Lecture 5: Class AB Stages

0. Review
1. Class AB Stage
2. Class AB Design

- Today: PreLab 2 due
- HW2 due Fri
- Lab 1 report due next Tue (10/1)
- Quiz next Tue (10/1)
- PreLab 3 due next lab session
  - ↳ Two week design project
    - (1) Breadboard prototype + testing
    - (2) Soldering

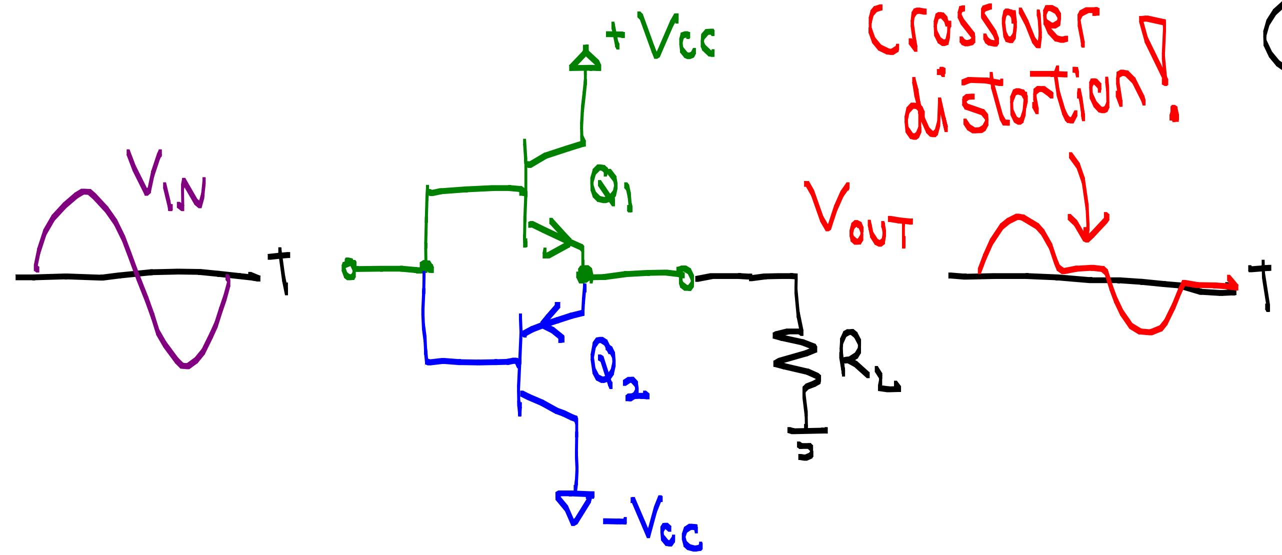
Buma will be out of town Oct 4-13

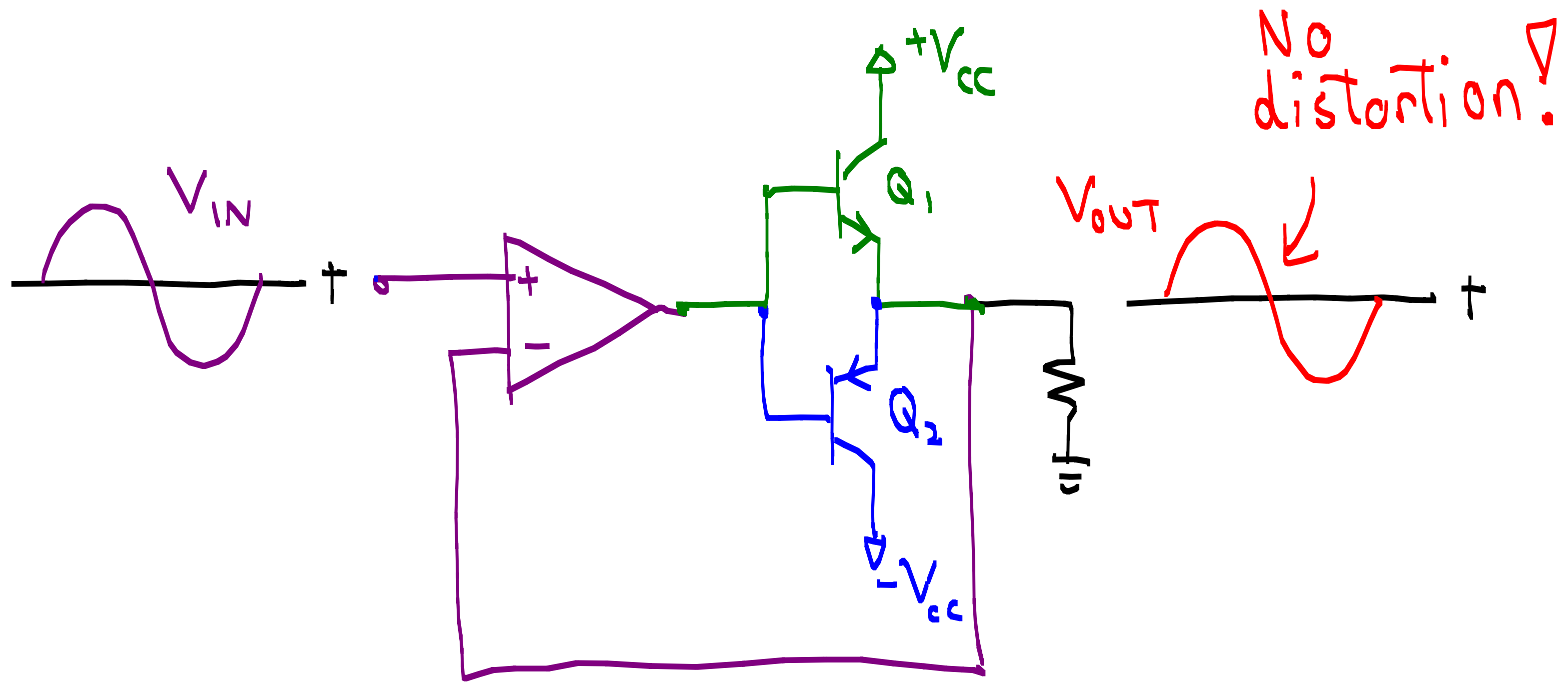
0. Review

- **Push-Pull Stage** "totem pole" "class B"

