3EJ4: Electronic Devices and Circuits II

Lab 1: Device Characterization and Biasing Circuits

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C. Questions for part 1

Q1. The following questions were answered from the simulated circuit in Part 1, shown below. The simulation run data was extracted and inserted in sheet "Steps 1.2-1.4" of the attached Excel file.

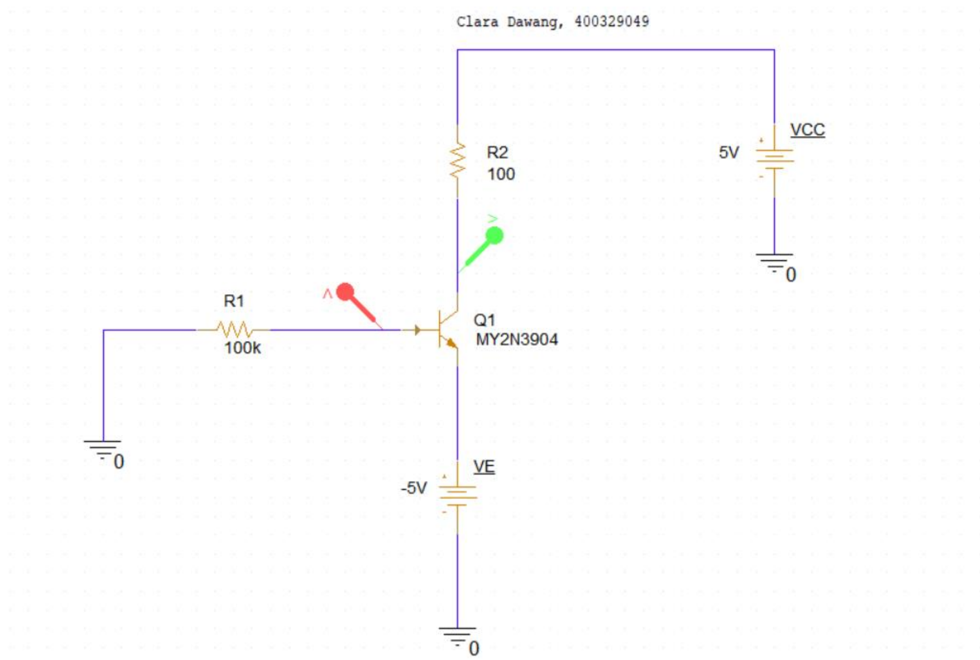

Figure 1 – Part 1 PSpice Schematic

If the device is biased to conduct a collector current $I_C \approx 1.00$ mA at the lowest V_{CE} value:

1. $V_{BEon} = 0.621$ V and the base current $I_B = 8.79$ µA
2. $\beta = I_C/I_B = 117$
3. $|V_A| = 1000$ V
4. $r_o = 976$ kΩ
5. $g_m = 41$ ms
6. $r\pi = 2.845$ kΩ

Q2. The following questions were answered from the measured data in step 1.8, using the same bias condition found in Q1 above.

1. $I_C = 2.16$ mA
2. $V_{BEon} = 0.6604$V and the base current $I_B = 8.40$ µA
3. $\beta = I_C/I_B = 257$
4. $|V_A| = 210$ V
5. $r_o = 97.4$ kΩ
6. $g_m = 86.2$ ms
7. $r\pi = 2.978$ kΩ

C. Questions for part 2

Q3. The following questions were answered from the simulated circuit in Part 2, shown below. The simulation run data was extracted and inserted in sheet "Steps 2.2-2.4" of the attached Excel file.

