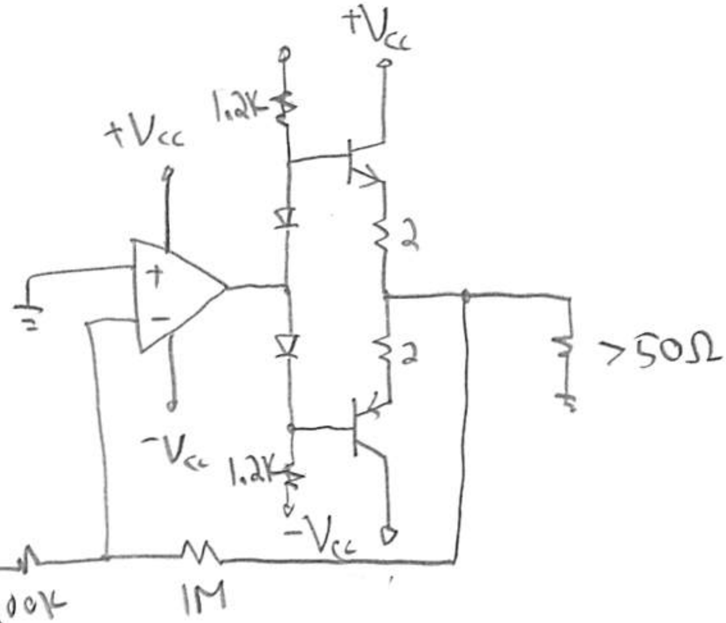
ECE363 HW3 Solns | Total = 100 pts

① ⓐ $G = -\frac{1M}{100K} = \underline{-10}$



Max $V_{OUT} = -10 \times (\pm 0.5V_p)$

$= \boxed{\mp 5V}$

$I_{OUT} = \frac{5V}{50\Omega} = \boxed{0.1A}$

ⓑ want $i_{Diode} = \frac{V_{CC} - V_{B1,max}}{1.2K} - i_{B1,max} > 1mA$

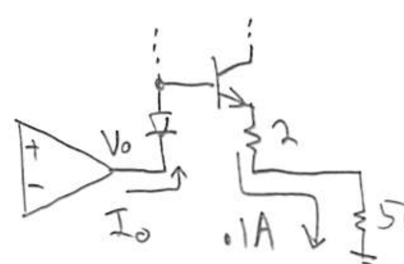
$V_{B1,max} = 5V + (0.1A)(2\Omega) + 0.7 = \underline{5.9V}$

$i_{B1,max} = \frac{0.1A}{100+1} = \underline{.99mA}$

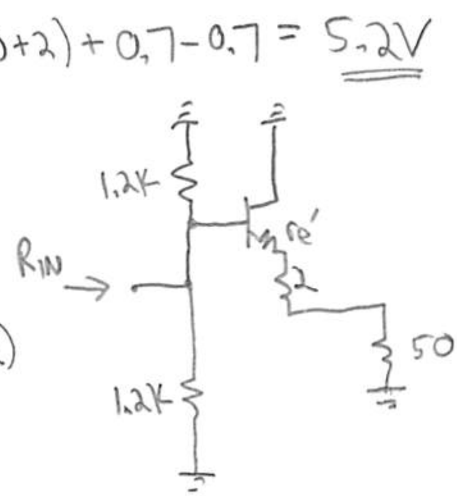
$\Rightarrow \frac{V_{CC} - 5.9}{1.2K} - .99mA > 1mA$

$V_{CC} > 8.29V \Rightarrow$ Choose $\boxed{V_{CC} = 9V}$

ⓒ $V_o = .1A \times (50+2) + 0.7 - 0.7 = \underline{5.2V}$



$I_o = \frac{V_o}{R_{IN}}$



$R_{IN} \approx 1.2K // 1.2K // (\beta+1)(52)$

$= 1200 // 1200 // 5252$

$= \underline{538.5\Omega}$

$\Rightarrow I_o = \frac{5.2V}{538.5\Omega} = \underline{9.7mA}$

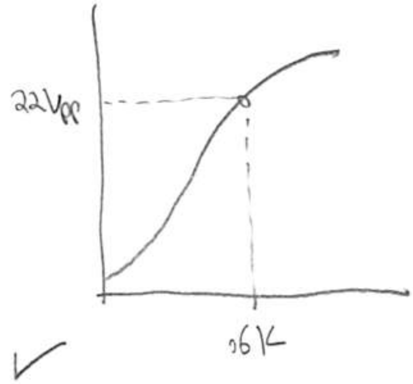
op amp head room: $9 - 5.2 = \underline{\underline{3.8V}}$

