Lab 1: Device Characterization and Biasing Circuits

Professor: Dr. Chih-Hung (James) Chen
Name: Erion Keka
Student Number: 400435050
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Q1. (7 Points) Based on the simulated data in Steps 1.2-1.4, use the bias condition giving the closest I_C value to the desired collector current, find out

(1) What are the simulated VBEon in volts and the base current IB in μA?
$V_{BEon} = 0.621$ V and $I_B = 8.79$ μA

(2) What is the β = I C/I B value at this IC?
$\beta = 117$

(3) What is the early voltage |VA| in volts?
$|VA| = 935$ V

(4) What is the output resistance ro in kΩ?
$r_o = 912$ kΩ

(5) What is the transconductance gm in mS?
$g_m = 41$ mS

(6) What is the input resistance rπ in kΩ?
$r_\pi = 2.845$ kΩ

Q2. (8 Points) Based on the measured data in Step 1.8, use the same bias condition found in Q1 (or the first reliable data if that bias condition is an outlier), find out

(1) How much is the measured collector current IC in mA?
$I_C = 1.22$ mA

(2) What are the measured VBEon in volts and the base current IB in μA?
$V_{BEon} = 0.64742$ V and $I_B = 3.52$ μA

(3) What is the β = IC/IB value at this IC?
$\beta = 346$

(4) What is the early voltage |VA| in volts?
$|V_A| = 260$ V

(5) What is the output resistance r o in kΩ?
$r_o = 214$ kΩ

(6) What is the transconductance gm in mS?
$g_m = 48.6$ mS

(7) What is the input resistance rπ in kΩ?
$r_\pi = 7.112$ kΩ

Q3. (7 Points) Based on the simulated data in Steps 2.2-2.4, use the bias condition giving the closest IC value to the desired collector current, find out.

(1) What are the simulated VEBon in volts and the base current IB in μA?
$V_{Ebon} = 0.66$ V and $I_B = 8.40\mu A$

(2) What is the β = IC/IB value at this IC?
$\beta = 126$

(3) What is the early voltage |VA| in volts?
$|V_A| = 140$ V

(4) What is the output resistance ro in kΩ?
$r_o = 131$ kΩ

(5) What is the transconductance gm in mS?
$g_m = 42.5$ mS

(6) What is the input resistance rπ in kΩ?
$r_\pi = 2.976$ kΩ

Q4. (8 Points) Based on the measured data in Step 2.8, use the same bias condition found in Q3 (or the first reliable data if that bias condition is an outlier), find out

(1) How much is the measured collector current IC in mA?
$I_C = 1.76$ mA

(2) What are the measured VEBon in volts and the base current IB in μA?
$V_{Ebon} = 0.685$ V and $I_B = 8.15\mu A$

(3) What is the β = IC/I B value at this IC?
$\beta = 216$

(4) What is the early voltage |VA| in volts?
$|V_A| = 32$ V

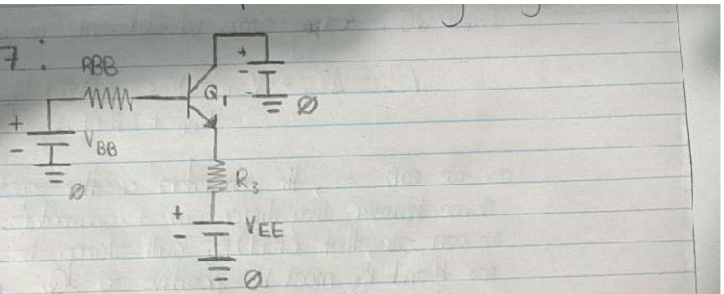
(5) What is the output resistance ro in kΩ?
$r_o = 18.3$ kΩ

(6) What is the transconductance gm in mS?
$g_m = 70.3$ mS

(7) What is the input resistance rπ in kΩ?
$r_\pi = 3.069$ kΩ

Q5. (10 Points) Express the base current IB as a function of VBB, R BB, V BEon, R3 , VEE, and β.

Fig. 7:



5.

