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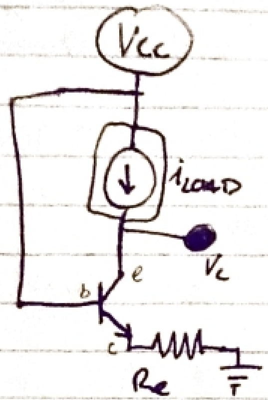
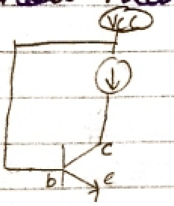
Sarah Clapoff — P490 A#1 — 02,12,2022

1.1 CURRENT SOURCE

In this problem, you will design and analyze a current source to drive a laser diode array from a 12V source.



a) Consider the above circuit. Using the general properties of transistors, show that $i_{LOAD} = \frac{\beta}{1+\beta} \frac{V_{cc} - 0.6V}{R_e}$



$V_e = V_b - 0.6V$, $V_b = V_{cc}$ $\Rightarrow$ $V_e = V_{cc} - 0.6V$

$i_e = \frac{V_e}{R_e} = \frac{V_{cc} - 0.6V}{R_e}$

$i_e = i_b + i_c = \frac{1}{\beta} i_c + i_c = i_c\left(\frac{1+\beta}{\beta}\right)$

$i_c = \frac{\beta}{1+\beta} i_e = i_{LOAD}$

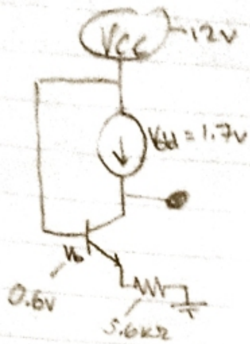
$\therefore$ $\boxed{i_{LOAD} = \frac{\beta}{1+\beta} \frac{V_{cc} - 0.6V}{R_e}}$

b) What emitter resistor Re should be used so that the current source provides 2mA? (Assume $\beta = 100$, but don't do this in real life – β varies from chip to chip)

$i_{LOAD} = 0.002A = \frac{100}{101} \frac{(12-0.6)V}{R_e}$ $\Leftrightarrow$ $R_e = \frac{100}{101}(11.4V)\left(\frac{1}{.002\,A}\right) = 5643.564\,\Omega$

$\Rightarrow$ $\boxed{R_e \approx 5.64\,k\Omega}$

1.1c) Using this value for R_e, a red diode is placed as the load, w/ $V_{dd} = 1.7V$. What is the voltage at the collector and the current through the diode?



$$V_c = 12 - 1.7 - 0.6 = 9.7v$$

$$i_{LOAD} = \frac{100}{101}\frac{V_e}{R_e}$$, $V_e = 9.7$ (as the base voltage has been accounted for) $R_e = 5.6k\Omega$

$$i_{LOAD} = \frac{100}{101}\frac{9.7v}{5643\Omega}$$
$$= 0.001701754\,A$$

$$\boxed{\begin{aligned} i_{LOAD} &\approx 1.7\,mA \\ V_c &= 9.7v \end{aligned}}$$

d) Now a string of LEDs is used. How many LEDs can be used (in series) so that they all remain lit up? What is the voltage at the base as a function of # of LEDs, up to the point where they all turn off?

$$\frac{(12 - 0.6)v}{1.7v} = 6.70588$$ ⇒ 6 LEDs can be connected in series. If any more, there will not be enough voltage to overcome the V_b needed to power the transistor.

$$V_b(n) = 11.4v - 1.7n \quad , n = \#\text{ LEDs}, \quad n \le 6$$

e) Now place a 10kΩ potentiometer as the load. Plot the current through the potentiometer and the base voltage as a function of resistance.

3 Transistor Based Switch

You are driving a 12 V, 60W heater using an arduino microcontroller. The Arduino is great for automation and computational logic, but not so great as a power source. The solution, of course, is a transistor. A power transistor is used so that a "beefy" power supply can source the required current at the operating voltage and the Arduino is placed at the base.

a) First lets choose components. We need a transistor that can safely pass the required components. If the heater is operating at full capacity, (12V, 60W), what is the required current?

$$P = iV, \quad i = \frac{60W}{12V} = \boxed{5A = i_c}$$

b) Lets pick a power transistor. Find a npn transistor that can handle this current and voltage. Look at the datasheet for the following models: PN2222A, 2ST31A, MJF15030G. Is there sufficient max collector current in any of these models? If so, which one? If not, try to find a better model.

$\boxed{\text{MJF15030G}}$ has max collector current $i_c = 8A$, $V_{EB} = 5V$

c) Assuming $\beta = 100$, what value of base resistor, R_b, should be chosen such that the transistor is saturated at 50% of the current from part a)?

