# Homework 6

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1. We may begin by finding the current flowing from the $-15$[V] source. Since we know the voltage at the node above the resistor (.7[V] due to $V_{BE} = .7$[V] and being connected to ground), we may get:

$$I_{-15} = \frac{15 + .7}{150000}$$
$$I_{-15} = 104.67[\mu\text{A}]$$

We may write the equation for the voltage across both the 4.7[kΩ] and 47[kΩ] resistors as:

$$V_{4.7k} = (I_{-15} + I_B)(47k)$$
$$V_{4.7k} = (I_{-15} + I_B + I_C)(4.7k)$$

Putting these together, we find the KVL equation to be:

$$15 = (I_{-15} + I_B)(47k) + (I_{-15} + I_B + I_C)(4.7k) + .7$$

Note that, per BJT equations, we know that:

$$I_C = \beta I_B$$

Using this, we combine the two equations to get:

$$15 = \left(11I_{-15} + \frac{(11+\beta)I_C}{\beta}\right)(4.7k) + .7$$

Now, we substitute known values, and solve for $I_C$:

$$14.3 = [\left(1.1514 \cdot 10^{-3}\right) + 1.055I_C](4.7k)$$

$$14.3 = 5.4116 + 4958.5 I_C$$
$$I_C = \frac{14.3 - 5.4116}{4958.5}$$
$$\boxed{I_C = 1.7926[\text{mA}]}$$

We can then obtain $V_{CE}$:

$$V_{CE} = 15 - (4.7)\left(1.7926 + \frac{1.7926}{200} + 104.67 \cdot 10^{-3}\right)$$
$$\boxed{V_{CE} = 6.04.07[\text{V}]}$$

2. (a) We may begin by writing the equation for the input of the circuit:

$$V_i + R_B I_B - V_{BE} - 9 + 8.2 = 0$$

Substituting our known values, we obtain:

$$V_{BE} - 8000 I_B = .2\sin(2000\pi t) - .8$$

Using the load line characteristic plots in the provided figure, we may observe (approximately):

$$\boxed{5 \leq I_B \leq 50[\text{µA}]}$$

At the Q-point, we see:

$$\boxed{I_{BQ} \approx 25[\text{µA}]}$$

At the output, we may find the equation as:

$$V_{CE} - 3000 I_C = -9$$

From this, we analyze the load-line plots to see:

$$\boxed{-8.25 \leq V_{CE} \leq -1.5[\text{V}]}$$

Furthermore, we may see that, at the Q-point:

$$\boxed{V_{CEQ} = -5.25[\text{V}]}$$

Given that $V_o = V_{CE} + 9$, we get:

$$\boxed{V_o(t) = \begin{cases} \text{min}, & .75 \\ \text{Q}, & 3.75 \\ \text{max}, & 7.5 \end{cases} [\text{V}]}$$

We may see that, because both the input and output are positive, this *pnp* common-emitter amplifier <u>does not invert</u> the signal.

(b) i. The circuit is constructed below:

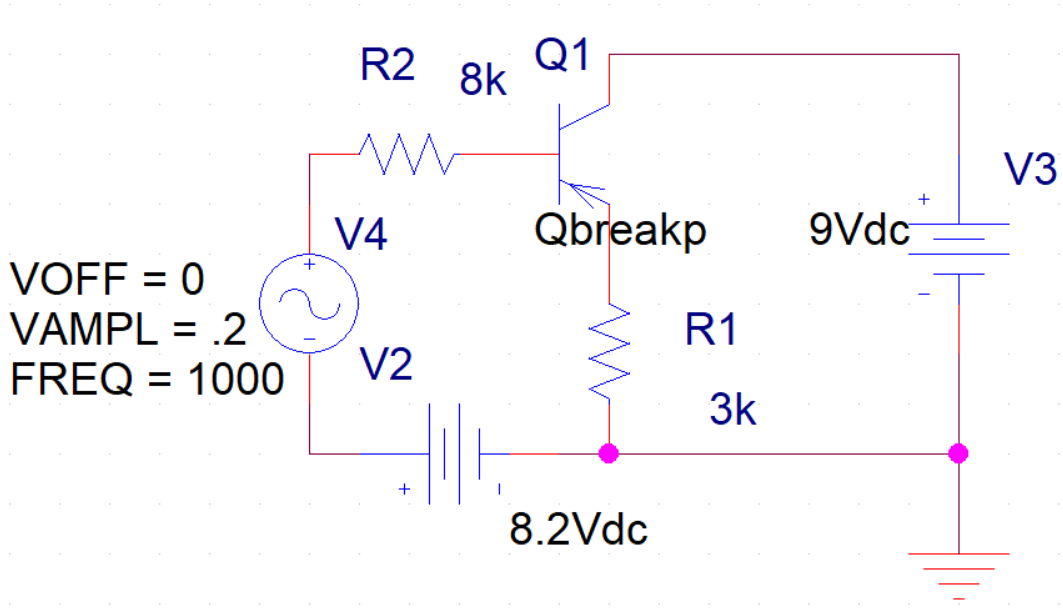


Figure 1: PSPICE Circuit Construction

ii. Running the bias point simulation, we obtain:

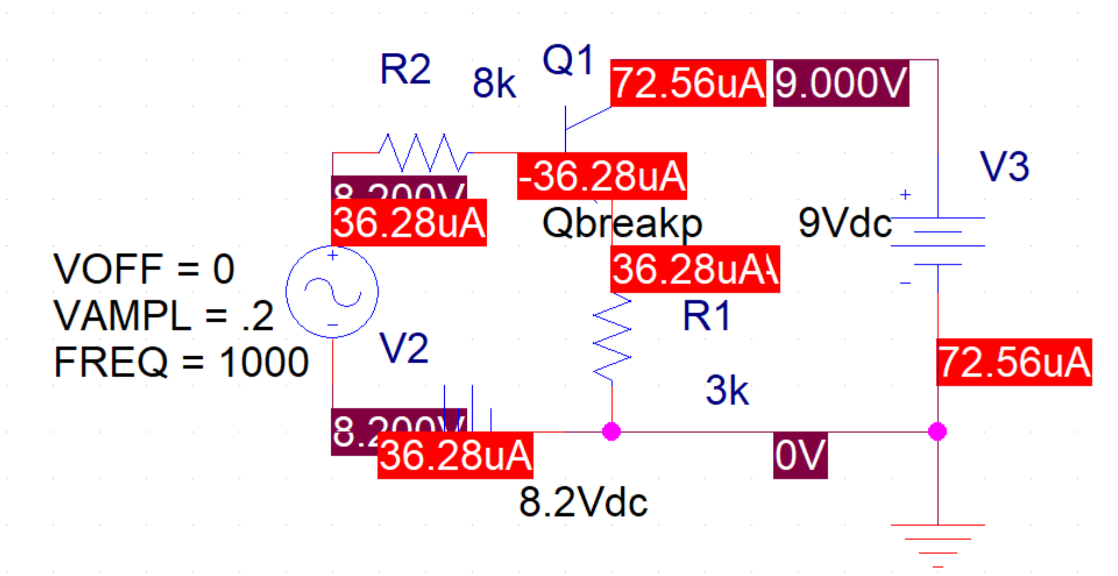


Figure 2: Bias Point Simulation Results

iii. First, we find the "hard set" value of $\beta$, highlighted below:

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 ****     BJT MODEL PARAMETERS

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               Qbreakp
               PNP
          IS  100.000000E-15
          BF    50
          NF     1
          BR     1
          NR     1
          CN     2.2
           D      .52
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Figure 3: Device $\beta$ Value

We may then see the values of $\beta_{DC}$ and $\beta_{AC}$:

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 ****     OPERATING POINT INFORMATION      TEMPERATURE =   27.000 DEG C

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**** BIPOLAR JUNCTION TRANSISTORS


NAME          Q_Q1
MODEL         Qbreakp
IB           -3.63E-05
IC            7.26E-05
VBE           8.38E+00
VBC          -5.10E-01
VCE           8.89E+00
BETADC       -2.00E+00
GM           -1.40E-03
RPI           5.00E+13
RX            0.00E+00
RO            7.13E+02
CBE           0.00E+00
CBC           0.00E+00
CJS           0.00E+00
BETAAC       -7.01E+10
CBX/CBX2      0.00E+00
FT/FT2       -2.23E+16
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Figure 4: Operating Point Simulation Values

iv. Simulating produced the following transients:

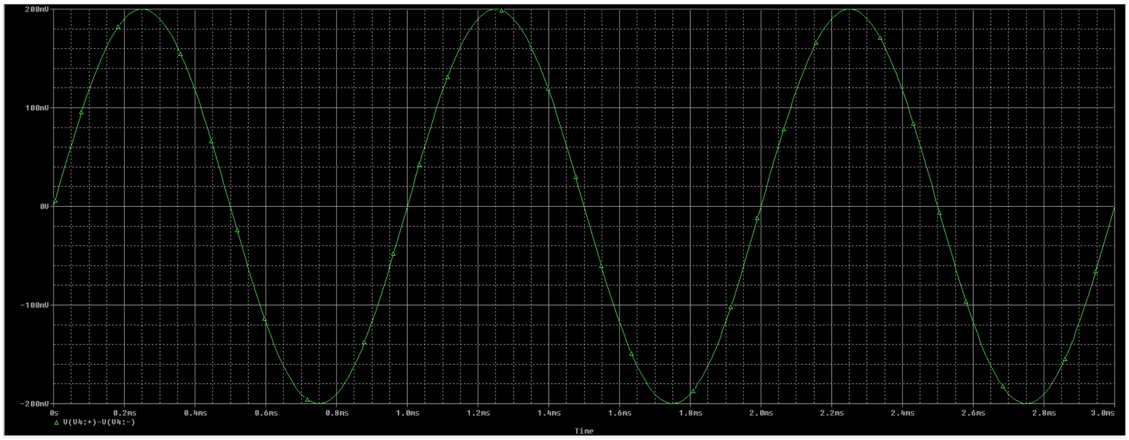


Figure 5: Circuit $V_{in}(t)$ Value

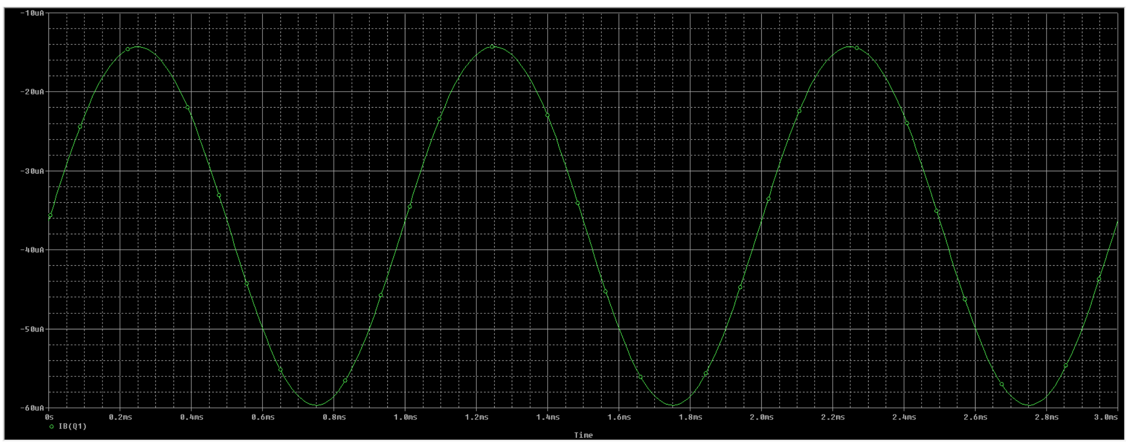


Figure 6: Circuit $I_B(t)$ Value

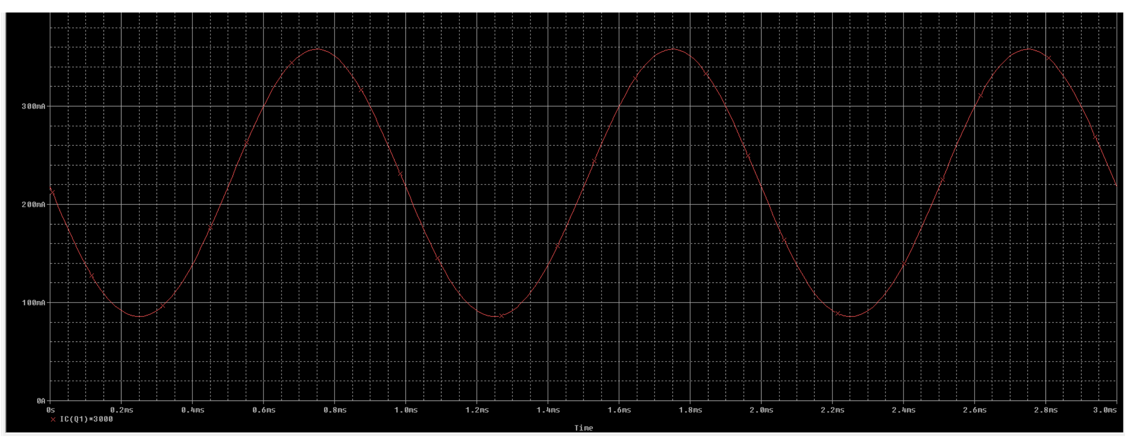


Figure 7: Circuit $V_o(t)$ Value

We may see that the simulated circuit, more or less, follows the expected values calculated in part (a).

3. (a) We use KVL at the base-emitter loop to obtain:

$$12 = (I_C + I_B)R_C + R_1 I_B + .7 + R_E I_E$$

