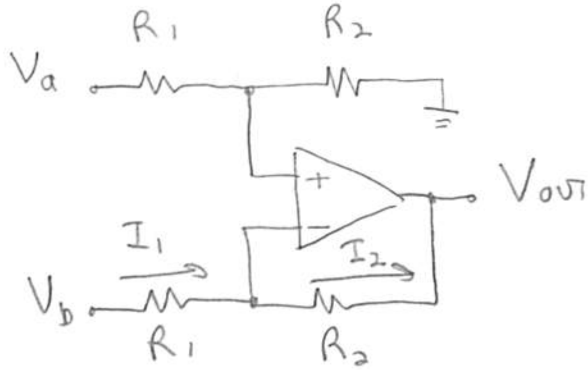
ECE 363
HW 2 Solns

Total = 100 pts



(1) (a) $V_- = V_+ = V_a \dfrac{R_2}{R_1+R_2}$ (1)

KCL at node (−):

$$I_1 = I_2 + 0$$

$$\frac{V_b - V_-}{R_1} = \frac{V_- - V_{OUT}}{R_2} \rightarrow \frac{V_b}{R_1} - \left(\frac{1}{R_1} + \frac{1}{R_2}\right)V_- = -\frac{V_{OUT}}{R_2}$$

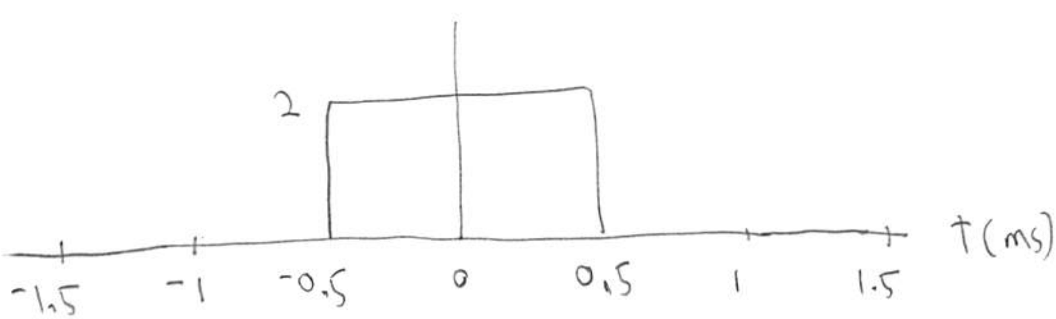
$$V_{OUT} = -\frac{R_2}{R_1}V_b + \cancel{R_2}\left(\frac{R_1+R_2}{R_1\cancel{R_2}}\right)V_- = -\frac{R_2}{R_1}V_b + \frac{\cancel{R_1+R_2}}{R_1} V_a \frac{R_2}{\cancel{R_1+R_2}}$$

$$\Rightarrow \boxed{V_{OUT} = \frac{R_2}{R_1}(V_a - V_b)}$$

(b) $\left.\begin{matrix} R_1 = 10K \\ R_2 = 100K \end{matrix}\right\}$ $V_{OUT} = 10(V_a - V_b)$

$$\begin{array}{r} V_a = 3 + 0.1\,\text{rect}(t/T) \\ -\quad V_b = 3 - 0.1\,\text{rect}(t/T) \\ \hline V_a - V_b = 0.2\,\text{rect}(t/T) \end{array}$$

SO, $V_{OUT} = 2\,\text{rect}(t/T)$

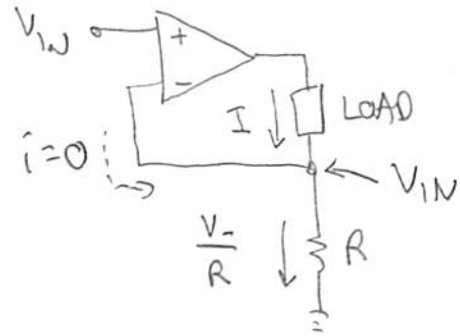


(2)

(a)

