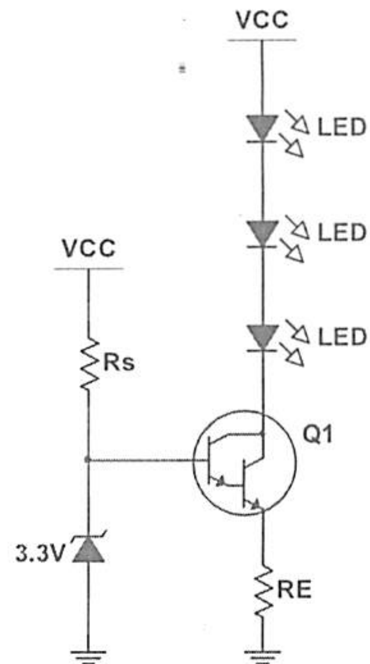
ECE 363 SAMPLE EXAM #1 (F19) NAME: Solutions

4 problems for 100 pts

Problem #1: LED Constant Current Driver (25 pts)

You are asked to design a current source to operate three power LEDs. You decide to use a zener diode with a Darlington transistor. The design specs are:

- LED current = 0.75 A (+/- 5% is OK)
- LED forward voltage = 3.1V - 3.4V
- Darlington is either a BC517 or MJE800
- V_{CC} is either 12, 15, 18, or 21V
- All resistors are standard 5% values.



(a) Perform a "quick" analysis to choose V_{CC}. Show all work.

(b) Perform a "quick" analysis to choose Q1. You must explain why you chose one transistor and not the other one. If Q1 needs a heat sink, you must compute the max θ_{SA} (assume θ_{CS} = 0.5°C/W).

(c) Choose R_E and R_S based on "typical" Q1 parameters.

(a) Want $V_{cc} > 3 \cdot V_{LED} + 2 + V_{CE,sat} + (3.3 - 1.4)$ (2 = head room; V_{LED} max = 3.4V; $V_{CE,sat}$ = 0.7)

$V_{cc} > 10.2 + 2 + 0.7 + 1.9 = \underline{14.8V}$ → Choose $\boxed{V_{cc} = 15V}$

(b) LED current = 0.75A $\xrightarrow{\times 2}$ 1.5A rating or higher

$P = \frac{.75A}{2501}(1.4) + \frac{2500}{2501}(.75A)V_{CE} = 2.85W \xrightarrow{\times 2}$ Need 5.7W rating

$V_{CE} = (15 - 3 \times 3.1) - (3.3 - 1.4) = 3.8V$

	Max I_c	P (no HS)	P (w/HS)
BC517	1.2A ✗	.625W ✗	
MJE800	4A ✓		40W ✓

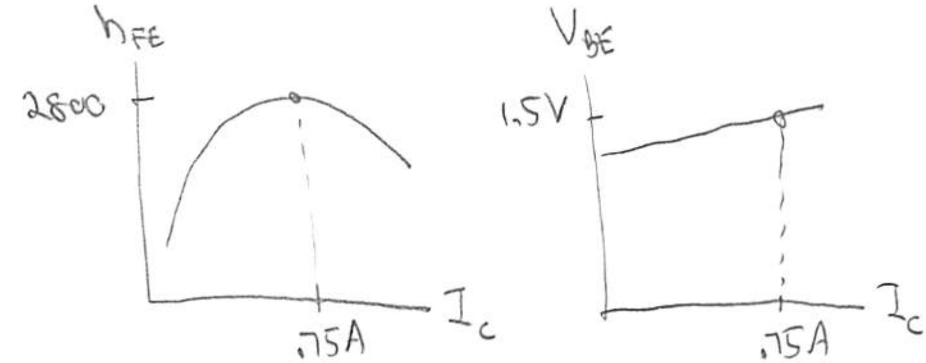
$25°C + 2.85W(3.12°C/W + .5°C/W + \theta_{SA}) < 85°C$

Choose MJE800

$\theta_{SA} < 17.4°C/W$

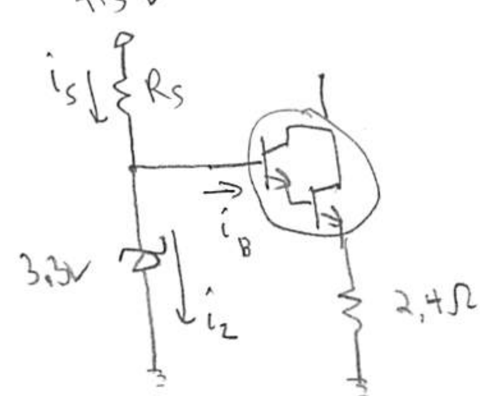
(extra sheet for work)

