ECE 363
HW1 Solns

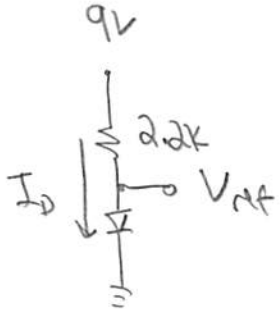
Total = 100 pts

① a) Assume diode ON ✓

$$9 - I_D \times 2.2K - 0.7 = 0$$

$$I_D = \frac{9-0.7}{2.2K} = \boxed{3.77mA}$$

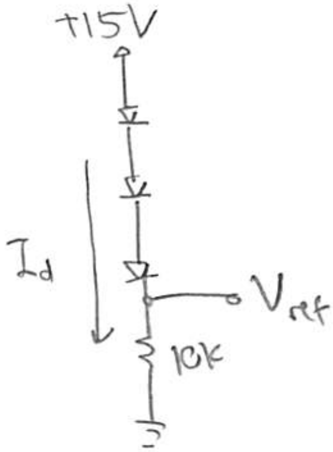
$$\boxed{V_{Ref} = 0.7V}$$



b) Assume diodes ON: ✓

$$V_{ref} = 15 - 3\times0.7 = \boxed{12.9V}$$

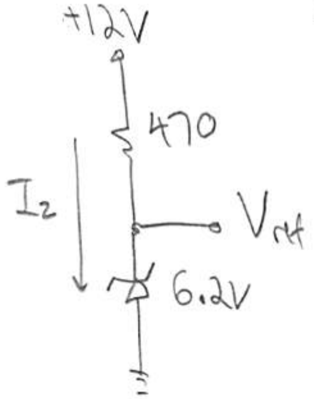
$$I_d = \frac{12.9-0}{10K} = \boxed{1.29mA}$$



c) $V_{ref} = V_z = \boxed{6.2V}$

(Assume zener ON). ✓

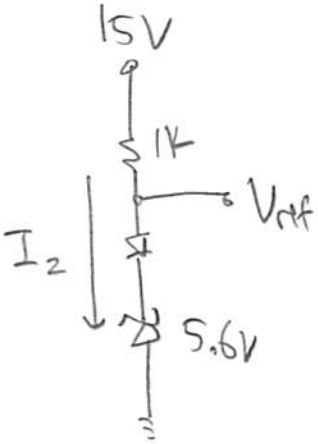
$$I_z = \frac{12-6.2V}{470} = .0123A = \boxed{12.3mA}$$



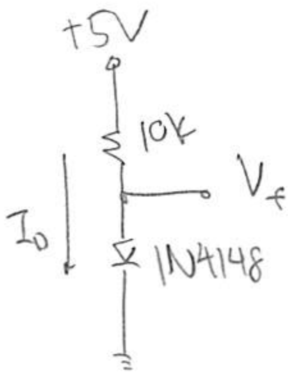
d) Assuming zener + diode ON: ✓

$$V_{ref} = 5.6 + 0.7 = \boxed{6.3V}$$

$$I_z = \frac{15-6.3}{1K} = \boxed{8.7mA}$$



②



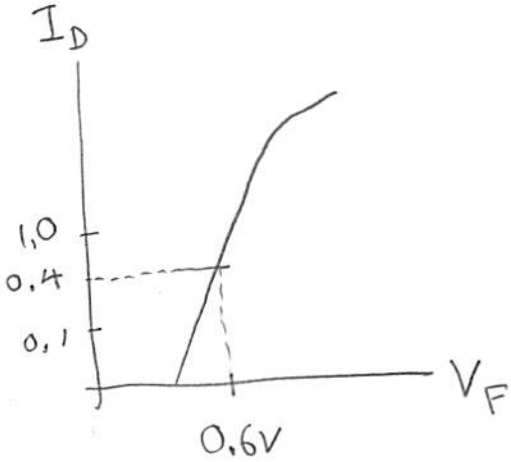
ⓐ "Quick" analysis means assume diode has 0.7V:

