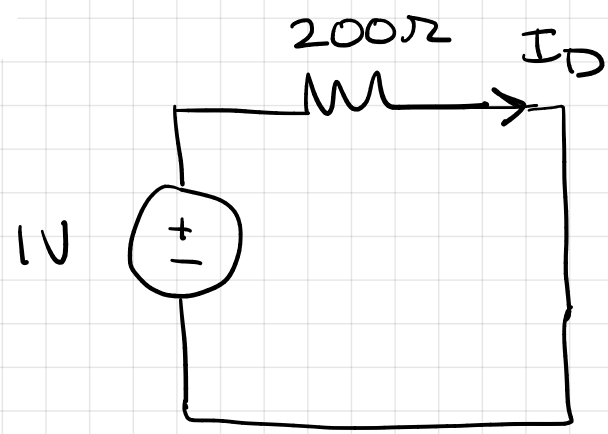
$$R = \frac{1.6}{45.4 \times 10^{-3}}$$

$$\boxed{R = 35.24\,\Omega}$$

7

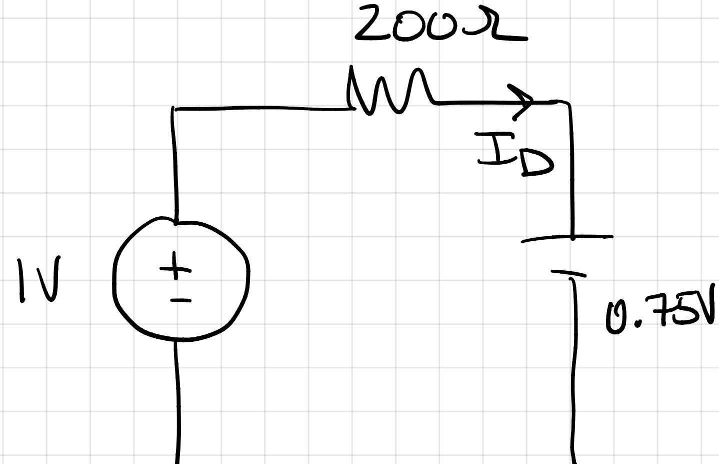


a) ideal



$$I_D = \frac{1}{200} = 5\,mA$$

b) constant drop



$$I_D = \frac{1 - 0.75}{200}$$

$$\boxed{I_D = 1.25\,mA}$$

c) let $V_{D_1} = 0.7\,V$

$$I_{D_2} = \frac{1-0.7}{200} = 1.5\,mA$$

$$(I_1, V_1) = (1\,mA, 0.7V)$$

$$(I_2, V_2) = (1.5\,mA, 0.71V) \quad V_2 = V_1 + V_T \ln\left(\frac{I_2}{I_1}\right) = 0.71V$$

$$I_{D3} = \frac{1-0.71}{200} = 1.45\,mA$$

$$V_{D3} = V_{D2} + V_T \ln\left(\frac{I_{D3}}{I_{D2}}\right)$$

$$= 0.709\,V$$

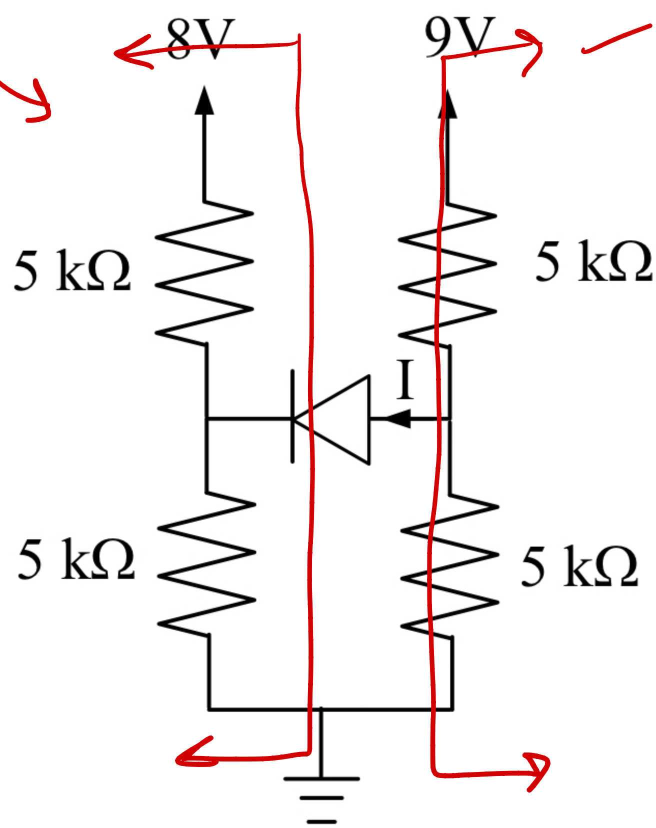
$$I_{D4} = \frac{1-0.709}{200} = 1.45\,mA$$