ⓒ MJE800 plots.



want $I_c = 0.75A = \alpha I_E$

$$= \frac{2800}{2801} \frac{3.3 - 1.5V}{R_E} = .75A \rightarrow \boxed{R_E = 2.4\Omega}$$



$i_z = i_s - i_B \gtrsim 10mA$

$$\frac{15-3.3}{R_s} - \frac{.75A}{2801} > .010A$$

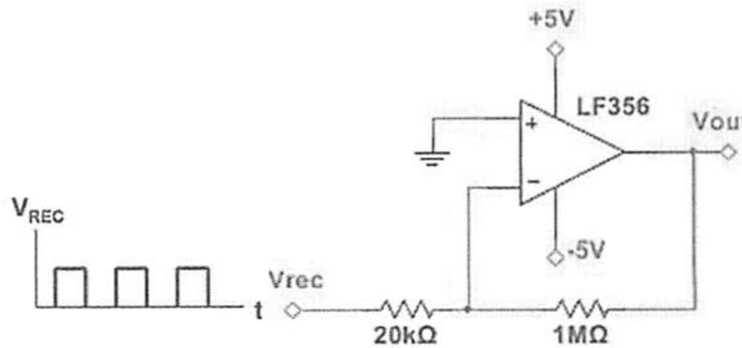
$R_s < 1139.5\Omega$

min $i_z = 10mA$ is not super strict, so OK to choose $\boxed{R_s = 1.1K}$

Problem #2: Amplifier Output Error (25 pts)

Consider an optical communication link for an infrared remote control. A transmitter sends a train of infrared pulses. The receiver converts the optical pulses into voltage pulses.

Suppose the receiver output V_{REC} consists of 50% duty cycle pulses with a 20 mV amplitude and 40 kHz frequency. These tiny pulses are sent to an inverting amplifier built with an LF356 op amp.



a) Is the amplifier output limited by small-signal bandwidth or slew rate? Show all work!

b) Compute the worst-case output error voltage (assume T_A = 25°C). Show all work!

c) Assuming worst-case output error voltage, sketch both V_{REC} and V_{OUT} over a 50 us interval. Label important features!

(a) Inverting amplifier: $G = -\dfrac{10^6\,\Omega}{20\times10^3\,\Omega} = -\dfrac{1000}{20} = \underline{-50}$

LF356: GBW = 5MHz, SR = 12 V/μs

$BW = \dfrac{5\,MHz}{50} = \underline{0.1\,MHz}$, $T_R = \dfrac{0.35}{0.1\,MHz} = \underline{3.5\,\mu s}$

$T_{SR} = \dfrac{0.8\,V_{OUT,pp}}{SR} = \dfrac{0.8\,(50 \times .020V)}{12\,V/\mu s} = \underline{.067\,\mu s}$

Limited by small signal BW

(b) $R_{TH(+)} = 0$

$R_{TH(-)} = 20k \,\|\, 1000k = \underline{19.61k}$

$I_{IN,Bias} = 200\,pA$

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

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

$\Delta V_{OUT} = (200\times10^{-12}A)(19.61\times10^3 - 0)\times|50| = \underline{0.196\,mV}$ ← $I_{IN,BIAS}$

$(50\times10^{-12})\left(\dfrac{19.61\times10^3+0}{2}\right)\times|50| = \underline{.0245\,mV}$