For $V_{cc} = 15V \rightarrow V_o = 15 - 3.8 = 11.2V$

$(22.4V_{pp})$

$i_o = \frac{11.2V}{.6K} = 18.7mA$

$> 9.7mA$ ✓



YES, op amp is OK! :)

(2)

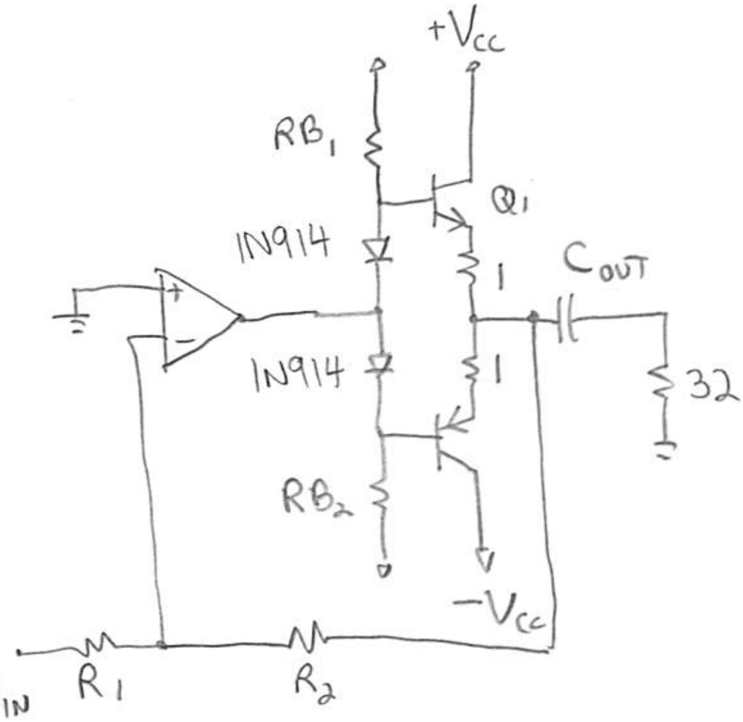
(a) For sine wave,

$$P = \frac{1}{2}\frac{V_{max}^2}{R} \qquad .4W$$

$$\rightarrow V_{max} = \sqrt{0.4W \times 2 \times 32\Omega}$$

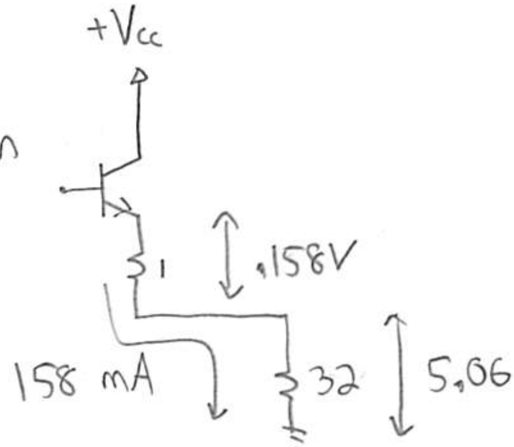
$$= \boxed{5.06V}$$

$$i_{max} = \frac{5.06V}{32\Omega} = \boxed{158mA}$$



(b) $V_{cc} > V_{L,max} + (i_{max} \times 1\Omega) + V_{CE,sat} + 2$

$i_{max} \times 1\Omega$ = .158V; $V_{CE,sat}$ = 0V for now; 2 = Head room



$$V_{cc} > 5.06 + .158 + 2 = \boxed{7.22V}$$

Choose $\boxed{V_{cc} = 9V}$ ← May need to change this later.