$$I_d = \frac{5-0.7}{10k} = \boxed{0.43mA}$$

ⓑ

For $I_d = 0.43mA$

→ $\boxed{V_F \sim 0.6V}$

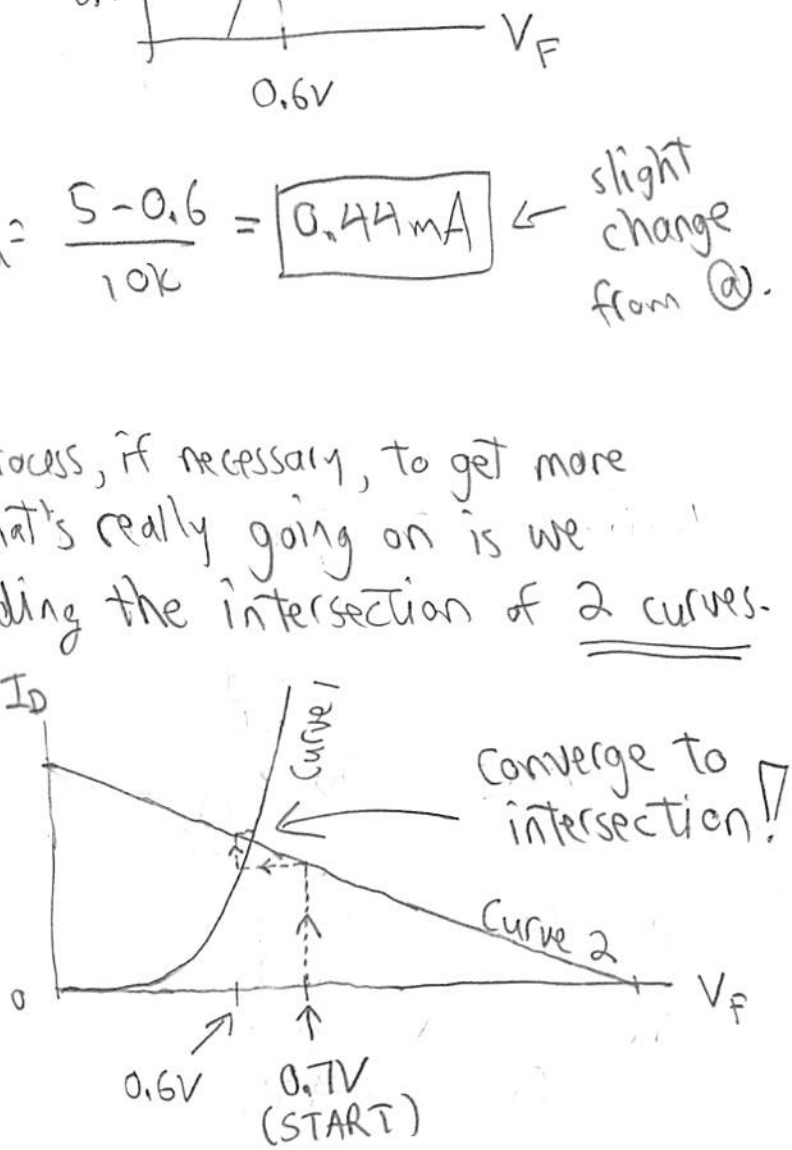


ⓒ using $V_F = 0.6V \rightarrow I_d = \frac{5-0.6}{10k} = \boxed{0.44mA}$ ← slight change from ⓐ.

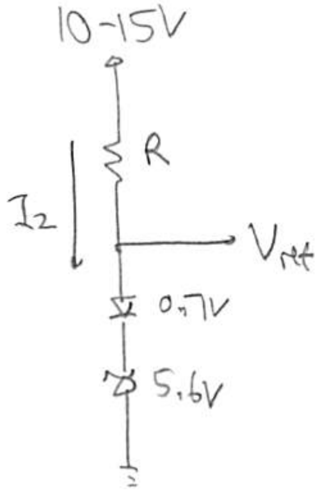
※ NOTE: You can repeat this process, if necessary, to get more accurate result. What's really going on is we are numerically finding the intersection of 2 <u>curves</u>.

① I_D-V_F plot

② $I_D = \frac{5-V_F}{10k}$



③



- want $I_z > 10mA$

$$\text{Min } I_z = \frac{10-(5.6+0.7)}{R} > .010A$$

$$R < 370\Omega \xrightarrow{\times .95} 351.5$$

$$\text{Choose } \boxed{R = 330\Omega}$$

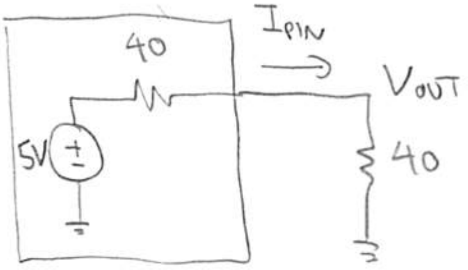
(360Ω would be OK)