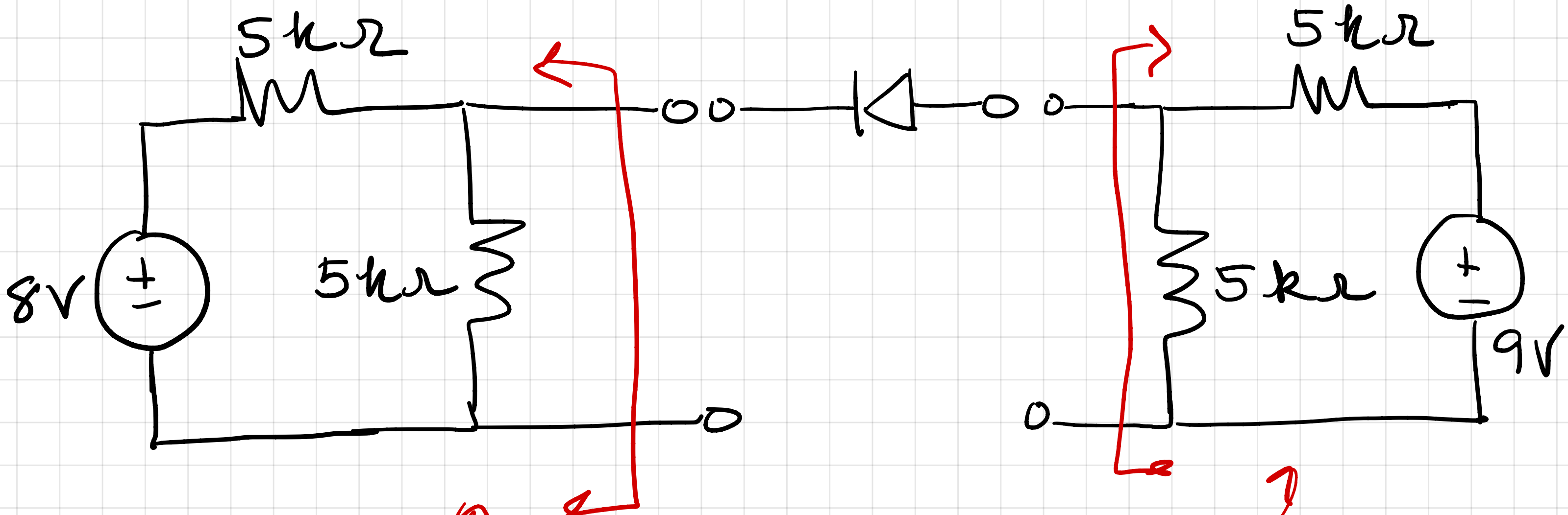
$$\boxed{I_D = 1.45\,mA}$$

8

Thev. ckt

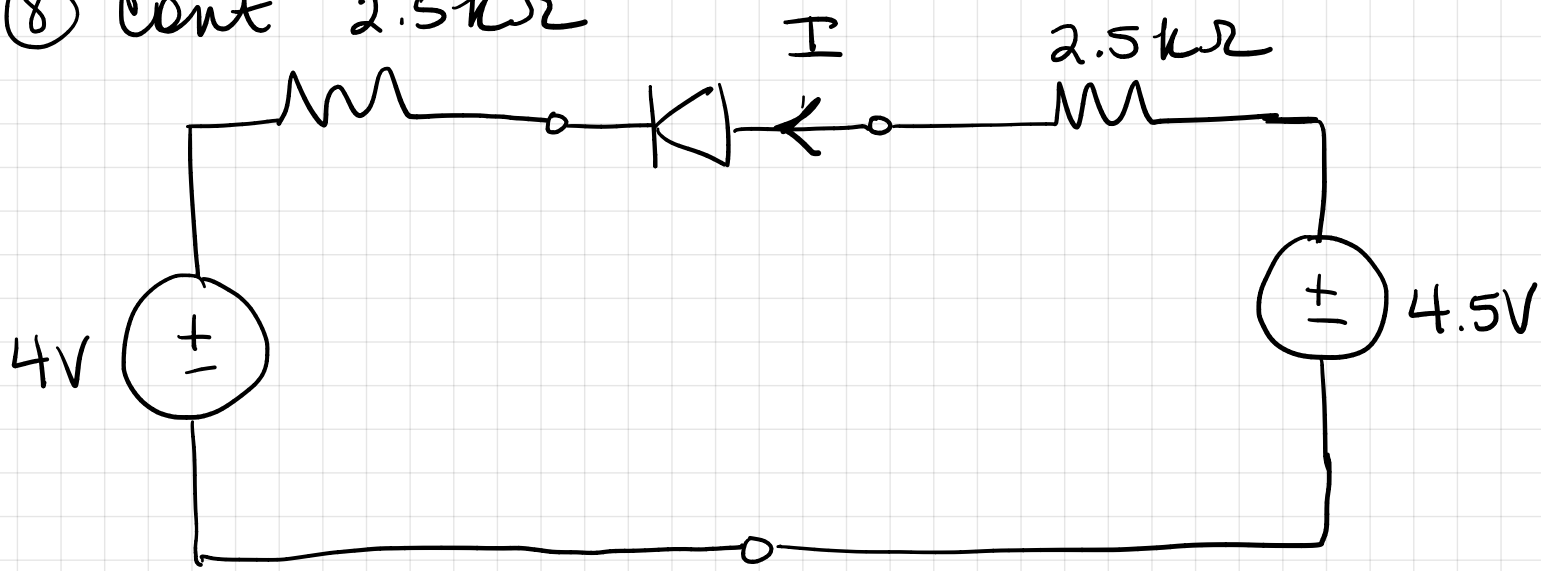
Thev. ckt





find Thev equivalent ckts

⑧ cont



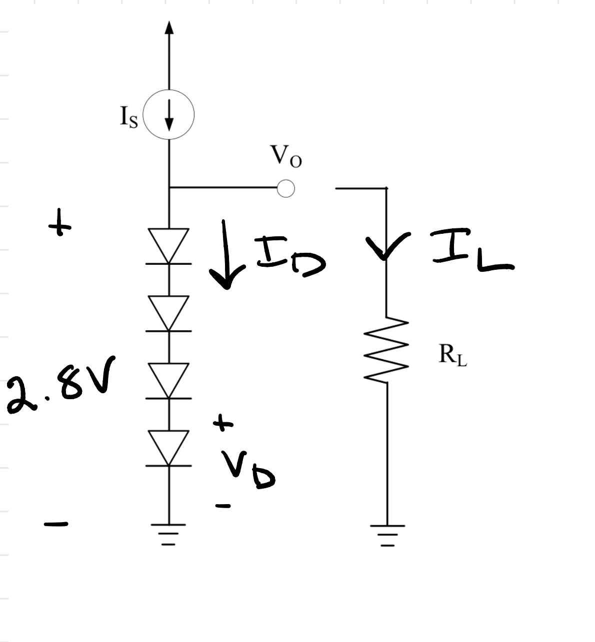
a) ideal $I = \dfrac{4.5 - 4}{5} = 0.1\,mA$

b) constant drop $I = \dfrac{4.5 - 0.7 - 4}{5}$

$I = -0.04\,mA$

current is negative
diode is off
$I = 0$!

(9)



sat current 10^{-16} A

$I_S = ?$ for $V_O = 2.8V$

diodes identical.

each diode has $\frac{2.8}{4}$ V or 0.7 V

$$I_D = (10^{-16})(\exp(.7/.025))$$

$$I_D = 0.145 \text{ mA} \quad \text{(no load)}$$

If $I_L = .1\text{mA}$

$$I_D = I_S - I_L = .145 - 0.1$$

$$I_D = 0.045 \text{mA}$$

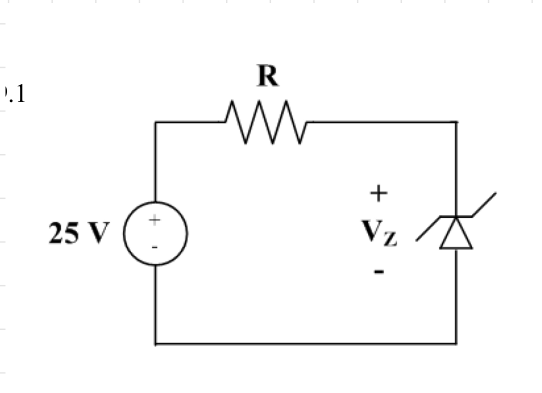
$$V_D = V_T \ln\left(\frac{I_D}{10^{-16}}\right)$$

$$= 0.025 \ln\left(\frac{.045 \times 10^{-3}}{10^{-16}}\right)$$

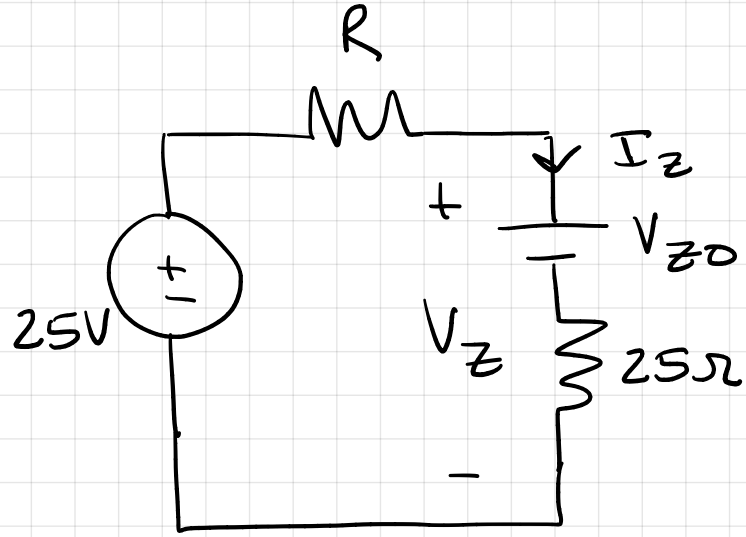
$$V_D = 0.671 \text{ V} \qquad V_O = 4V_D = 2.68V$$

$$\boxed{\Delta V_O = 2.68 - 2.8 = -0.12V}$$

(10)



$\Rightarrow$



$$V_Z = 9.1V$$
$$I_Z = 3mA$$

$$V_{Z0} = V_Z - I_Z r_Z$$
$$= 9.1 - (.003)(25)$$
$$V_{Z0} = 9.025V$$

for $I_Z = 5mA$

$$V_Z = V_{Z0} + I_Z r_Z$$
$$V_Z = 9.025 + (.005)(25)$$
$$\boxed{V_Z = 9.15\,V}$$

$$R = \frac{25 - V_Z}{I_Z}$$

$$R = \frac{25 - 9.15}{5 \times 10^{-3}}$$

$$\boxed{R = 3.17\,k\Omega}$$

(1)

