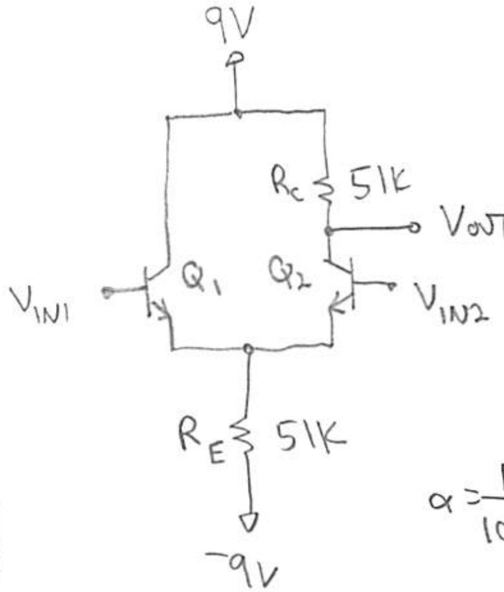
ECE 363
HW6 Solns

Total = 100 pts



$\alpha = \frac{100}{101} = .99$

(1)

(a) For quiescent,

assume $V_{IN1} = V_{IN2} = 0$

$$I_T = \frac{-0.7-(-9)}{51K} = \boxed{0.163\,mA}$$

$$V_{CQ} = 9 - .99\,\frac{.163mA}{2}(51K) = \boxed{4.885V}$$

(b)

$$r_e' = \frac{.026}{.5\,(.163mA)} = \underline{\underline{0.319K}}$$

$$A_d = \frac{.99 \times 51K}{2\,(.319K)} = \boxed{79.1}$$

$$A_{CM} = \frac{-.99 \cdot 51K}{2\,(51K)} = \boxed{-0.495}$$

$$CMRR = 20\log_{10}\left|\frac{79.1}{-.495}\right| = \boxed{44.1\,dB}$$

(c)

$$V_{OUT} = V_{CQ} + \overbrace{\Delta V_{OUT}}^{A_d \Delta V_{IN} + A_{CM} V_{CM}}$$

$$= 4.885 + (79.1)\times(4-3.98) + (-0.495)\left(\frac{4+3.98}{2}\right)$$

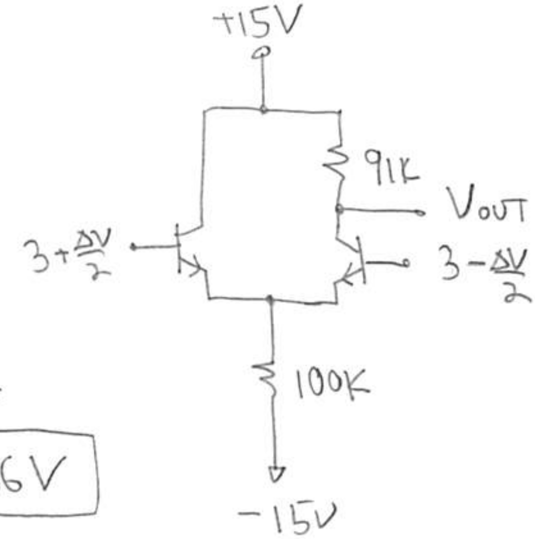
$$= 4.885 + 1.582 - 1.975 = \boxed{4.492V}$$

(d)

$$Z_{IN} = 2(\beta+1)\,r_e' = 2(101)(.319K) = \boxed{64.44\,K}$$

2)

(a) $V_{CQ} = V_{CC} - \alpha \frac{I_T}{2} R_C$



Need I_T!

$$I_T = \frac{-0.7-(-15)}{100K} = \underline{\underline{.143\,mA}}$$

$$V_{CQ} = 15 - .99\,\frac{.143mA}{2}(91K) = \boxed{8.56V}$$

(b) $$r_e' = \frac{.026}{.5(.143mA)} = \underline{\underline{0.364K}} \qquad A_d = \frac{.99 \times 91K}{2(.364K)} = \boxed{123.8}$$

