ELECENG 3EJ4

Lab Report #1

Instructor: Dr. Chen

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Part 1 Questions

Q1. (7 Points)

V+ (VCC)	V- (VE)	V(Q1C) (Volt)	V(Q1B) (Volt)	VCE (Volt)	VBEon (Volt)	RC (ohm)	RB (ohm)	IC (A)	IB (A)	β = IC/IB	|VA| (V)	ro=VA/IC	gm = IC/25mV	rπ = 25mV/IB
0.5	-1.5	0.397558296	-0.878689331	1.898	0.621	100	1.00E+05	1.02E-03	8.79E-06	117	1000	9.76E+05	4.10E-02	2845

(1) $V_{BEon} = 0.621V, I_B = 8.79 \times 10^{-6}A = 8.79\mu A$

(2) $\beta = 117$

(3) $|V_A| = 1000V$

(4) $r_o = 9.76 \times 10^5\Omega \times \frac{1k\Omega}{10^3\Omega} = 9.76 \times 10^2\mathrm{k}\Omega = 976k\Omega$

(5) $g_m = 4.1 \times 10^{-2}S \times \frac{1mS}{10^{-3}S} = 41mS$

(6) $r_\pi = 2845\Omega \times \frac{1k\Omega}{10^3\Omega} = 2.845k\Omega$

Q2. (8 Points)

V+ (VCC)	V- (VE)	V(Q1C) (Volt)	V(Q1B) (Volt)	VCE (Volt)	VBEon (Volt)	RC (ohm)	RB (ohm)	IC (A)	IB (A)	β = IC/IB	|VA| (V)	ro=VA/IC	gm = IC/25mV	rπ = 25mV/IB
1	-1.5	0.76768	-0.82146	2.26768	0.67854	100	1.00E+05	2.32E-03	8.21E-06	283	55	2.73E+04	9.29E-02	3043

(1) $I_C = 2.32 \times 10^{-3}A = 2.32mA$

(2) $V_{BEon} = 0.67854V, I_B = 8.21 \times 10^{-6}A = 8.21\mu A$

(3) $\beta = 283$

(4) $|V_A| = 55V$

(5) $r_o = 2.73 \times 10^4\Omega \times \frac{1k\Omega}{10^3\Omega} = 2.73 \times 10^1\mathrm{k}\Omega = 27.3k\Omega$

(6) $g_m = 9.29 \times 10^{-2}S \times \frac{1mS}{10^{-3}S} = 92.9mS$

(7) $r_\pi = 3043\Omega \times \frac{1k\Omega}{10^3\Omega} = 3.043k\Omega$

Part 2 Questions

Q3. (7 Points)

V+ (VE)	V- (VCC)	V(Q1C) (Volt)	V(Q1B) (Volt)	VEC (Volt)	VEBon (Volt)	RC (ohm)	RB (ohm)	IC (A)	IB (A)	β = IC/IB	|VA| (V)	ro=VA/IC	gm = IC/25mV	rπ = 25mV/IB
1.5	-0.5	-0.39709332	0.839935339	1.90	0.660	100	1.00E+05	1.03E-03	8.40E-06	123	143	1.39E+05	4.12E-02	2976

(1) $V_{BEon} = 0.660V, I_B = 8.40 \times 10^{-6}A = 8.40\mu A$

(2) $\beta = 123$

(3) $|V_A| = 143V$

(4) $r_o = 1.39 \times 10^5\Omega \times \frac{1k\Omega}{10^3\Omega} = 1.39 \times 10^2\text{k}\Omega = 139k\Omega$

(5) $g_m = 4.12 \times 10^{-2}S \times \frac{1mS}{10^{-3}S} = 41.2mS$

(6) $r_\pi = 2976\Omega \times \frac{1k\Omega}{10^3\Omega} = 2.976k\Omega$

Q4. (8 Points)