$V_- = V_+ = V_{IN}$

$I_{Load} = \frac{V_-}{R} = \boxed{\frac{V_{IN}}{R}}$



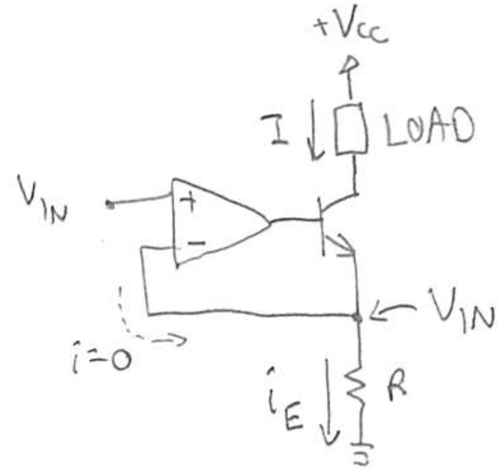
(b)

$V_- = V_+ = V_{IN}$

$\hat{i}_E = \frac{V_{IN}}{R}$

$\hat{i}_{LOAD} = \hat{i}_C = \alpha \hat{i}_E$

$= \boxed{\alpha \frac{V_{IN}}{R}}$



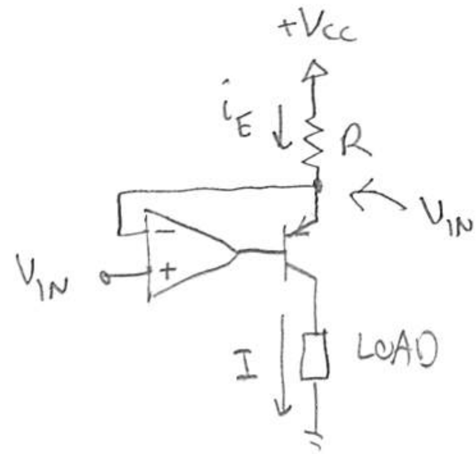
(c)

$V_- = V_+ = V_{IN}$

$\hat{i}_E = \frac{V_{cc} - V_{IN}}{R}$

$\hat{i}_{LOAD} = \hat{i}_C = \alpha \hat{i}_E$

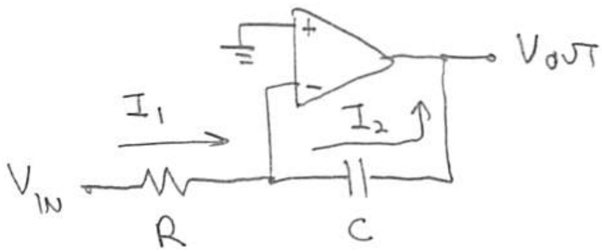
$= \boxed{\alpha \frac{V_{cc} - V_{IN}}{R}}$ ← This is a little tricky to use, since $V_{IN} = 0$ (no signal) produces large current!



(3)

(a) $V_- = V_+ = 0$

KCL at node (-):



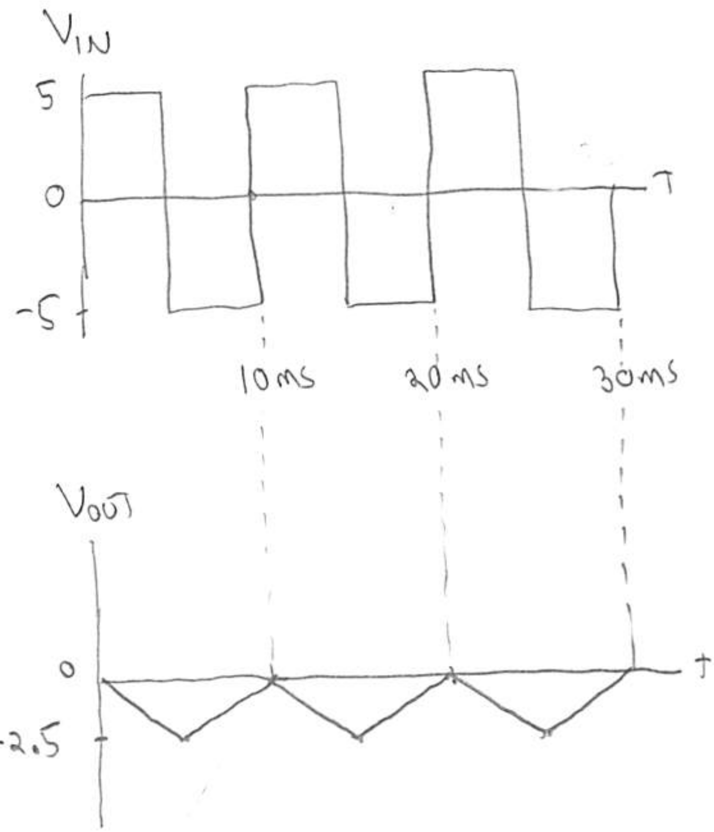
$$\frac{V_{IN} - 0}{R} = C \frac{d}{dt}(0 - V_{OUT})$$