(c) Max $I_c \cong 160mA \xrightarrow{\times 2}$ 320mA rating

$$P \sim \frac{.158A}{101}(0.7V) + .99(.158A)(3.78V) \quad [3.78V = 9 - 5.22]$$

$$= \underline{\underline{0.592W}}$$

↓ ×2

$\underline{\underline{>1.18W \text{ rating}}}$

Max $V_{CE} = 9 - (-5.22) = 14.22 \xrightarrow{\times 2}$ $\underline{\underline{28V \text{ rating}}}$

	Max I_c	Max V_{CE}	P_{rating} (no HS)	P_{rating} (w/HS)
2N3904	200mA X			
2N4401	600mA ✓	40V ✓	.625W X	1.5W ✓

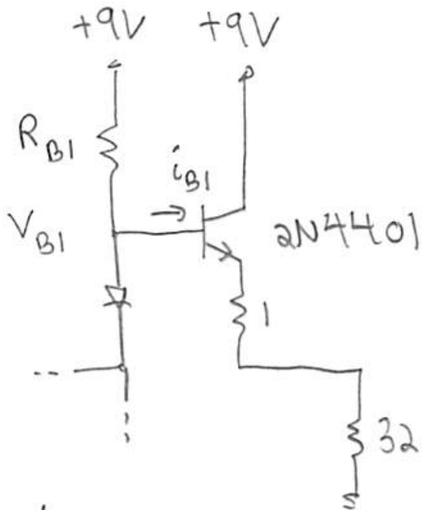
Need to find Θ_{SA}: $T_J = 25^\circ C + .592W \cdot (83.3\frac{^\circ C}{W} + 0.5\frac{^\circ C}{W} + \Theta_{SA}) < 85^\circ C$

$\rightarrow \Theta_{SA} < \boxed{17.6^\circ C/W}$ ✓

Choose $\boxed{2N4401 + 2N4403}$

(d) Choose R_{B1}:

$$i_{Diode} = \frac{9 - V_{B1,max}}{R_{B1}} - i_{B1,max} > 1mA$$



$$V_{B1,max} = (.158A)(33\Omega) + \underbrace{0.95V}_{\text{Max } V_{BE} \text{ @ } I_C = 150mA}$$

$$= \underline{\underline{6.16V}}$$

$$i_{B1,max} = \frac{158mA}{100+1} = 1.56mA$$

↑ β_{min} @ 150mA

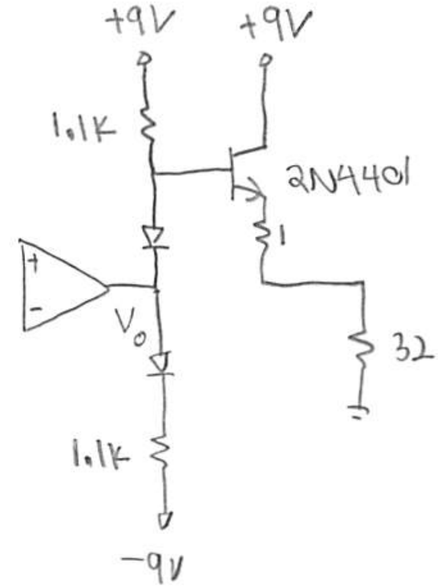
$$\frac{9 - 6.16V}{R_{B1}} - 1.56mA > 1mA$$

$\rightarrow R_{B1} < 1.11K$ Choose $\boxed{R_{B1} = 1.1K} = R_{B2}$

(e) $V_o = 5.21 + V_{BE,max} - V_F$

max = 0.95 min = 0.62V

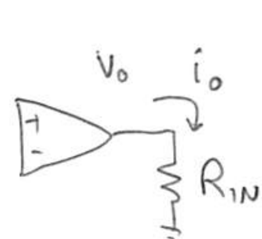
$= \underline{\underline{5.54V}}$



min β

$R_{IN} = 1.1K // 1.1K // (100+1)(33\Omega)$

$= \underline{\underline{472\Omega}}$

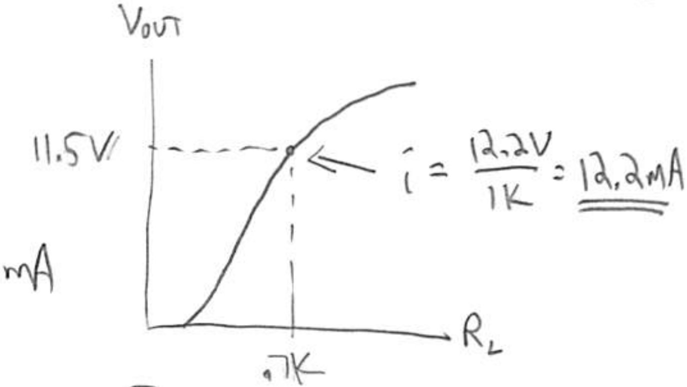


$$i_o = \frac{5.54V}{472\Omega} = \underline{\underline{11.7mA}}$$

op amp head room = $9 - 5.54 = 3.46V$

$V_{cc} = 15V \rightarrow V_o = 15 - 3.46 = 11.54V$

$i_o = \frac{11.5V}{.7K} = 16.5mA > 11.7mA$



YES, op amp is OK! :)