$V_{BB} - I_B R_{BB} - V_{BE_{ON}} - I_E R_3 - V_{EE} = \emptyset$ note: $I_E = (\beta+1) I_B$

$V_{BB} - V_{BE_{ON}} - V_{EE} = I_B R_{BB} + [I_B(\beta+1)]R_3$

$V_{BB} - V_{BE_{ON}} - V_{EE} = I_B[R_{BB} + (\beta+1)R_3]$

$\therefore I_B = \dfrac{V_{BB} - V_{BE_{ON}} - V_{EE}}{R_{BB} + (\beta+1)R_3}$

Q6. (10 Points) Comparing the IB expressions obtained in Q5 and in (3), what is the difference between these two equations? For a change ΔVEE in the power supply VEE, derive equations for the resulting change in the base current ΔI B using the I B expressions obtained in Q5 and in (3). Show that the emitter resistor R3 reduces the change in the base current ΔI B as a result of the change ΔVEE in the power supply VEE.

6. I_B expression (3): $I_B = \dfrac{V_{BB} - (V_{EE} + V_{BE_{on}})}{R_{BB}}$

I_B expression Q5: $I_B = \dfrac{V_{BB} - V_{BE_{ON}} - V_{EE}}{R_{BB} + (\beta+1)R_3}$

from first glance, we notice that these two equations differ in (3) lacking R_3. Equation (3) lacks R_3 as we have taken it to be Ø based on $V_{BE_{on}}$ as mentioned in the lab manual. The presence of R_3 in Q5 is due to not taking it to be Ø thus, we get $(\beta+1)R_3$ in Q5 equation.

derived equation (3): let $\Delta V_{EE} = V_{EE} + \Delta V_{EE}$ and $\Delta I_B = I_B + \Delta I_B$

$$\Delta I_B = \frac{V_{BB} - [(V_{EE} + \Delta V_{EE}) + V_{BE_{on}}]}{R_{BB}}$$

derived Q5: using same let statements as above

$$\Delta I_B = \frac{V_{BB} - V_{BE_{ON}} - (V_{EE} + \Delta V_{EE})}{R_{BB} + (\beta+1)R_3}$$

as we can see, the numerators of the equations are same however they differ in denominators. from this, we can see that $(\beta+1)R_3$ will always be non-negative as β and R_3 must be positive so Q_5 will always result in a larger denominator than (3) so this confirms the addition of an emitter resistor, R_3 will reduce the change in I_B.

Q7. (10 Points) Inserting the feedback R3 at the emitter of the BJT improves the stabilization of the Q-point at the cost of increased Vo,min. What is the Vo,min of the constant current sink when R3 ≠ 0? Express Vo,min as a function of Io, which is the I C of Q1.

7. assuming $R_3 \neq \emptyset$

→ consider voltage drop across resistor : $V_{R3} = I_e R_3$

$V_{o,min} = V_{EE} + 0.3V + I_e R_3$

now in terms of I_o : $V_{o,min} = V_{EE} + 0.3V + [I_o(1 + 1/\beta)] R_3$

Q8. (15 Points) For VEE = -5V, if we want to design a current sink with Io = 1.0 mA and Vo,min= -1.5 V using the NPN-BJT 2N3094 characterized in Q1, what is the resistance value for R3? To reduce the DC power consumption of R1 and R2 , we usually choose large resistance values (in tens or hundreds of kΩ) for R1 and R2 . Suppose we choose R2 = 100 kΩ, calculate R1 in kΩ. Verify the Io vs. VCC characteristics of the design by sweeping VCC from -5V to 5V with a 0.05V step and post the waveform of the simulated Io vs. VCC characteristics using the command “Window -> Copy to Clipboard” in the PSpice simulator window.