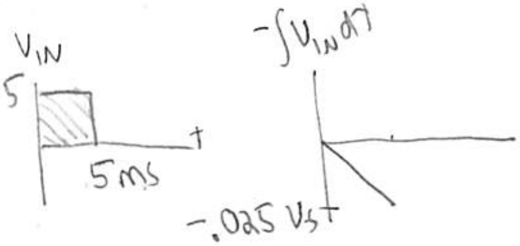
$$\rightarrow \frac{dV_{OUT}}{dt} = -\frac{1}{RC} V_{IN} \Longrightarrow \boxed{V_{OUT} = -\frac{1}{RC}\int V_{IN}\, dt}$$

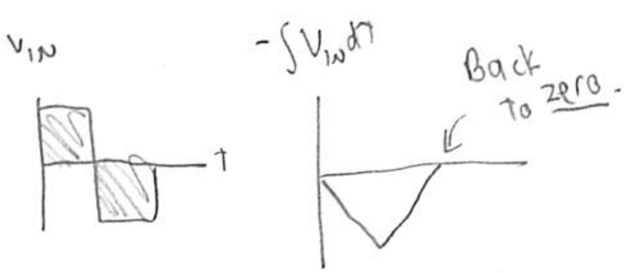
(b) $R = 100K$, $C = 100nF$ $\Big\}$ $\frac{1}{RC} = \frac{1}{10^5 \times 10^{-7}} = 100\ s^{-1}$

$$\rightarrow V_{OUT} = -100 \int V_{IN}\, dt$$

$\int V_{IN}\, dt$ = Area under curve





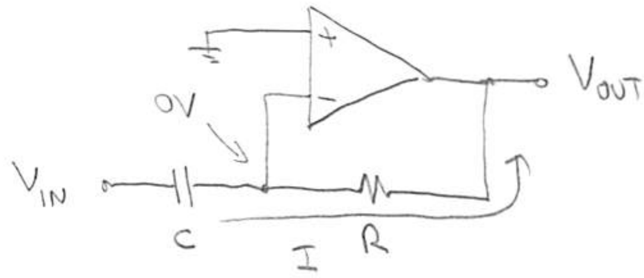


$$\text{Peak} = -100 \int V_{IN}\, dt = -100\,(.025) = \underline{\underline{-2.5\,V}}$$

(4) (a) $V_+ = 0 = V_-$

$V_{OUT} = 0 - IR$

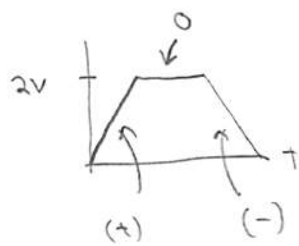
$I = C\frac{d}{dT}(V_{IN} - 0)$



$$\boxed{V_{OUT} = -RC\frac{dV_{IN}}{dT}}$$

(b) Derivative is the slope of curve

$\frac{T}{8} = \frac{100\,ms}{8} = 12.5\,ms$



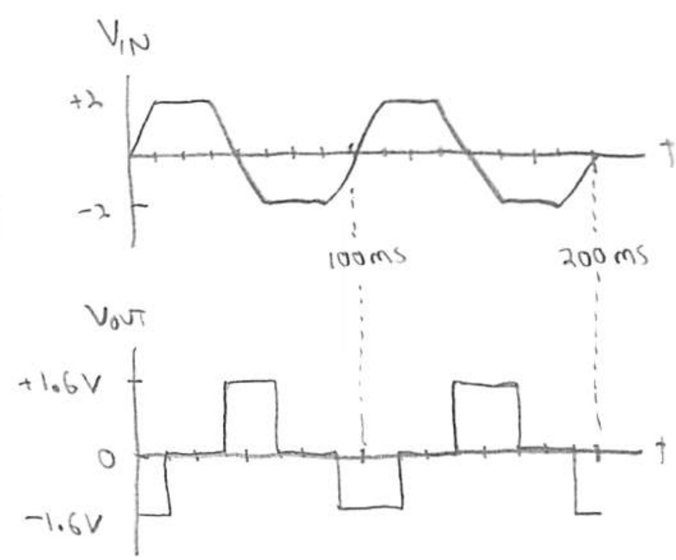
Slope $= \frac{2V}{.0125\,s} = 160\ V/s$