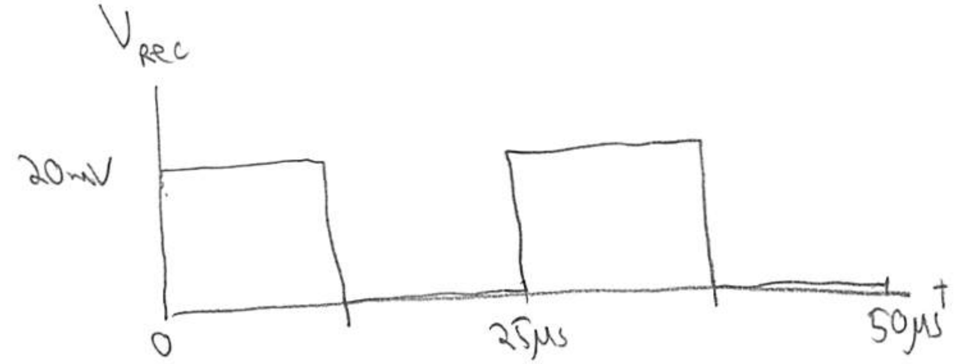
$10\,mV \times |50| = 500\,mV$

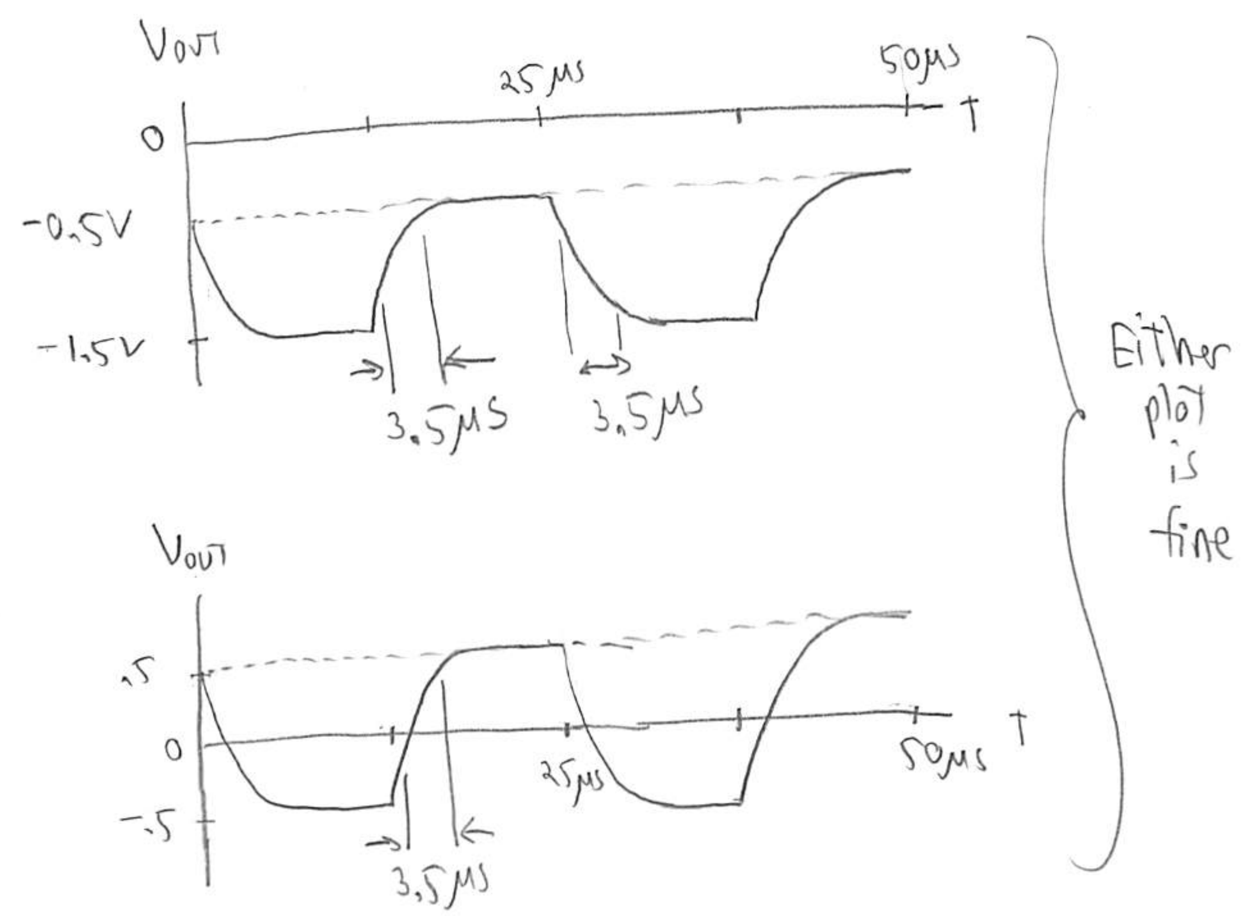
Worst-case V_{OUT} = .196mV + .0245 mV + 500mV = $\boxed{500.2\,mV}$

(extra sheet for work)