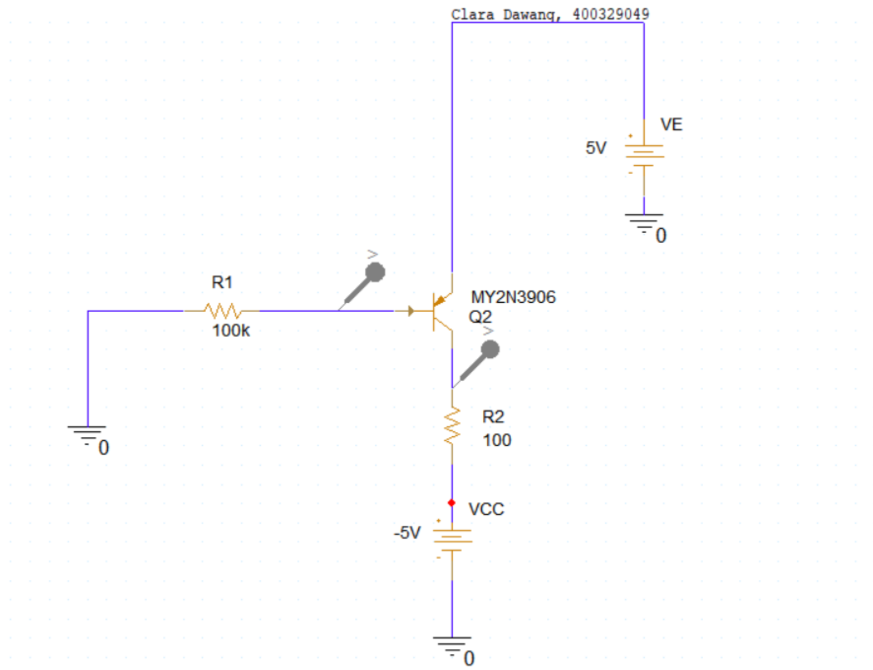

Figure 2 - Part 2 PSpice Schematic

If the device is biased to conduct a collector current $I_C \approx 1.00$ mA at the lowest V_{CE} value:

1. $V_{BEon} = 0.660$V and the base current $I_B = 8.40$ µA
2. $\beta = I_C/I_B = 123$
3. $|V_A| = 143$ V
4. r_o = 139 kΩ
5. $g_m = 41.2$ ms
6. $r\pi = 2.976$ kΩ

Q4. The following questions were answered from the measured data in step 1.8, using the same bias condition found in Q3 above.

1. I_C = 1.92 mA
2. $V_{BEon} = 0.658$V and the base current $I_B = 8.42$ µA
3. $\beta = I_C/I_B = 228$
4. $|V_A| = 26$ V
5. $r_o = 13.5$ kΩ
6. $g_m = 76.8$ ms
7. $r\pi = 2.969$ kΩ

Q5.

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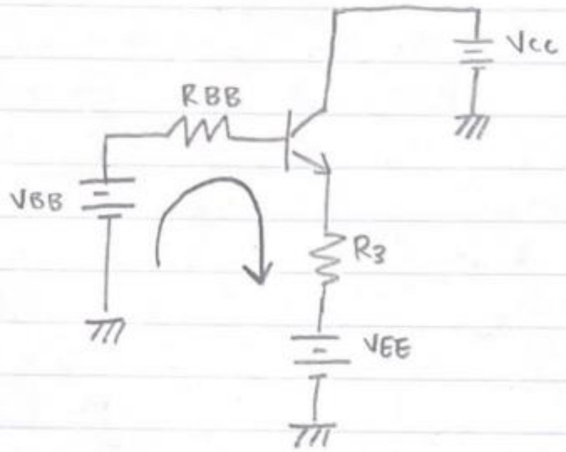

$$I_B = I_E - I_C$$
$$I_C = \beta I_B$$

$$I_B + \beta I_B = I_E$$
$$I_B(1+\beta) = I_E$$

$$0 + V_{BB} - I_B R_{BB} - V_{BE} - I_E R_3 - V_{EE} = 0$$
$$V_{BB} - I_B R_{BB} - V_{BE} - I_B(1+\beta) R_3 - V_{EE} = 0$$
$$V_{BB} - V_{BE} - V_{EE} = I_B R_{BB} + I_B(1+\beta) R_3$$
$$V_{BB} - V_{BE} - V_{EE} = I_B(R_{BB} + (1+\beta) R_3)$$
$$I_B = \frac{V_{BB} - V_{BE} - V_{EE}}{R_{BB} + R_3(1+\beta)}$$

Q6.