Slope $= -\frac{2V}{.0125\,s} = -160\ V/s$

$RC = 10^5 \times 10^{-7} = .01\,s$

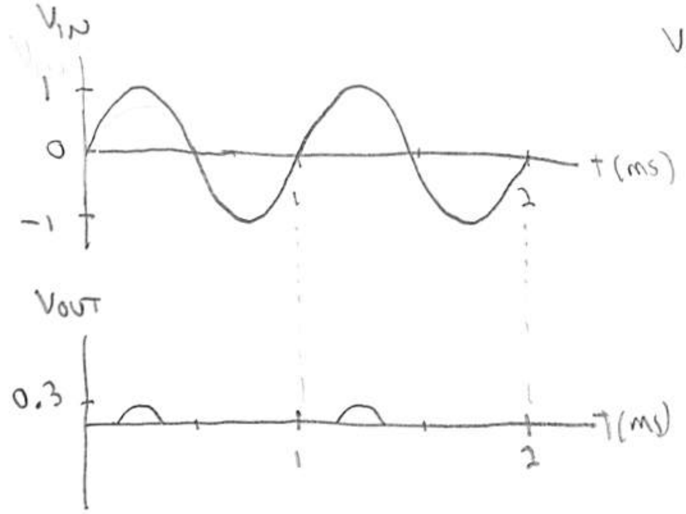
$-RC\frac{dV}{dT} = -1.6V$

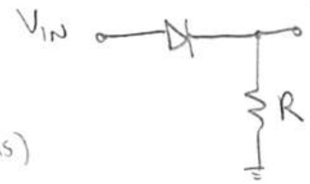
$-RC\frac{dV}{dT} = 1.6\,V$



(5)

(a)





$V_{OUT} = V_{IN} - 0.7$

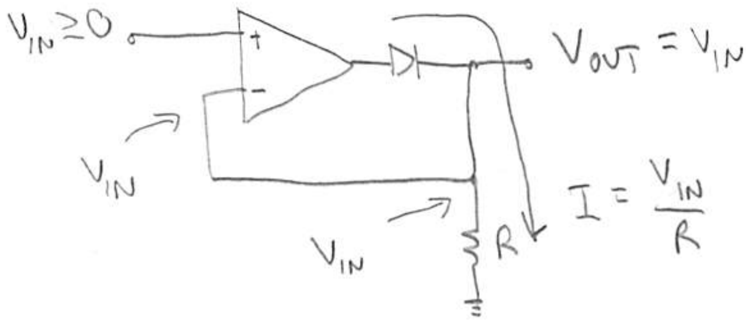
(For $V_{IN} > .7$)

(b)

$V_{IN} \geq 0$:

$V_+ = V_{IN} = V_-$

Current through R is $I = \frac{V_{IN}}{R}$

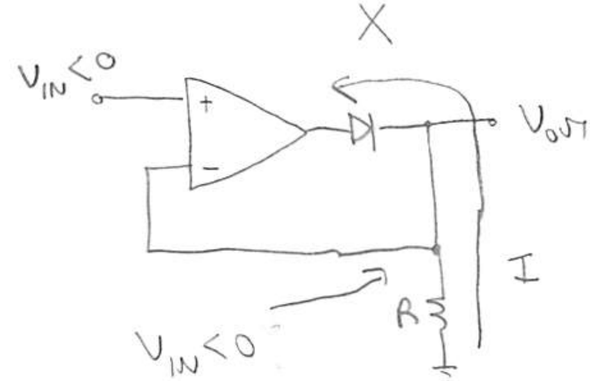


→ $\boxed{V_{OUT} = IR = V_{IN}}$ when $V_{IN} \geq 0$

$V_{IN} < 0$:

$V_+ = V_{IN} = V_-$?

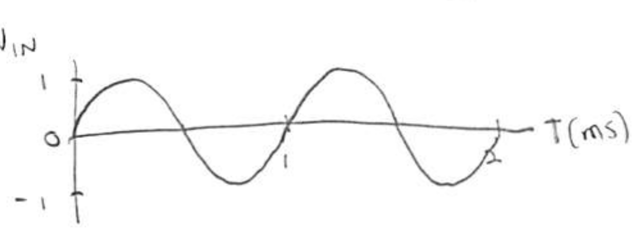
If this were true, then current must flow against the diode!