(c) $V_{OUT} = (0.020V)(-50) = -1V$

40 kHz: 1 cycle = 25 μs



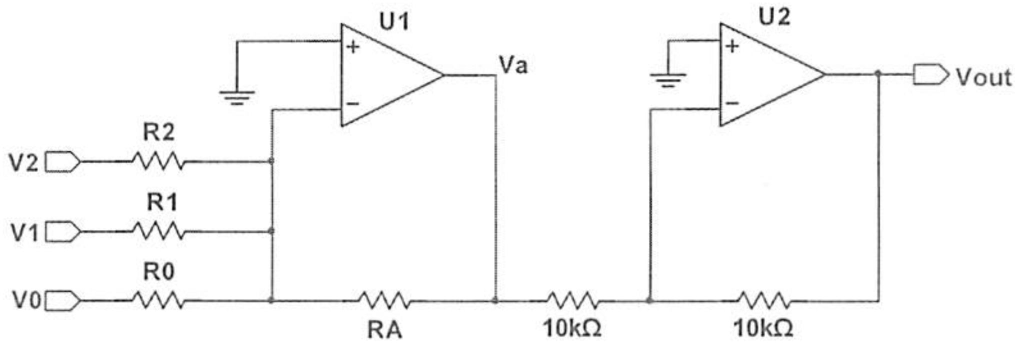


Problem #3: Digital-to-Analog Converter (25 pts)

Recall binary numbers from ECE 118. A 3-bit binary number (B_2 B_1 B_0) is equal to $B_2*2^2 + B_1*2^1 + B_0*2^0$. For example, (110) is equal to $1 \cdot 4 + 1 \cdot 2 + 0 \cdot 1 = 6$. As another example, (011) is equal to $0 \cdot 4 + 1 \cdot 2 + 1 \cdot 1 = 3$.

How do we use hardware to convert a binary number into decimal? The digital outputs from a microcontroller are typically 5V logic. Therefore, a binary "1" is really +5V, while a binary "0" is really 0V.

A simple 3-bit digital-to-analog converter (DAC) is shown below. The input voltages V_2, V_1, V_0 come from a microcontroller. The output V_{OUT} is an "integer" from 0 to 7V. For example, the binary number (110) should produce Vout = 6V, while the binary number (011) should produce Vout= 3V.



(a) Use the Golden Rules to derive an expression for V_{OUT} in terms of V_2, V_1, and V_0. Show all work!

Hint: Think about V_{OUT} in terms of Va, and then Va in terms of the inputs.

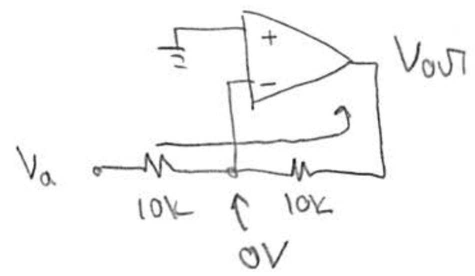
(b) Suppose R_A = 40 kohm. Determine the ideal values for R_2, R_1, and R_0. Show all work!

(c) Suppose you are using LF356 op amps, and assume the final output is connected to a load $R_L \geq 10$ kohm. Would you use Vcc = 8V for this circuit? How about Vcc = 9V? Show all work!

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

$$i = \frac{V_a - 0}{10K} = \frac{0 - V_{OUT}}{10K}$$

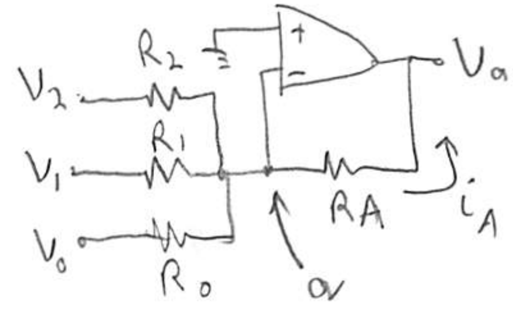
$$\rightarrow V_{OUT} = -V_a \quad (1)$$



$V_- = V_+ = 0$

$$i_2 + i_1 + i_0 = i_A$$

$$\frac{V_2 - 0}{R_2} + \frac{V_1 - 0}{R_1} + \frac{V_0 - 0}{R_0} = \frac{0 - V_a}{RA} \quad (2)$$



(1) into (2): $\frac{V_2}{R_2} + \frac{V_1}{R_1} + \frac{V_0}{R_0} = \frac{V_{OUT}}{RA} \Rightarrow \boxed{V_{OUT} = \frac{RA}{R_2} V_2 + \frac{RA}{R_1} V_1 + \frac{RA}{R_0} V_0}$