Difference between equation (3) and equation from Q.5 is the second denominator term:

equation (3): $$I_B = \frac{V_{BB} - (V_E + V_{BE_{ON}})}{R_{BB}}$$

question 5: $$I_B = \frac{V_{BB} - V_E - V_{BE\,ON}}{R_{BB} + R_3(1+\beta)}$$

Equation (3) with ΔV_{EE}

$$I_B = \frac{R_2}{R_1+R_2} - \frac{V_{EE}}{R_{BB}} - \frac{V_{BE_{ON}}}{R_{BB}}$$

$$I_{Bend} = \frac{R_2}{R_1+R_2} - \frac{(V_{EE} + \Delta V_{EE})}{R_{BB}} - \frac{V_{BE\,ON}}{R_{BB}}$$

$$\Delta I_B = \left(\frac{R_2}{R_1+R_2} - \frac{V_{EE}}{R_{BB}} - \frac{V_{BE_{ON}}}{R_{BB}}\right) - \left(\frac{R_2}{R_1+R_2} - \frac{(V_{EE}+\Delta V_{EE})}{R_{BB}} - \frac{V_{BE_{ON}}}{R_{BB}}\right)$$

$$\Delta I_B = \left(\frac{R_2}{R_1+R_2}\right)\left(-\frac{\Delta V_{EE}}{R_{BB}}\right)$$

Question 5 with ΔV_{EE}:

$$I_B = \left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-V_{EE}}{R_{BB}+R_3(1+\beta)}\right) - \frac{V_{BEon}}{R_{BB}+R_3(1+\beta)}$$

$$I_{Bend} = \frac{R_2}{R_1+R_2}\left(\frac{-(V_{EE}+\Delta V_{EE})}{R_{BB}+R_3(1+\beta)}\right) - \frac{V_{BEon}}{R_{BB}+R_3(1+\beta)}$$

$$\Delta I_B = \left(\left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-(V_{EE}+\Delta V_{EE})}{R_{BB}+R_3(1+\beta)}\right) - \frac{V_{BEon}}{R_{BB}+R_3(1+\beta)}\right) - \left(\left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-V_{EE}}{R_{BB}+R_3(1+\beta)}\right) - \frac{V_{BEon}}{R_{BB}+R_3(1+\beta)}\right)$$

$$\Delta I_B = \left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-\Delta V_{EE}}{R_{BB}+R_3(1+\beta)}\right)$$

Final comparison with ΔV_{EE}

equation 3: $\Delta I_B = \left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-\Delta V_{EE}}{R_{BB}}\right)$

question 5 : $\Delta I_B = \left(\frac{R_2}{R_1+R_2}\right)\left(\frac{-\Delta V_{EE}}{R_{BB}+R_3(1+\beta)}\right)$

When there is change ΔV_{EE} applied, the R_3 term is present in the denominator of the question 5 equation. As ΔV_{EE} is divided by R_3 in this term, the emitter resister reduces the change in the base current.

Q7.

When $R_3 \neq 0$:

$$V_{o,min} = V_{EE} + I_E R_3 + 0.3\,V$$
$$= V_{EE} + I_o R_3 + 0.3\,V$$
$$= V_{EE} + 1mA(R_3) + 0.3V$$

Q8.

$$V_{o,min} = V_{EE} + 1\,mA\,R_3 + 0.3$$
$$-1.5V = -5V + R_3 + 0.3$$
$$R_3 = 3.2\,k\Omega$$

at node V_{BB}: $V_{BB} - I_B R_{BB} - V_B = 0$

$$V_B - V_{BE} - I_E R_3 - V_{EE} = 0$$
$$V_B = 0.621 + \frac{118}{117}(3.2) - 5$$
$$V_B = -1.15165$$

