

# ECE 320 - Homework #4

Transistors, BJT Switch, Schmitt Triggers, H-Bridge

## Transistors

1) Determine the current gain,  $\beta$ , for the transistor show below. Also label the off, active, and saturated regions.

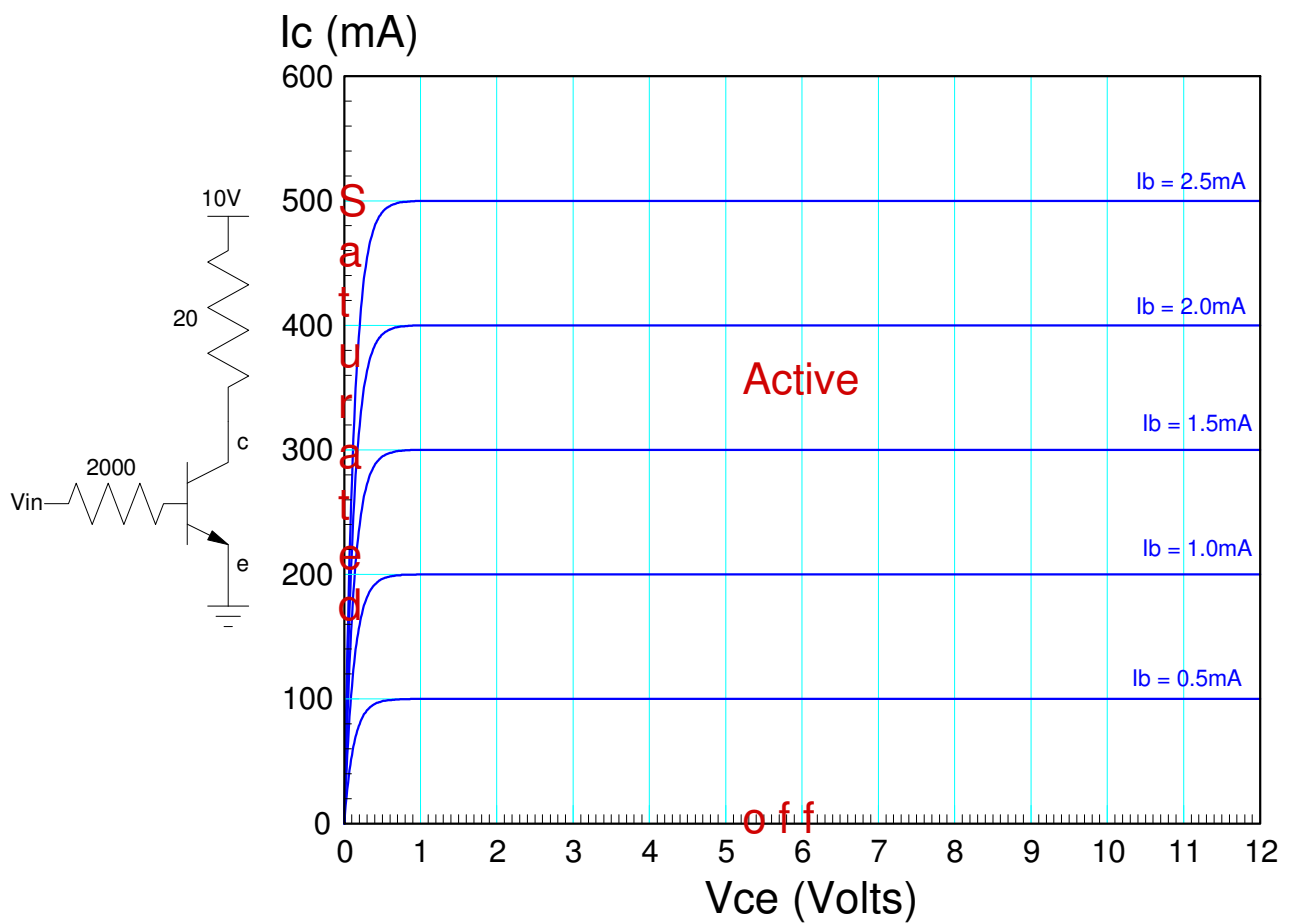
Pick a point in the active region, such as

- $I_b = 2.5\text{mA}$
- $I_c = 500\text{mA}$
- $V_{ce} = 11\text{V}$  (doesn't matter)