- want $P_{rating} > 2\times\underbrace{(\text{max power dissipation})}$

$$\text{Max } P = \frac{(15-6.3)^2}{330} = 0.23W$$

$$P_{rating} > 2\times .23 = .46W \rightarrow \text{Choose } \boxed{\tfrac{1}{2}W \text{ rating}}$$

④



(a) $I_{PIN} = \frac{5-0V}{80\Omega}$

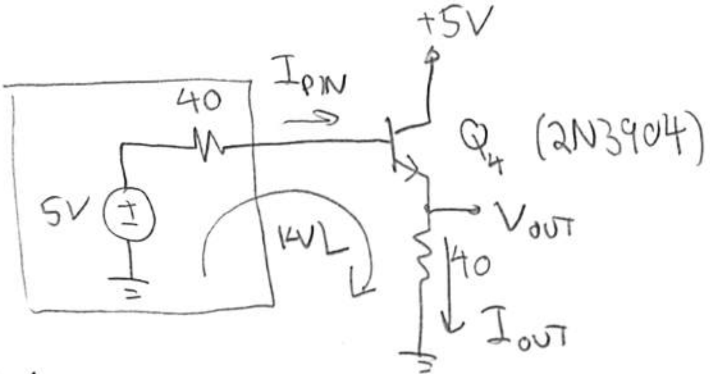
$= \boxed{62.5mA}$

$V_{OUT} = (.0625A)(40\Omega) = \boxed{2.5V}$

(b) $V_{OUT} << 4V$ ← NOT ACCEPTABLE! ☹

(c) KVL: $\frac{1}{101}I_{OUT}$

$5 - I_{PIN}\cdot 40 - 0.7 - I_{OUT}\times 40 = 0$



$I_{OUT} = \frac{5-0.7V}{\frac{40}{101}+40} = \underline{106.4mA}$

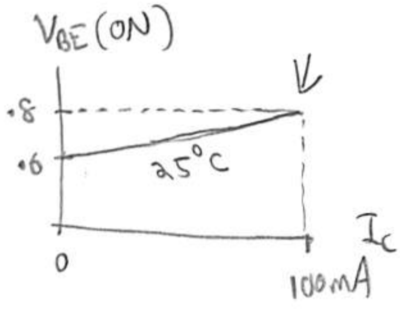
$\rightarrow V_{OUT} = (.1064)(40) = \boxed{4.26V}$ ← OK!

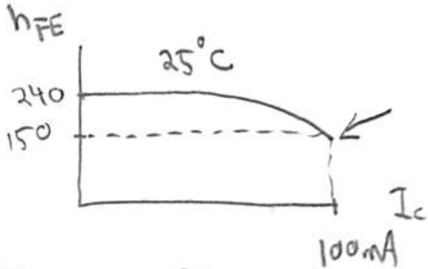
(d) Since $I_c \sim 0.99(106.4mA) = 105.3mA$

$V_{BE} = 0.8V$

$\beta = 150$

} From plots on page 3 of data sheet





$\rightarrow I_{OUT} = \frac{5-0.8V}{\frac{40}{150+1}+40} = 104.3mA$

$\rightarrow V_{OUT} = (.1043)(40) = \boxed{4.17V}$ ← OK!

4.2

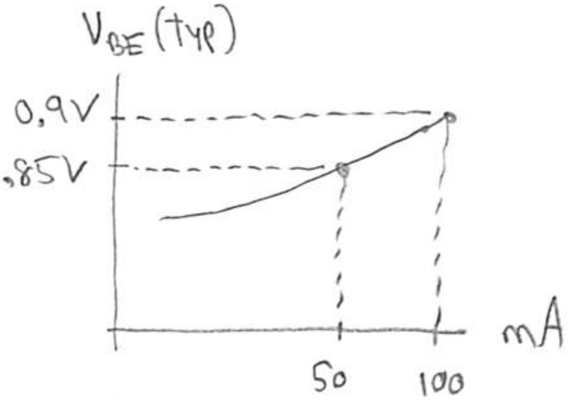
$$I_{PIN} = \frac{I_{OUT}}{\beta + 1} = \frac{104{,}3\,mA}{150+1} = \boxed{0{,}69\ mA}$$ ← Nice and small! ☺

ⓔ Worst-Case:

- Table says min $h_{FE} = 30$ @ $I_c = 100\,mA$ ← use this!