$V_{DS} = .1V$

$V_t = 1.5V$

$k'_n = 25\mu A/V^2$

$\frac{W}{L} = 10$

$V_{GS} = 0V$

$V_{GS} < V_t$ $I_D = 0 \rightarrow$ cutoff

$V_{GS} = 1V$

$V_{GS} < V_t$ $I_D = 0 \rightarrow$ cut off

$V_{GS} = 2V$

$V_{DS} < V_{GS} - V_t$

$.1 < 2 - 1.5$ → triode region

$$I_D = k'_n \frac{W}{L}\left[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

$$I_D = 25(10)\left[(0.5)(.1) - \frac{1}{2}(.1)^2\right]$$

$$\boxed{I_D = 11.25\mu A}$$

$V_{GS} = 3V$

$0.1 < 3 - 1.5$

triode

$$I_D = 25(10)\left[(1.5)(.1) - \frac{1}{2}(.1)^2\right]$$

$$= 36.25\ \mu A$$

(see my additional clarification note in the Module 4 lecture)

2 $V_{DS} = 3.3V$ $\quad k'_n = 37.5\ \mu A/V^2$

$V_t = 1V$ $\quad W/L = 10$

$V_{GS} = 0V$ cutoff $I_D = 0$

$V_{GS} = 1V$ cutoff $I_D = 0$

$V_{GS} = 2V$ saturation

$V_{DS} > V_{GS} - V_t$

$3.3 > 2 - 1$

$$I_D = \frac{1}{2}\left(k'_n \frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$I_D = \frac{1}{2}(37.5)(10)(1)^2$$

$$\boxed{I_D = 187.5\ \mu A}$$

$V_{GS} = 3V$

$V_{DS} > V_{GS} - V_t$

$3.3 > 3 - 1$

saturation

$\boxed{I_D = 750 \mu A}$

3 $k'_n = 25 \frac{\mu A}{V^2}$ $V_t = 1V$ $\frac{W}{L} = 10$

a) $V_{GS} = 5V$ $V_{DS} = 6V$

$V_{DS} > V_{GS} - V_t$ => saturation

$$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$$

$$= \frac{1}{2} (25)(10)(4)^2$$

$\boxed{I_D = 2mA}$ or $2000 \mu A$ ☺

b) $V_{GS} = 0$ $V_{DS} = 6V$

cutoff $I_D = 0$

c) $V_{GS} = 2V$

$V_{DS} = -0.5V$

$V_{DS} < 0$

cutoff

$I_D = 0$

(4) $V_t = 0.8V$ $\frac{W}{L} = 2$

$k'_n = 0.05 \frac{mA}{V^2}$ $V_{GS} = 2.5V$

a) $\underline{\lambda = 0}$

$V_{DS} = 2V$

$V_{DS} > V_{GS} - V_t$

$2 > 1.7$

saturation

$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$

$I_D = 0.14 mA$

$V_{DS} = 10V$

$V_{DS} > V_{GS} - V_t$

$10 > 1.7$

saturation

$I_D = 0.14 mA$

b) $\lambda = 0.02 V^{-1}$

$V_{DS} = 2V$

saturation

$r_o = \frac{1}{\lambda I_D}$

$r_o = \frac{1}{(.02)(.14mA)}$

$r_o = 375.14 k\Omega$

$V_{DS} = 10V$

saturation

$r_o = \frac{1}{\lambda I_D}$

$r_o = 375.14 k\Omega$

$$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)(1 + \lambda V_{DS})$$

$I_D = 0.15\,mA$ $\qquad\qquad$ $I_D = 0.17\,mA$

---

c) $V_A = 35\,V$

$V_{DS} = 2\,V$ $\qquad$ still saturation $\qquad$ $V_{DS} = 10\,V$

$$r_o = \frac{V_A}{I_D}$$

$r_o = 250\,k\Omega$ $\qquad\qquad$ $r_o = 250\,k\Omega$

$I_D = 0.153\,mA$ $\qquad\qquad$ $I_D = 0.19\,mA$

5) $k'_p = 1\,\frac{mA}{V^2}$ $\qquad$ $\frac{W}{L} = 2$ $\qquad$ $V_t = -2\,V$

$V_{SG} = 3\,V$

a) $V_{SD} = 0.5\,V$ $\qquad$ triode

$V_{SD} < V_{SG} - |V_t|$

$0.5\,V < 1\,V$

$$I_D = k'_p \frac{W}{L} \left[(V_{SG} - |V_{tp}|) v_{SD} - \frac{1}{2} v_{SD}^2 \right]$$

$$= 0.75\,\mu A$$

b) $V_{SD} = 2V$

$V_{SD} > V_{SG} - |V_t|$

saturation

$I_D = \frac{1}{2} k'p \frac{W}{L} (V_{SG} - |V_t|)^2$

$I_D = 0.1mA$

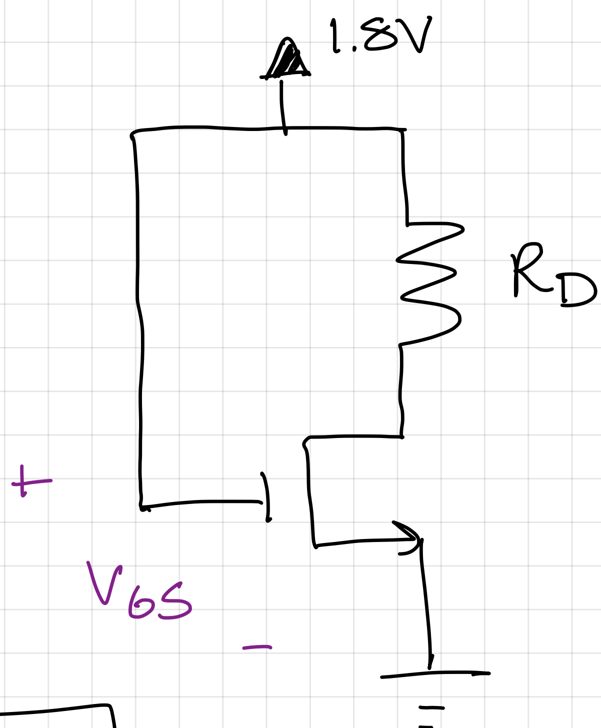
c) $V_{SD} = 5V$

$V_{SD} > V_{SG} - |V_t|$

saturation

$I_D = 0.1mA$

(6)



$V_t = 0.5V$

$k'n = 0.4 \frac{mA}{V^2}$

$\frac{W}{L} = 5$

at edge of saturation

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

$V_{DS} = 1.8 - 0.5$

$\boxed{V_{DS} = 1.3V}$

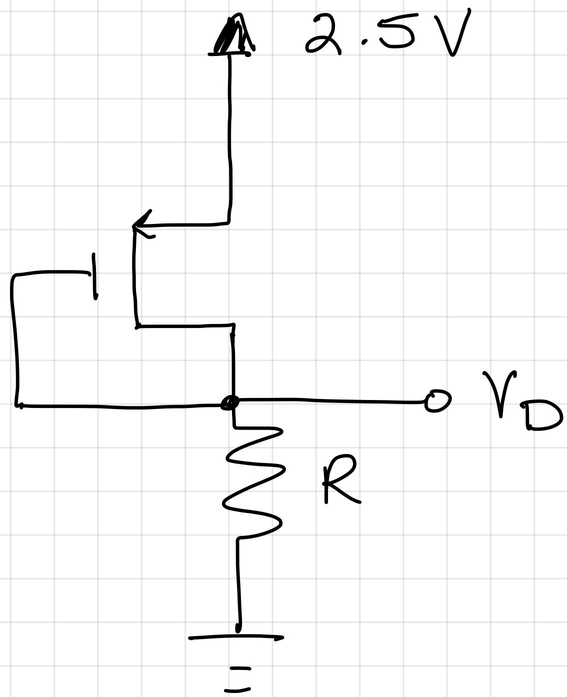
$I_D = 1mA$

$\boxed{V_{GS} = 1.8V}$

$\boxed{V_D = 1.3V}$

$$R_D = \frac{1.8 - V_D}{I_D} = \frac{1.8 - 1.3}{1 \times 10^{-3}} = 0.5\ k\Omega$$

7



$|V_t| = 0.6V$

$k'_p = 250\ \mu A/V^2$

$L = 0.25\ \mu m$

$I_D = 0.8mA$

$V_D = 1.5V$

gate & drain are tied together so device in saturation.