The gain is

$$I_c = \beta I_b$$

$$\beta = \left( \frac{500\text{mA}}{2.5\text{mA}} \right) = 200$$



2) Draw the load-line and determine the Q-point for

- $V_{in} = 0V, 3V, 6V$

$V_{in} = 0V$

- $I_b = 0$
- $I_c = 0$
- $V_c = 5 - 20 I_b = 5V$

$V_{in} = 3V$

$$I_b = \left( \frac{3-0.7}{2000} \right) = 1.15mA$$

$$I_c = 200I_b = 230mA$$

$$V_{ce} = 10 - 20I_c = 5.40V$$

$V_{in} = 6V$

$$I_b = \left( \frac{6-0.7}{2000} \right) = 2.65mA$$

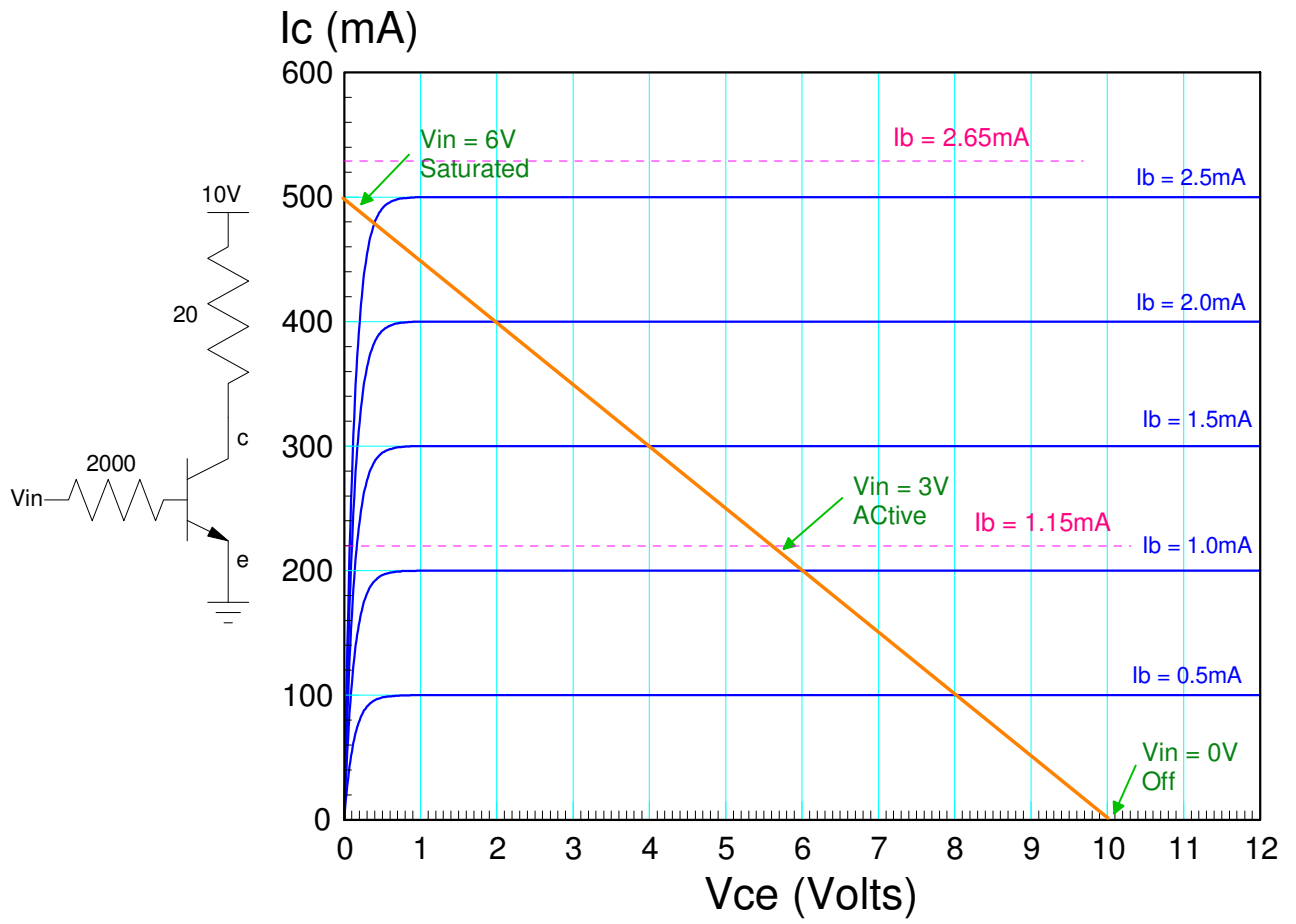
$$I_c = 200I_b = 530mA \quad \text{if active}$$

$$V_{ce} = 10 - 20I_b = -0.60V \quad \text{if active}$$

*That can't happen, so it's not active. Instead, it's saturated*

$$V_{ce} = 0.2V$$

$$I_c = \left( \frac{10V-0.2V}{20} \right) = 490mA$$



## Transistor Switch (NPN & PNP)

For the following circuits, assume TIP31 and TIP32 transistors

|       |     | beta | Vbe  | Vce(sat) | Ic(max) |
|-------|-----|------|------|----------|---------|
| TIP31 | NPN | 100  | 0.7V | 0.2V     | 3A      |
| TIP32 | PNP | 100  | 0.7V | 0.2V     | 3A      |

NPN Switch (TIP31)

3) Determine the voltages and currents { Vb, Vc, Ib, Ic }

- What is the largest Rb can be to keep the transistor in the saturated region?