(extra sheet for work)

$V_2 \quad V_1 \quad V_0$

(b) Binary (001) $\Rightarrow$ (0, 0, 5V) $\rightarrow V_{out} = \frac{40K}{R_0} \times 5V = 1V$

$R_0 = 200K$

Binary (010) $\Rightarrow$ (0, 5V, 0) $\rightarrow V_{out} = \frac{40K}{R_1} \times 5V = 2V$

$R_1 = 100K$

Binary (100) $\Rightarrow$ (5V, 0, 0) $\rightarrow V_{out} = \frac{40K}{R_2} \times 5V = 4V$

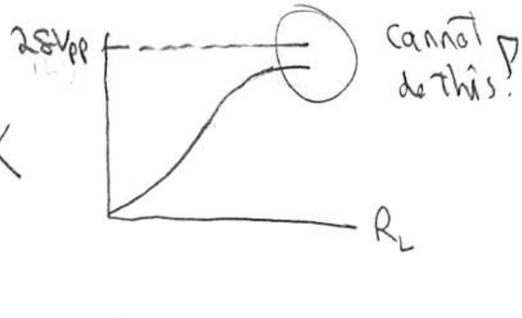
$R_2 = 50K$

(c) Max $V_0 = 7V \leftarrow$ Binary (111)

If $V_{cc} = 8V \rightarrow$ op amp headroom $= 8 - 7 = 1V$, $i_0 = \frac{7V}{10K} = .7mA$ max

Cannot use $V_{cc} = 8V$

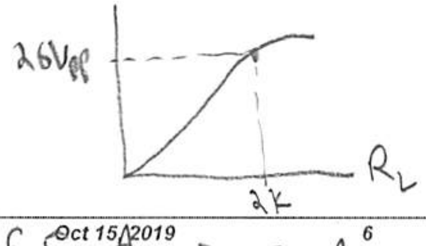
- For $V_{cc} = 15V$
  - $\rightarrow V_0 = 15 - 1 = 14V$ X



If $V_{cc} = 9V \rightarrow$ op amp headroom $= 9 - 7 = 2V$

OK to use $V_{cc} = 9V$

- For $V_{cc} = 15V$
  - $\rightarrow V_0 = 15 - 2 = 13V$

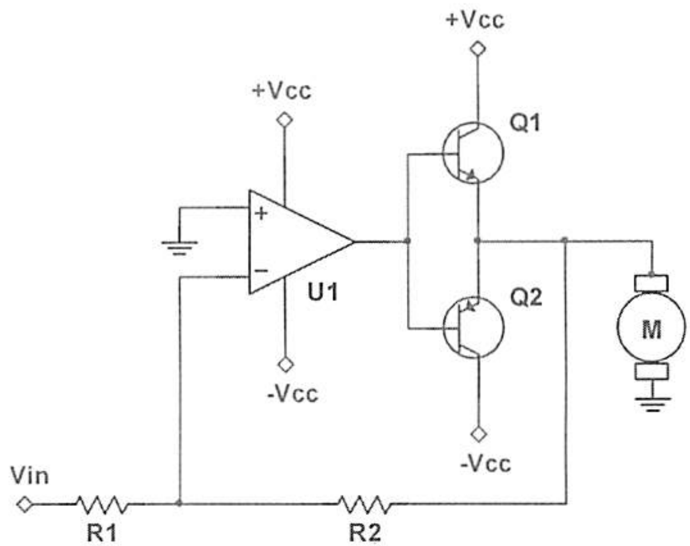


$i_0 = \frac{13V}{2K} = 6.5mA >> .7mA$ ✓

Problem #4: Push-Pull Current Booster (25 pts)

Design a voltage amplifier to drive a 6V DC motor with a max power consumption of 1.2W. The motor voltage must not exceed 6V by more than 5%. The input signal can swing between -0.2V and 0.2V. The design constraints are the following:

- Use an LF356 op amp.
- Q1 is either a 2N4401 or TIP31.
  NOTE: The pnp versions are the 2N4403 and TIP32.
- V_{CC} is either 4.5, 6, 9, or 12V
- Input impedance $Z_{IN} \geq 10$ kohm
- All resistors are 5% standard values.



(a) Perform a "quick" analysis to choose V_{CC}. Show all calculations!

(b) Perform a "quick" analysis to choose Q1. You must explain why you chose one transistor and not the other one. If Q1 needs a heat sink, you must compute the max θ_{SA} (assume $\theta_{CS} = 0.5°C/W$).