$V_D = V_G = 1.5V$

$V_{SG} = 2.5 - 1.5 = 1.0V$

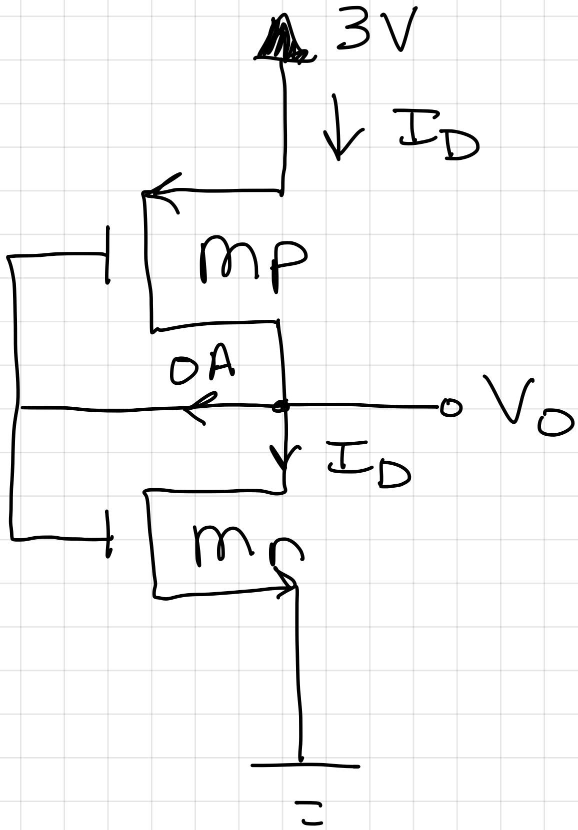
$$I_D = \frac{1}{2} k'_p \frac{W}{L} (V_{SG} - |V_t|)^2$$

$$0.8 \times 10^{-3} = \frac{1}{2}(250 \times 10^{-6})\left(\frac{W}{0.25\mu m}\right)(1 - .6)^2$$

$$\boxed{W = 10\ \mu m}$$

$$R = \frac{V_D}{I_D} = \frac{1.5}{.8 \times 10^{-3}} = 1.875\,k\Omega$$

(8)



$V_{tn} = |V_{tp}| = 1V$

$k'_n = 20\,\mu A/V^2$

$k'_p = 8\,\mu A/V^2$

$\frac{W}{L} = 3$

step 1: what mode is each device in?

for both devices: the drain and gate are tied together

$\Downarrow$

Saturation

$V_{GSn} = V_o$ $\quad$ $V_{SGp} = 3 - V_o$

② write current equations

$$I_{Dp} = \frac{1}{2} k'_p \left(\frac{W}{L}\right)\left(V_{SG} - |V_{tp}|\right)^2$$

$$I_{Dn} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)\left(V_{GS} - V_{tn}\right)^2$$

$$I_{Dp} = \frac{1}{2}(8)(3)((3 - V_O) - 1)^2$$

$$I_{Dn} = \frac{1}{2}(20)(3)(V_O - 1)^2$$

$$I_{Dp} = I_{Dn}$$

$$\frac{1}{2}(8)(3)(2 - V_O)^2 = \frac{1}{2}(20)(3)(V_O - 1)^2$$

$$1.5V_O^2 - V_O - 1.5 = 0$$

two solutions $\boxed{V_O = 1.39V}$

$V_O = -0.72V$

results in cutoff

$$\boxed{I_D = 4.56\,\mu A}$$

Practice Problems #5

1. $v_{BE_1} = 0.74\ V$ $\quad v_{BE2} = 0.714\ V$

$i_{C_1} = 9.5\ mA$ $\quad i_{c2} =$ ____

$$\frac{i_{c2}}{i_{c1}} = \exp\left(\frac{v_{BE2} - v_{BE1}}{V_T}\right)$$

$$i_{c2} = (9.5)\left(\exp\left(\frac{.714 - .74}{.025}\right)\right)$$

$$\boxed{i_{c2} = 3.36\ mA}$$

2. $I_B = 0.01\ mA$

$I_C = 0.6\ mA$

$I_E = I_C + I_B$

$$\boxed{I_E = 0.61\ mA}$$

$I_C = \alpha I_E$

$\alpha = \frac{I_C}{I_E} = 0.984$

$$\boxed{\alpha = 0.984}$$

$I_B = \frac{I_C}{\beta}$

$\beta = \frac{I_C}{I_B}$

$$\boxed{\beta = 60}$$

3. $I_C = I_S \exp\left(\frac{v_{BE}}{V_T}\right)$

$$= 5\times10^{-15} \exp\left(\frac{.64}{.025}\right)$$

$$\boxed{I_C = 0.656\,mA}$$

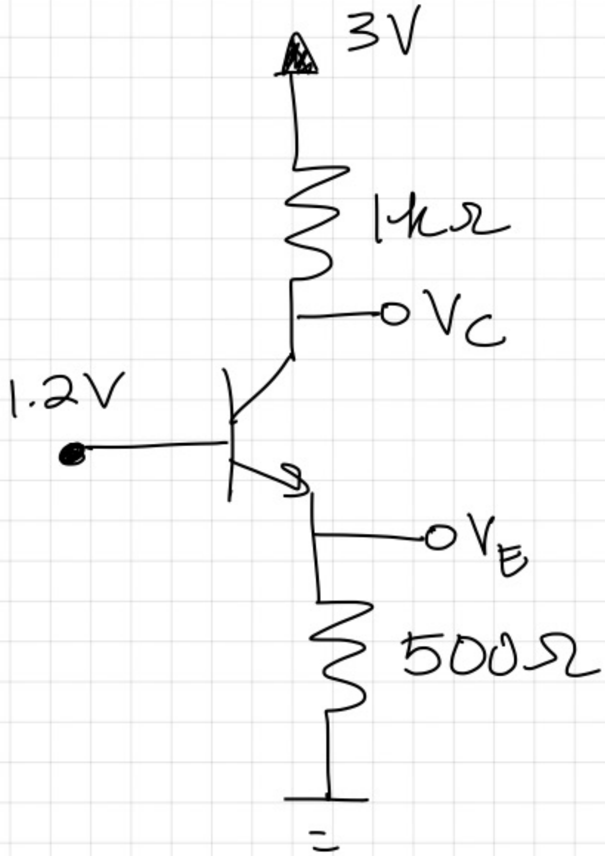
$$I_B = \frac{I_C}{\beta} \Rightarrow \frac{.656\times10^{-3}}{50} \text{ to } \frac{.656\times10^{-3}}{500}$$