Assume saturated

$$I_c = \left( \frac{5V - 0.2V}{8\Omega} \right) = 600mA$$

$$I_b = \left( \frac{5V - 0.7V}{330\Omega} \right) = 13.03mA$$

Check: Is this saturated?

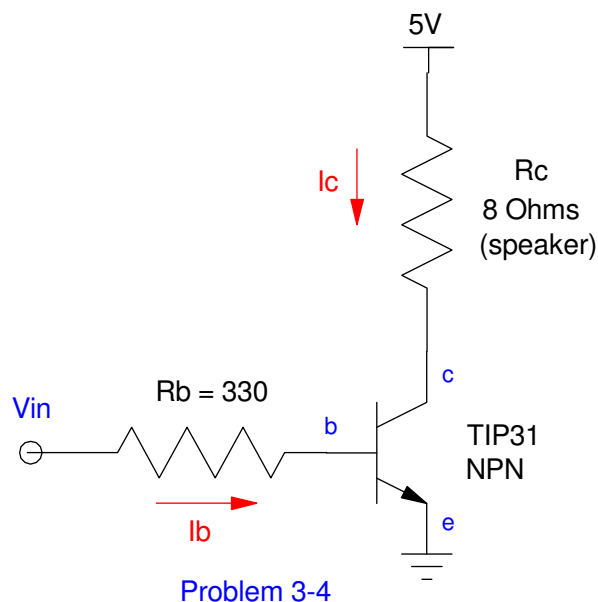
$$\beta I_b > I_c \quad (?)$$

$$1303mA > 600mA \quad \text{yes - it's saturated}$$

The largest Rb can be and still be saturated is

$$I_b = \left( \frac{I_c}{\beta} \right) = 6.00mA$$

$$R_b = \left( \frac{5V - 0.7V}{6.00mA} \right) = 717\Omega$$



4) Simulate this circuit in CircuitLab. From CircuitLab, determine  $\{V_b, V_c, I_b, I_c\}$

|       | Calculated | Simulated |
|-------|------------|-----------|
| $V_b$ | 0.7V       | 840.2mV   |
| $V_c$ | 0.2V       | 59.91mV   |
| $I_b$ | 13.03mA    | 12.61mA   |
| $I_c$ | 600.0mA    | 512.5mA   |

▼ DC

|          |          |  |  |
|----------|----------|--|--|
| V(V1)    | 5.000 V  |  |  |
| V(Vb)    | 840.2 mV |  |  |
| V(Vc)    | 59.91 mV |  |  |
| I(Q1.nC) | 617.5 mA |  |  |
| I(R1.nA) | 12.61 mA |  |  |

Add Expression

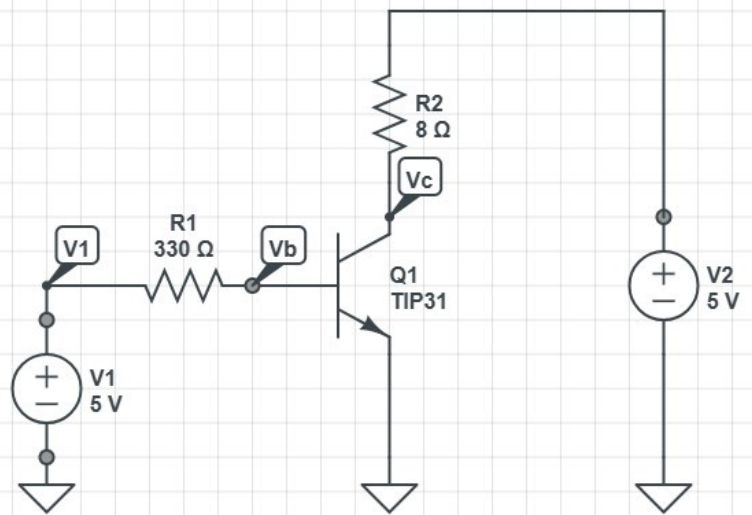
Export Results...