V+ (VE)	V- (VCC)	V(Q1C) (Volt)	V(Q1B) (Volt)	VEC (Volt)	VEBon (Volt)	RC (ohm)	RB (ohm)	IC (A)	IB (A)	β = IC/IB	|VA| (V)	ro=VA/IC	gm = IC/25mV	rπ = 25mV/IB
1.5	-0.5	-0.09822	0.899	1.60	0.601	100	1.00E+05	4.02E-03	8.99E-06	447	19	4.73E+03	1.61E-01	2781

(1) $I_C = 4.02 \times 10^{-3}A = 4.02mA$

(2) $V_{BEon} = 0.601V, I_B = 8.99 \times 10^{-6}A = 8.99\mu A$

(3) $\beta = 447$

(4) $|V_A| = 19V$

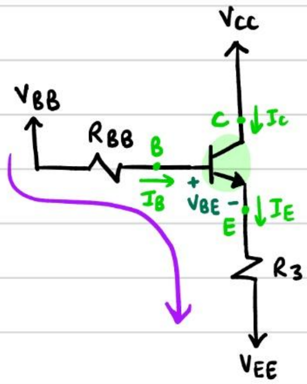
(5) $r_o = 4.73 \times 10^3\Omega \times \frac{1k\Omega}{10^3\Omega} = 4.73\text{k}\Omega$

(6) $g_m = 1.61 \times 10^{-1}S \times \frac{1mS}{10^{-3}S} = 161mS$

(7) $r_\pi = 2781\Omega \times \frac{1k\Omega}{10^3\Omega} = 2.781k\Omega$

Part 3 Questions

Q5. (10 Points)



① Since BJT F.A.

(i) $V_{BE} = 0.7V$

(ii) $I_E = I_B + I_C$, $\because \beta = \frac{I_C}{I_B} \Rightarrow I_E = I_B + \beta I_B$

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

② Find a 3rd KVL eqn on a path that includes V_{BE}:

KVL: $V_{BB} - I_B R_{BB} - V_{BEon} - I_E R_3 = V_{EE}$ $\quad I_E = (\beta+1) I_B$

$V_{BB} - I_B R_{BB} - V_{BEon} - (\beta+1) I_B R_3 = V_{EE}$

$V_{BB} - V_{EE} - V_{BEon} = (\beta+1) I_B R_3 + I_B R_{BB}$

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

$$\boxed{I_B = \frac{V_{BB} - V_{EE} - V_{BEon}}{(\beta+1) R_3 + R_{BB}}}$$

Q6. (10 Points)

(i) Comparing I_B Expressions:

The main difference between equations 3 and 5 is the presence of R_3. Equation (3) does not contain R_3 because it was set to 0. Therefore, equation 5 contains the additional term $(\beta + 1)R_3$.

$$I_B = \frac{V_{BB} - V_{EE} - V_{BEon}}{R_{BB}} \tag{3}$$

$$I_B = \frac{V_{BB} - V_{EE} - V_{BEon}}{(\beta + 1)R_3 + R_{BB}} \tag{5}$$

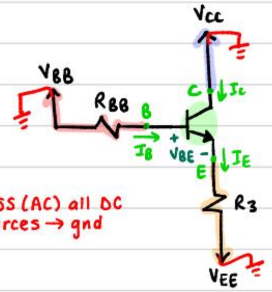
(ii) Deriving Equations:

Applying a change in power supply ΔV_{EE} to the equations above gives,

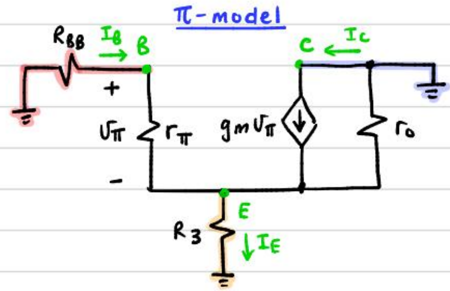
$$\Delta I_{B2} = \frac{V_{BB} - (V_{EE} + \Delta \boldsymbol{V_{EE2}}) - V_{BEon}}{R_{BB}} \quad (3.1) \qquad \Delta I_{B1} = \left[\frac{V_{BB} - (V_{EE} + \Delta \boldsymbol{V_{EE1}}) - V_{BEon}}{(\beta + 1)R_3 + R_{BB}}\right] \quad (5.1)$$