Q_1: ON during (+) output

Q_2: ON during (−) output





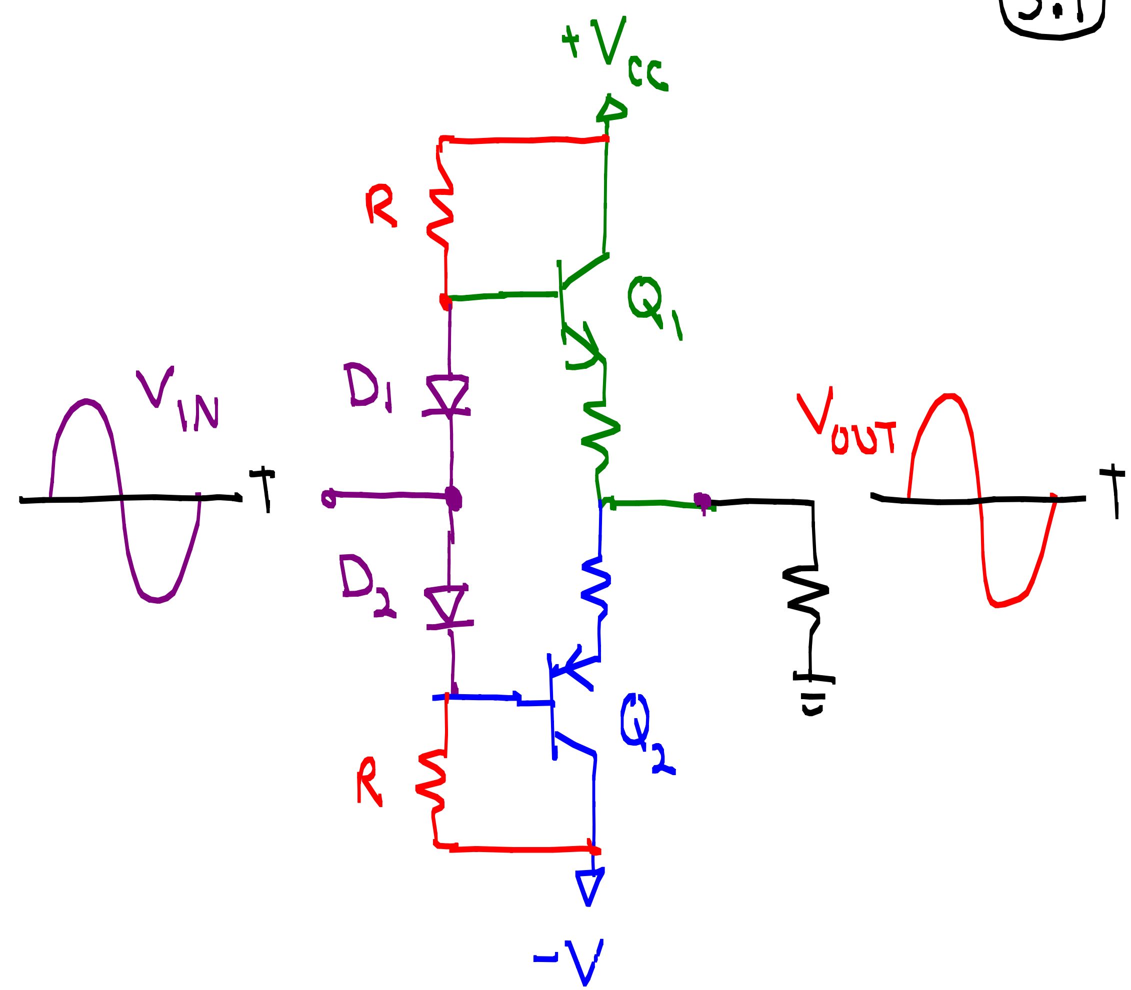
1. Class AB Stage

- Crossover distortion is due to <u>both</u> Q_1 and Q_2 being OFF when $|V_{IN}| < V_{BE}$.

- Class AB stage avoids this problem by keeping Q_1 and Q_2 <u>slightly on</u> when $|V_{IN}| < V_{BE}$.

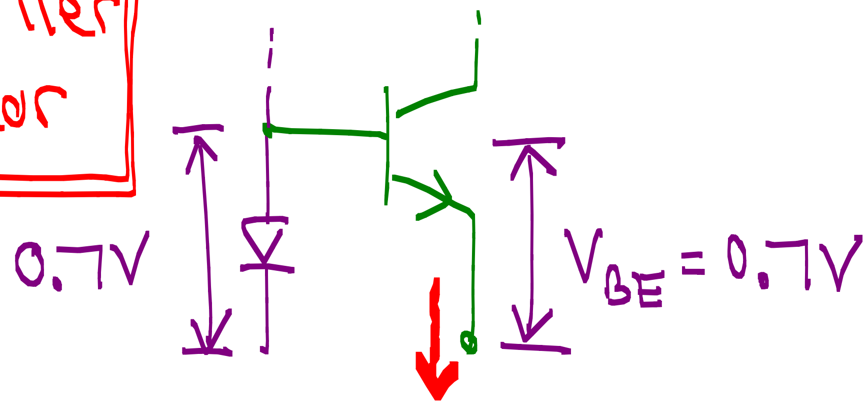
→ Diode D_1 applies ~0.7V to V_{BE} of Q_1

D_2 applies ~0.7V to V_{BE} of Q_2



- The small emitter resistors are important to avoid <u>thermal runaway</u>!