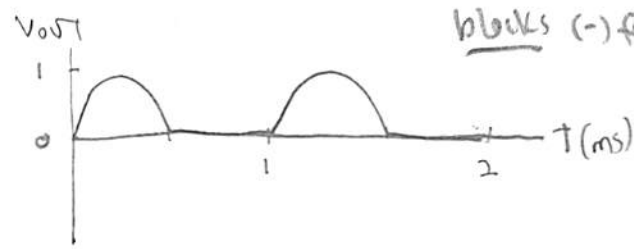


→ $\boxed{\text{Since } I = 0,\ V_{OUT} = 0 \text{ when } V_{IN} < 0}$

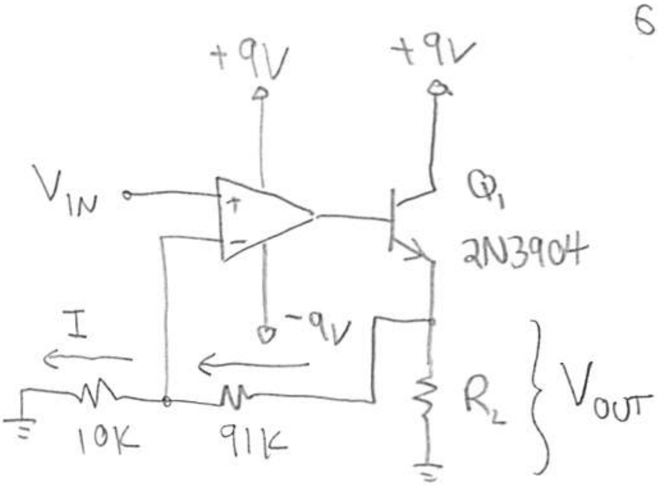
NOTE: Golden Rules are violated when $V_{IN} < 0$ because diode blocks (−) feedback loop.

(c)





(6)



(a) $V_- = V_+ = V_{IN}$

$$I = \frac{V_{IN} - 0}{10K} = \frac{V_{OUT} - V_{IN}}{91K}$$

$$\frac{91K}{10K} V_{IN} = V_{OUT} - V_{IN}$$

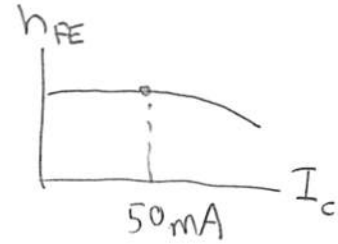
$$\frac{V_{OUT}}{V_{IN}} = (1 + 9.1) = \boxed{10.1}$$

(b) $V_{OUT} = 10.1 \times 0.5 = \boxed{5.05V}$ $\quad I_{Load} = \frac{5.05V}{100\Omega} = \boxed{50.5mA}$

(c) 2N3904 data sheet: $h_{FE} = 200$ (typ)

$= 60$ (min) @ 50mA

↖ From table



Typical op amp current $= \frac{50.5mA}{200+1} = \boxed{0.25mA}$ ← OK to ignore current in 91K resistor (negligible)

NOTE: worst case op amp current $= \frac{50.5mA}{60+1} = 0.83mA$

(d) For Q_1, $P = I_B V_{BE} + I_C V_{CE}$

$$= (0.83mA)(0.78V) + \frac{200}{201}(50.5mA)(9 - 5.05)$$

$$= \boxed{199.1mW}$$

Data sheet

Typical $V_{BE} = .78V$, $\beta = 200$ at $I_C = 50mA$

(e) Need $> 199.1mW \times 2 = $ 398.2mW rating.

2N3904 has 625mW rating ⟶ NO heat sink needed!

(7)