$$A_{CM} = -\frac{.99 \times 91K}{2(100K)} = \boxed{-0.45}$$

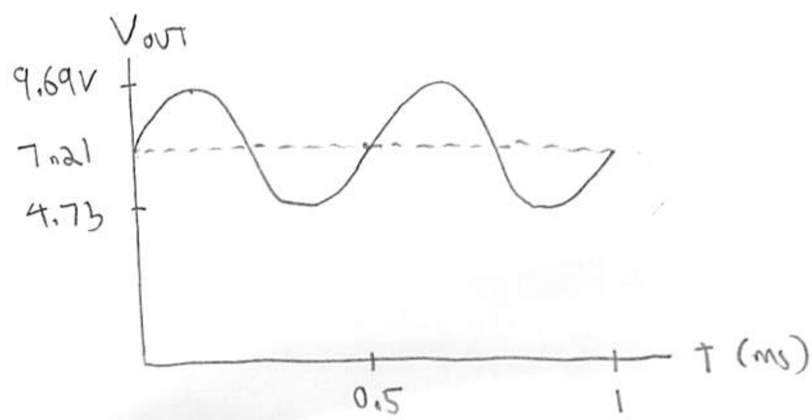
(c) $$\Delta V_{IN} = \left(3+\frac{\Delta V}{2}\right) - \left(3-\frac{\Delta V}{2}\right) = \Delta V = \underline{\underline{.02 \sin 2\pi f_o T}}$$

$$V_{CM} = \frac{\left(3+\frac{\Delta V}{2}\right) + \left(3-\frac{\Delta V}{2}\right)}{2} = \underline{\underline{3V}}$$

$$V_{OUT} = V_{CQ} + A_d \Delta V_{IN} + A_{CM} V_{CM}$$

$$= 8.56 + 123.8\,(.02 \sin 2\pi f_o t) + (-.45) \cdot 3$$

$$= 7.21 + 2.48 \sin 2\pi f_o T \qquad f_o = 2KHz \rightarrow 1\text{ period} = .5\text{ ms}$$



(d) $\Delta V = .05 \sin 2\pi f_o t \rightarrow A_d \Delta V = 6.19 \sin 2\pi f_o t$

Sorry, typo in handout! :(

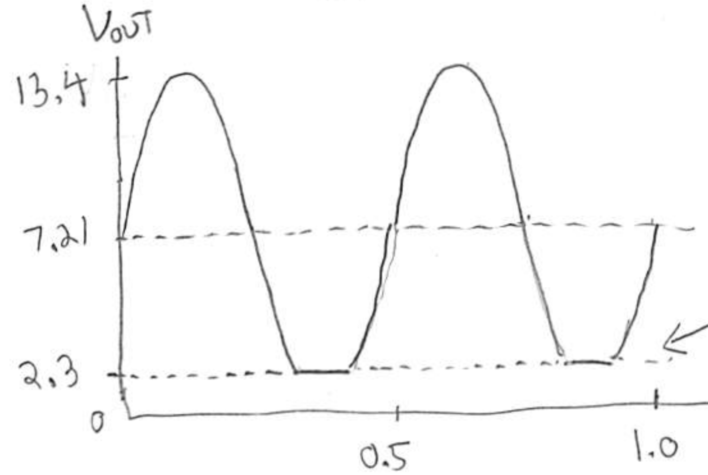
Max $V_{OUT} = 7.21 + 6.19 = 13.4V \leftarrow$ Less than +15V ✓

Min $V_{OUT} = 7.21 - 6.19 = 1.02V \leftarrow$ Clipping?

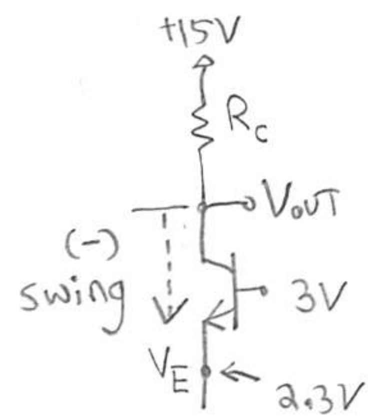
For Q_2, V_C cannot go too low (limited by saturation)!

$$V_{CE} > \underbrace{V_{CE(sat)}}_{0V} \rightarrow V_C > V_E \cong V_{CM} - 0.7 \quad \left(\begin{matrix}\text{assuming} \\ \Delta V << V_{CM}\end{matrix}\right)$$

$$= \underline{\underline{2.3V}} \leftarrow \text{Min } V_{OUT} \text{ is clipped!}$$