Run DC Solver

▸ DC Sweep

▸ Time Domain

▸ Frequency Domain



### PNP Switch (TIP32)

|       |     | beta | Vbe  | Vce(sat) | Ic(max) |
|-------|-----|------|------|----------|---------|
| TIP31 | NPN | 100  | 0.7V | 0.2V     | 3A      |
| TIP32 | PNP | 100  | 0.7V | 0.2V     | 3A      |

5) Determine the voltages and currents { Vb, Vc, Ib, Ic }

Assume saturated

$$I_c = \left( \frac{5V - 0.2V}{8\Omega} \right) = 600mA$$

$$I_b = \left( \frac{5V - 0.7V}{330\Omega} \right) = 13.03mA$$

Check if it's saturated

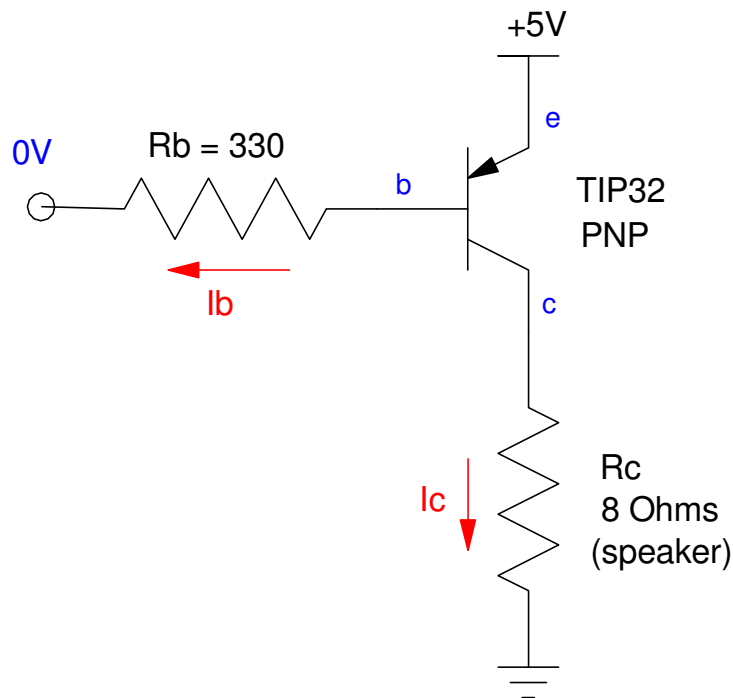
$$\beta I_b > I_c$$

$$1303mA > 600mA \quad \text{yes - it's saturated}$$

The largest Ib can be is when

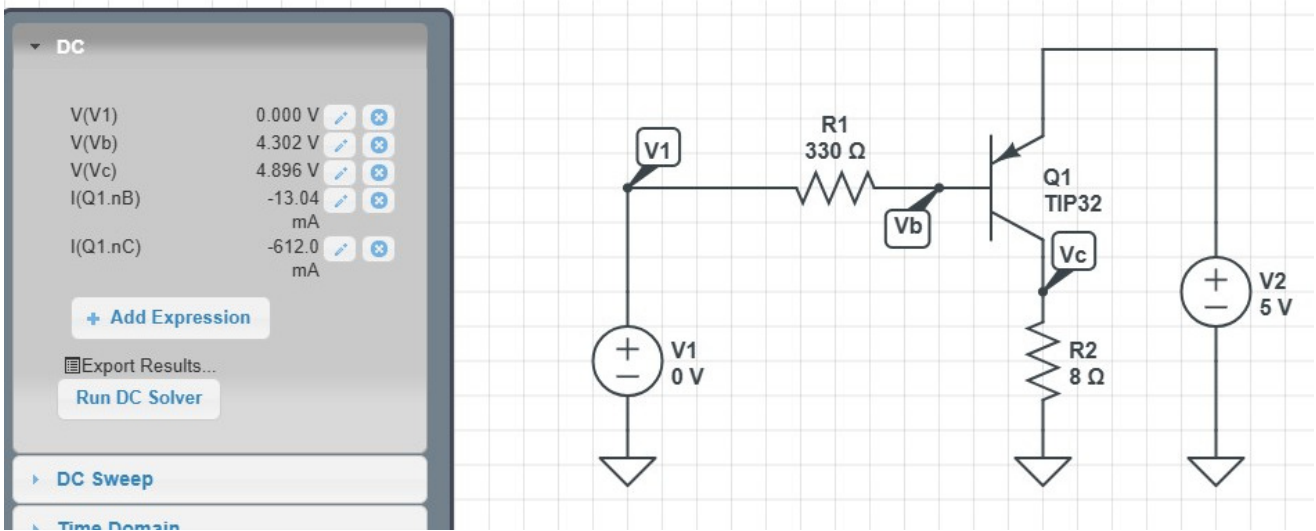
$$I_b = \left( \frac{I_c}{\beta} \right) = 6.00mA$$

$$R_b = \left( \frac{5V - 0.7V}{6.00mA} \right) = 717\Omega$$



6) Simulate this circuit in CircuitLab. From CircuitLab, determine {Vb, Vc, Ib, Ic}

|    | Calculated | Simulated |
|----|------------|-----------|
| Vb | 4.3V       | 4.302V    |
| Vc | 4.8V       | 4.896V    |
| Ib | 13.03 mA   | 13.04 mA  |
| Ic | 600.0 mA   | 612.0 mA  |