max $V_{BE} = {,}95V$ @ $I_c = 50\,mA$ ← kind of far away from 100mA

$$\frac{V_{BE(max)}}{V_{BE(typ)}} = \underbrace{\frac{{,}95V}{{,}85V}}_{50mA} = \underbrace{\frac{?}{{,}9V}}_{100mA}$$



$$\rightarrow\ ? = 1{,}006 \approx \underline{\underline{1{,}01V}}$$

SO, $$I_{OUT} = \frac{5 - 1{,}01}{\frac{40}{30+1} + 40} = {,}0966A = \underline{\underline{96.6mA}}$$

$$V_{OUT} = ({,}0966)(40) = \boxed{3.865V}$$ ← Just below minimum acceptable value!

$$I_{PIN} = \frac{96{,}6mA}{30+1} = \boxed{3.12\ mA}$$ ← OK

Need a slightly "tougher" transistor.
2N4401 has $\beta_{min} = 100$
max $V_{BE} = {,}95V$ } $\underline{\underline{I_c = 150mA}}$

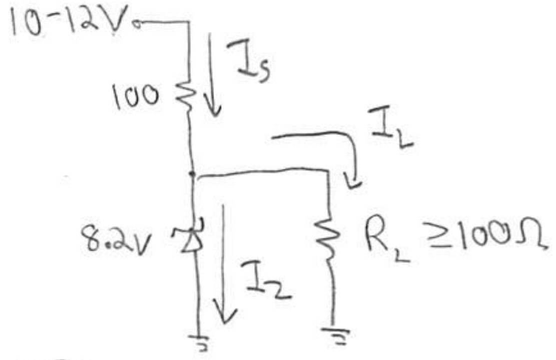
⑤ ⓐ want $I_Z > 10mA$

$$I_Z = I_S - I_L > 10mA$$

$$I_Z = \frac{10-8.2}{100} - \frac{8.2-0}{100}$$

$$= 18mA - 82mA = \underline{\underline{-64mA}} \times$$

$\boxed{NO!}$

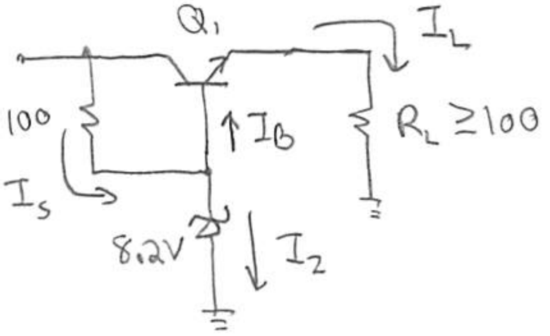


ⓑ

$$I_Z = I_S - \overset{\frac{I_L}{\beta+1}}{I_B} > 10mA?$$

$$= \frac{10-8.2V}{100\Omega} - \frac{1}{101}\left[\frac{8.2-0.7V}{100\Omega}\right]$$

$$= 18mA - 0.74mA = \underline{\underline{17.3mA}} \quad \boxed{YES}$$



ⓒ

$$\text{Max } I_L = \frac{8.2-0.7V}{100\Omega} = 75mA$$

↖ worst case load

← $V_{BE} \approx 0.8V$, $\beta \approx 200$] from 2N3904 data sheet

$$P = i_B V_{BE} + i_C V_{CE}$$

$$= \frac{i_E}{\beta+1} V_{BE} + \alpha i_E V_{CE}$$

$$i_E = \frac{8.2-0.8V}{100\Omega} = 74mA$$

$$= \frac{74mA}{201} \cdot 0.8V + .995(74mA)\left[12-(8.2-0.8)\right] \qquad \alpha = \frac{200}{201} = .995$$

↖ worst case supply

$$= 0.3mW + 338.7mW$$

$$= \underline{\underline{339mW}}$$

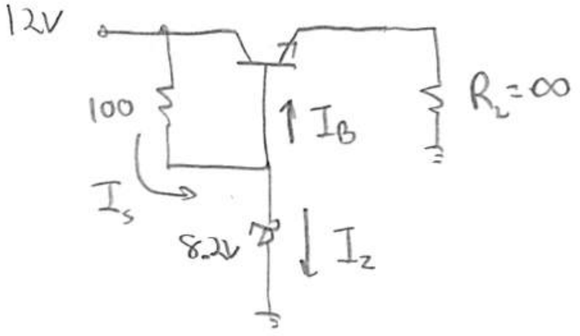
$$T_J = 25°C + .339W \times 200°C/W = \underline{\underline{92.8°C}} > 85°C!$$