$$= 13.1\,\mu A \text{ to } 1.31\,\mu A$$

$$I_E = I_C + I_B$$

$$I_E \Rightarrow 0.669\,mA \text{ to } 0.657\,mA$$

④ $\beta = 50$ $|V_{BE}| = 0.8V$



$V_B = 1.2V$

$V_E = 0.4V$

$$I_E = \frac{V_E}{500}$$

$$\boxed{I_E = 0.8mA}$$

$$\alpha = \frac{\beta}{\beta+1} = \frac{50}{51} = 0.98$$

$$I_C = \alpha I_E$$

$$\boxed{I_C = 0.78mA}$$

$$I_C = \frac{3 - V_C}{1k\Omega}$$

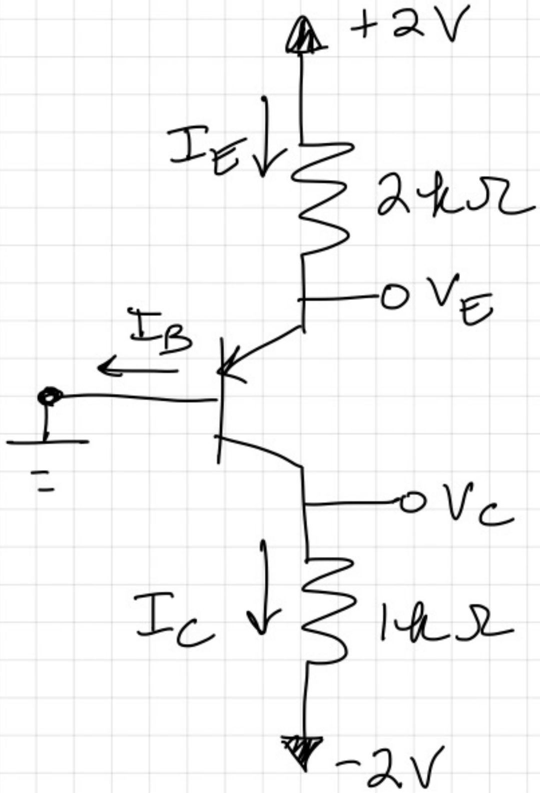
$V_C = 2.22V$

$$I_B = I_E - I_C$$

$$\boxed{I_B = 0.02mA}$$

$V_C > V_B > V_E \Rightarrow$ active

④ cont



$|V_{BE}| = 0.8V$

$\beta = 50$

$\boxed{V_B = 0}$

$V_E - \cancel{V_B}^{\,0} = 0.8V$

$\boxed{V_E = 0.8V}$

$I_E = \frac{2 - V_E}{2000}$

$\boxed{I_E = 0.6mA}$

$\frac{V_C + 2}{1000} = I_C$

$V_C = -1.41$

$I_C = \alpha I_E = (.98)(.6)$

$\boxed{I_C = 0.59mA}$

$V_C < V_B < V_E$

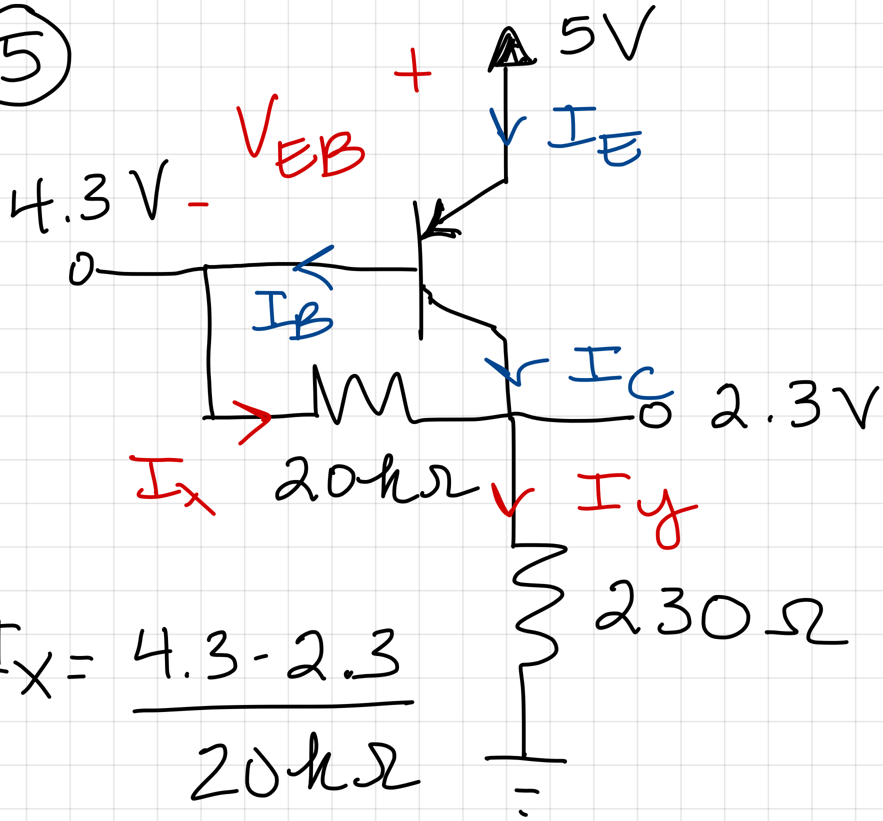
$\Downarrow$

<u>active</u>

$I_B = I_E - I_C$

$\boxed{I_B = 0.01mA}$

(5)



$V_{EB} = 0.7V$

Active

$$I_x = \frac{4.3 - 2.3}{20k\Omega}$$

$I_x = 0.1mA = I_B$

$$\beta = \frac{I_C}{I_B}$$

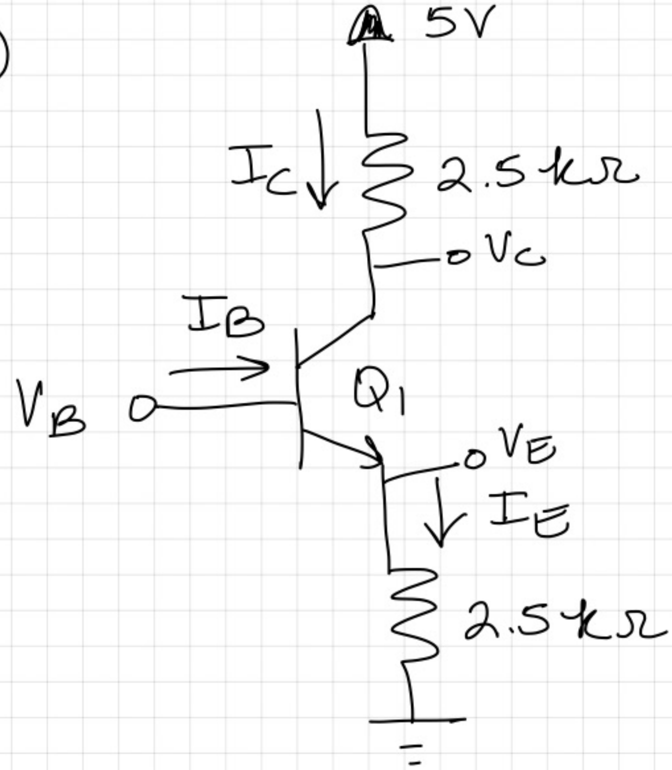
$$I_y = \frac{2.3}{230} = 10mA$$

$$\boxed{\beta = 99}$$

$I_C = I_y - I_x$

$= 9.9mA$

(6)