## Comparator & Schmitt Trigger

Assume a thermistor with

$$R = 2000 \cdot \exp\left(\frac{3904}{T+273} - \frac{3904}{298}\right) \Omega$$

7) Design a circuit which outputs

- 0V for  $T < 30^\circ\text{C}$  and
- 5V for  $T > 30^\circ\text{C}$

Assume a 1k resistor for a voltage divider

At  $30^\circ\text{C}$

$$R = 1611.176 \Omega$$

$$V_x = \left(\frac{R}{R+1000}\right) 5V = 3.085V$$

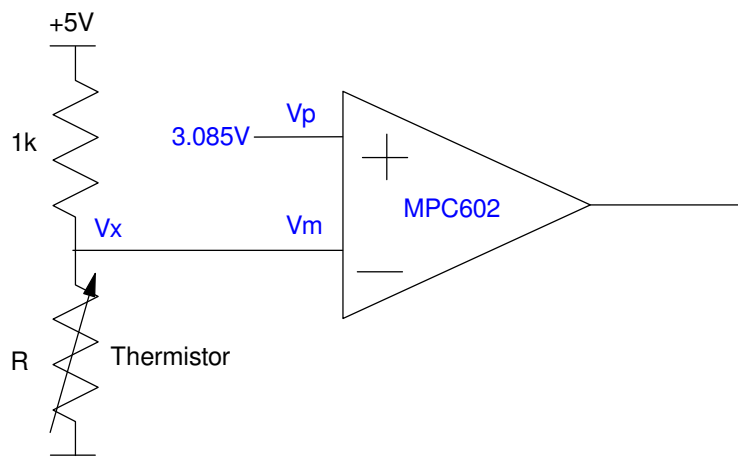
Set  $V_p = 3.085V$

- switch at  $30^\circ\text{C}$

Set  $V_m = V_x$

- As temperature goes to infinity
- $R = 0$
- $V_x = 0$
- $V_o = 5V$

Connect to the minus input



8) Design a circuit with hysteresis

- $V_o = 0V$  for  $T < 30C$
- $V_o = 5V$  for  $T > 35C$
- No change for  $30C < T < 35C$

Assume a voltage divider with a 1k resistor

At 30C (Off)

$$R = 1611.17\Omega$$

$$V_x = \left( \frac{R}{R+1000} \right) 5V = 3.0851V \quad V_{(off)}$$

At 35C (On)

$$R = 1307.08\Omega$$

$$V_x = \left( \frac{R}{R+1000} \right) 5V = 2.8327V \quad V_{(on)}$$

$V_{(on)} < V_{(off)}$

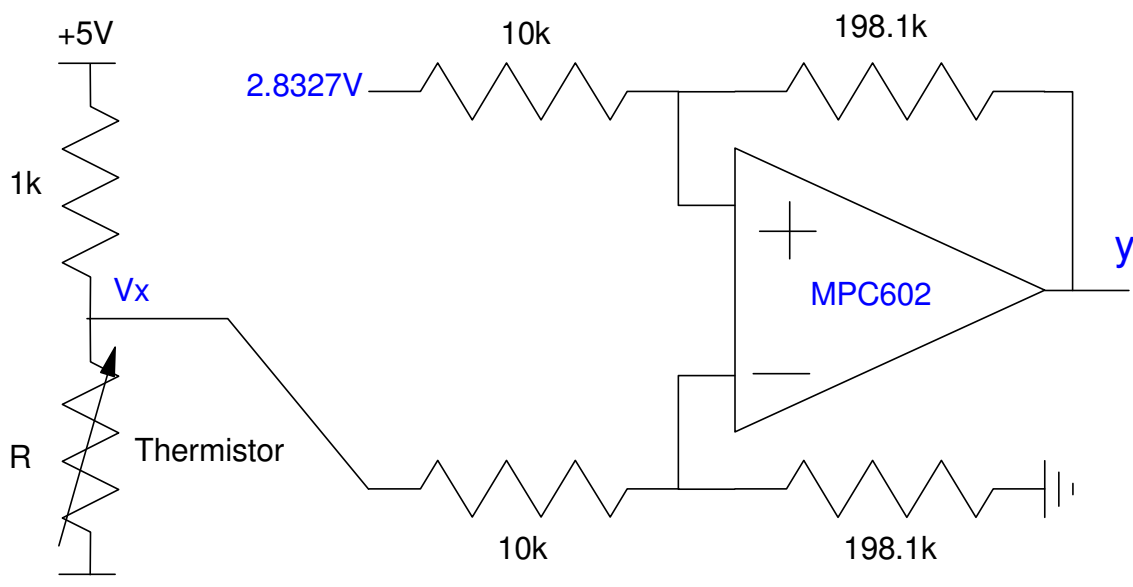
Connect to the minus input

$V_{(on)} = 2.8327V$

Make the offset 2.8327V

Gain:

$$gain = \left( \frac{5V-0V}{3.0851V-2.8327V} \right) = 19.81$$



## H-Bridge

9) Determine the voltages and currents for the following H-bridge.