8. $V_{EE} = -5V$

$I_o = 1.0mA = I_c$

$V_{o,min} = -1.5V$

$R_2 = 100K\Omega$

$R_1 = ?$, $R_3 = ?$

$I_e = I_c(1 + 1/\beta)$

$\beta = 117$

$V_{BE\,on} = 0.621V$

← from part 1

$V_{o,min} = V_{EE} + I_e R_3 + 0.3$

$R_3 = \dfrac{V_{o,min} - V_{EE} - 0.3}{I_e}$

$R_3 = \dfrac{V_{o,min} - V_{EE} - 0.3}{I_c(1 + 1/\beta)}$

$R_3 = \dfrac{(-1.5)-(-5)-0.3}{1(1 + 1/117)}$ so $R_3 = 3.17K\Omega$

given $V_{BB} = \dfrac{R_1}{R_1 + R_2} V_{EE}$

and $R_{BB} = R_1 // R_2 = \dfrac{R_1 R_2}{R_1 + R_2}$

First find V_B : $V_B - V_{BE\,on} - I_E R_3 - V_{EE} = \emptyset$

$V_B = V_{BE\,on} + I_E R_3 + V_{EE}$

$V_B = 0.621 + (1 + 1/117)(1)(3.17) - 5$

$= -1.18V$

now : $V_{BB} - I_B R_{BB} = V_B$

$(-5)\left(\dfrac{R_1}{R_1+R_2}\right) - \left(\dfrac{I_c}{\beta}\right)\left(\dfrac{R_1 R_2}{R_1 + R_2}\right) = V_B \rightarrow (-5)\left(\dfrac{R_1}{R_1+100}\right) - \left(\dfrac{1}{117}\right)\left(\dfrac{100R_1}{R_1+100}\right) = -1.18$

$\therefore R_1 = 25.3K\Omega$

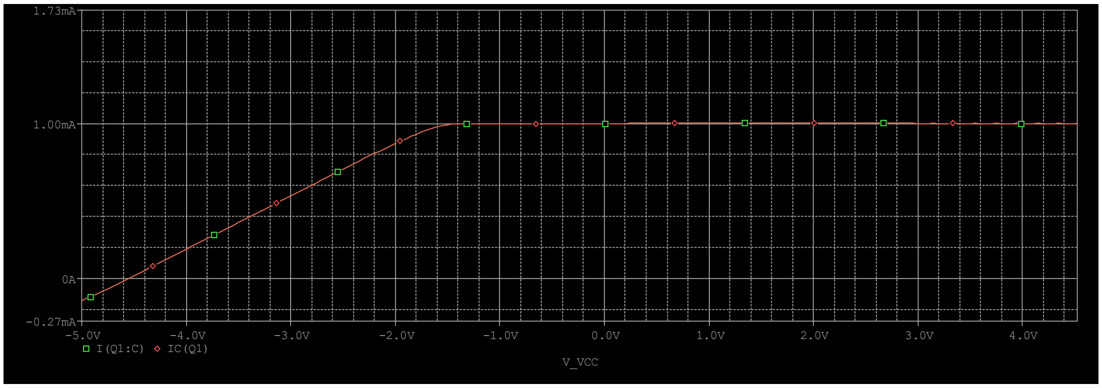


Figure 1: Plot of I_o VS V_{CC}

Q9. (10 Points) When designing the constant current sink shown in Fig. 6, we assume that |VCE| ≥ 0.3V and Q1 works in the active region. Based on the resistance values obtained in Q8, sweep VCC in Fig. 6 from -5 V to +5 V with a 0.05 V step and measure VE and IC to determine the |VCE| required for Q1 to work in the active region.

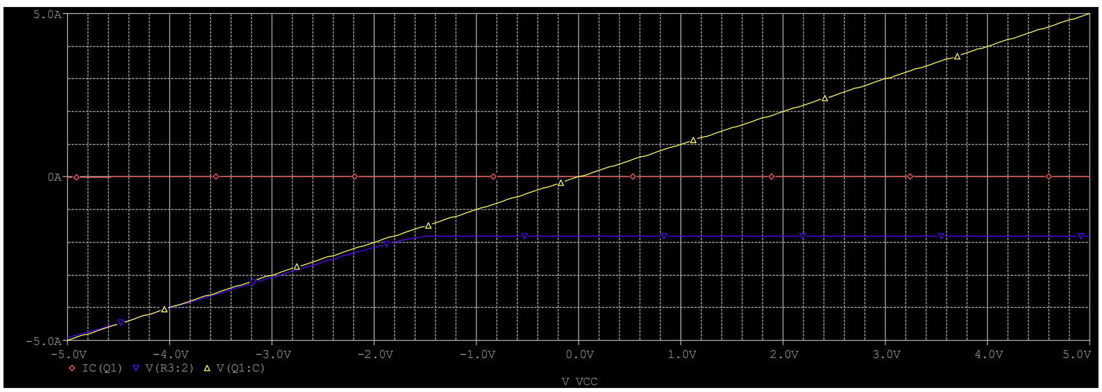


Figure 2: Plot of I_c VS V_E VS V_{CC}

From the graph, we can see that V_E = -1.72 V and V_{CC} = -1.34 V. From this, we can calculate $|V_{CE}|$ to be $V_E - V_{CC}$ = -1.72 V + 1.34 V = 0.38 V which verifies the condition that $|V_{CE}| \geq 0.3$V.