In equation 3.1, the change in power supply is directly related to the change in current ($V_{EE2} \propto \Delta I_{B2}$). Whereas the presence of R_3 in equation 5.1 reduces ΔI_{B1} because they are inversely proportional $\left(I_{B1} \propto \frac{1}{R_3}\right)$.

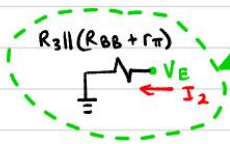
Q7. (15 Points)

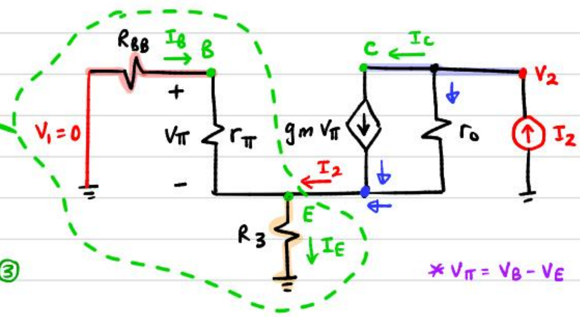


* In SS (AC) all DC sources → gnd



For g-parameters, $R_o = g_{22} = \frac{v_2}{i_2}\Big|_{v_1=0}$





① Inspection: $V_E = [R_3 \| (R_{BB}+r_\pi)]\, I_2 \to ③$

$* \; V_\pi = V_B - V_E$

② Node C: $I_2 = g_m V_\pi + \frac{(V_2 - V_E)}{r_o}$

$$I_2 = g_m V_\pi + \frac{V_2}{r_o} - \frac{V_E}{r_o} \to ①$$

③ Node B: $\frac{V_B}{R_{BB}} + \frac{(V_B - V_E)}{r_\pi} = 0$

$$\frac{V_B}{R_{BB}} + \frac{V_\pi}{r_\pi} = 0$$

$$V_B = -\frac{R_{BB}}{r_\pi} V_\pi$$

$$V_\pi + V_E = -\frac{R_{BB}}{r_\pi} V_\pi$$

$$V_\pi\left(1 + \frac{R_{BB}}{r_\pi}\right) = -V_E$$

$$V_\pi\left(\frac{r_\pi + R_{BB}}{r_\pi}\right) = -V_E$$

$$V_\pi = -V_E\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) \to ②$$

④ 2 in 1: $I_2 = g_m\left[-V_E\left(\frac{r_\pi}{r_\pi + R_{BB}}\right)\right] + \frac{V_2}{r_o} - \frac{V_E}{r_o}$

$$I_2 = -g_m V_E\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{V_2}{r_o} - \frac{V_E}{r_o}$$

$$\frac{V_2}{r_o} = I_2 + g_m V_E\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{V_E}{r_o}$$

sub ③

$$\frac{V_2}{r_o} = I_2 + V_E\left[g_m\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{1}{r_o}\right]$$

$$r_o \times \left(\frac{V_2}{r_o} = I_2 + [R_3 \| (R_{BB}+r_\pi)]\, I_2\left[g_m\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{1}{r_o}\right]\right)$$

$$V_2 = r_o I_2 + [R_3 \| (R_{BB}+r_\pi)]\, I_2\left[g_m\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{1}{r_o}\right] r_o$$

$$V_2 = I_2\left[r_o + [R_3 \| (R_{BB}+r_\pi)]\left[g_m\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + \frac{1}{r_o}\right] r_o\right]$$

$$\boxed{\frac{V_2}{I_2} = r_o + [R_3 \| (R_{BB}+r_\pi)]\left[g_m r_o\left(\frac{r_\pi}{r_\pi + R_{BB}}\right) + 1\right]}$$