Clipping due to Q_2 saturation

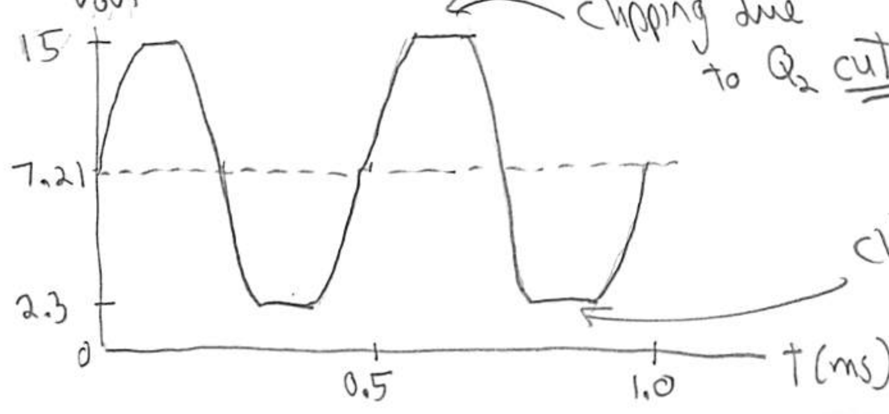


(e) $\Delta V = .08 \sin 2\pi f_o t \rightarrow A_d \Delta V = 9.9 \sin 2\pi f_o t$

Sorry, typo in handout! :(

Max $V_{OUT} = 7.21 + 9.9 = \underbrace{17.1}_{\text{cannot exceed } V_{CC}} \leftarrow$ Clipped at 15V! $\leftarrow$ Due to Q_2 cut-off

Min $V_{OUT} = 7.21 - 9.9 = -2.7V \leftarrow$ clipped at 2.3V! $\leftarrow$ Due to Q_2 saturation



Clipping due to Q_2 cut-off

Clipping due to Q_2 saturation

(3)

(a) $Z_{IN} = 2(\beta+1) r_e' = 2(\beta+1)\dfrac{.026}{.5\, I_T} \geq 50K$

$$I_T \leq 2(\beta+1)\,\frac{.026}{.5(50K)}$$

?

- Start with "Quick" analysis: $\beta = 100 \rightarrow I_T \leq 2(101)\dfrac{.026}{.5(50K)} = \underline{.21mA}$
- 2N3904 Datasheet: $\beta \sim 225$ @ $.2mA$

$$\Rightarrow I_T \leq 2(226)\frac{.026}{.5(50K)} = \boxed{0.47mA}$$

(b) Data sheet: $V_{BE} \cong \underline{0.63V}$ @ $I_c = \dfrac{I_T}{2} = .235mA$

$$\text{So, } I_T = \frac{12 - .63}{R_E} \leq .47mA \rightarrow R_E \geq 24.2K$$

use $\boxed{R_E = 27K}$

(c) Actual $I_T = \dfrac{12-.63}{27K} = \boxed{0.42mA}$ $\quad Z_{IN} = 2(225+1)\dfrac{.026}{\frac{1}{2}(.42mA)}$

$$= \boxed{56K} > 50K \checkmark$$

(d) $r_e' = \dfrac{.026}{\frac{1}{2}(.42mA)} = 0.124K \quad A_d = .996\dfrac{R_c}{2(.124K)} \geq 100 \rightarrow R_c \geq 24.9K$

Choose $\boxed{R_c = 27K}$

$$\alpha = \frac{225}{226} = .996$$

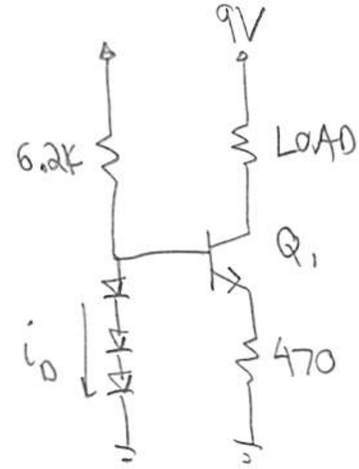
(e) Actual $A_d = .996\dfrac{27K}{2(.124K)} = \boxed{108.4}$ $\quad V_{CQ} = 12 - .996\dfrac{.42mA}{2}(27K) = \boxed{6.35V}$