And at the collector-emitter loop, we get:

$$12 = (I_C + I_B)R_C + V_{CE} + R_E I_E$$

We may apply:

$$I_E = (\beta + 1)I_B \quad \text{and} \quad I_E = I_B + I_C$$

To get:

$$12 = (I_E)R_C + R_B\left(\frac{I_E}{\beta + 1}\right) + .7 + R_E I_E$$

Substituting known values, we get:

$$11.3 = (I_E)1000 + 10000\left(\frac{I_E}{\beta + 1}\right) + 200 I_E$$

Solving for $I_E$, we get:

$$1396.1 I_E = 11.3$$

$$\boxed{I_E = 8.0941[\text{mA}]\Big|_{\beta=50}}$$

From this, we get:

$$I_B = \frac{I_E}{\beta + 1} \quad \text{and} \quad I_C = \left(\frac{\beta}{\beta + 1}\right) I_E$$

$$\boxed{I_B = 158.71[\mu\text{A}] \quad \text{and} \quad I_C = 7.9354[\text{mA}]\Big|_{\beta=50}}$$

Using our collector-emitter loop, we see:

$$V_{CE} = 12 - I_E(R_C + R_E)$$

$$V_{CE} = 12 - 8.0941(.2 + 1)$$

$$\boxed{V_{CE} = 2.2871[\text{V}]\Big|_{\beta=50}}$$

For $\beta = 250$, we repeat the analysis at this point:

$$11.3 = (I_E)1000 + 10000\left(\frac{I_E}{\beta+1}\right) + 200I_E$$

This gives us:

$$1239.8I_E = 11.3$$

$$\boxed{I_E = 9.1141[\text{mA}]\Big|_{\beta=250}}$$

Then:

$$\boxed{I_B = 36.311[\mu\text{A}] \quad \text{and} \quad I_C = 9.0778[\text{mA}]\Big|_{\beta=250}}$$