$\boxed{\text{YES, need a heat sink}}$

5.2

ⓓ

Max Zener power dissipation is max I_Z



$$I_Z = I_S - \underbrace{I_B}_{0}$$

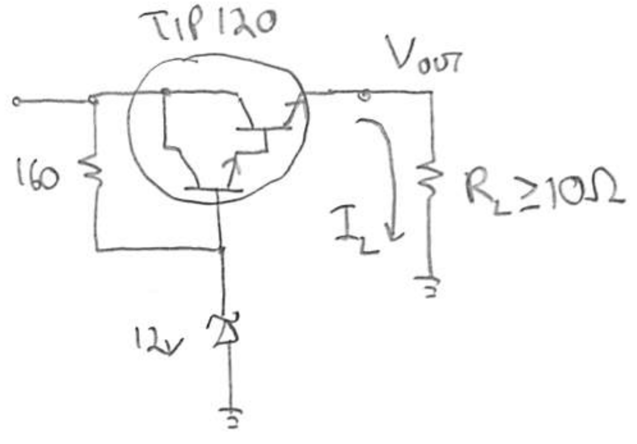
$$= \frac{12-8.2V}{100\Omega} = .038A$$

$$P = (.038A)(8.2V) = \underline{0.312W} < \tfrac{1}{2}(1W) \checkmark$$

$$\boxed{\text{YES, zener is OK!}}$$

6) ⓐ $I_Z = I_S - I_B$

$$= I_S - \frac{I_L}{\beta+1}$$



Darlington "quick" analysis:

$V_{BE} = 1.4V$, $\beta = 2500$

$$\min I_S = \frac{14-12V}{160\Omega} = 12.5\,mA$$

$$\max I_B = \frac{1}{2501} \times \frac{(12-1.4)}{10\Omega} = \frac{1.06A}{2501} = \underline{0.42\,mA}$$

$$\Rightarrow \min I_Z = 12.5\,mA - .42\,mA = \underline{12.08\,mA} > 10\,mA ✓$$

$\boxed{\text{YES, zener is happy!}}$

ⓑ $P = I_B V_{BE} + I_C V_{CE}$

$$= (.42 \times 10^{-3})(1.4) + \frac{2500}{2501}(1.06A)\left(16 - \overbrace{(12-1.4)}^{10.6V}\right)$$

$$= .0006 + 5.7217 = \boxed{5.72W}$$

$$T_J = 25^\circ C + 5.72W \times \underbrace{62.5\,^\circ C/W}_{\Theta_{JA}} = \boxed{382.5^\circ C}$$ ← Yikes! Need a heat sink!

ⓒ $T_J = 25^\circ C + 5.72W \times (\Theta_{JC} + \Theta_{CS} + \Theta_{SA}) < 85^\circ C$

$$\Rightarrow \Theta_{SA} < \frac{85-25^\circ C}{5.72W} - 1.92\,^\circ C/W - 0.5\,^\circ C/W$$

$$< \underline{8.07\,^\circ C/W}$$

use $\boxed{5\,^\circ C/W \text{ heat sink}}$

7)

ⓐ 2N3904: $\theta_{JA} = 200^\circ C/W$

$$\text{Max } P = \frac{150 - 25^\circ C}{200^\circ C/W} = \boxed{.625W}$$

$$\frac{150 - 50}{200} = \boxed{0.5W}$$

$$\frac{150 - 75}{200} = \boxed{.375W}$$

ⓑ TIP31: $\theta_{JA} = 62.5^\circ C/W$

$$\text{Max } P = \frac{150 - 75^\circ C}{62.5^\circ C/W} = 1.2W$$

$$\text{Actual } P = .75W \xrightarrow{\times 2} 1.5W$$

NO! TIP31 cannot handle .75W @ $T_A = 75^\circ C$

ⓒ $$T_J = 40^\circ C + 15W \times \left(\underbrace{3.125^\circ C/W}_{\theta_{JC}} + \underbrace{.5^\circ C/W}_{\theta_{CS}} + \theta_{SA} \right) < 85^\circ C$$

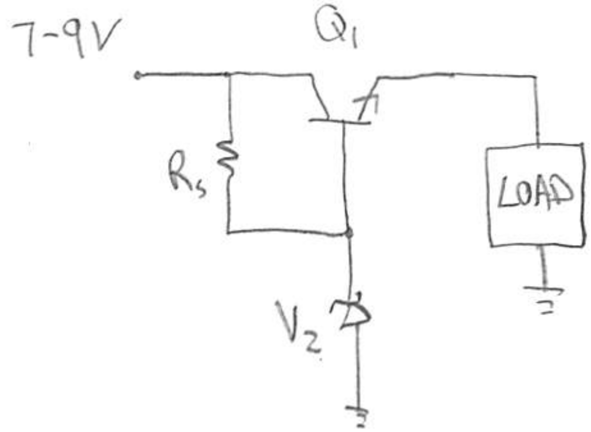
$$\rightarrow \boxed{\theta_{SA} < -.625^\circ C/W}$$ ← NOT possible!