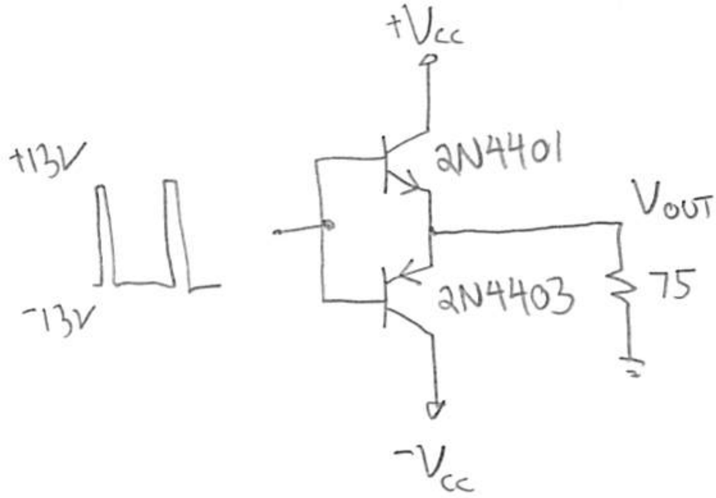
(a) Require

$$V_{cc} > V_{OUT} + V_{CE,sat} + 2 \quad \text{(Head room)}$$

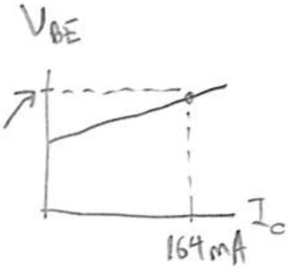
$$> 12.3 + 0 + 2$$

$$> \underline{\underline{14.3V}}$$

Choose $\boxed{V_{cc} = 15V}$

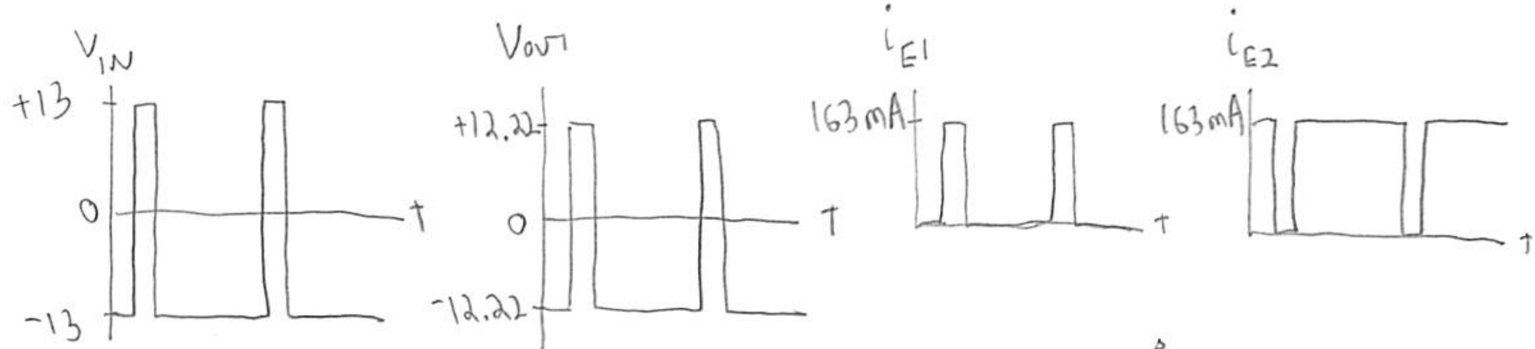


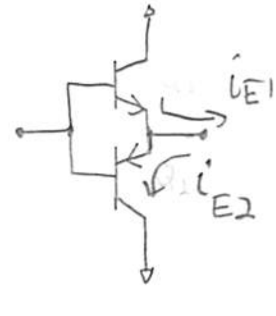
(b) Max $I_L \sim \frac{12.3V}{75\Omega} = \underline{\underline{164 mA}} \rightarrow V_{BE} \cong 0.78V$



$$\rightarrow V_{OUT} = 13 - .78 = \underline{\underline{12.22V}}$$

$$I_{Load} = \frac{12.22V}{75\Omega} = 0.163 = \underline{\underline{163mA}}$$





(c) 2N4401 data sheet: $\max V_{BE} = 0.95V$, $\min h_{FE} = 100$ } $I_c = 150mA$

2N4401: worst case $V_{Load} = 13 - .95 = \underline{\underline{12.05V}}$

$$I_{Load} = 160.7\,mA$$

$$I_B = \frac{160.7}{100+1} = \underline{\underline{1.59\,mA}}$$

- Q_1 is on 25% of time:

$$\langle P \rangle = 0.25\left[i_B V_{BE} + i_C V_{CE} \right] = 0.25\left[(1.59mA)(0.95V) + \tfrac{100}{101}(160.7mA)(15-12.05V) \right]$$

