Lab 1

ELECENG 2EJ4

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Part 1

For the NPN-BJT 2N3904 characterized, if we want to bias this device to conduct a collector current $I_C \approx 1.0$ mA at the lowest V_{CE} value, answer the following questions.

1. (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
   a. What are the simulated V_{BEon} in volt and the base current I_B in μA?
      $V_{BEon} = 0.621V$
      $I_B = 8.79\mu A$
   b. What is the $\beta = I_C/I_B$ value at this I_C?
      117
   c. What is the early voltage $|V_A|$ in volt?
      1000V
   d. What is the output resistance r_0 in kΩ?
      976kΩ
   e. What is the transconductance g_m in mS?
      41 mS
   f. What is the input resistance r_π in kΩ?
      2.845kΩ

2. (8 Points) Based on the measured data in Step 1.8, use the same bias condition used in Q1 (or the first reliable data if that bias condition is an outlier), find out
   a. How much is the measured collector current I_C in mA?
      1.74mA
   b. What are the measured V_{BEon} in volt and the base current I_B in μA?
      $V_{BEon} = 0.675V$
      $I_B = 8.25\mu A$
   c. What is the $\beta = I_C/I_B$ value at this I_C?
      211
   d. What is the early voltage $|V_A|$ in volt?
      360V
   e. What is the output resistance r_0 in kΩ?
      207kΩ
   f. What is the transconductance g_m in mS?
      69.6mS
   g. What is the input resistance r_π in kΩ?
      3.03kΩ

Part 2

For the PNP-BJT 2N3906 characterized, if we want to bias this device to conduct a collector current $I_C \approx 1.0$ mA at the lowest V_{EC} value, answer the following questions.

3. (7 Points) Based on the simulated data in Steps 2.2-2.4, use the bias condition giving the closest I_C value to the desired collector current, find out
   a. What are the simulated V_{EBon} in volt and the base current I_B in μA?
      $V_{BEon} = 0.66V$
      $I_B = 8.4\mu A$
   b. What is the $\beta = I_C/I_B$ value at this I_C?
      123
   c. What is the early voltage $|V_A|$ in volt?
      133
   d. What is the output resistance r_0 in kΩ?
      139kΩ
   e. What is the transconductance g_m in mS?
      41.2mS
   f. What is the input resistance r_π in kΩ?
      2.976kΩ

4. (8 Points) Based on the measured data in Step 2.8, use the same bias condition used in Q1 (or the first reliable data if that bias condition is an outlier), find out
   a. How much is the measured collector current I_C in mA?
      1.24mA
   b. What are the measured V_{BEon} in volt and the base current I_B in μA?
      $V_{BEon} = 0.64V$
      $I_B = 3.56\mu A$
   c. What is the $\beta = I_C/I_B$ value at this I_C?
      348
   d. What is the early voltage $|V_A|$ in volt?
      40V
   e. What is the output resistance r_0 in kΩ?
      32.2kΩ
   f. What is the transconductance g_m in mS?
      49.7mS
   g. What is the input resistance r_π in kΩ?
      7.015kΩ

Part 3

5. (10 Points) Express the base current I_B as a function of V_{BB}, R_{BB}, V_{BEon}, R_3, V_{EE}, and β.

$$i_B = i_e - i_c$$

$$i_c = \beta i_B$$

$$i_B = i_e - \beta i_B$$

$$i_e = i_B(\beta + 1)$$

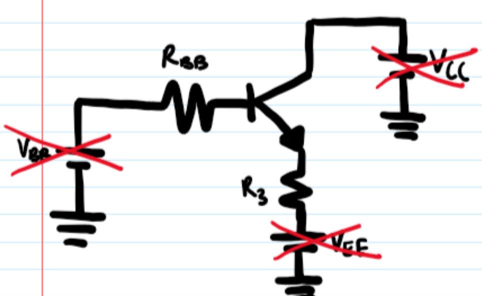
$$V_{BB} - i_B R_{BB} - V_{BEon} - i_e R_3 - V_{EE} = 0$$
$$V_{BB} - i_B R_{BB} - V_{BEon} - i_B(\beta + 1)R_3 - V_{EE} = 0$$
$$V_{BB} - i_B\left[R_{BB} + (\beta + 1)R_3\right] - V_{BEon} - V_{EE} = 0$$
$$i_B = \frac{V_{BB} - (V_{BEon} + V_{EE})}{R_{BB} + R_3(\beta+1)}$$

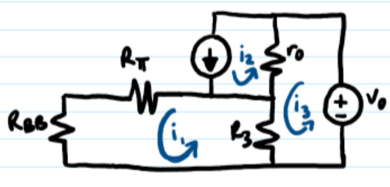
6. (10 Points) Comparing the I_B expression obtained in Q5 with (3), what is the difference between these two equations? For a change ΔV_{EE} in the power supply V_{EE}, derive equations for the resulted change in the base current ΔI_B using (3) and the I_B expression obtained in Q5. Show that the emitter resistor R_3 reduces the change in the base current ΔI_B as a result of the change ΔV_{EE} in the power supply V_{EE}.