No emitter Resistor



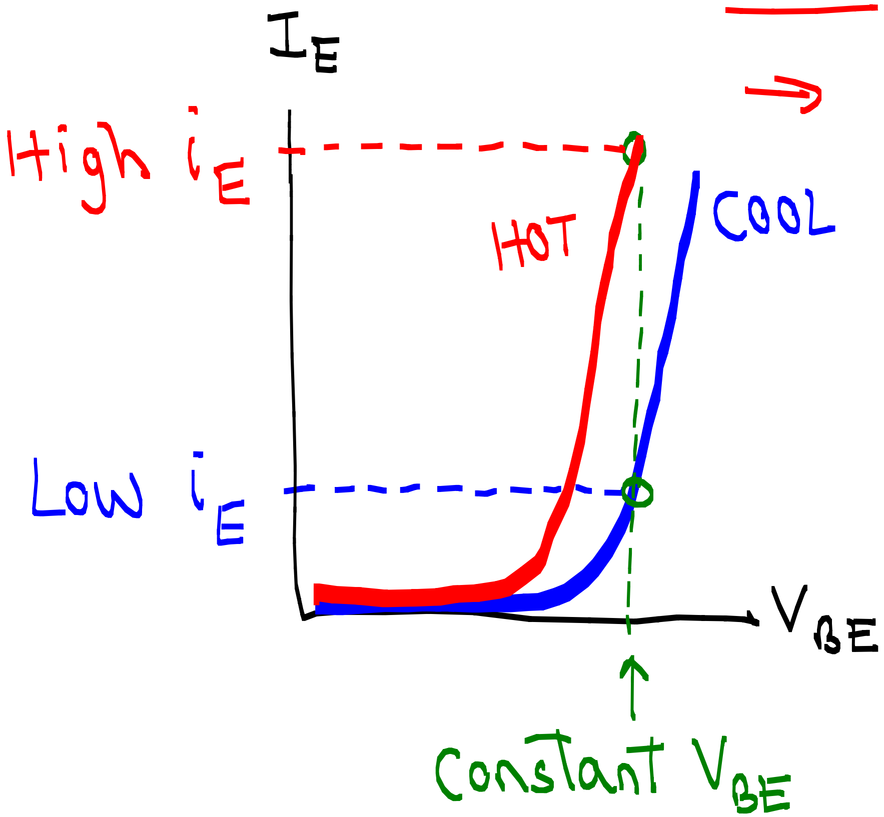
When BJT gets warm, same V_{BE} produces more current

→ more heating

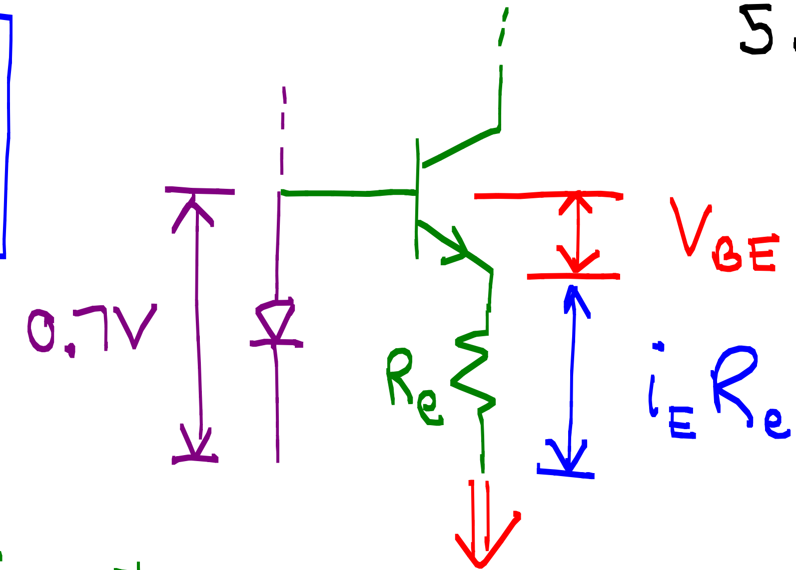
→ even more current

⋮

Thermal runaway!



with emitter resistor



✭ If i_E tries to increase, R_e will make V_{BE} shrink.

I_E stays the same :)

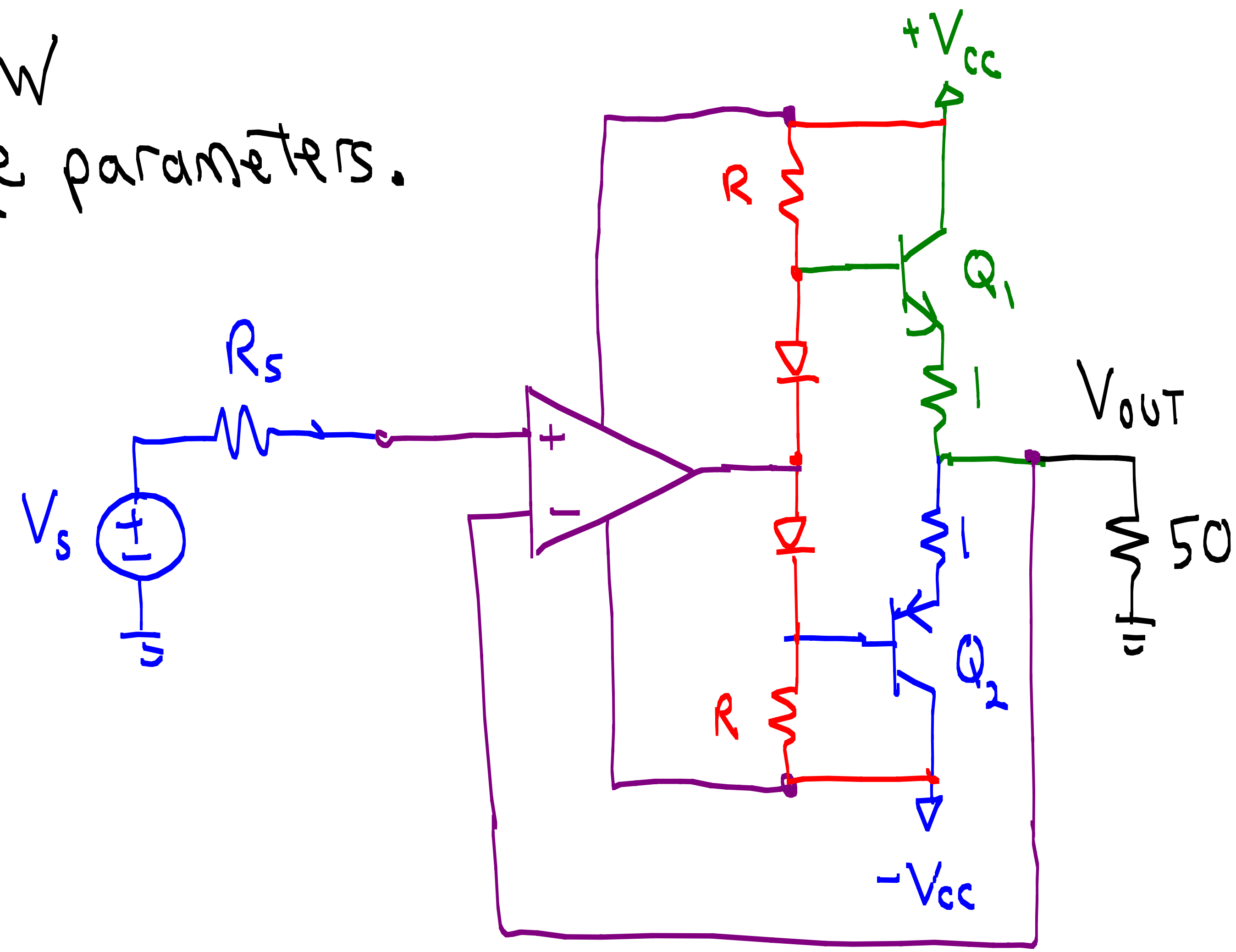
$$0.7V = \underbrace{i_E R_e}_{\text{If this } \uparrow} + \underbrace{V_{BE}}_{\text{then this } \downarrow}$$