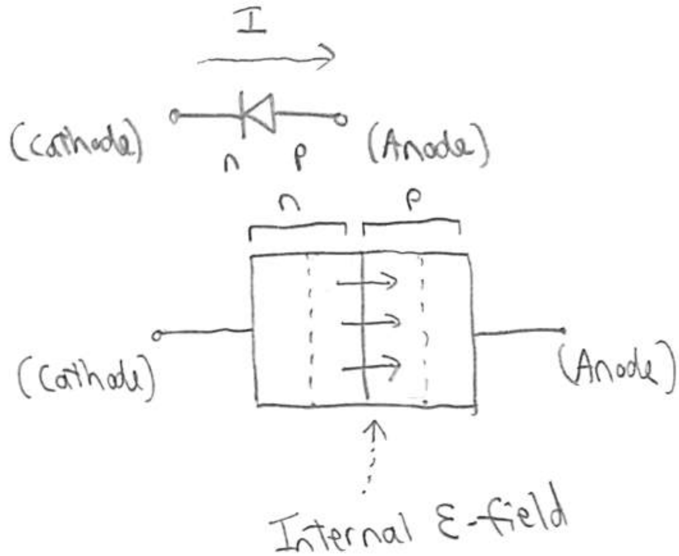
$$= \boxed{117.7mW}$$

- Q_2 is on 75% of time:

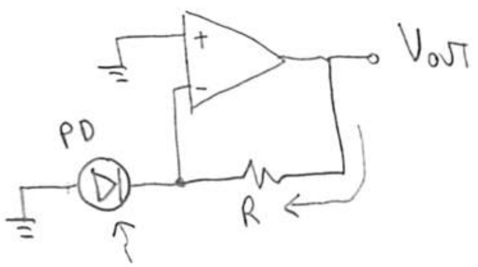
$$\langle P \rangle = 0.75\left[|i_B V_{BE}| + |i_C V_{CE}| \right] = 0.75\left[(1.59mA)(.95V) + \left| \tfrac{100}{101}(160.7mA)(-15+12.05) \right| \right]$$

$$= \boxed{353.1\,mW}$$

(8) (a) Photodiode current flows from cathode to anode.



For positive V_{OUT}:



(b) BPV22F data sheet: $\lambda = 950\,nm \Rightarrow I = 9\,\mu A$ @ $E = 0.1\,mW/cm^2$

want $V_{OUT} = (9\,\mu A) \times R \geq 5V$

$R \geq 555.6K$

Choose $\boxed{R = 560K}$

NOTE: 620K is safer choice due to ±5% tolerance

(c) $\lambda = 850\,nm \Rightarrow S \sim 0.35$

$\Rightarrow V_{OUT} = 0.35 \times 9\,\mu A \times 560K = \boxed{1.76V}$

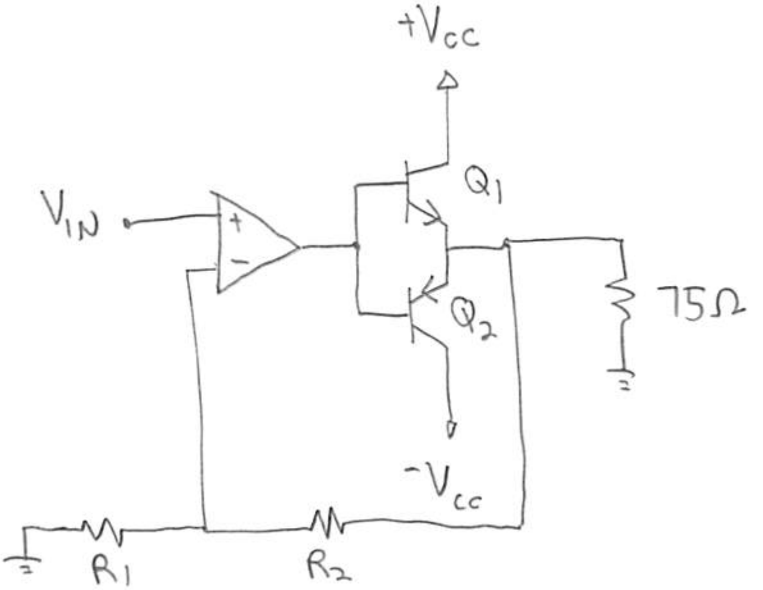
(9)