$A_{cm} = -.996\dfrac{27K}{2(27K)} = \boxed{-0.498}$ $\quad CMRR = 20\log_{10}\left(\left|\dfrac{108.4}{-.498}\right|\right) = \boxed{46.8\ dB}$

4)

ⓐ Assuming diodes are ON:

$$i_E = \frac{2.1 - 0.7V}{470\Omega} = 2.98mA$$



$\beta = 100$

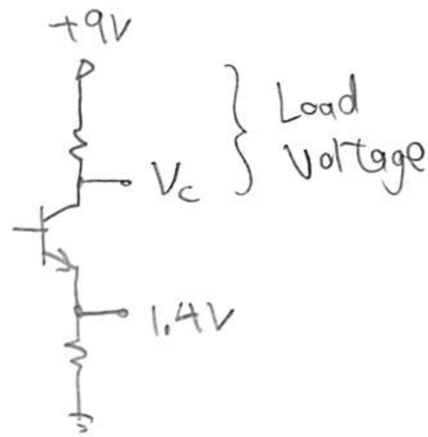
$\alpha = \frac{100}{101} = 0.99$

$$i_L = (0.99)(2.98mA)$$
$$= \boxed{2.95 mA}$$

$$i_D = \frac{9 - 2.1V}{6.2K} - \frac{2.98mA}{101} = \boxed{1.08 mA}$$ ← Diodes are happy :)

ⓑ Voltage Compliance = Max load voltage

$$= 9 - V_{c,min}$$
$$= 9 - (1.4 + \underbrace{V_{CE,sat}}_{0V})$$
$$= \boxed{7.6V}$$



ⓒ $V_{cc} = 7.5V.$

$$\rightarrow i_E = \frac{2.1 - 0.7}{470} = 2.98mA$$

$$i_L = (0.99)(2.98) = \boxed{2.95mA}$$ ← SAME as $V_{cc} = 9V$! :)

$$i_D = \frac{7.5 - 2.1}{6.2K} - \frac{2.98mA}{101} = \boxed{0.84 mA}$$ ← Fairly close to 1mA, so diodes are still OK.

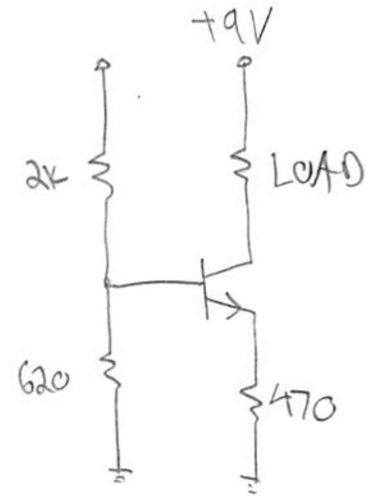
Voltage Compliance $= 7.5 - 1.4 = \boxed{6.1V}$ ← Less than $V_{cc} = 9V$.

5)

(a) Stiff divider?

$$\underbrace{2000 \parallel 620}_{473.3} \overset{?}{<} \underbrace{\frac{1}{100}(101)\,470}_{474.7\,\Omega}$$

$\boxed{\text{YES}}$



$\beta = 100$

$\alpha = \frac{100}{101} = 0.99$

(b) $I_L = \alpha I_E = 0.99 \; \frac{V_{BB} - 0.7}{470}$ $V_{BB} = 9 \cdot \frac{620}{620 + 2000} = 2.13V$

$= \boxed{3.01\, mA}$

(c) V_{cc} drops to 7.5V.

$\rightarrow V_{BB} = 7.5 \cdot \frac{620}{620 + 2000} = \underline{\underline{1.775V}}$

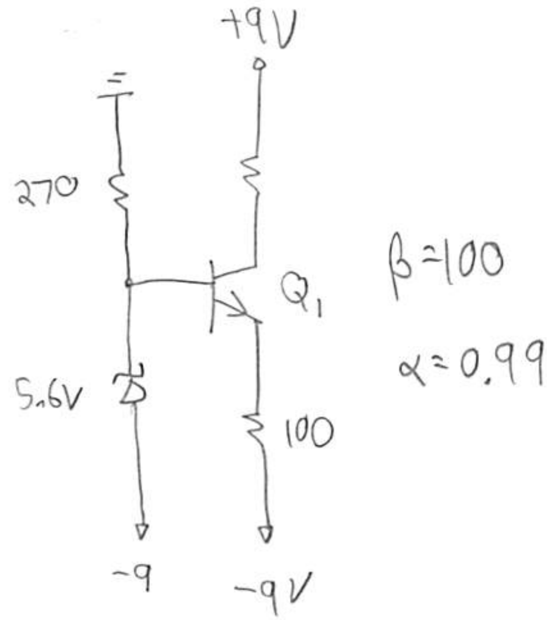
$\Rightarrow I_L = .99 \; \frac{1.775 - 0.7}{.470K} = \boxed{2.26mA}$

↑

Much Lower than $V_{cc} = 9V$!