✭ R_e acts like a voltage "cushion"

2. Class AB Design Example

$V_{cc} = 5, 7, 9, \text{ or } 11V$

- Drive a 50Ω load with up to 250 mW of sinusoidal signal. Use worst-case parameters.



- Start with desired max output

$$P_{max} = 0.25 = \frac{V_{MAX}^2}{2 \times 50\Omega}$$

$$\Rightarrow V_{MAX} = \pm\sqrt{25}$$

$$= \pm 5V$$

$$i_{MAX} = \frac{5\,V}{50\Omega} = 0.1A$$

- Choose V_{cc}:

☆ Make sure max load voltage does not saturate Q_1!

Headroom

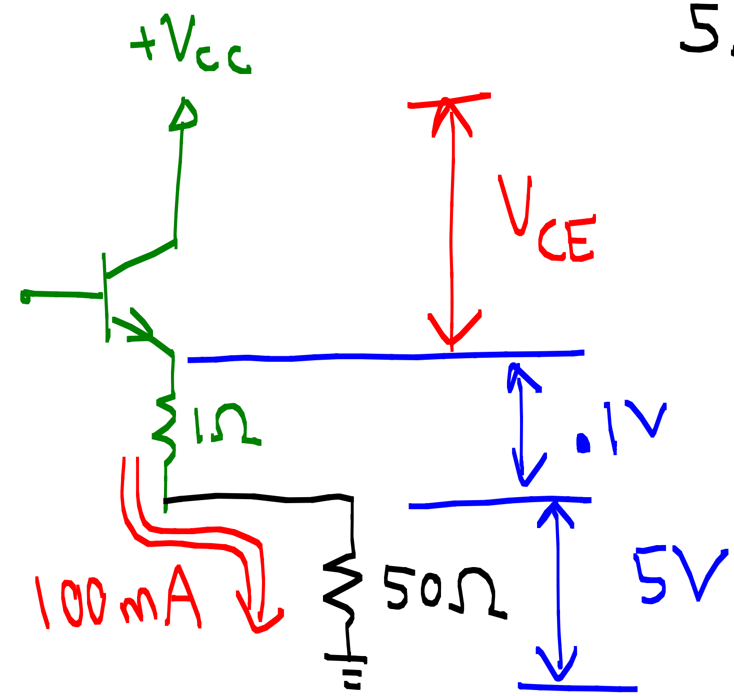
$$V_{cc} > \left[\text{Max } V_{LOAD}\right] + \left[\text{Voltage across } R_e\right] + \left[V_{CE,sat}\right] + 2V$$

$$> 5V + .1A \times 1\Omega + 0V + 2V$$

Initial "quick" analysis

$$> 7.1V$$

↳ Try $\boxed{V_{cc} = 9V}$ ← May need to change later (depends on op amp analysis)

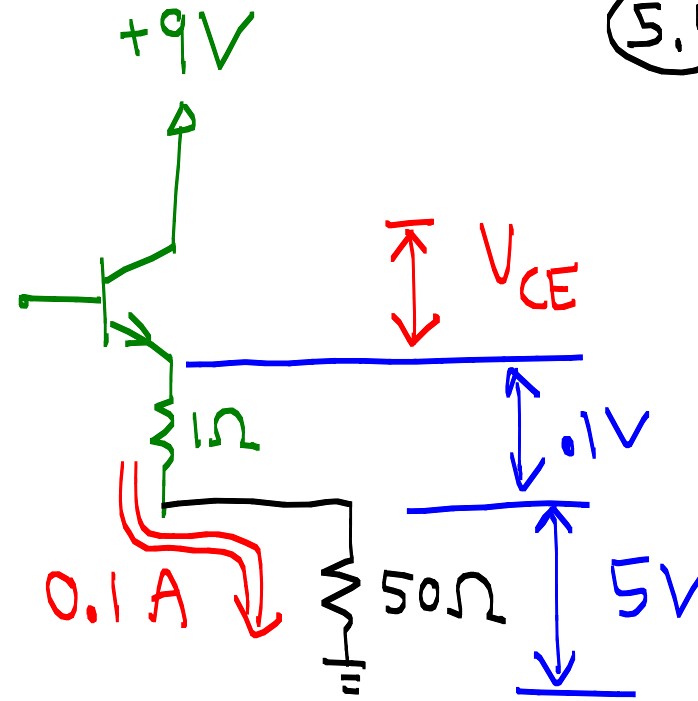


- **Choose Transistor** First, do quick analysis:

Max $i_E = 0.1$ A $\xrightarrow{\times 2}$ 0.2A rating or higher

$V_{CE} = 9 - 5.1 = 3.9V \xrightarrow{\times 2} > 7.8V$ rating

$P = \frac{.1}{101}(0.7) + .99(.1)(3.9) = .387W \xrightarrow{\times 2} > 0.78W$ rating



	Max I_c	Max V_{CE}	P_{rating} (no HS)	P_{rating} (w/HS)
2N4401	600 mA ✓	40V ✓	.625W	1.5W ✓
TIP29	1A ✓	40V ✓	2W ✓	
			$T_A = 25°C$	$T_c = 25°C$

Heat Sink

$T_A + P(\theta_{JC} + \theta_{CS} + \theta_{SA}) < 85°C$

$\Rightarrow \theta_{SA} < 71\ °C/W$

$(T_A = 25°C)$

Either would work, but 2N4401 has higher β.