ⓓ MJE3055: $\theta_{JC} = 1.67^\circ C/W$

$$40 + 15(1.67 + .5 + \theta_{SA}) < 85^\circ C$$

$$\rightarrow \boxed{\theta_{SA} < 0.83^\circ C/W}$$ ← YES! Need a really big heat sink (Fan might be necessary)

8)



ⓐ $V_z - 0.7 \sim 6V$

$V_z \sim 6.7V$

Choose $\boxed{V_z = 6.8V}$

ⓑ

	Max I_c	Power Rating No HS	Power Rating w/HS
2N3904	200mA ✓	625mW ✓	
TIP31	3A ✓	2W	
MJE3055	10A ✓		75W

- Max $I_L \sim 50mA$
- Max $P \sim \frac{50mA}{101}(.7) + \frac{100}{101}(50mA)(9-6.1)$

$= \underline{143.9mW} \xrightarrow{\times 2}$

Need $> 287.8mW$ rating

$\Rightarrow$ use $\boxed{2N3904}$

other 2 transistors would work, but they are much larger than necessary!

ⓒ Want min $I_z > 10mA$

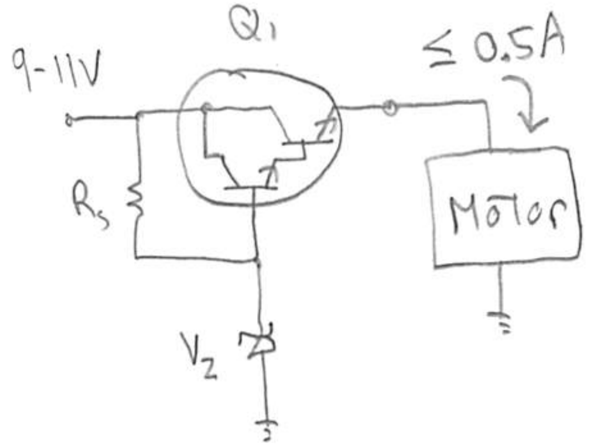
$$I_z = \frac{7 - 6.8}{R_s} - \frac{50mA}{101} > 10mA \rightarrow R_s < .0191K \xrightarrow{\times .95} 18.1\Omega$$

Choose $\boxed{R_s = 18\Omega}$

Max Power dissipation: $\frac{(9-6.8)^2}{18} = 0.269W \xrightarrow{\times 2} .538W$

$\boxed{\text{Choose } 1W}$ (although ½W probably OK)

9)



ⓐ Choose Zener:

$V_z - 1.4 \sim 6V$

$V_z \sim 7.4V$

Choose $\boxed{V_z = 7.5V}$

ⓑ

	Max I_c	P_{rating} (No HS)	P_{rating} (with HS)
KSP 13	500 mA ✓	625 mW ✗	
TIP120	5 A ✓	2 W ✗	65W ✓
TIP140	10 A ✓		125W ✓

Since max $I_L = 0.5A$,

$$\max P \sim \left(\frac{.5A}{2501}\right)(1.4) + \frac{2500}{2501}(.5A)\Big(11 - \overbrace{(7.5 - 1.4)}^{6.1V}\Big)$$

$$= .0003W + 2.4490W \cong \underline{\underline{2.45W}} \xrightarrow{\times 2} \underline{\underline{4.9W}}$$

Need 4.9W rating

Choose $\boxed{\text{TIP120 + heat sink}}$

KSP13 → can't handle power

TIP140 → would work, but larger than necessary.