6)

(a) Assuming zener is ON:



$$I_E = \frac{5.6-0.7}{100} = .049A$$

$$I_L = 0.99(.049A) = \boxed{48.5\,mA}$$

(b) $I_Z = I_S - I_B$

$$= \frac{0-(-9+5.6)}{.27K} - \frac{49mA}{101} = \boxed{12.1\,mA} > 10mA \checkmark$$

YES!

(c) Voltage compliance $= 9 - \underbrace{V_{C,min}}$

$$= V_E + V_{CE,sat}$$

$$= (-9+5.6-0.7) + 0V$$

$$= -4.1V$$

$$= 9-(-4.1) = \boxed{13.1V}$$

(7)

(a) $Z_{IN} = 2(\beta+1)r_e' = 2(\beta+1)\frac{.026}{.5 I_T} \geq 50K \rightarrow I_T \leq 2(\beta+1)\frac{.026}{.5(50K)}$

? ↗

- "Quick" analysis to start:

$$\beta = 100 \rightarrow I_T \leq 2(101)\frac{.026}{.5(50K)} = .21mA$$

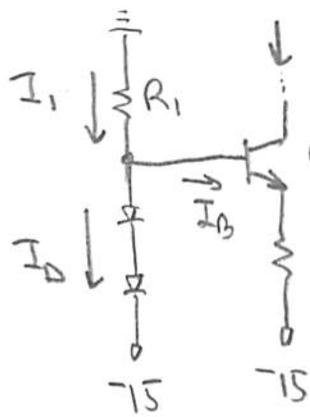
For 2N3904, typical $\beta \sim \underline{225}$ @ $\underbrace{I_C = .1mA}_{\frac{1}{2}I_T}$

- $I_T \leq 2(226)\frac{.026}{.5(50K)} = \boxed{0.47mA}$

(b) Want $I_D \sim 1mA$

1N4148: Typical $V_F = .62V$ @ 1mA

2N3904: Typical $V_{BE} = .65V$ @ .47mA



$\alpha = \frac{225}{226} = .996$

- $I_T = .996\frac{2\times .62 - .65}{R_2} \leq .47mA$

$$R_2 \geq 1.25K \xrightarrow{\times 1.05} 1.31K \quad \text{Choose } \boxed{R_2 = 1.5K}$$

- Actual $I_T = .996\frac{2\times .62 - .65}{1.5K} = \underline{0.39mA}$

(1.3K would probably be OK)

- $I_D = I_1 - I_B = \frac{0-(-15+2\times .62)}{R_1} - \frac{.39mA}{225} \sim 1mA$

$$R_1 \sim 13.7K \rightarrow \text{Choose } \boxed{R_1 = 13K}$$

(c) Actual $I_T = .996\frac{2\times .62 - .65}{1.5K} = \boxed{0.39mA}$

(d) $A_d = \frac{\alpha R_C}{2r_e'} \geq 120$, $r_e' = \frac{.026V}{.5(.39mA)} = .133K \rightarrow R_C \geq 32.0K \xrightarrow{\times 1.05} 33.7K$