★ R must be small enough to deliver ...

① $\gtrsim$ 1mA to diode (maintain ~ 0.7V)

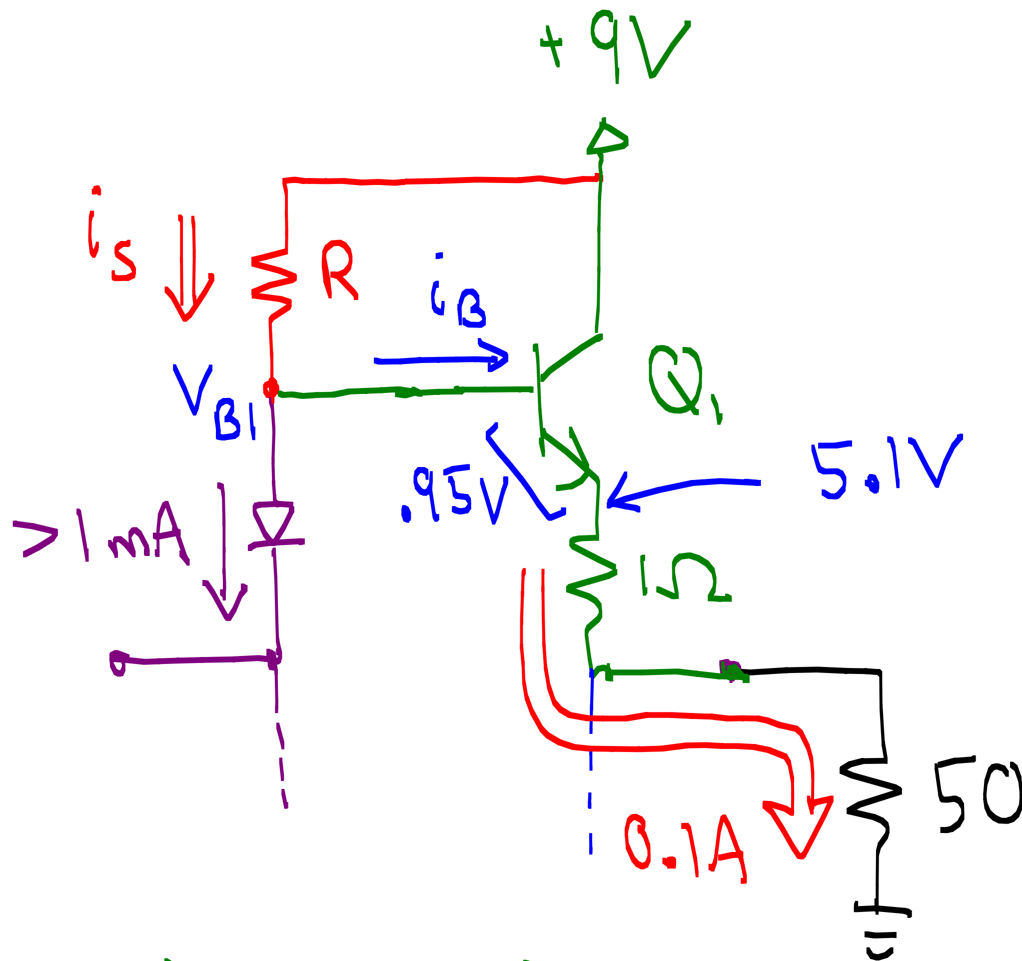
② sufficient base current to Q_1!

$$i_{Diode,min} = i_{s,min} - i_{B,max} > 1mA$$

$$= \frac{V_{CC} - V_{B1,max}}{R} - \frac{i_{E,max}}{\beta_{min}+1} > 1mA$$

$V_{BE,max}$

$$= \frac{9-(5.1+0.95)}{R} - \frac{100\,mA}{100+1} > 1mA$$

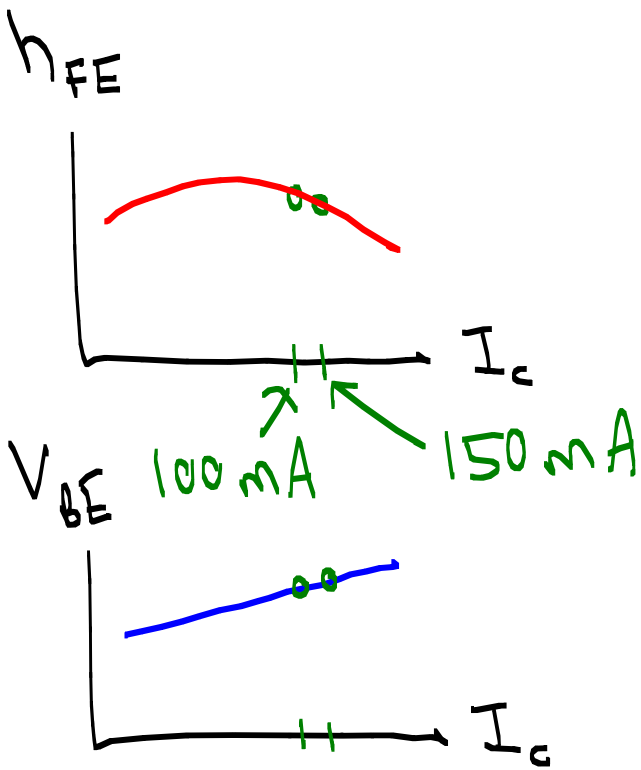


$\Rightarrow R < 1.48K$

Choose 1.3K

(1.5K would probably be fine)

2N4401 worst-case parameters



β and V_{BE} are pretty similar for 100 mA vs. 150 mA

h_{FE}	MIN
(I_C = 0.1 mAdc, V_{CE} = 1.0 Vdc)	20
(I_C = 1.0 mAdc, V_{CE} = 1.0 Vdc)	40
(I_C = 10 mAdc, V_{CE} = 1.0 Vdc)	80
(I_C = 150 mAdc, V_{CE} = 1.0 Vdc)	100 ☆
(I_C = 500 mAdc, V_{CE} = 2.0 Vdc)	40

Max $V_{CE,sat}$ → MAX

			MAX	
Collector-Emitter Saturation Voltage	I_C = 150 mA, I_B = 15 mA		0.4	V
	I_C = 500 mA, I_B = 50 mA		0.75	V

Max V_{BE} → MAX

			MAX	
Base-Emitter Saturation Voltage	I_C = 150 mA, I_B = 15 mA	0.75	0.95	V
	I_C = 500 mA, I_B = 50 mA		1.2	V

- op amp must be able to provide enough voltage and current to the Class AB stage.