(f) Since $P_{Load} \leq 400mW$, $V_{Load} \leq 5.06V$ } $|V_{Load}| = |G\,V_{IN,max}| \leq 5.06V$

$$|G| \leq \frac{5.06V}{0.5V} = 10.12$$

using $|G| = \frac{R_2}{R_1}$ and $Z_{IN} = R_1 \geq 10K$

Choose $R_1 = 11K$, $R_2 = 110K$ ← $G = \frac{110K}{11K} = 10$ ✓

(g) Lowest freq of interest = 200Hz

$$\left|\frac{1}{j\omega C_{OUT}}\right| = \frac{1}{2\pi(200Hz)C_{OUT}} < \frac{1}{10} \cdot 32\Omega \Rightarrow C_{OUT} > 2.49 \times 10^{-4} F$$

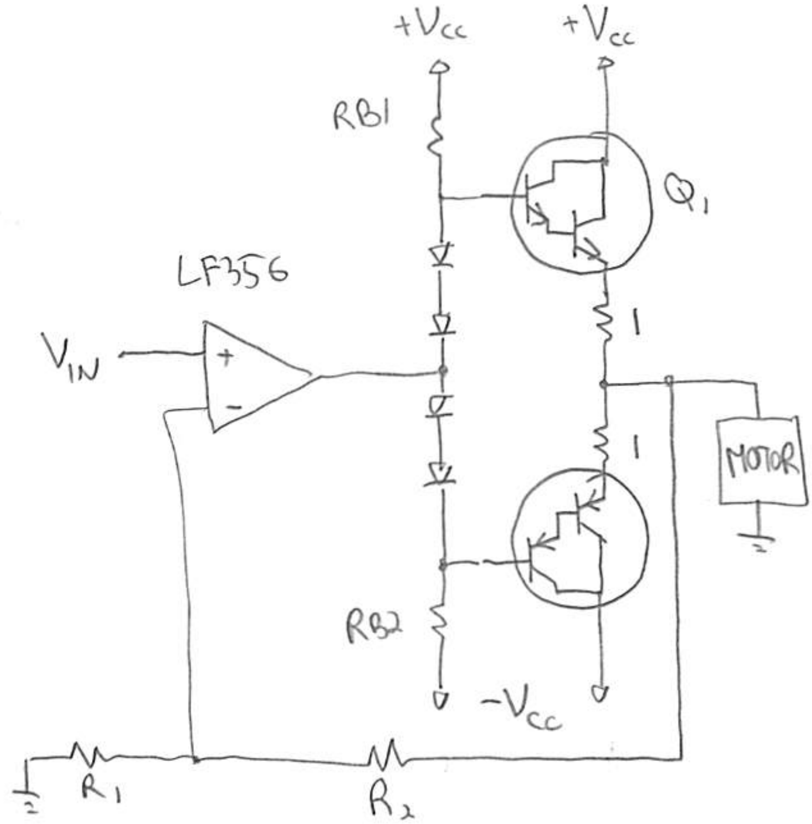
$$> 249 \times 10^{-6} F$$

Choose $C_{OUT} = 470\mu F$

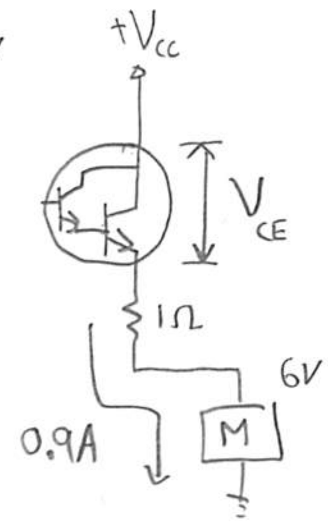
(3)