Substitute V_B and R_{BB} using lab manual equation ②

$$V_{BB} = I_B\left(\frac{R_1 R_2}{R_1 + R_2}\right) - 1.15165$$

using lab manual equation ①

$$V_{BB} = V_{EE}\left(\frac{R_1}{R_1 + R_2}\right)$$
$$-5\left(\frac{R_1}{R_1 + 100K}\right) = \frac{1}{117}\left(\frac{100k\,R_1}{100k + R_1}\right) - 1.15165$$

$$\frac{-5R_1 - 0.8547R_1}{100k + R_1} = -1.15165$$

$$-5.8547R_1 = -1.15165(100k + R_1)$$
$$-5.8547R_1 = -115.165K - 1.15165R_1$$
$$-5.8547R_1 + 1.15165R_1 = -115.165K$$
$$-4.6982\,R_1 = -115.165K$$
$$R_1 = 24.51258\,k\Omega$$

To verify the above results, the following circuit was constructed in PSpice and used to sweep V_{CC} from -5V to 5V.

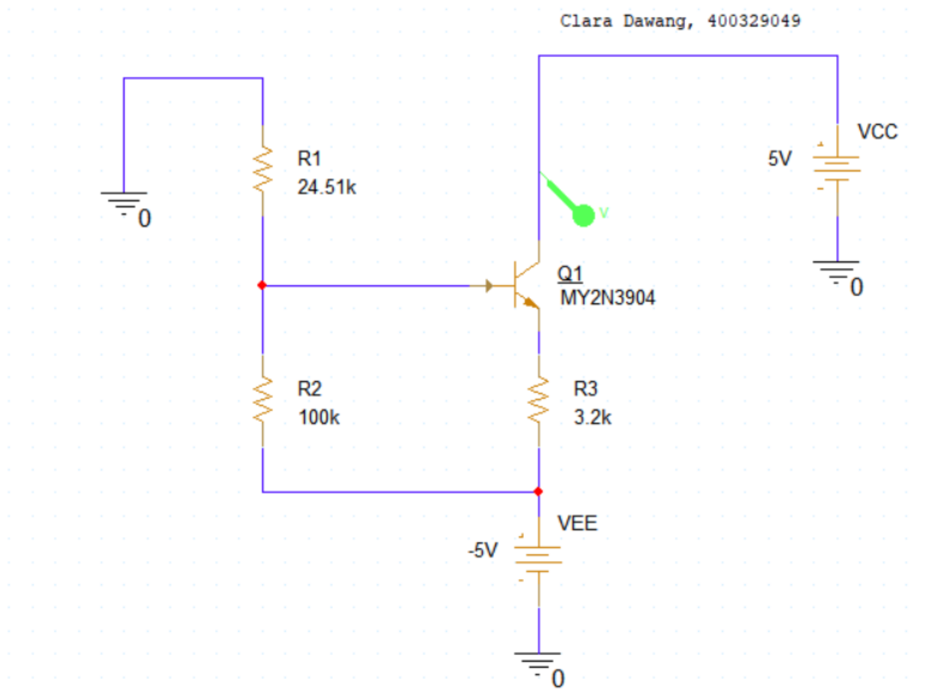

Figure 3 – Question 8 PSpice Schematic

The following waveform was obtained, with the voltage V_{CC} plotted in green and the output current I_o (I_C) plotted in red.