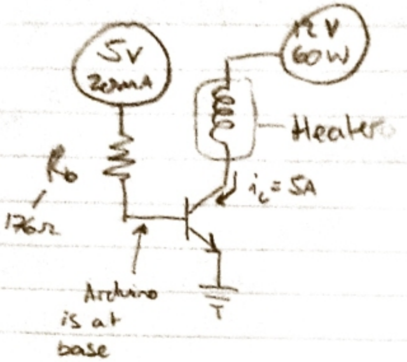
Want saturated (aka turned on) at $0.25A = i_c$

Turned on when $V_c > V_b$

$$i_b = \frac{i_c}{\beta} = \frac{2.5A}{100} = 0.025A$$

$$R_b = \frac{V}{i_b} = \frac{(5 - 0.6)V}{0.025A} = 176\Omega$$

d) Setting R_b to this value, what is the current required of the Arduino when i_c is as determined in part a)?



$i_c = 5A$
$R_b = 176\Omega$

Arduino is placed at the base, so current through arduino is the same as i_b

$\Rightarrow \boxed{i_{ARDUINO} = 0.025A}$

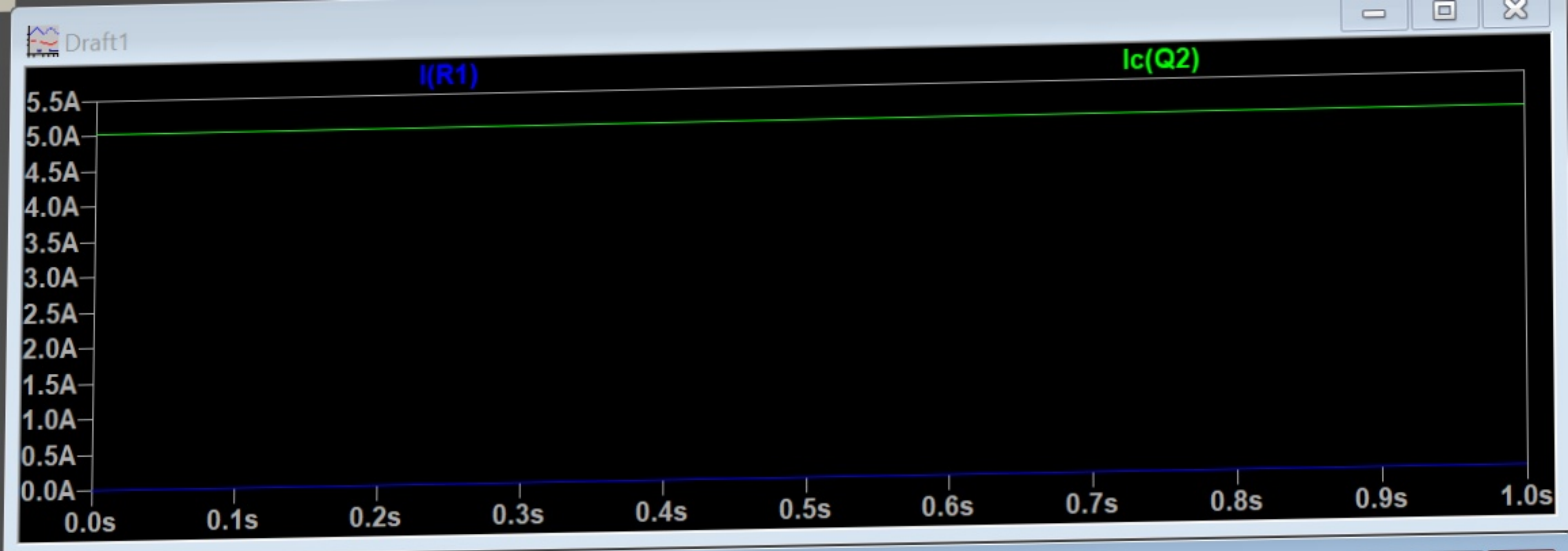
e) Create a LTspice simulation and verify results.