(a) Max $V_{Load} = 6V$

$I_{Load} = 900\ mA$



(b) $V_{cc} > \underbrace{V_{Load}}_{6V} + \underbrace{I_{Load} \times 1\Omega}_{0.9V} + \underbrace{V_{CE,sat}}_{0.7V \text{ for Darlington}} + 2V = 9.6V$



Need > 1.8A rating

Choose $\boxed{V_{cc} = 12V}$

(c) Max $V_{CE} = 12 - (-6.9) = 18.9V \xrightarrow{\times 2} 37.8V$ rating

$$P = \frac{.9A}{2501}(1.4V) + \frac{2500}{2501}(.9A)\overbrace{(5.1V)}^{12-6.9} = \underbrace{4.64W}! \rightarrow 9.28W \text{ rating or higher}$$

	Max I_C	Max V_{CE}	(no HS) P_{Rating}	(w/HS) P_{Rating} ×2
MPSA29	800mA X			
TIP110	2A	60V ✓	2W X	50W ✓

↑ Typical $h_{FE} = 2800$ ✓

This works!

Heat sink: $T_J = 25°C + (4.64W)(2.5\,°C/W + .5\,°C/W + \theta_{SA}) < 85°C$

$$\Rightarrow \theta_{SA} < \frac{85-25°C}{4.64W} - 3°C/W$$

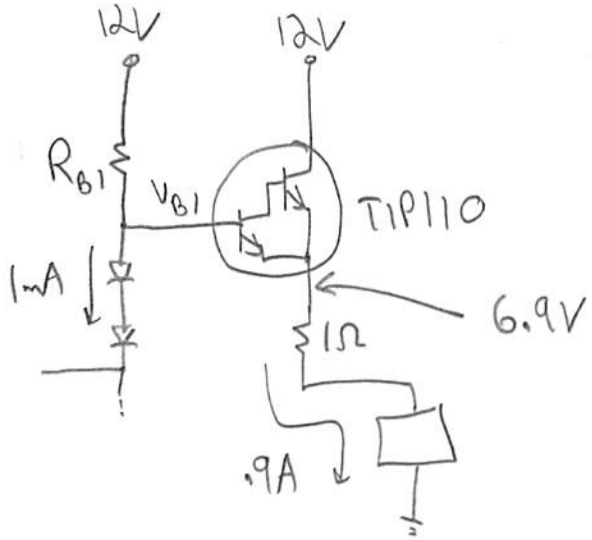
$$< 9.93°C/W \checkmark$$

Choose **TIP110**

Complement is Q_2 = **TIP115**

(d)

Want $i_{Diode} = \frac{12 - V_{B1,max}}{R_{B1}} - i_{B1,max} > 1mA$



$V_{B1,max} = 6.9 + \underbrace{2.8V}_{\text{Max } V_{BE}} = \underline{\underline{9.7V}}$ ← worst case

$i_{B1,max} = \frac{.9A}{1000+1} = 0.9mA$

↑ min β @ 1A

So, $\frac{12-9.7V}{R_{B1}} - 0.9mA > 1mA$

$R_{B1} < 1.21K$ Choose $\boxed{R_{B1} = 1.2K}$ (1.1K is fine)

(e)

(worst case)

Max V_o = Max $V_{B1} - 2 \times \min V_F$

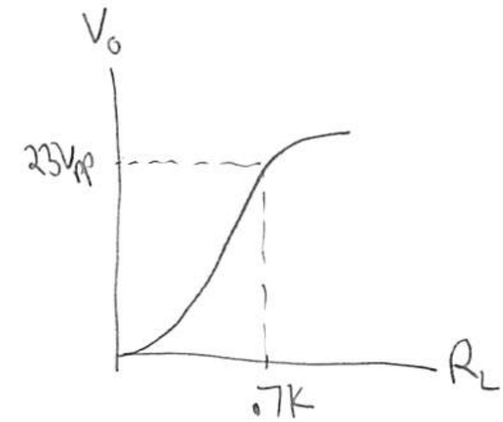
$= 9.7 - 2 \times .62 = \underline{\underline{8.46V}}$

$R_{IN} = 1200 \,//\, 1200 \,//\, (1000+1)\left(1 + \frac{6V}{.9A}\right)$ ← For this problem, OK to treat motor as simple resistor.