Finally, we get:

$$V_{CE} = 12 - 9.1141(1.2)$$

$$\boxed{V_{CE} = 1.0631[\text{V}]}$$

(b) Repeating Part (a) with $R_E = 0$, we get:

$$11.3 = (I_E)1000 + 10000\left(\frac{I_E}{\beta+1}\right)$$

From which we obtain:

$$1039.8I_E = 11.3 \quad \text{and} \quad 1196.1I_E = 11.3$$

$$\boxed{I_E = .010867[\text{A}]\Big|_{\beta=250} \quad \text{and} \quad I_E = 9.4474[\text{mA}]\Big|_{\beta=50}}$$

From this, we can get:

$$\boxed{I_B = 43.295[\mu\text{A}] \quad \text{and} \quad I_C = .010824[\text{A}]\Big|_{\beta=50}}$$

$$\boxed{I_B = 185.24[\mu\text{A}] \quad \text{and} \quad I_C = 9.2622[\text{mA}]\Big|_{\beta=250}}$$

Finally, we reach:

$$V_{CE} = 12 - I_E(1000)$$

$$V_{CE} = 12 - 10.867 \quad \text{and} \quad 12 - 9.4474$$

$$\boxed{V_{CE} = 1.133[\text{V}]\Big|_{\beta=250} \quad \text{and} \quad V_{CE} = 2.5526[\text{V}]\Big|_{\beta=50}}$$

(c) The circuit was constructed as follows:

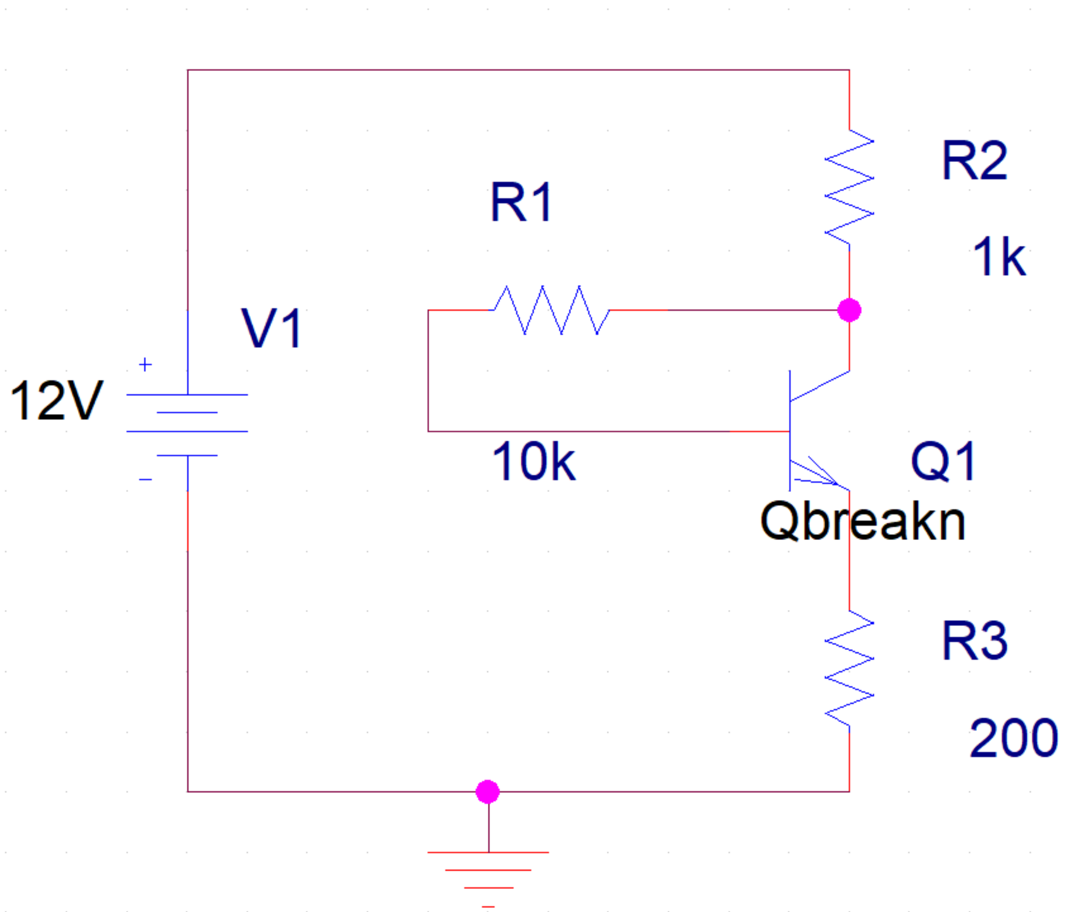


Figure 8: Circuit Construction

We then simulate with $\beta = 50$:

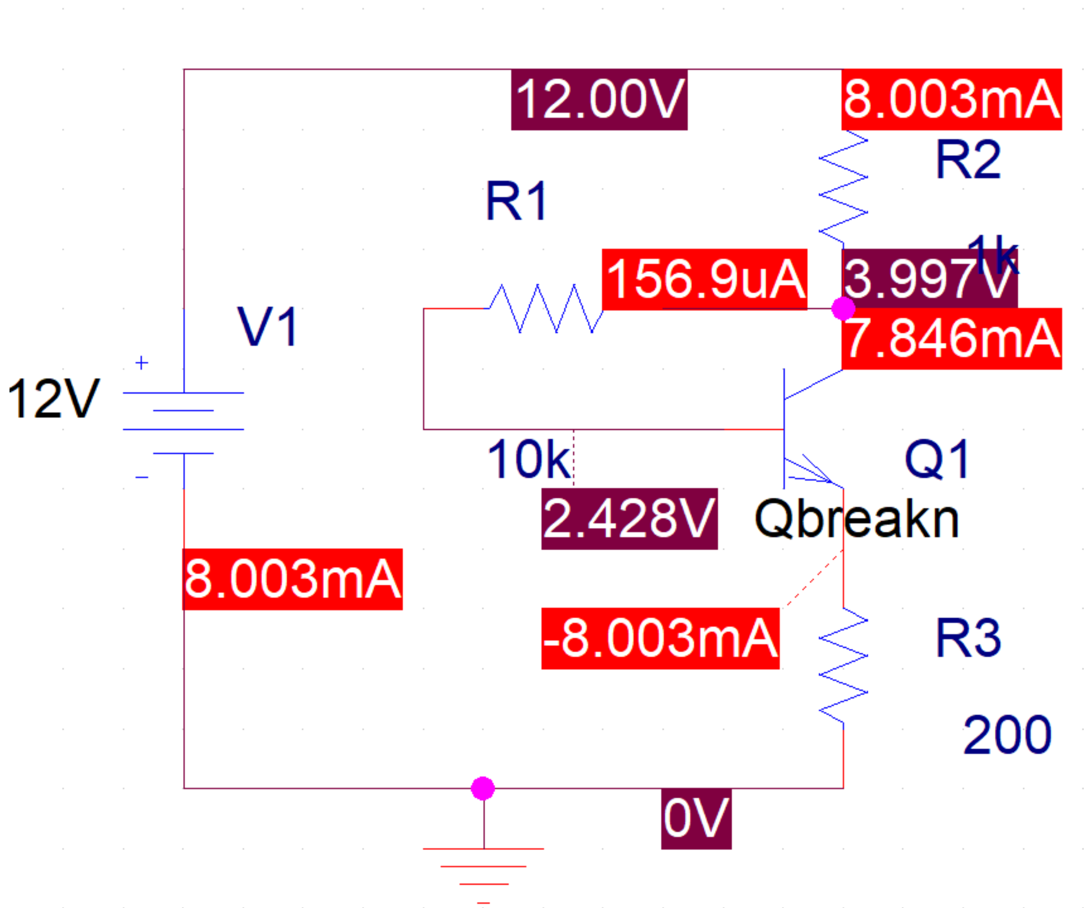


Figure 9: $\beta = 50$ Simulation Result

And then with $\beta = 250$:

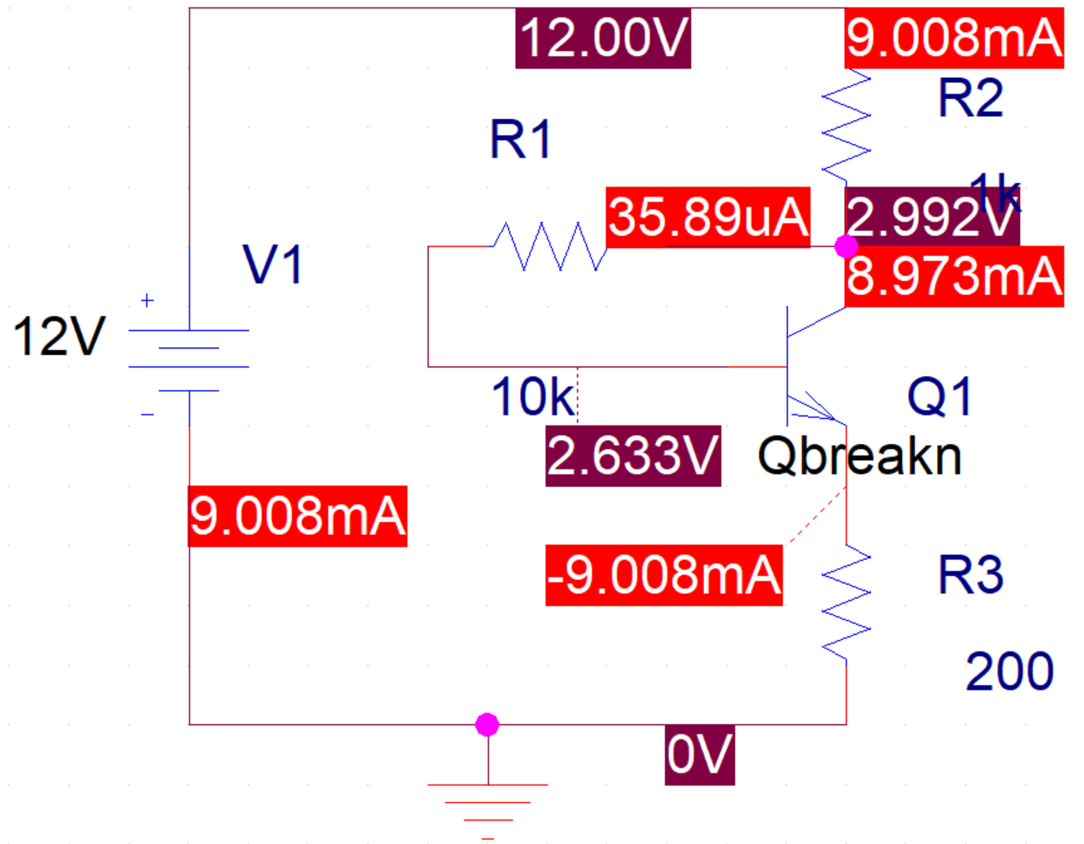


Figure 10: $\beta = 250$ Simulation Result

We may observe that the simulation result is quite similar to what we calculated in Part (a), with the biggest difference being a slightly offset $V_{CE}$ value.