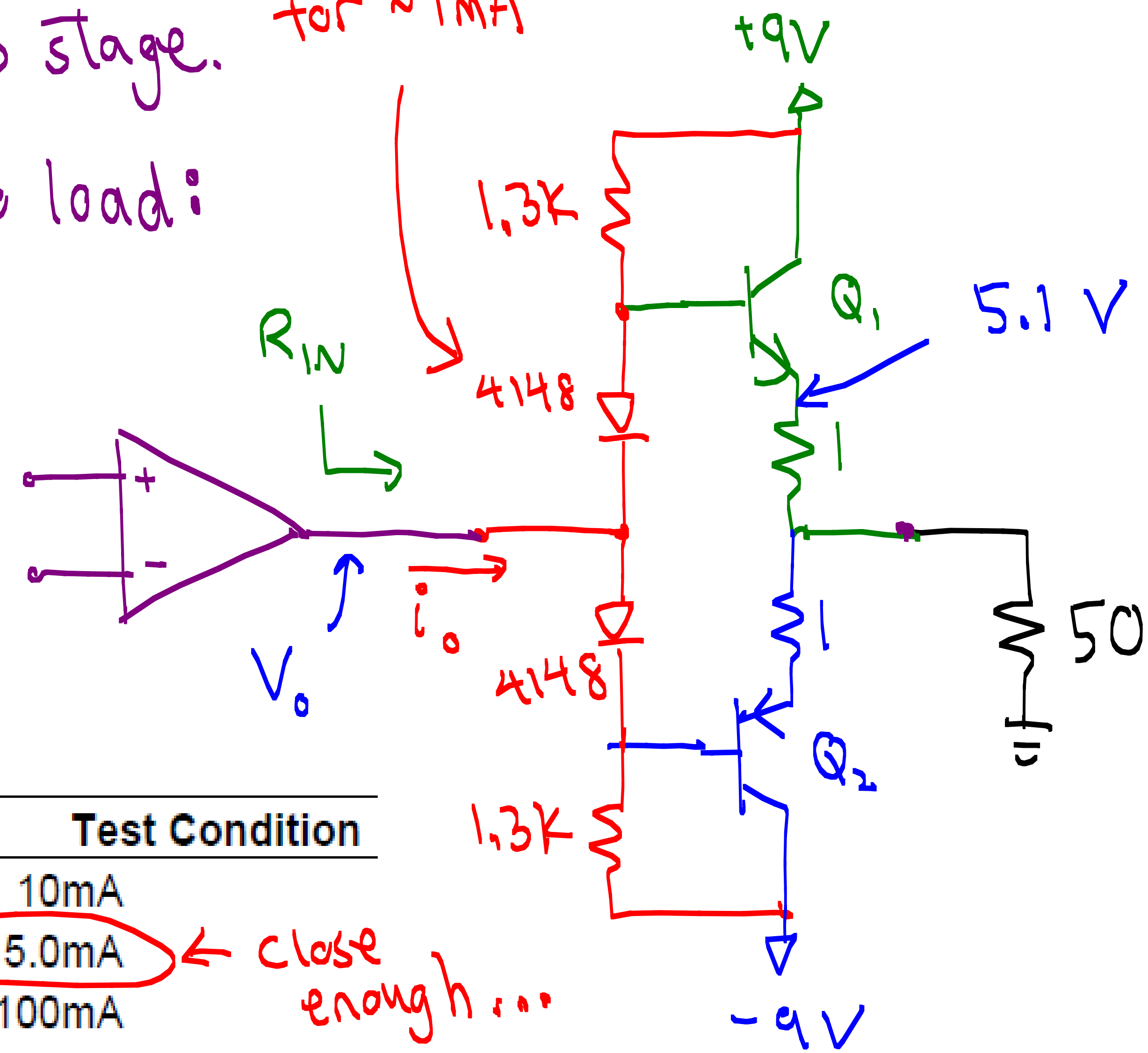
These are good choice for ~1mA

Need to estimate for max output to load:

① $V_o \approx 5.1 + V_{BE} - V_F$

worst case: Max $\to V_o = 5.1 + 0.95 - 0.62$ (0.95: Max; 0.62: min)