(1000+1) ← min β

$\Rightarrow R_{IN} = \underline{556.5\,\Omega}$

So, $i_o = \frac{8.46V}{556.5\Omega} = 15.2mA$



op amp headroom $= 12 - 8.46 = 3.54V$

$V_{cc} = 15V \therefore V_o = 15 - 3.54 = 11.46V$

$(22.9V_{pp})$

$\rightarrow$ max $i_o = \frac{11.46V}{.7K} = 16.4mA > 15.2mA$ (barely!)

YES, op amp can produce desired max output!

(f) Set $G = 1 + \frac{R_2}{R_1} = \frac{6}{.5} = 12 \Rightarrow \frac{R_2}{R_1} = 11$

Let $R_1 = 10K$, $R_2 = 110K$

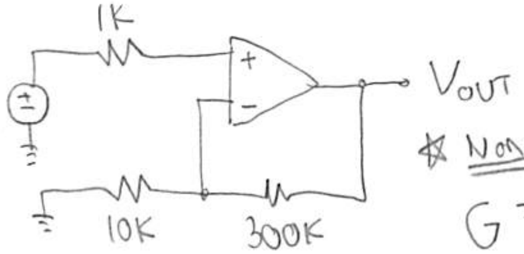
(4)

(a) LF356: (Max)

$I_{IN(BIAS)} = 200\,pA$

$I_{IN(OS)} = 50\,pA$

$V_{IN(OS)} = 10\,mV$



* Non-inv op amp

$G = 1 + \frac{300K}{10K} = \underline{\underline{31}}$

$R_{TH(+)} = 1K$

$R_{TH(-)} = 10K // 300K = 9.68K$

$I_{IN(BIAS)}$: $\Delta V_{OUT} = 31 \times (200 \times 10^{-12})(9.68 \times 10^{3} - 10^{3}) = \boxed{53.8\,\mu V}$

$I_{IN(OS)}$: $\Delta V_{OUT} = 31 \times (50 \times 10^{-12}) \frac{9.68 \times 10^{3} + 10^{3}}{2} = \boxed{8.28\,\mu V}$

$V_{IN(OS)}$: $\Delta V_{OUT} = 31 \times 10\,mV = \boxed{310\,mV}$ ←

(b) Main source of error is $V_{IN(OS)}$

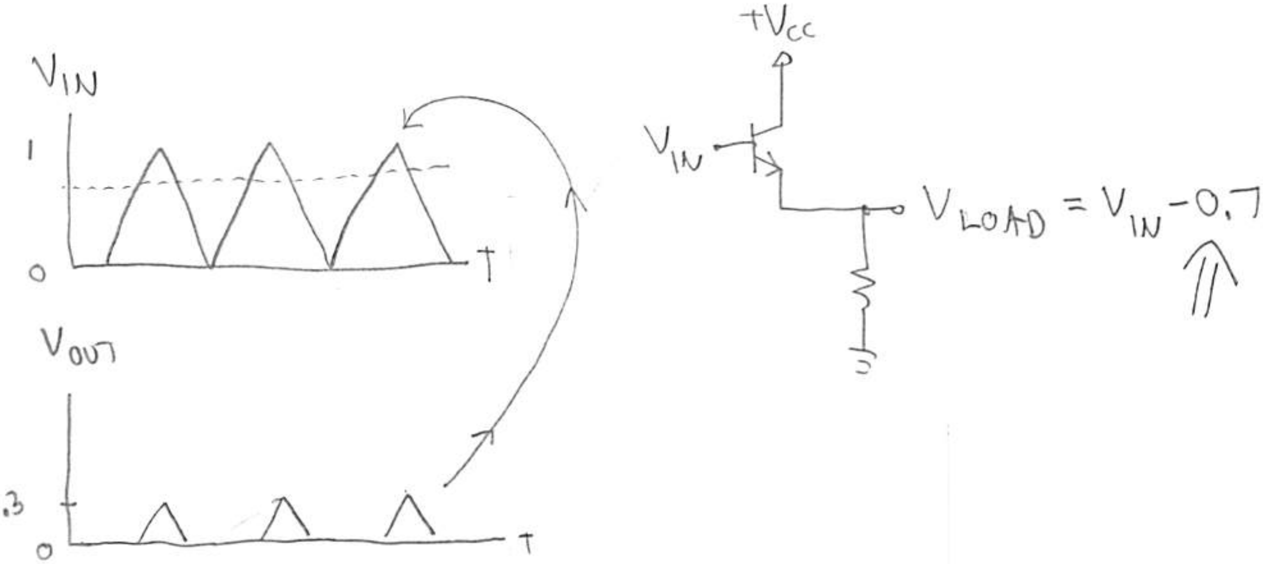
(c) Worst case is to add all three together.