Q8. (10 Points)

When $R_3 = 0$:

$$V_{o,min} = V_{EE} + 0.3V \tag{1}$$

Since $R_3 \neq 0$, the voltage drop across this resistor needs to be considered. Thus, an additional factor of $V_{R3} = I_E R_3$ will be added to (1) to give us a new expression:

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

Since $I_C = \alpha I_E$ and $I_C = I_o$:

$$V_{o,min} = V_{EE} + \frac{I_o}{\alpha} R_3 + 0.3V \tag{2}$$

This is illustrated in the figures below:

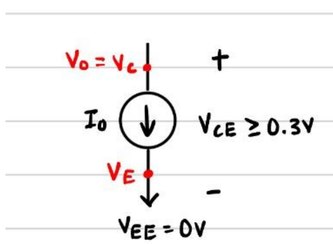


Fig 1. Ideal Current Sink when $R_3 = 0$

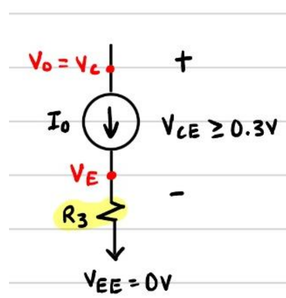


Fig 2. Ideal Current Sink when $R_3 \neq 0$

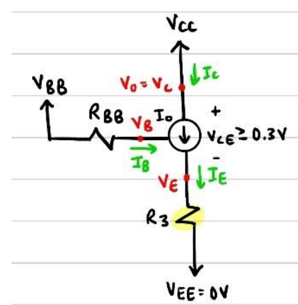


Fig 3. Real Current Sink when $R_3 \neq 0$

Q9. (15 Points)

(i) Finding R_3:

$$\beta = 117$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{117}{118}$$

$$V_{o,min} = V_{EE} + \frac{I_o}{\alpha} R_3 + 0.3V$$

$$R_3 = \left(V_{o,min} - V_{EE} - 0.3V\right)\frac{\alpha}{I_o}$$

$$= \left[-1V - (-5V) - 0.3V\right]\left[\frac{117}{118} \cdot \frac{1}{(1mA)}\right]$$

$$\boxed{R_3 = 3.669k\Omega}$$

(ii) Finding R_1:

KVL eqn from Q5:

$$V_{BB} - I_B R_{BB} - V_{BEon} - I_E R_3 = V_{EE}$$

$$\frac{R_1}{R_1+R_2} V_{EE} - \frac{I_0}{\beta}\left(\frac{R_1 R_2}{R_1+R_2}\right) - V_{BEon} - \frac{I_0}{\alpha} R_3 = V_{EE}$$

$$\frac{R_1}{R_1+100K}(-5V) - \frac{1mA}{117}\left(\frac{R_1(100K)}{R_1+100K}\right) - 0.621 - 1mA\left(\frac{118}{117}\right)(3.669k\Omega) = -5V$$

$$\frac{-5R_1}{R_1+100K} - \frac{100}{117}\left(\frac{R_1}{R_1+100K}\right) - 0.621 - 3.7 = -5$$

$$\frac{-5R_1}{R_1+100K} - 0.854\left(\frac{R_1}{R_1+100K}\right) = -0.679$$

$$\frac{-5R_1 - 0.854R_1}{R_1+100K} = -0.679$$

$$-5R_1 - 0.854R_1 = -0.679(R_1+100K)$$

$$-5R_1 - 0.854R_1 = -0.679R_1 - 67.9K$$

$$R_1(-5-0.854+0.679) = -67.9K$$

$$-5.175R_1 = -67.9K$$

$$\boxed{R_1 = 13.12k\Omega}$$

(iii) Verifying I_o vs. V_{CC} characteristics:

Below is a graph of the I_o vs. V_{CC} characteristics and the PSpice Schematic used to generate them.