Choose $\boxed{R_C = 35K}$

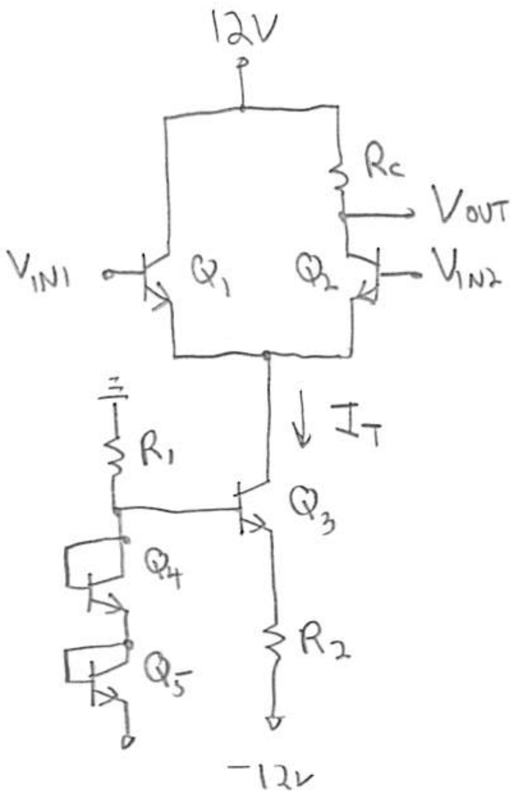
(33K probably ok)

(e) Actual $A_d = .996 \frac{35K}{2(.133K)} = \boxed{131.1}$

$V_{CQ} = 15 - .996\left(\frac{.39mA}{2}\right)(35K) = \boxed{8.2V}$

$CMRR = 20\log_{10}\left(\frac{5\times10^{3}K}{.133K}\right) = \boxed{91.5\ dB}$

8) Start with "Quick":



(a) $2(101)r_e' = 2(101)\dfrac{.026V}{.5\,I_T} \geq 10K$

$I_T \leq \underline{\underline{1.05mA}}$

For $I_c \sim \dfrac{I_T}{2} = .5mA$

$\hookrightarrow$ Typ $h_{FE} \approx 93$

So, $2(94)\dfrac{.026}{.5\,I_T} \geq 10K$

$I_T \leq \boxed{.98\,mA}$

(b) From LM3046 plots:

Q_3: $h_{FE} \sim \underline{\underline{100}}$ @ .98 mA $\left(\alpha = \dfrac{100}{101} = .99\right)$ and $V_{BE} \sim \underline{\underline{.72V}}$

Q_4, Q_5: $V_{BE} \sim .72V$ @ 1 mA

$\rightarrow \dfrac{12 - 2(.72)}{R_1} - \dfrac{.98mA}{.99\,(101)} \sim 1mA$

$\rightarrow R_1 \sim 10.5K \Rightarrow$ Choose $\boxed{R_1 = 10K}$

(c) $I_T = .99\,I_E = .99\left[\dfrac{2 \times .72 - .72}{R_2}\right] \leq .98\ mA$

$R_2 \geq .727K$ > Choose $\boxed{R_2 = 820\Omega}$

$\hookrightarrow$ .76K

$\times 1.05$

(750Ω probably OK)

(d) $A_d = \frac{\alpha R_c}{2 r_e'}$

$r_e' = \frac{.026}{\frac{1}{2} I_T}$ ← Actual $I_T = .99 \left[\frac{2 \cdot .72 - .72}{.82K} \right] = 0.87mA$

$= \frac{.026}{\frac{1}{2}(.87mA)} = .06K$

For Q_2: Typical $h_{FE} \approx 90$ @ $\overbrace{.435mA}^{\frac{1}{2} I_T} \rightarrow \alpha = \frac{90}{91} = 0.989$

$A_d = .989 \frac{R_c}{2(.06K)} \geq 100 \Rightarrow R_c \geq 12.1K$

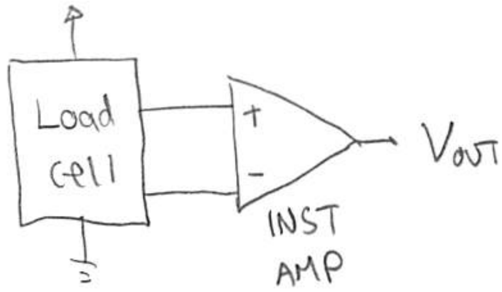
Choose $\boxed{R_c = 13K}$

(e) Actual $A_d = .989 \frac{13K}{2(.06K)} = \boxed{107.1} > 100$ ✓

$Z_{IN} = 2(90+1)(.06K) = \boxed{10.92K} > 10K$ ✓

(9)

(a) $V_{OUT} = A_d \Delta V + \underbrace{\cancel{A_{CM}}}_{0} V_{CM}$



$= A_d \, V_s \cdot RO \cdot \frac{L}{L_{Rated}}$

$= 500 \times 10V \times \frac{3mV}{V} \times \frac{.020 kg}{20 kg} = \boxed{15 mV}$