$\text{Max } \Delta V_{OUT} = 0.0538\,mV + 0.00828\,mV + 310\,mV$

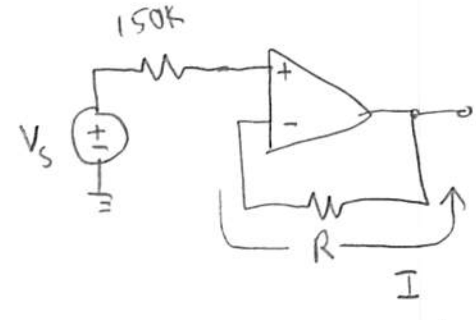
$= \boxed{310.062\,mV}$

(5)

(a)



(b)



$V_- = V_+ = V_S$

Since $I = 0$

$\rightarrow V_{OUT} = V_- = V_S$

$\Rightarrow \boxed{V_{OUT} = V_{sensor}}$

(c) To minimize error due to $I_{IN(BIAS)}$, make $R_{TH(+)} = R_{TH(-)}$

$\rightarrow \boxed{R = 150K}$

(d) Worst-case: ← use max value (unless stated otherwise in problem)

$I_{IN(BIAS)}$: $1 \times (500\,nA) \times (150K - 150K) = 0V$

$I_{IN(OS)}$: $1 \times (200 \times 10^{-9}) \times \frac{150K + 150K}{2} = 30\,mV$

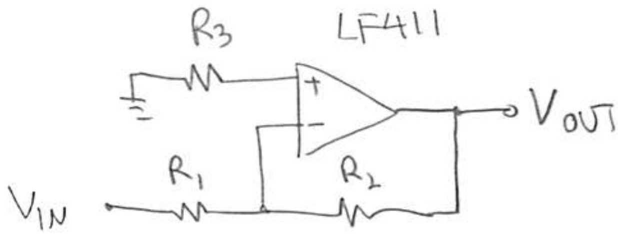
$V_{IN(OS)}$: $1 \times 6\,mV = 6\,mV$

worst-case $\Delta V_{OUT} = 0 + 30 + 6\,mV = \boxed{36\,mV}$

(6)

(a) For inverting amplifier,

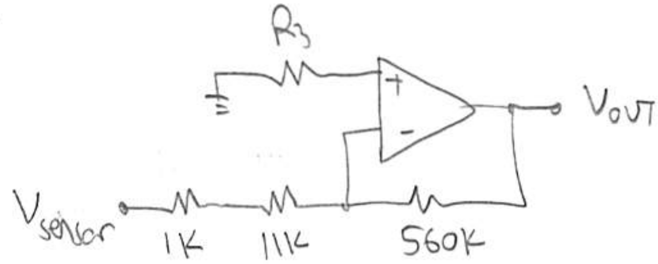
$Z_{IN} = R_1 \geq 10K$



Choose $R_1 = 11K$, $R_2 = 560K$ → $G = -\frac{560K}{11K} = -50.9$ ✓

(b) $R_{TH(-)} = (1K + 11K) // 560K$

$= 11.75K$

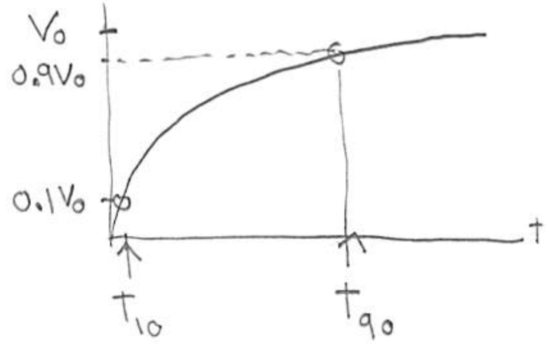


Choose $R_3 = 12K$

(c) For LF411, GBW = 4MHz

→ $BW = \frac{4MHz}{50.9} = 78.6\ KHz$

⑦



$$V(t) = V_0\left(1 - e^{-t/RC}\right)$$

ⓐ $$0.1V_0 = V_0\left(1 - e^{-t_{10}/RC}\right)$$

$$e^{-t_{10}/RC} = 0.9$$

$$-\frac{t_{10}}{RC} = \ln(0.9) \rightarrow \boxed{t_{10} = -RC\ln 0.9}$$

ⓑ $$0.9V_0 = V_0\left(1 - e^{-t_{90}/RC}\right)$$

$$e^{-t_{90}/RC} = 0.1 \Rightarrow -\frac{t_{90}}{RC} = \ln 0.1 \rightarrow \boxed{t_{90} = -RC\ln 0.1}$$