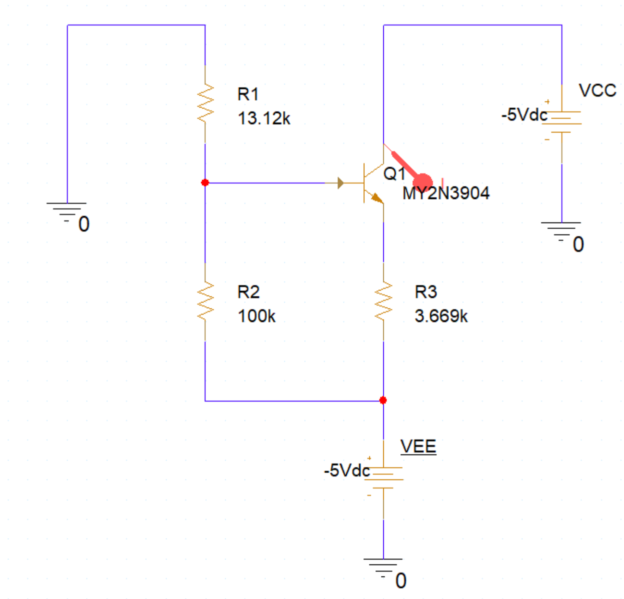


Fig 4. PSpice Schematic

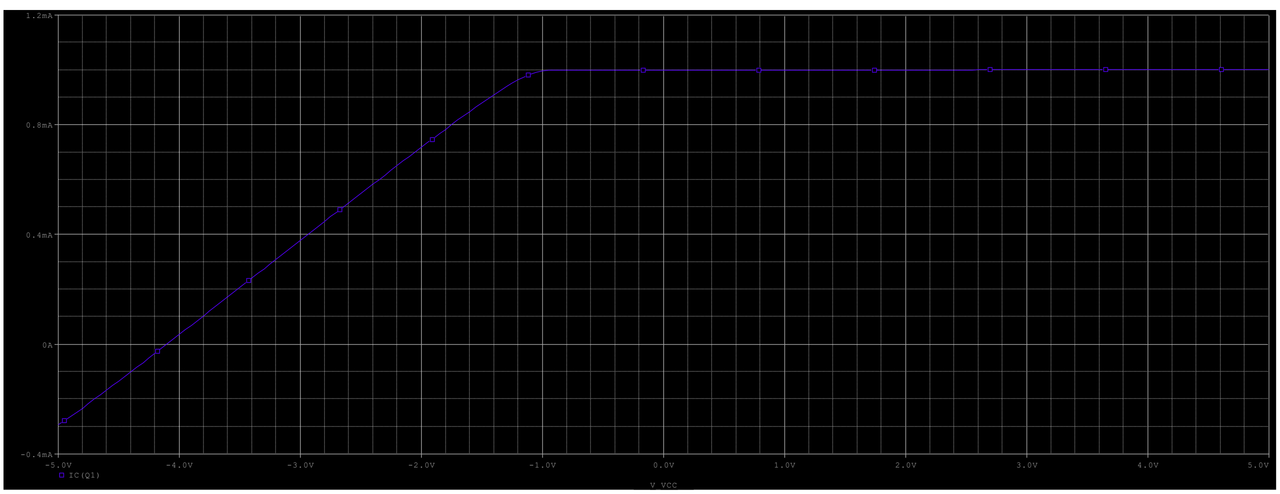


Fig 5. I_o vs. V_{CC} characteristics

From Figure 5, it shows that when $V_{CC} = -1V = V_{o,min}$, I_o saturates to the designed constant of 1.0mA. This was the desired outcome.