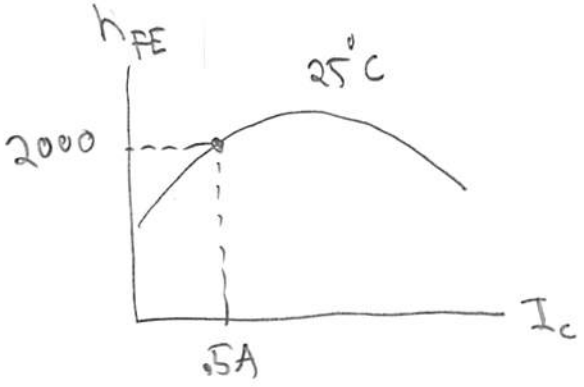
9,2

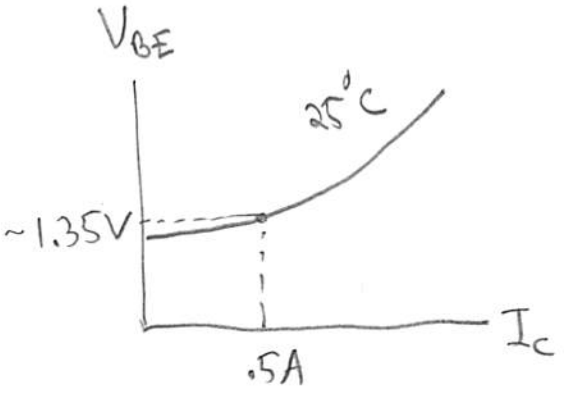
(c) $$T_J = 40^\circ C + 2{,}45W \times \left(\underbrace{1{,}92\,^\circ C/W}_{\Theta_{JC}} + \underbrace{{,}5\,^\circ C/W}_{\Theta_{CS}} + \Theta_{SA} \right) < 85^\circ C$$

$$\Theta_{SA} < \frac{85 - 40^\circ C}{2{,}45W} - 1{,}92\,^\circ C/W - {,}5\,^\circ C/W$$

$$< 15{,}95\,^\circ C/W \quad \boxed{\text{Choose } 12\,^\circ C/W}$$

(d) TIP120 data sheet (OK to use 25°C curves, since hand calculations are estimates)





$$I_2 = I_s - I_B > {,}01A$$

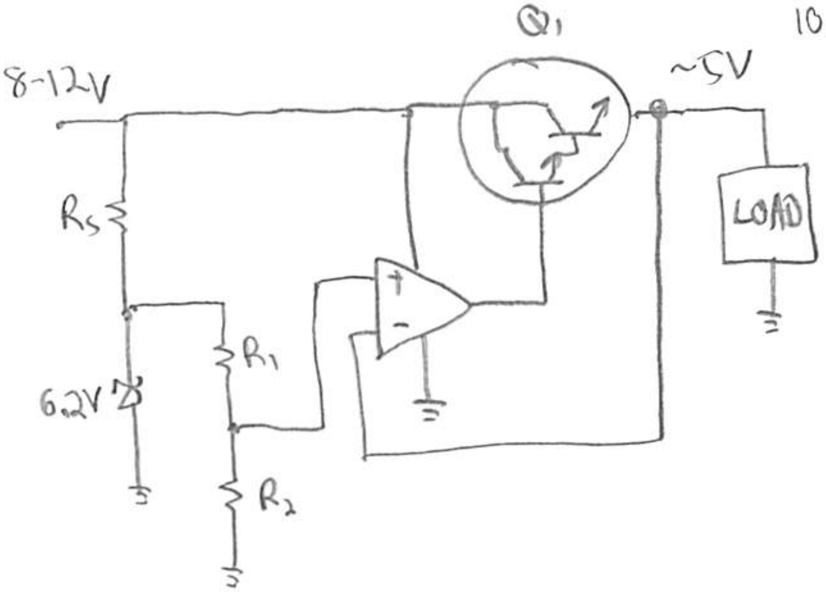
$$\frac{9 - 7{,}5}{R_s} - \frac{{,}5A}{2001} > {,}01A \rightarrow R_s < 146{,}3\,\Omega \xrightarrow{\times ,95} 139\,\Omega$$

Choose $\boxed{R_s = 130\,\Omega}$

Max p: $$\frac{(11 - 7{,}5)^2}{130} = {,}094W \xrightarrow{\times 2} {,}19W \text{ rating or higher}$$

$\boxed{\text{1/4W rating is fine}}$

10)



ⓐ • Want $6.2 \times \frac{R_2}{R_1+R_2} \sim 5V$

$$\frac{6.2}{5} = \frac{R_1+R_2}{R_2} = \frac{R_1}{R_2} + 1$$

$$\rightarrow \frac{R_1}{R_2} = 0.24 \quad (1)$$

• Also want $\frac{6.2V}{R_1+R_2} < 1mA \rightarrow R_1 + R_2 > \underline{\underline{6.2K}} \quad (2)$

Put (1) into (2): $.24R_2 + R_2 > 6.2K$

$R_2 > 5K$

Try $\underline{\underline{R_2 = 5.1K}} \rightarrow R_1 = .24 \times 5.1 = 1.22K$