$= 5.43V$



1N4148 data sheet

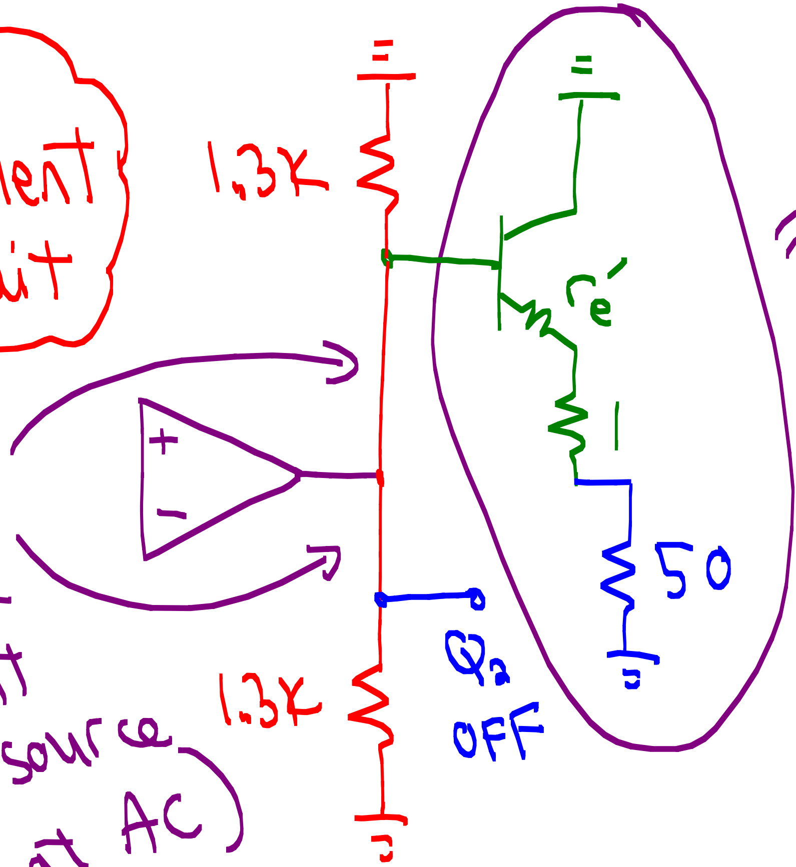
Min	Max	Unit	Test Condition
—	1.0	V	I_F = 10mA
0.62	0.72		I_F = 5.0mA
—	1.0		I_F = 100mA

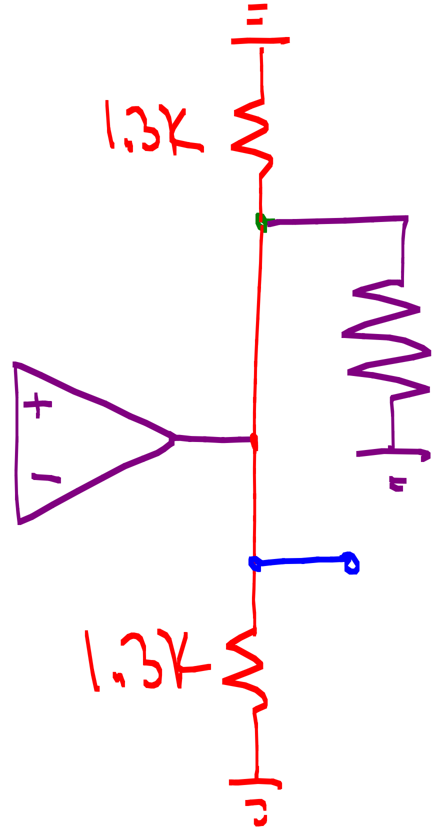
← close enough...

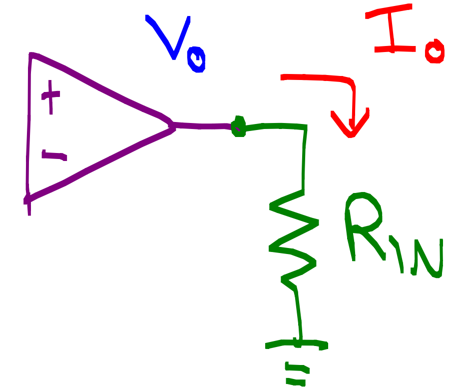
② $i_o \sim \frac{V_o}{R_{IN}}$? ← Only need to consider one transistor (e.g. Q_1) of push-pull pair

AC Equivalent circuit

Diodes act like constant 0.7V source (short at AC)







$$R_{IN} = 1.3K \,//\, 1.3K \,//\, \left[(\beta+1)(r_e' + 51)\right]$$

$$\approx 1.3K \,//\, 1.3K \,//\, \left[(\beta+1)(51)\right]$$

OK to ignore $r_e' = \frac{.026V}{i_E} = \frac{.026V}{.12A}$

$= 0.2\Omega << 51\Omega$

$\Rightarrow R_{IN} \approx (1.3K \,//\, 1.3K) \,//\, (101 \times 51) = \underline{\underline{577\ \Omega}}$ $\Longrightarrow$ $I_o \sim \frac{5.43\,V}{577\,\Omega} = \underline{\underline{9.4\,mA}}$

5.10

Q: When $V_{cc} = \pm 9V$, can the op amp produce <u>5.4 V @ 9.4 mA</u>?

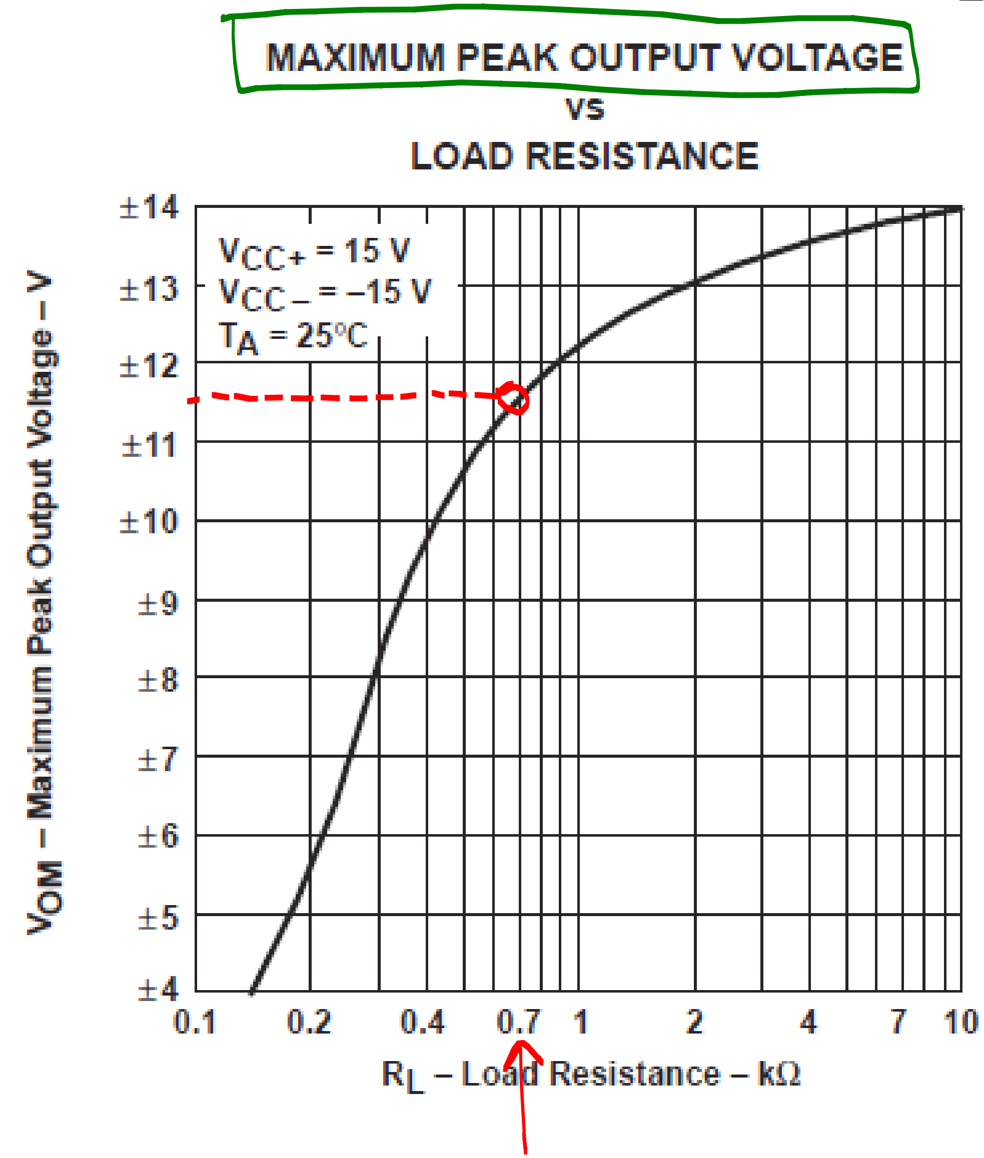
→ Headroom $= 9 - 5.4 = \underline{3.6V}$