Q10. (10 Points)

Below is a graph of $\boldsymbol{I_C}$, $\boldsymbol{V_{CC}}$, $\boldsymbol{V_E}$ and the PSpice Schematic used to generate them.

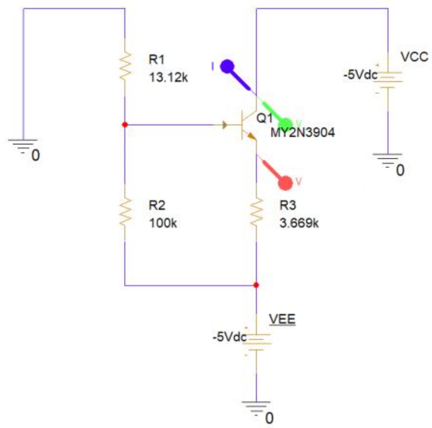


Fig 6. PSpice Schematic 2

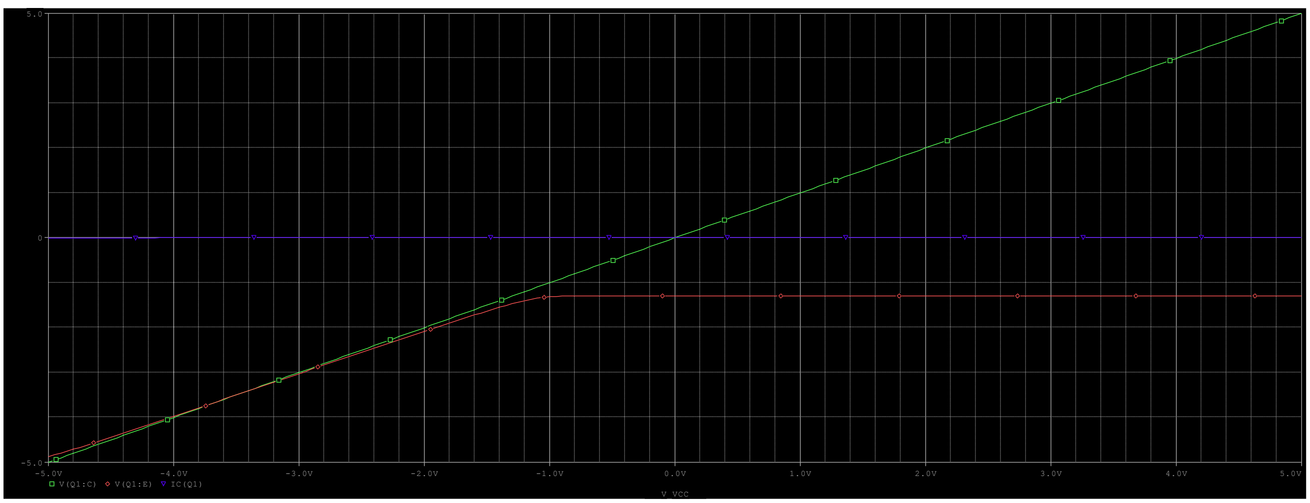


Fig 7. Characteristics 2

To determine $|V_{CE}|$, in Figure 7 we see that the BJT enters active mode at $\boldsymbol{V_E} = -1.3114V$. The corresponding $\boldsymbol{V_{CC}}$ value at this point is $\boldsymbol{V_C} = -1V$ (see Figure 8) thus

$$|V_{CE}| = \boldsymbol{V_{CC}} - \boldsymbol{V_E} = -1V - (-1.3114V) = 0.3114V$$

Since $|V_{CE}| \geq 0.3V$, this confirms that the BJT is operating in active mode.

Trace Color	Trace Name	Y1
	X Values	-1.0000
CURSOR 1,2	IC(Q1)	0.9958m
	V(Q1:C)	-1.0000
	V(Q1:E)	-1.3114

Fig 8. Voltage values