ⓐ Max DC power:

$$300\,mW = \frac{V_{max}^2}{75\,\Omega}$$

$\Rightarrow$ $\boxed{V_{max} = 4.74\,V}$

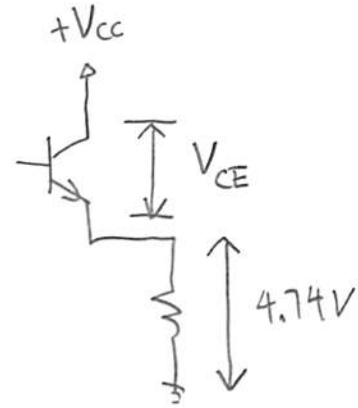
$$I_{max} = \frac{4.74V}{75\,\Omega} = \boxed{63.2\,mA}$$



ⓑ want $V_{cc} > 4.74 + \underbrace{V_{CE(sat)}}_{0 \text{ for quick analysis}} + 2$

$\boxed{V_{cc} > 6.74V}$

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



ⓒ • Max load: $i_E = 63.2mA$

$V_{CE} = 9 - 4.74 = 4.26V$ ← (for $i_L = 63.2mA$)

• V_{CE} rating $> 2 \times (\underbrace{9 - (-4.74)}_{13.74})$

$\therefore$ > $\underline{\underline{27.5V}}$

	Max I_C	Max V_{CE}
2N3904	200 mA	40V ✓

↑ useful h_{FE} is up to 100mA ✓

$$P = \frac{.063A}{101}(0.7V) + 0.99(.063A)(9 - 4.74V) = 0.266W$$

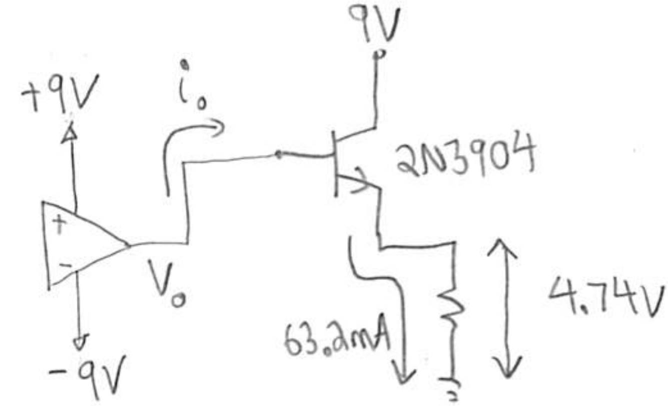
→ $T_J = 25°C + (0.266W)(200°C/W) = \underline{\underline{78.2°C}}$ ✓ No heat sink needed?

→ 2N4401 and TIP31 are "bigger" transistors (higher I_c).

⇒ Since 2N3904 works, and is the "smallest" transistor, choose the **2N3904** (npn) and **2N3906** (pnp)

(d) Max $V_o = 4.74 + V_{BE}$

Max = 0.95V for $I_c = 50mA$



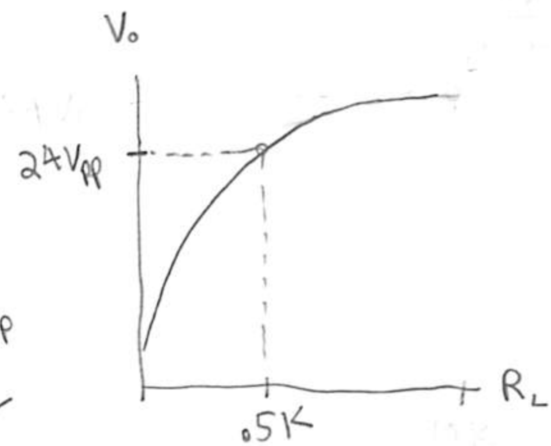
→ Max V_o = $\underline{5.69V}$

$$\text{Max } i_o = \frac{63.2mA}{\beta_{min}+1} = \frac{63.2mA}{60+1} = \underline{1.04\,mA}$$

↑ at $I_c = 50mA$

Op amp head room = 9 − 5.69 = $\underline{3.31V}$

LF411: Max V_o = 15 (V_{cc}) − 3.31 = 11.69V → ×2 → 23.4V_{pp}



$$\text{Max } i_o = \frac{11.69V}{.5K} = \underline{23.4mA} > \underline{1.04mA} \checkmark$$

Op amp is OK! :)

(e) For non-inverting op amp,

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

$$G_{dB} = 20\log_{10}(G) \Rightarrow G = 10^{12dB/20} = 4$$

$$1 + \frac{R_2}{R_1} = 4$$

Choose **$R_1 = 1K$, $R_2 = 3K$** ← 3.3K is fine