(c) Show that the op amp can provide the required output voltage and current, even under worst-case transistor conditions.

(d) Choose R1 and R2. Show all work!

(a) Load: $V_{max} = 6V$, $I_{max} = \frac{1.2W}{6V} = 0.2A$

$V_{cc} > 6 + 0 + 2 = 8V \rightarrow$ Choose $\boxed{V_{cc} = 9V}$

(b) Max $I_c \approx 0.2A$, Max $V_{CE} = 9 - (-6) = 15V$

$\downarrow$ $> 0.4A$ rating; $\times 2 \rightarrow > 30V$ rating

$P = \frac{.2A}{101}(0.7) + .99(.2A)(9-6) = .595W \xrightarrow{\times 2} 1.19W$ rating

	Max I_c	Max V_{CE}	P (no HS)	P (w/HS)
2N4401	.6A ✓	40V ✓	.625W ✗	1.5W ✓
TIP31A	3A ✓	40V ✓	2W ✓	40W

← 2N4401 needs HS.

↑ TIP31 does not need HS

(extra sheet for work)

min = 100 @ .2A

For 2N4401: $25^\circ C + .595W(83.3 + .5 + \Theta_{SA}) < 85^\circ C$

$\boxed{\Theta_{SA} < 17.0\ ^\circ C/W}$

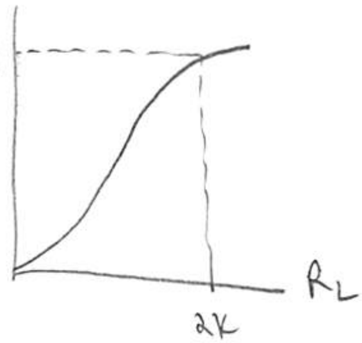
Either transistor would work. Choose 2N4401 for higher β_{min}

(c) Max $V_o = 6 + .95 = \underline{6.95V}$ (.95 = max V_{BE} @ $I_C = 150mA$) | Max $i_o = \frac{.2A}{100+1} = \underline{1.98mA}$ (100 = min β)

- Op amp headroom: $9 - 6.95 = 2.05V$
- $V_{cc} = 15V$, max $V_o = 15 - 2.05 = 12.95V$ ($26V_{pp}$)

$i_o = \frac{12.95V}{2K} = \underline{6.48mA}$ ✓

op amp is OK?



(d) Want $|G V_{IN}| = 6V \rightarrow |G| = \frac{6V}{0.2V} = 30 = \frac{R_2}{R_1}$

Since $Z_{IN} \geq 10K$

Choose $\boxed{R_1 = 11K}$

$R_2 = 30 \times 11 = \boxed{330K}$

Max $V_{OUT} = -30 \times .2V = \underline{-6V}$ ✓

(extra sheet for work)

Appendix If you chose TIP31 without HS:

$$\frac{\text{Max } V_{BE}}{\text{Typ } V_{BE}} = \underbrace{\frac{1.8V}{1.2V}}_{3A} = \underbrace{\frac{?}{0.7V}}_{0.2A} \rightarrow \min V_{BE} = \underline{\underline{1.05V}}$$

Max V_o = 6 + 1.05 = $\underline{\underline{7.05V}}$

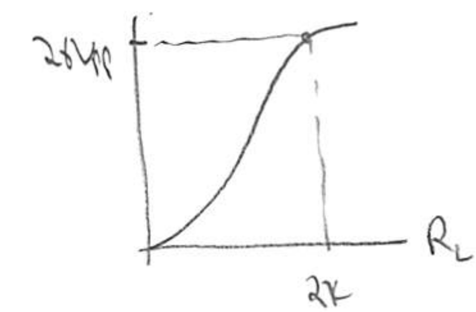
$$\frac{\text{Min } h_{FE}}{\text{Type } h_{FE}} = \underbrace{\frac{25}{65}}_{1A} = \frac{?}{130} \rightarrow \min h_{FE} = \underline{\underline{50}}$$

Max $i_o = \frac{.2A}{51} = \underline{\underline{3.9mA}}$

op amp headroom: $9 - 7.05 = 1.95V$

If $V_{cc} = 15V$, then max V_o = $15 - 1.95 = \underline{\underline{13.05V}}$

max $i_o = \frac{13.05V}{2k} = \underline{\underline{6.5mA}}$ ✓



op amp is ok with TIP31!