(b) $V_{OUT} = \underbrace{A_d \Delta V}_{15mV} + \boxed{A_{CM} V_{CM}}$

want this < 15 mV

$A_{CM} \times 5V < 15 mV$

$A_{CM} < \frac{15mV}{5V} = .003$

$CMRR = 20 \log_{10} \left(\frac{500}{.003} \right) = \boxed{104.4 \, dB}$

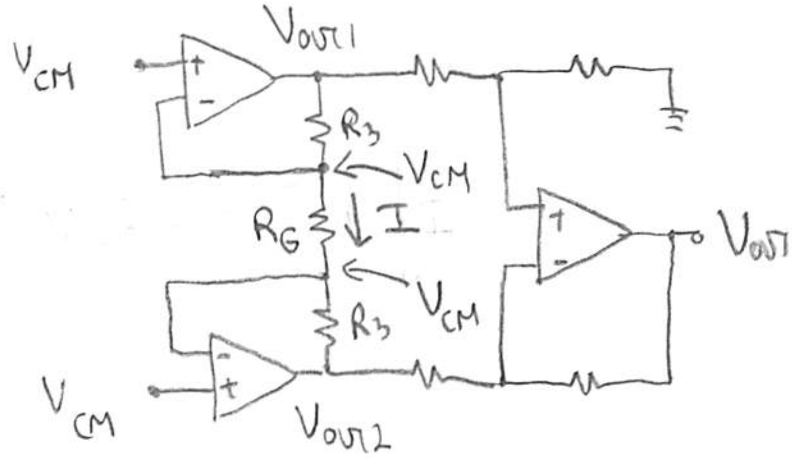
10

(a) When $V_{IN1} = V_{IN2} = V_{CM}$

$$\Rightarrow I = \frac{V_{CM} - V_{CM}}{R_G} = 0$$

Therefore,

$$\boxed{V_{OUT1} = V_{CM} = V_{OUT2}}$$

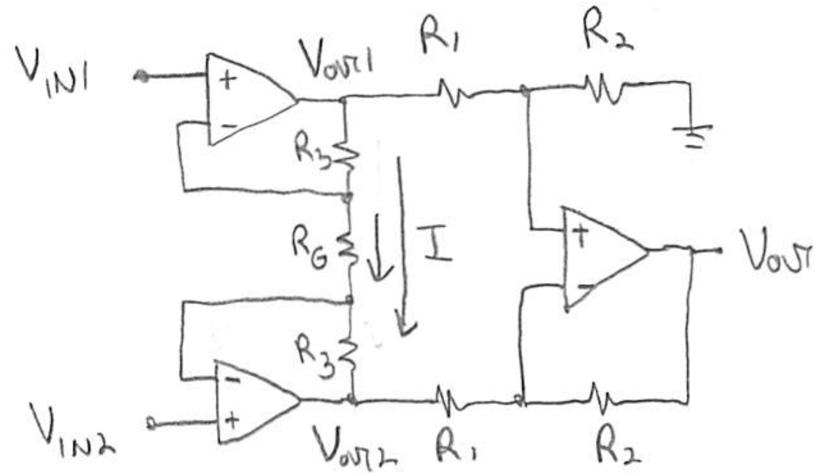


(b)

$$I = \frac{V_{IN1} - V_{IN2}}{R_G}$$

$$= \frac{V_{OUT1} - V_{OUT2}}{R_3 + R_G + R_3}$$

$$= \frac{V_{OUT1} - V_{OUT2}}{R_G + 2R_3}$$



So, $V_{OUT1} - V_{OUT2} = \frac{R_G + 2R_3}{R_G}(V_{IN1} - V_{IN2}) = \boxed{\left(1 + \frac{2R_3}{R_G}\right)(V_{IN1} - V_{IN2})}$

(c) Since $V_{OUT} = \frac{R_2}{R_1}(V_{OUT1} - V_{OUT2})$

$$= \underbrace{\frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_G}\right)}_{A_d}(V_{IN1} - V_{IN2})$$

$$\Rightarrow \boxed{A_d = \left(1 + \frac{2R_3}{R_G}\right) \times \frac{R_2}{R_1}}$$