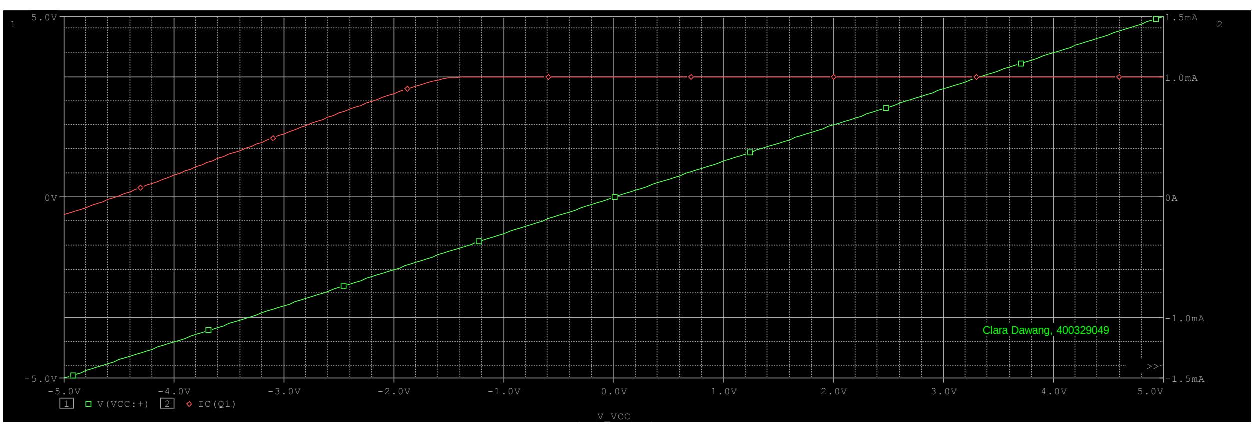

Figure 4 - Question 8 waveform of Io vs. Vcc

Q9. The circuit in Figure 3 shows a DC sweep of V_{CC} to measure V_E (green) and I_C (red), shown in the waveform below.

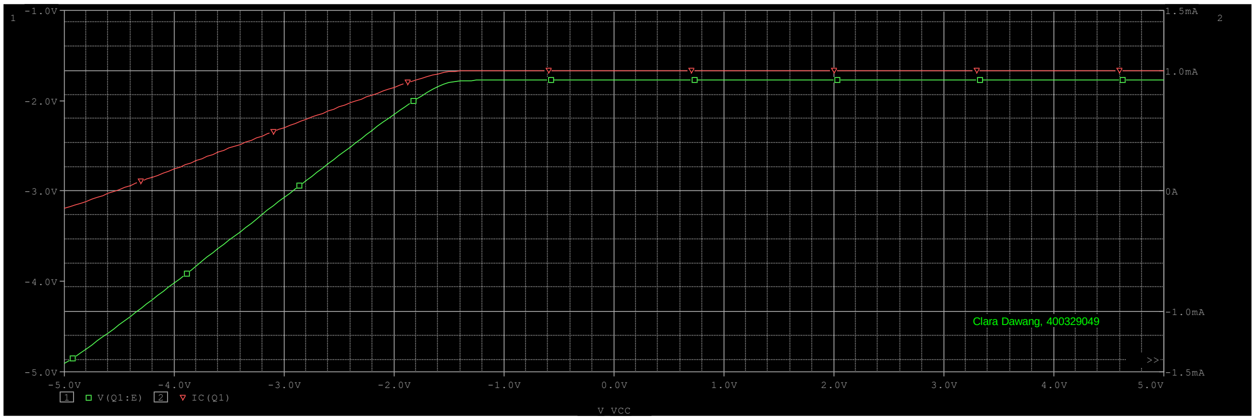

Figure 5 - Question 9 waveform of Ve and Ic

The active region is shown by the flat collector current I_C. When the horizontal trend begins, $V_C \approx$ -1.2V. At this point, the V_E value is extrapolated to be -1.7744V. To find V_{CE}:

$V_{CE} = V_C - V_E$

$V_{CE} = |-1.2V| - |-1.7744V|$

$V_{CE} = |-0.5744V|$

$|0.5744V| \geq 0.3V$

Therefore, when the condition |VCE| ≥ 0.3V is met and Q_1 is in active region, the $|V_{CE}|$ required is approximately |0.5744V|.