$V_{BE} = 0.7V$

$V_E = V_B - V_{BE}$

note: $\beta \equiv$ very large

$I_B = \dfrac{I_C}{\beta}$

$I_B \to 0$

$I_E \cong I_C$

$\beta = 100$ $(\alpha = 0.99)$

$V_B = 0$

$V_E = -0.7$

$Q_1 \equiv$ cutoff

$V_B = 1V$

$V_E = 0.3V$

$I_E = \dfrac{.3}{2.5 \times 10^3} = 0.12 mA$

$I_C = \alpha I_E = 0.119 mA$

$\beta \equiv$ very large

$V_B = 0$

$V_E = -0.7V$

$Q \equiv$ cutoff

$V_B = 1V$

$V_E = 0.3V$

$I_E = 0.12mA$

$I_C \cong 0.12mA$

$I_B \cong 0$

$I_B = I_E - I_C = 0.001\,mA$

$V_B = 2V$

$V_E = 1.3V$

$I_E = \dfrac{1.3}{2.5 \times 10^3} = 0.52\,mA$

$I_C = \alpha I_E = 0.515\,mA$

$I_B = 0.005\,mA$

$V_B = 2V$

$V_E = 1.3V$

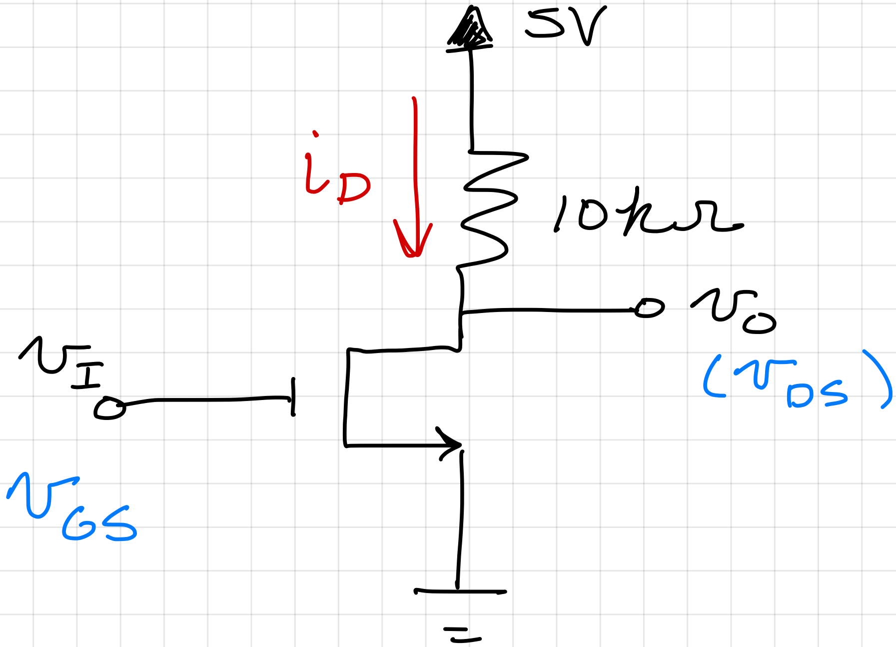
$I_E = 0.52\,mA$

$I_C \cong 0.52\,mA$

$I_B \cong 0$

Module 6 Practice Problems
Solutions

1



$V_t = 1.5V$

$k'_n \frac{W}{L} = 0.2 \frac{mA}{V^2}$

point A: $v_I = V_t$ (cutoff)

$v_O = V_{DD}$

point B: edge of saturation

$$\underset{v_{DS}}{v_O} = \underset{v_{GS}}{v_I} - V_t$$

$$v_I = v_{GS} = V_t + \frac{\sqrt{1 + 2(R_D k'_n \frac{W}{L} V_{DD})} - 1}{R_D k'_n \frac{W}{L}}$$

$v_I = 3.29V$ or $-1.29V$

$$v_O = v_{DS} = v_I - V_t$$

$$= 3.29 - 1.5$$

$$v_O = 1.79V$$

point C: $v_{GS} = v_I = V_{DD} = 5V$

$$v_{DS} = v_O = \frac{v_{GS}}{1 + R_D k'_n \frac{W}{L}(v_{GS} - V_t)}$$

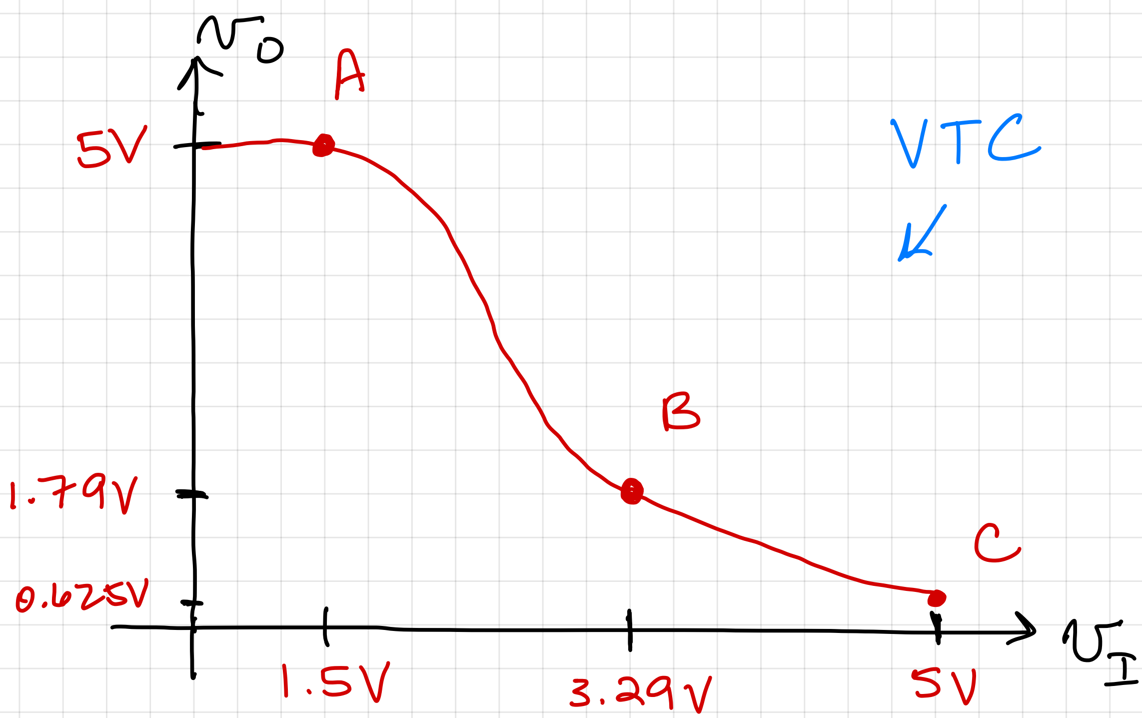
$$v_O = v_{DS} = 0.625\ V$$

v_O, v_I

point A : $(5V, 1.5V)$

point B : $(1.79V, 3.29V)$

point C : $(0.625V, 5V)$



b) $I_{DQ} = 0.15\,mA$

$$V_{OQ} = V_{DSQ} = V_{DD} - I_{DQ} R_D$$

$$= 5 - (0.15)(10)$$

$$\boxed{V_{OQ} = 3.5V}$$

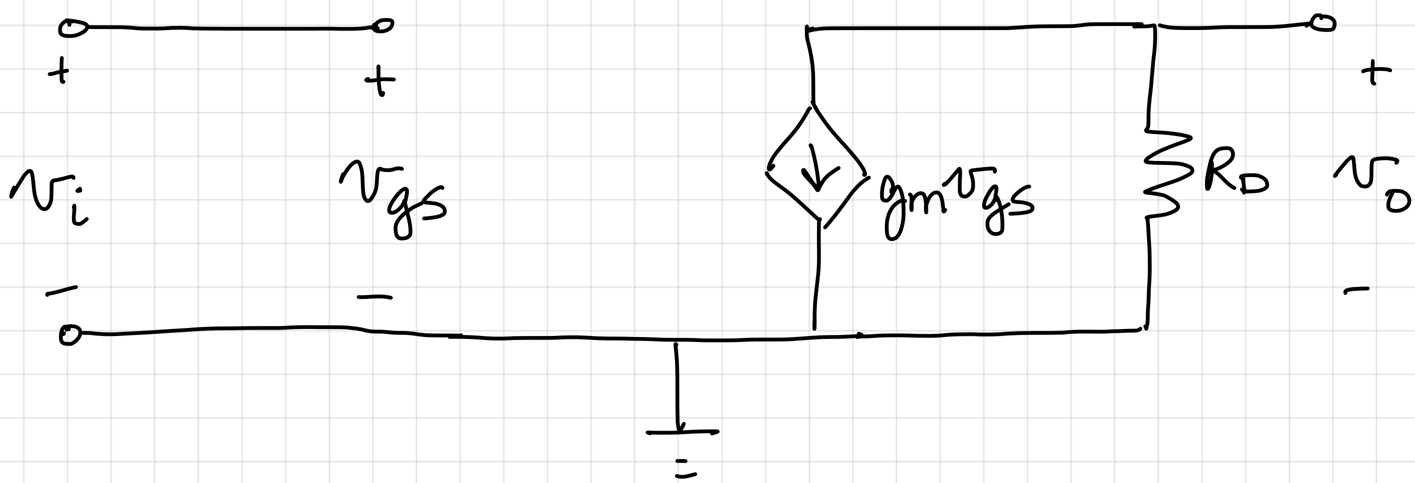
$V_{IQ} = V_{GSQ}$

$$I_{DQ} = \frac{1}{2} k'_n \frac{W}{L} (V_{IQ} - V_t)^2$$

$$0.15 = \frac{1}{2}(.2)(V_{IQ} - 1.5)^2$$

$$\boxed{V_{IQ} = 2.72\,V}$$

c)