Assume all transistors are saturated.

For T1:

$$I_{b1} = \left( \frac{10V - 0.7V}{5k} \right) = 1.860mA$$

$$\beta I_{b1} = 186.0mA$$

For T4:

$$I_{b4} = \left( \frac{10V - 0.7V}{20k} \right) = 465\mu A$$

$$\beta I_{b4} = 46.5mA$$

For the 100 Ohm load

$$I_L = \left( \frac{10V - 0.2V - 0.2V}{100\Omega} \right) = 96mA$$

The smallest current wins (46.5mA)

- T4 is active
- T1 is saturated

Result:

$$I_1 = 1.860mA$$

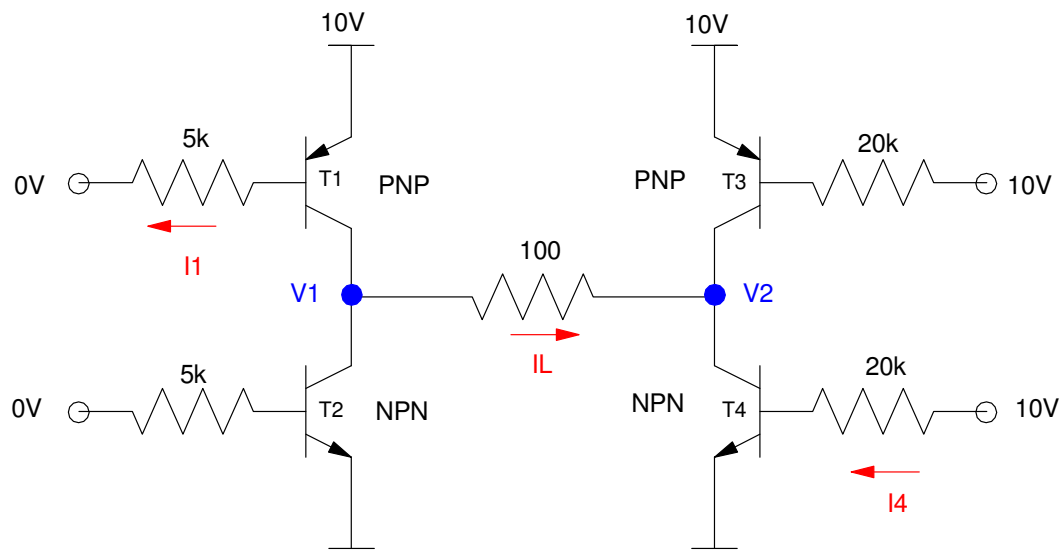
$$I_4 = 465\mu A$$

$$I_L = 46.5mA$$

Since T1 is saturated,  $V_1 = 9.8V$  ( $V_{ce} = 0.2V$ )

$V_2$  is calculated using  $I_L \cdot R$

$$V_2 = 9.8V - (46.5mA)(100\Omega) = 5.15V$$



10) Change the base resistors so that the transistors are either off or saturated

- Determine the voltages and currents for your modified H-bridge.