using the 741 op amp as an example

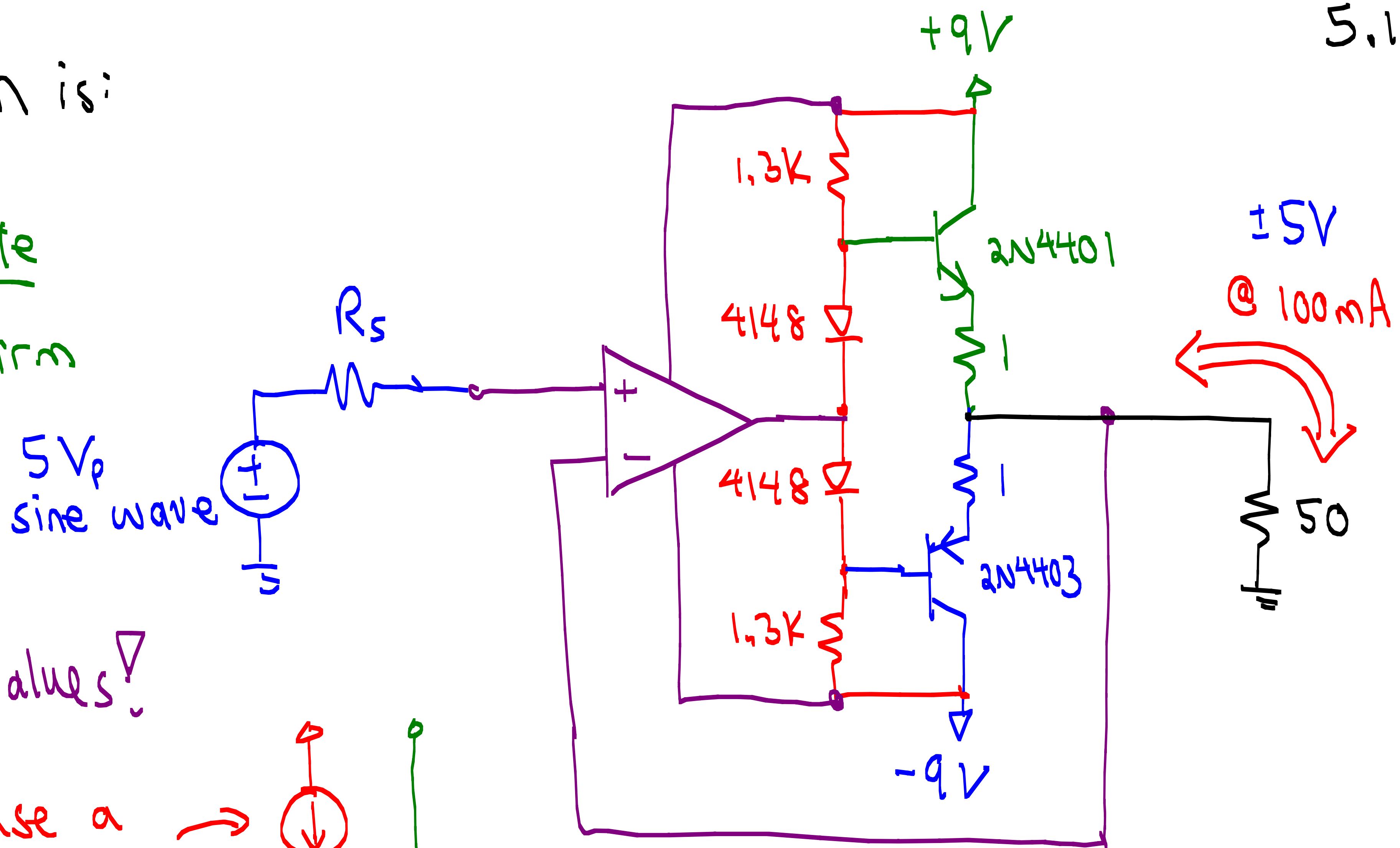
At $V_{cc} = 15$,

max $V_o = V_{cc} - \text{headroom} = 15 - 3.6 = \underline{11.4V}$

$\text{Current} = \frac{11.4V}{0.7K} = 16.3\,mA > 9.4mA$ ✓



- SO, our final design is:



- Good idea to <u>simulate</u> the circuit to confirm proper operation

→ May need to slightly adjust component values!

NOTE: Better to use a <u>current source</u> to bias a Class AB stage →