ⓒ $$T_R = t_{90} - t_{10} = -RC\ln 0.1 - (-RC\ln 0.9)$$

$$= RC\left[\ln 0.9 - \ln 0.1\right] = RC\ln\frac{0.9}{0.1}$$

$$\boxed{T_R = RC \times \ln 9 = 2.2RC}$$

ⓓ $$f_c = \frac{1}{2\pi RC} \rightarrow RC = \frac{1}{2\pi f_c}$$

so, $$T_R = 2.2\frac{1}{2\pi f_c} = \boxed{\frac{0.35}{f_c}}$$

(8)

(a) 741 data sheet does not give f_{unity}

but does give rise time = 0.3μs (for G=1)

$$T_R = \frac{0.35}{f_c} \rightarrow f_c = \frac{0.35}{T_R}$$

$$f_{unity} = \frac{0.35}{0.3\mu s} = 1.2MHz$$

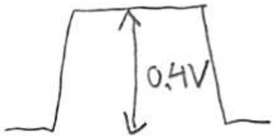
$$BW = \frac{f_{unity}}{G} \qquad G = 10^{26dB/20} = 19.95$$

$$= \frac{1.2MHz}{19.95} = \boxed{60kHz} \qquad T_R = \frac{0.35}{.060MHz} = \boxed{5.83\mu s}$$

(b) Slew rate affects op amp output

$$V_{OUT} = GV_{IN} = 19.95 \times .020V_{pp} = 0.399V_{pp} \sim 0.4V_{pp}$$

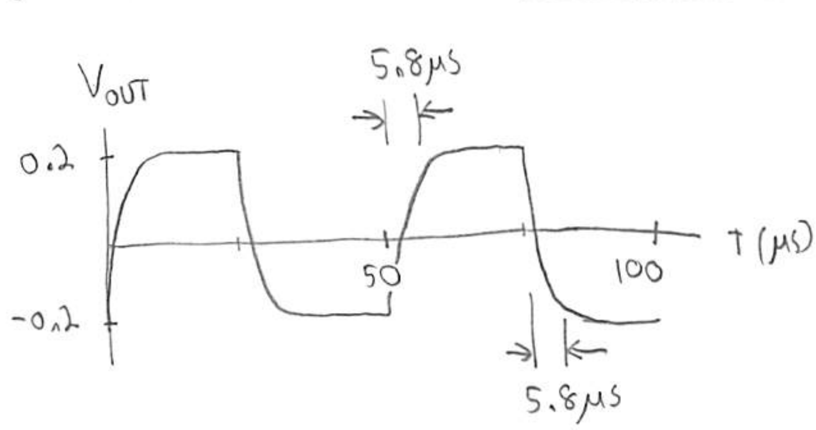
$$T_{SR} = \frac{0.8 \times 0.4V}{0.5V/\mu s} = \boxed{0.64\mu s}$$



(c) Since $T_R >> T_{SR}$, amplifier is limited by **small-signal BW**

(d) 20kHz

1 cycle = 50μs



(9)

(a) Slew rate affects op amp output

$$|G| = 30\,dB \Rightarrow G = 10^{30/20} = \underline{31.6}$$

$$V_{OUT} = -31.6 \cdot 0.1 V_p = -3.16\, V_p$$

Only for sine waves?

$$\Rightarrow \underbrace{\text{Large-signal}}_{\text{same as ``power''}}\ BW = \frac{SR}{2\pi V_p} = \frac{15\ V/\mu s}{2\pi\,(3.16V)} = 0.755\,MHz$$

$$= \boxed{755\ KHz}$$

(b) $$\text{Small-signal } BW = \frac{f_{unity}}{G} = \frac{4\,MHz}{31.6} = 0.127\,MHz = \boxed{127\ KHz}$$

(c) Since 127 KHz < 755 KHz

→ Limited by **small-signal BW**