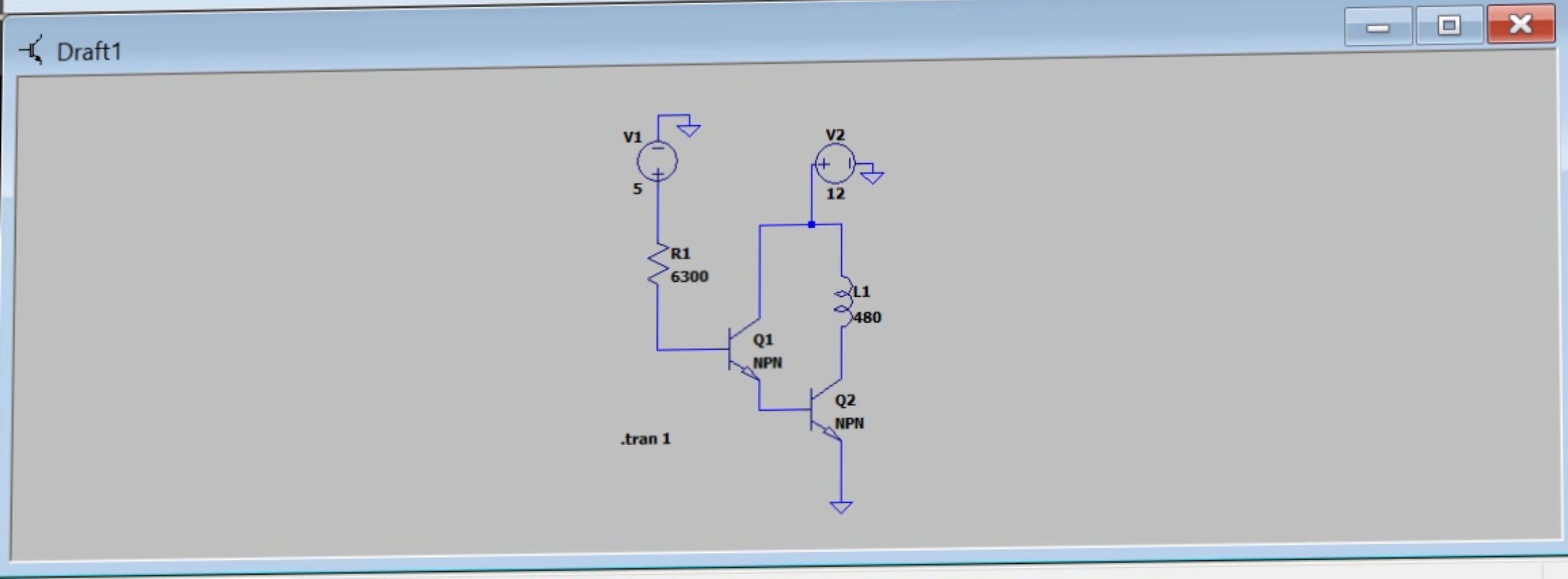
f) This is still a bit much so we'll do a trick to make it easier on our poor little arduino :) This is similar to a "Darlington Pair" diagrammed in the insert of Figure 7b). In this case you can get away w/ a much larger base resistor and therefore smaller base current while remaining in saturation. Simulate this circuit in spice and find out how large R_b can be before the current drops below i from part a). What current is the Arduino supplying in this case?

$i_c \geq 5A$

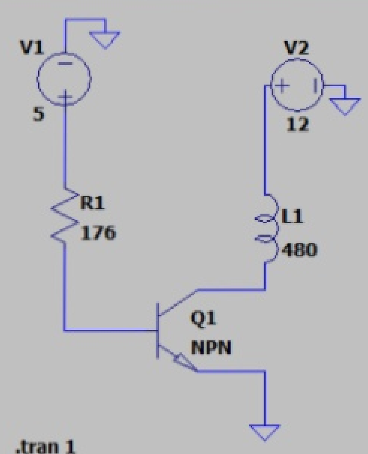
Max $R_b = 6300\Omega$ (see Figure 2)

$i_b = i_{ARDUINO} = 0.50\,mA$


Draft1
I(R1)
Ic(Q2)
5.5A
5.0A
4.5A
4.0A
3.5A
3.0A
2.5A
2.0A
1.5A
1.0A
0.5A
0.0A
0.0s
0.1s
0.2s
0.3s
0.4s
0.5s
0.6s
0.7s
0.8s
0.9s
1.0s


Draft1
V1
5
V2
12
R1
6300
L1
480
Q1
NPN
Q2
NPN
.tran 1


Draft1
V(n003)
V(n004)
I(L1)
I(R1)
13V
12V
11V
10V
9V
8V
7V
6V
5V
4V
3V
2V
1V
0V
2.4A
2.2A
2.0A
1.8A
1.6A
1.4A
1.2A
1.0A
0.8A
0.6A
0.4A
0.2A
0.0A
0.0s
0.1s
0.2s
0.3s
0.4s
0.5s
0.6s
0.7s
0.8s
0.9s
1.0s


V1
5
V2
12
R1
176
L1
480
Q1
NPN
.tran 1