$$v_i = v_{gs}$$

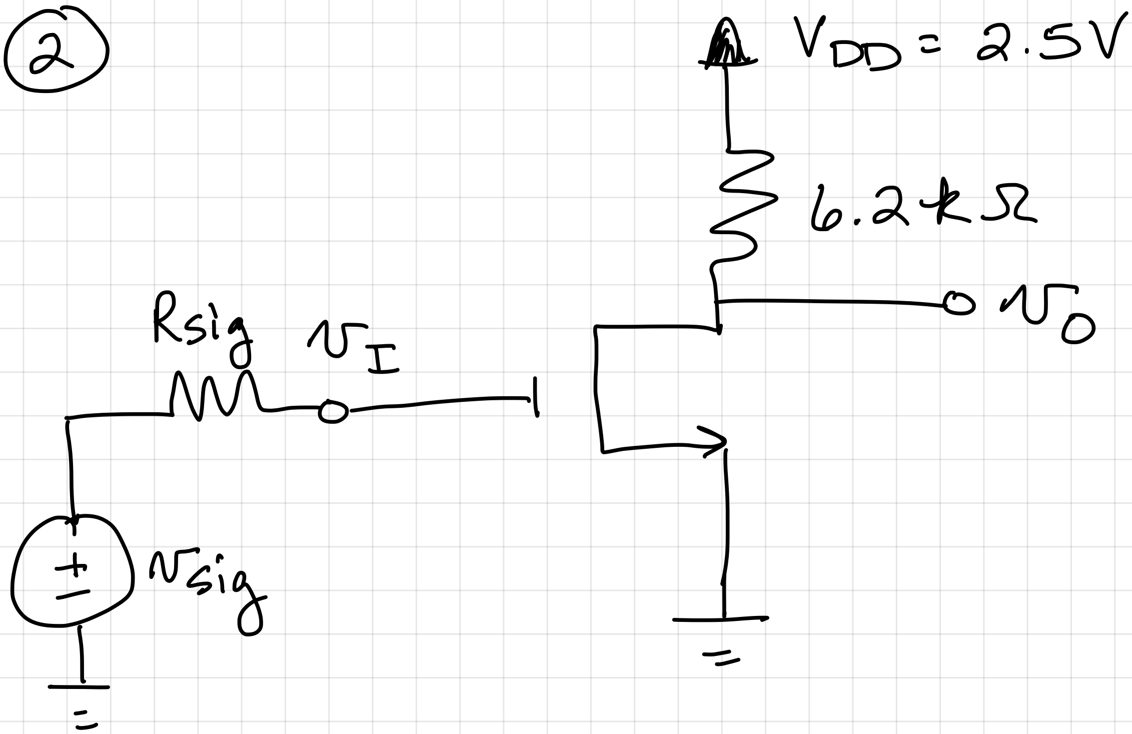
$$A_{vo} = \frac{v_o}{v_i} = -g_m R_D$$

$$= -\left(k'_n \frac{W}{L}(V_{IQ} - V_t)\right) R_D$$

$$A_{vo} = -(.2)(2.72-1.5)(10)$$

$$\boxed{A_{vo} = -2.45\ V/V}$$

(2)



$k'_n = 0.4 \frac{mA}{V^2}$ $\frac{W}{L} = 10$ $V_t = 0.4V$

$V_A = 10V$

a) $I_{DQ} = 0.2mA = \frac{1}{2} k'_n \frac{W}{L} (V_{GSQ} - V_t)^2$

$V_{GSQ} = 0.716V$

$V_{DSQ} = 2.5 - I_{DQ} R_D = 1.26V$

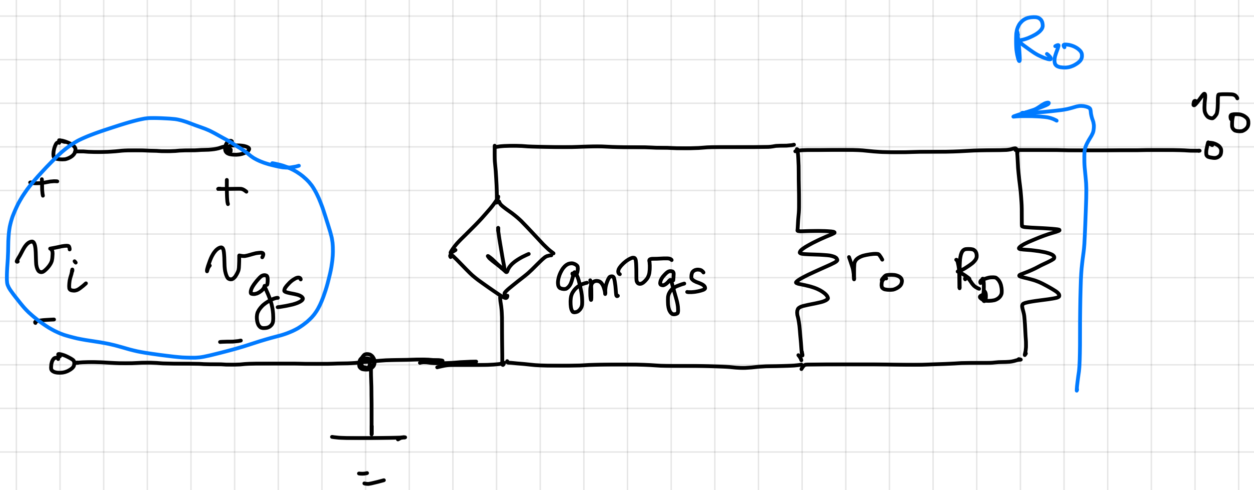
b) $R_{in} = \infty$

$$g_m = k'_n \frac{W}{L}(V_{GSQ} - V_t)$$

$$= 0.4(10)(0.716 - 0.4)$$

$$g_m = 1.264 \text{ mA/V}$$

$$r_o = \frac{V_A}{I_{DQ}} = \frac{10}{.2\times10^{-3}} = 50k\Omega$$

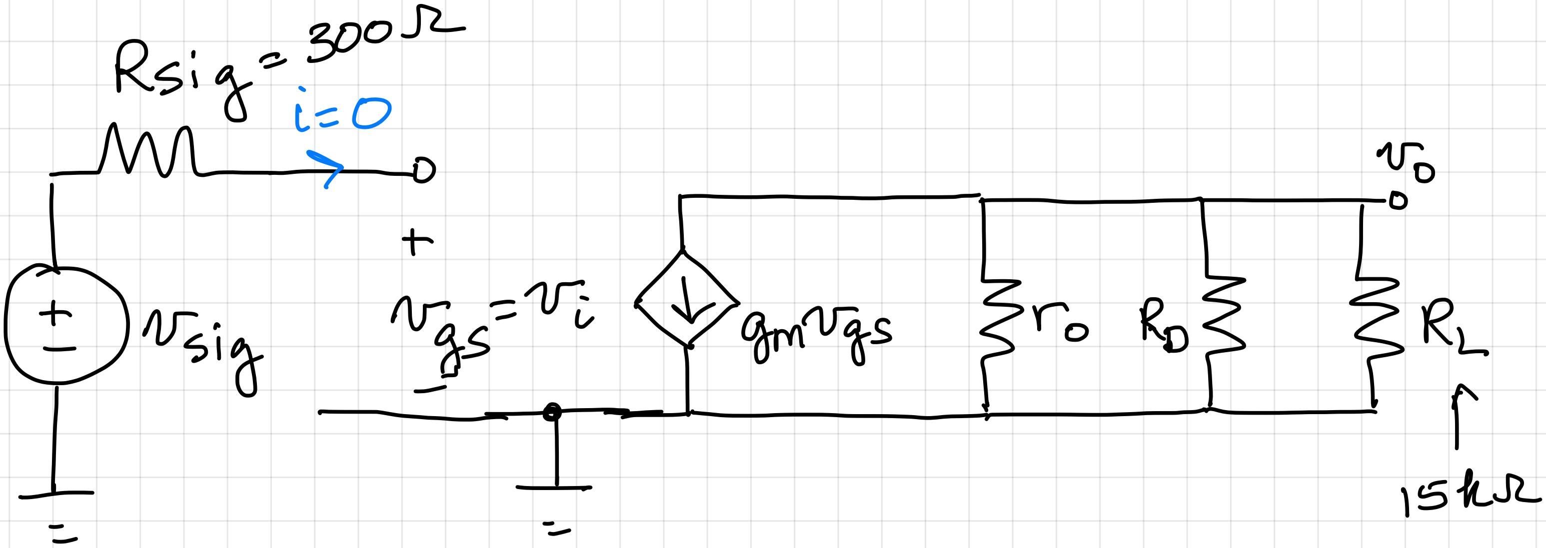


$$R_O = r_o \| R_D = 50 \| 6.2 = 5.52k\Omega$$

$$A_{vo} = \frac{v_o}{v_i} = -g_m(r_o \| R_D)$$

$$= -1.264(5.52)$$

$$= -6.98 \text{ V/V}$$



c) $A_v = \dfrac{v_o}{v_i} = -g_m(r_o \| R_D \| R_L)$

$= -1.264(50 \| 6.2 \| 15)$

$A_v = -5.1 \text{ V/V}$

d)