$\Rightarrow \underline{\underline{R_1 = 1.2K}}$

Power ratings:

$i = \frac{6.2V}{1.2K + 5.1K} = .98mA$

$P_1 = (.98mA)^2(1.2K) = 1.15mW$

$P_2 = (.98mA)^2(5.1K) = 4.9mW$

$\boxed{\frac{1}{4}W \text{ is fine}}$

• Check V_{OUT}: $V_{OUT} = 6.2 \frac{5.1K}{1.2K + 5.1K} = \underline{\underline{5.02V}}$ ← within 0.4% of 5V! ☺

• R_s: Assuming amplifier inputs draw negligible current:

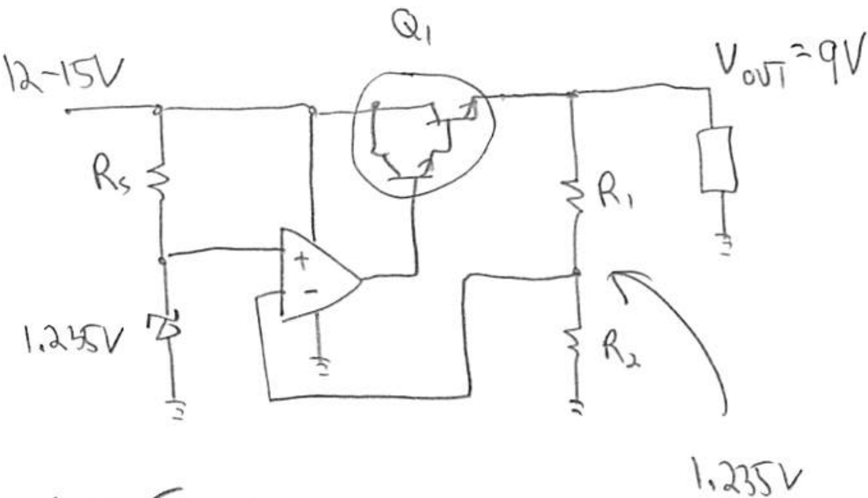
$$\frac{8 - 6.2}{R_s} - \frac{6.2}{1.2K + 5.1K} > 10mA$$

$$R_s < .1639K \xrightarrow{\times.95} 156\Omega \quad \text{Choose } \boxed{R_s = 150\Omega}$$

$$\text{Power: } \frac{(12-6.2)^2}{150} = .224W \xrightarrow{\times 2} .45W \quad \boxed{\tfrac{1}{2}W \text{ rating}}$$

10.2

(b)



• For R_1 and R_2:

Want $1.235V = 9 \times \frac{R_2}{R_1+R_2}$

$$\frac{R_1+R_2}{R_2} = \frac{9}{1.235}$$

$$1+\frac{R_1}{R_2} = \frac{9}{1.235} \rightarrow \frac{R_1}{R_2} = 6.2875 \quad (1)$$

$$1.235 = V_{OUT}\frac{R_2}{R_1+R_2}$$

$$\rightarrow \underbrace{V_{OUT} = 1.235\left(1+\frac{R_1}{R_2}\right)}$$

• Also, $\frac{9V}{R_1+R_2} \lesssim 1mA \rightarrow R_1+R_2 \gtrsim 9K$ (2)

Put (1) into (2): $6.2875R_2 + R_2 \geq 9K$

$$R_2 \geq 1.235K$$

Some combinations:

R_2	R_1	$V_{OUT} = 1.235\left(1+\frac{R_1}{R_2}\right)$	
☆ 1.3K	8.2K	9.025V ✓	+.28%
1.5K	9.1K	8.73V ✓	-3%
1.6K	10K	8.954V ✓	-.5%

All OK, but $R_2 = 1.3K$ is closest.

Power ratings:

$$i = \frac{9.025V}{1.3K+8.2K} = .95mA$$

$P_1 = (.95mA)^2(8.2K) = 7.4mW$

$P_2 = (.95mA)^2(1.3K) = 1.2mW$

$\boxed{\tfrac{1}{4}W \text{ is fine}}$

• R_s: $\frac{12-1.235}{R_s} \sim 1mA$

$\rightarrow R_s \sim 10.77K \Rightarrow \boxed{R_s = 10K}$

Power: $\text{Max}P = \frac{(15-1.235)^2}{10K} = 18.95mW$

$\boxed{\tfrac{1}{4}W \text{ is fine}}$