Change all of the base resistors to 5k

- small enough to saturate each transistor

Then

$$I_1 = \left( \frac{10V - 0.7V}{5k} \right) = 1.86mA$$

$$I_4 = \left( \frac{10V - 0.7V}{5k} \right) = 1.86mA$$

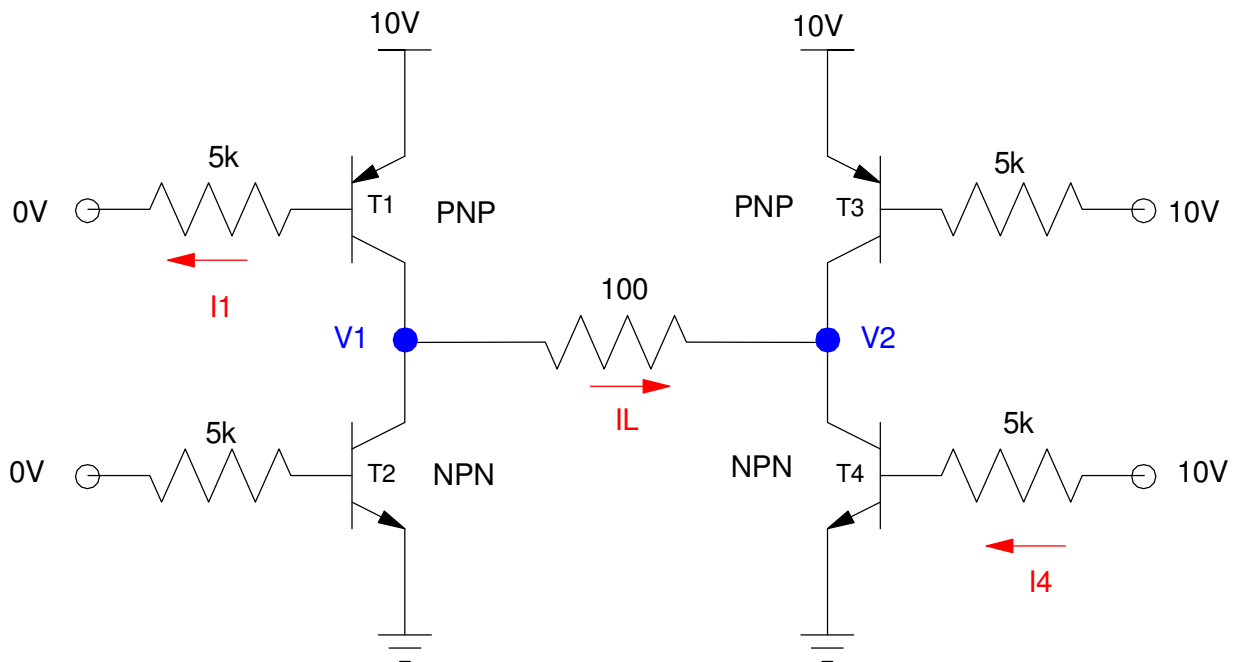
$$I_L = \left( \frac{10V - 0.2V - 0.2V}{100\Omega} \right) = 96mA$$

$$\beta I_b = 186mA > I_c = 96mA$$

Both transistors are saturated

$$V_1 = 9.8V \quad |V_{ce}| = 0.2V$$

$$V_2 = 0.2V \quad |V_{ce}| = 0.2V$$



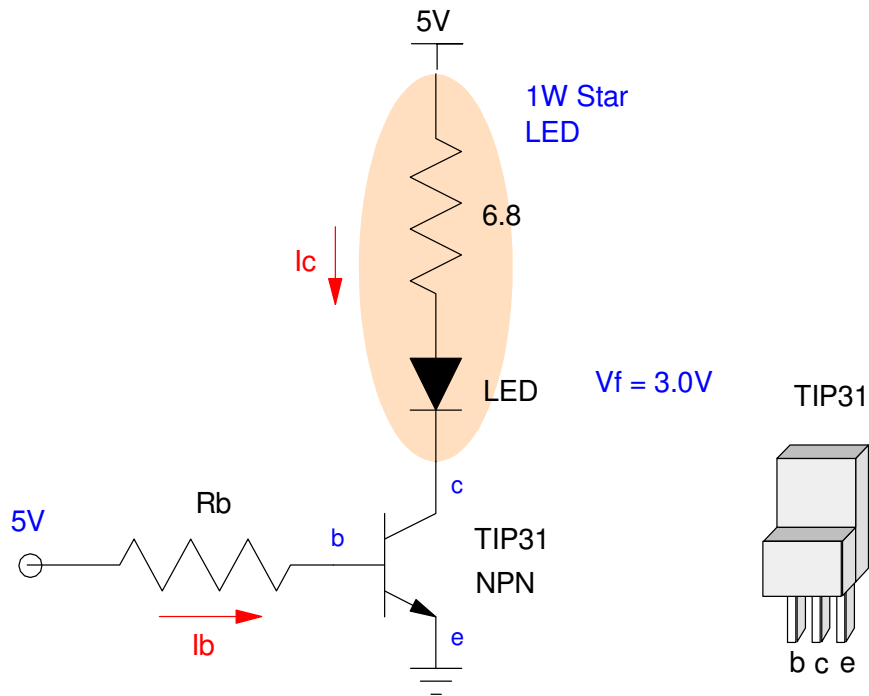
Lab: NPN Transistor Switch

|       |     | beta | Vbe  | Vce(sat) | Ic(max) |
|-------|-----|------|------|----------|---------|
| TIP31 | NPN | 100  | 0.7V | 0.2V     | 3A      |

11) Calculate the currents and voltages for the following NPN switch as Rb varies

- Assume the star LED has  $V_f = 3.0V$
- Also note the state of the transistor (off - active - saturated)