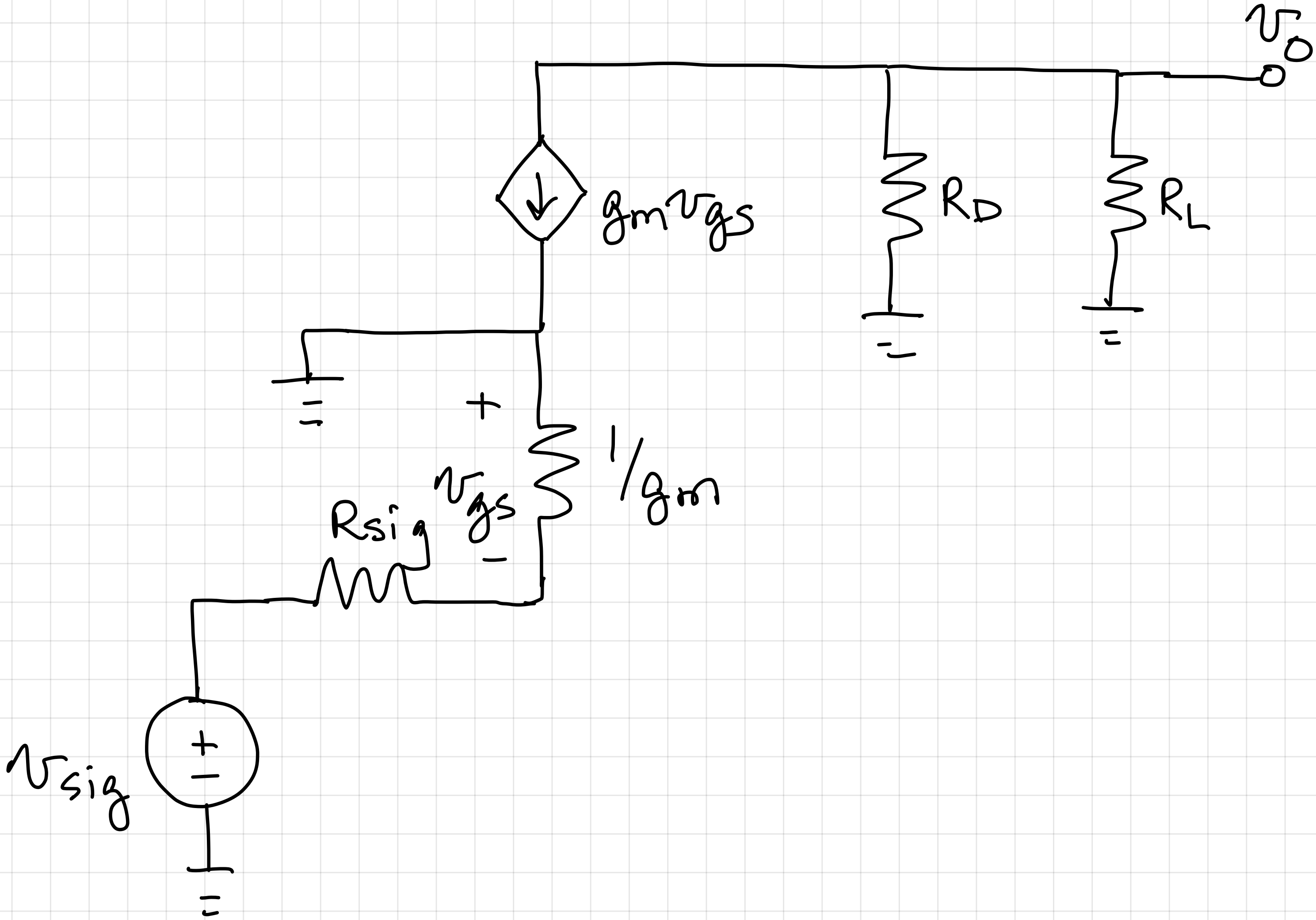
$G_v = \dfrac{v_o}{v_{sig}} = -5.1 \text{ V/V}$

3 $g_m = \dfrac{4\text{mA}}{\text{V}}$ $R_D = 5k\Omega$

$R_L = 7.5k\Omega$

$R_{sig} = 500\Omega$

a) $R_{in} = \dfrac{1}{g_m} = \dfrac{1}{4\times10^{-3}} = 250\Omega$



$$G_V = \frac{(R_D \parallel R_L)}{R_{sig} + 1/g_m} = \frac{(5 \parallel 7.5)}{500 + 250}$$

$$= \frac{3000}{750}$$

$$\boxed{G_V = 4 \text{ V/V}}$$

b) $R_{in} = R_{sig}$ at the Q pt

what would the I_{DQ} need to change to.

$R_{sig} = 500$

$R_{in} = 250 = \frac{1}{g_m}$ $\quad g_{m1} = \frac{4mA}{V}$

$$\boxed{\frac{1}{g_m} = 500 \qquad g_m = 2\frac{mA}{V}}$$

$$I_{DQ} = \frac{1}{2} k'_n \frac{W}{L} (V_{GSQ} - V_t)^2$$

$$g_m = k'_n \frac{W}{L} (V_{GSQ} - V_t)$$

$$g_m = \frac{2 I_{DQ}}{(V_{GSQ} - V_t)}$$

$$(V_{GSQ} - V_t)^2 = \frac{2 I_{DQ}}{k'_n W/L}$$

$$(V_{GSQ} - V_t) = \sqrt{\frac{2 I_{DQ}}{k'_n W/L}}$$

$$g_m = \sqrt{\underbrace{2 k'_n \frac{W}{L}}_{\text{constant}} I_{DQ}}$$

g_m reduces by a factor of $\frac{1}{2}$

I_{DQ} reduce by a factor $\frac{1}{4}$

4 $\underline{CD}$

$k'_n = 0.1 \frac{mA}{V^2}$ $\quad V_t = 0.6V$

$V_{OSQ} = 0.85V$

a) $R_o = 300\Omega$ - what is $\frac{W}{L}$

$$R_o = \frac{1}{g_m} = 300$$

$$g_m = 3.33 \frac{mA}{V} = k'_n \frac{W}{L}(V_{OSQ} - V_t)$$

$$3.33 = .1\left(\frac{W}{L}\right)(0.85 - 0.6)$$

$$\frac{W}{L} = 133.2$$

b) $I_{DQ} = \frac{1}{2} k'_n \frac{W}{L}(V_{OSQ} - V_t)^2$

$$I_{DQ} = \frac{1}{2}(.1)(133.2)(.85 - .6)^2$$

$I_{DQ} = 0.416 mA$

c) $R_L =$ 10kΩ pot $\quad 0 \rightarrow 10k\Omega$

$$G_V = \frac{R_L}{R_L + 1/g_m} = \frac{R_L}{R_L + 300}$$

for $R_L = 0 \qquad G_V = 0$

$R_L = 10k\Omega \qquad G_V = 0.97 \ V/V$