The main difference between the expression obtained in Q5 and (3) is that in (3) we are only dividing by R_{BB} while in Q5 we are dividing by $R_{BB}+R_3(\beta+1)$. The $R_3(\beta+1)$

7. (15 Points) Inserting the feedback R_3 at the emitter of the BJT not only stabilizes the I_B but also improves (or increases) the output resistance R_0 of the current sink shown in Fig. 6/Fig. 7 (i.e. I_0 is more stable when there is a change in V_{CE}). Using a π-model for the BJT, prove that the output resistance of the current sink is

$$R_0 = r_0 + \left[r_3 || (R_{BB} + r_\pi)\right]\left[1 + g_m r_0\left(\frac{r_\pi}{R_{BB} + r_\pi}\right)\right].$$





① $R_0 = \frac{v_0}{i_0} = \frac{v_0}{i_3}$

② $i_2 = g_m V_\pi = -g_m r_\pi i_1$

③ $v_0 - r_0(i_3 - i_2) - R_3(i_3 - i_1) = 0$

$$i_1 = \frac{v_0 - r_0 i_3 - R_3 i_3}{r_0 g_m r_\pi - R_3}$$

④ $-R_2(i_1 - i_3) - R_{BB} i_1 - r_\pi i_1 = 0$

$$i_1 = \frac{R_3 i_3}{r_\pi + R_B + R_3}$$

⑤ $$\frac{R_3 i_3}{r_\pi + R_B + R_3} = \frac{v_0 - r_0 i_3 - R_3 i_3}{r_0 g_m r_\pi - R_3}$$

$$R_0 = r_0 + \left[\frac{R_3 R_{BB} + R_3 r_\pi}{R_3 + R_{BB} + r_\pi}\right]\left[\frac{1 + g_m r_0 r_\pi}{R_{BB} + r_\pi}\right)$$

$$R_0 = r_0 + \left(R_3 // R_{BB} + r_\pi\right)\left[1 + g_m r_0\left(\frac{r_\pi}{R_{BB} + r_\pi}\right)\right]$$

8. (10 Points) Inserting the feedback R_3 at the emitter of the BJT improves the stabilization of the Q-point at the cost of increased $V_{o,min}$. What is the $V_{o,min}$ of the constant current sink when $R_3 \neq 0$?

$R_3 \neq 0$ = voltage drop

$V_{o,\,min} = V_E + 0.3V$

$V_{R_3} = i_e R_3$

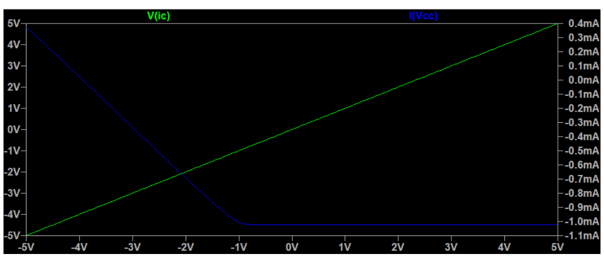
$V_{o,\,min} = V_E + 0.3V + i_e R_3$

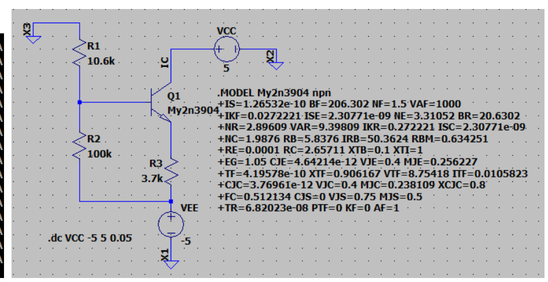
9. (15 Points) For V_{EE} = -5V, if we want to design a current sink with I_0 = 1.0 mA and $V_{o,min}$ = -1 V using the NPN-BJT 2N3094 characterized in Q1, what is the resistance value for R_3? To reduce the DC power consumption of R_1 and R_2, we usually choose large resistance values (in tens or hundreds of kΩ) for R_1 and R_2. Suppose we choose R_2 = 100 kΩ, calculate R_1 in kΩ. Verify the I_0 vs. V_{CC} characteristics of the design by sweeping V_{CC} from -5V to 5V with a 0.05V step and post the screenshot of the simulated I_0 vs. V_{CC} characteristics.

$V_{o,\,min} = V_E + 0.3V + i_e R_3$

$-1V = -5V + 0.3V + (1mA)R_3$

$3.7k = R_3$





10. (10 Points) When designing the constant current sink shown in Fig. 6, we assume that $|V_{CE}| \geq 0.3V$ and Q_1 works in the active region. Based on the resistance values obtained in Q9, sweep V_{CC} in Fig. 6 from -5 V to +5V with a 0.05 V step and measure V_E and I_C to determine the $|V_{CE}|$ required for Q_1 to work in the active region.

$|V_{CE}|$ and Q_1 are only active when V < 0V.