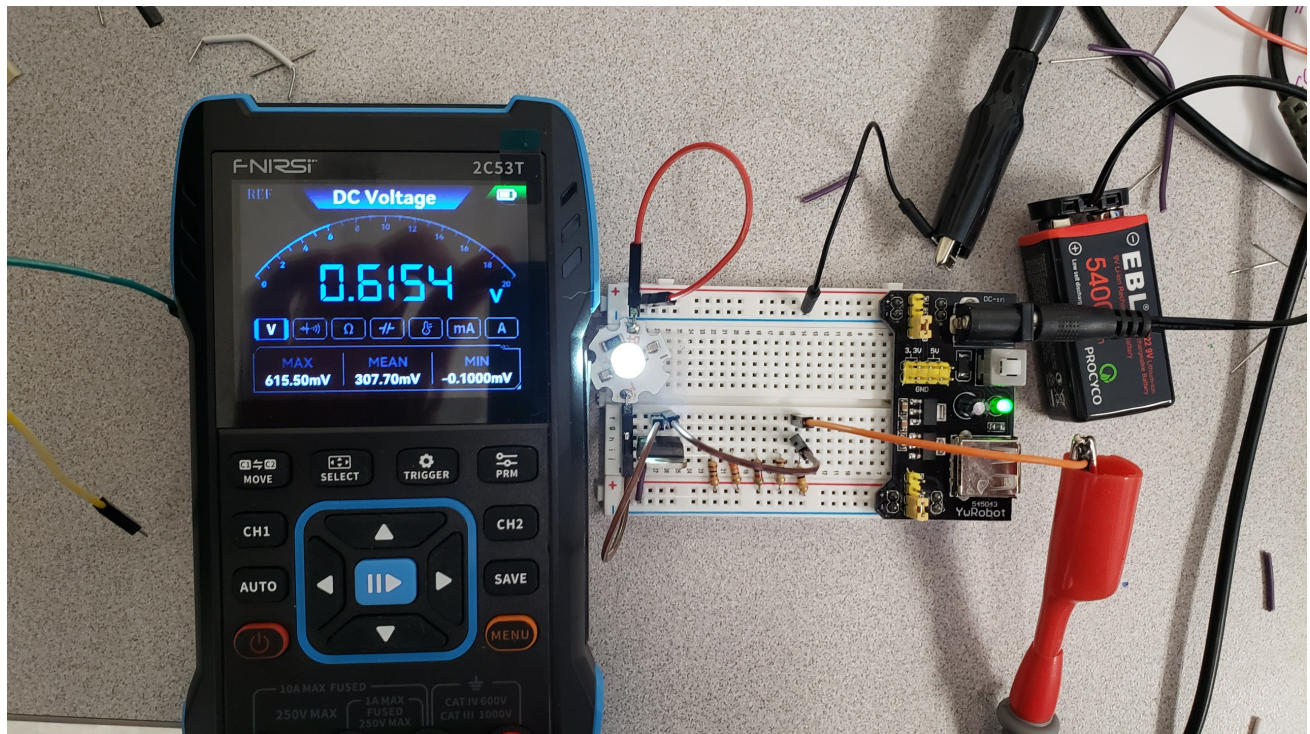
| Rb       | Vbe  | Vce    | Ib     | Ic    | State     |
|----------|------|--------|--------|-------|-----------|
| 100      | 0.7V | 0.2V   | 43.0mA | 265mA | saturated |
| 330      | 0.7V | 0.2V   | 13.0mA | 265mA | saturated |
| 1k       | 0.7V | 0.2V   | 4.30mA | 265mA | saturated |
| 10k      | 0.7V | 1.708V | 430uA  | 43mA  | active    |
| 100k     | 0.7V | 1.971V | 43uA   | 4.3mA | active    |
| infinite | n/a  | n/a    | 0uA    | 0mA   | off       |



12) Build this circuit and measure the voltages and currents

- note: Currents are computed using voltage measurements and resistances
- Include a photo for full credit

| Rb       | Vbe     | Vce     | Ib     | Ic    | State     |
|----------|---------|---------|--------|-------|-----------|
| 100      | 0.7914V | 21.5mV  | 42.1mA | 291mA | saturated |
| 330      | 0.7470V | 30.4mV  | 12.9mA | 289mA | saturated |
| 1k       | 0.7201V | 54.2mV  | 4.28mA | 286mA | saturated |
| 10k      | 0.6778V | 417.3mV | 432uA  | 269mA | active    |
| 100k     | 0.6144V | 723.3mV | 43.8uA | 188mA | active    |
| infinite | n/a     | n/a     | 0uA    | 0mA   | off       |



13) Plot the measured  $I_c$  vs.  $V_{ce}$  along with the load line for this circuit

