K. J. SOMAIYA COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Single Stage BJT Amplifier

Numerical 1: For the circuit shown in figure 1, Determine I_{CQ}, V_{CEQ} and A_V

Given: $\beta = 75$, $r_o = \infty\ \Omega$

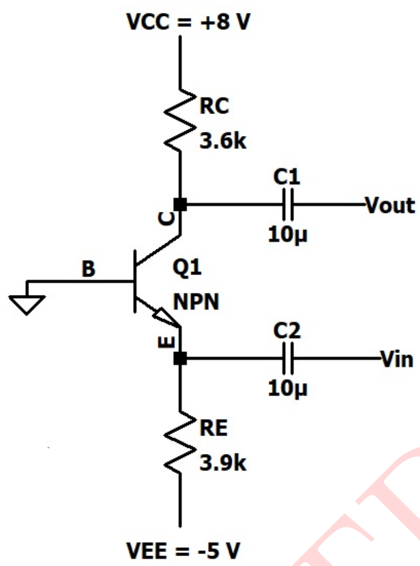

Figure 1: Circuit 1

Solution:

The given circuit 1 is a common base configuration employing npn BJT.

For DC biasing, the capacitors acts as an open source.

DC Analysis:

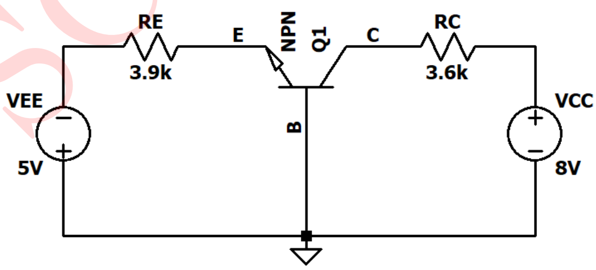

Figure 2: DC Biasing Circuit

I_E can be calculated by applying KVL to the base-emitter loop,

$-R_E I_E - V_{BE} + V_{EE} = 0$

$R_E I_E = V_{EE} - V_{BE}$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$I_E = \frac{5 - 0.7}{3.9 \times 10^3} = \mathbf{1.1\ mA}$$

$$I_B = \frac{I_E}{1+\beta} \qquad ...(\because I_E = (1+\beta)I_B)$$

$$I_B = \frac{1.1 \times 10^{-3}}{1+75} = \mathbf{14.5\ \mu A}$$

$$I_{CQ} = \beta I_B$$

$$I_{CQ} = 75 \times 14.47 \times 10^{-6} = \mathbf{1.08\ \mu A}$$

V_{CEQ} can be calculated by applying KVL to the collector-emitter loop,

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E + V_{EE} = 0$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E + V_{EE}$$

$$V_{CE} = 8 - 1.08 \times 10^{-3} \times 3.6 \times 10^3 - 1.1 \times 10^{-3} \times 3.9 \times 10^3 + 5 = \mathbf{4.822\ V}$$

AC Analysis:

$$r_\pi = \frac{\beta V_T}{I_E}$$

$$r_\pi = \frac{75 \times 26 \times 10^{-3}}{1.1 \times 10^{-3}} = \mathbf{1.77\ k\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$g_m = \frac{1.08 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{41.538\ mA/V}$$

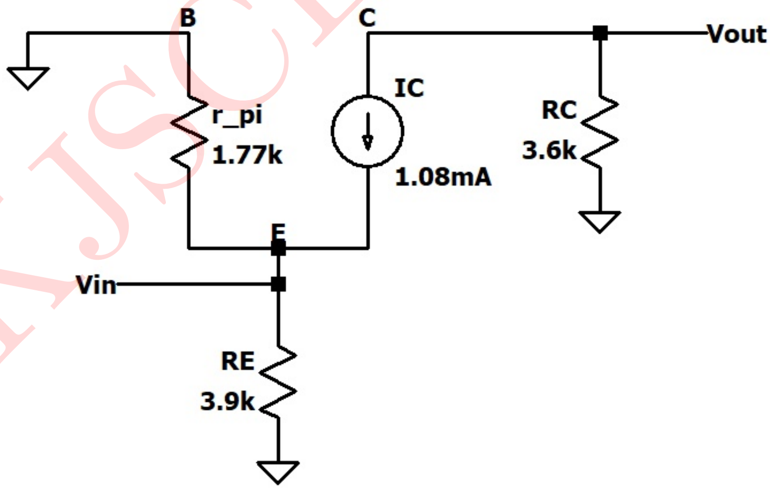

Figure 3: Small Signal Equivalent Circuit

Input Impedance:

$$R_i = \frac{r_\pi}{1+\beta}$$

$$R_i = \frac{1.77 \times 10^3}{1+75} = 23.29\ \Omega$$

Output Impedance:

$R_o = R_C = 3.6\ \mathrm{k\Omega}$

Voltage Gain:

$$A_V = \frac{V_o}{V_i}$$

$$A_V = \frac{-g_m V_\pi R_C}{-V_\pi}$$

$$A_V = g_m R_C$$

$$A_V = 41.538 \times 10^{-3} \times 3.6 \times 10^{3} = \mathbf{149.54}$$

SIMULATED RESULT:

Above circuit is simulated in LTspice. The results are presented below:

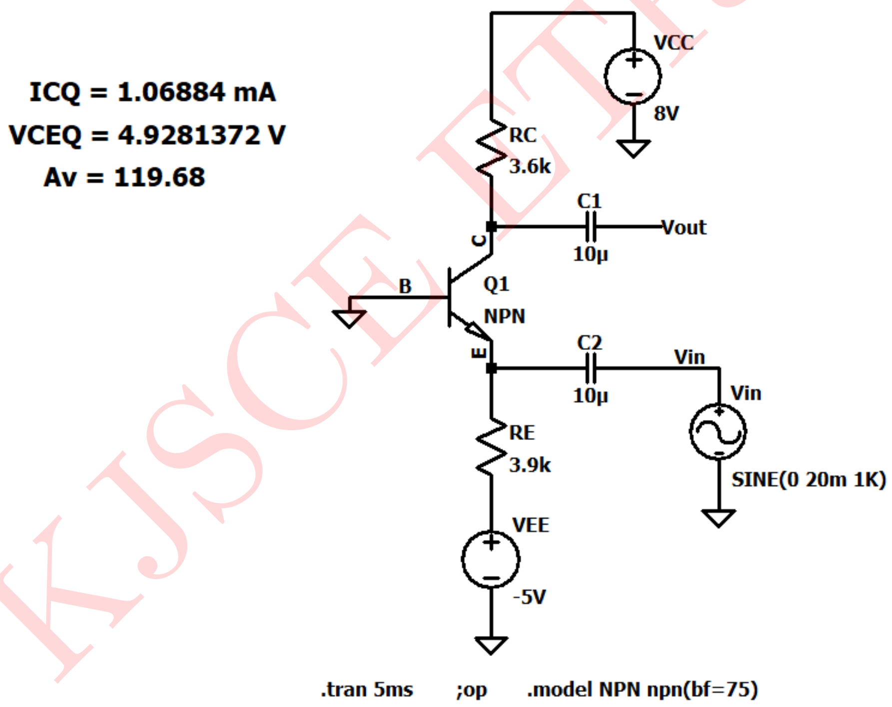

Figure 4: Circuit Schematic 1: Results

The input and output waveforms are shown in figure 5.

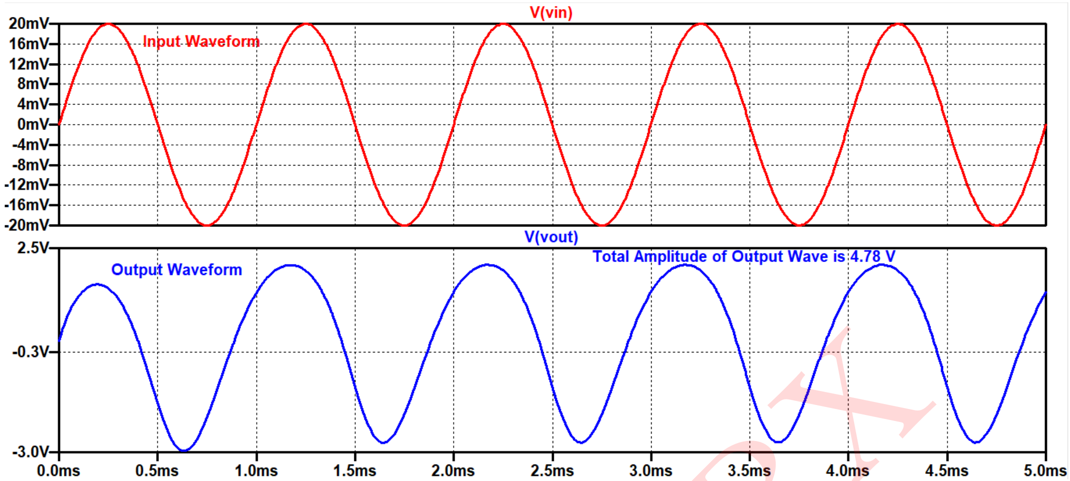

Figure 5: Input & Output waveforms

Comparison of theoretical and simulated values:

Parameters	Theoretical Values	Simulated Values
I_{CQ}	1.08 mA	1.0688 mA
V_{CEQ}	4.822 V	4.9281 V
A_V	149.54	119.68

Table 1: Numerical 1

Numerical 2: For the circuit shown in figure 6, Determine r_π, Z_i, Z_o and A_V

Given: $\beta = 120$, $r_o = 40$ kΩ

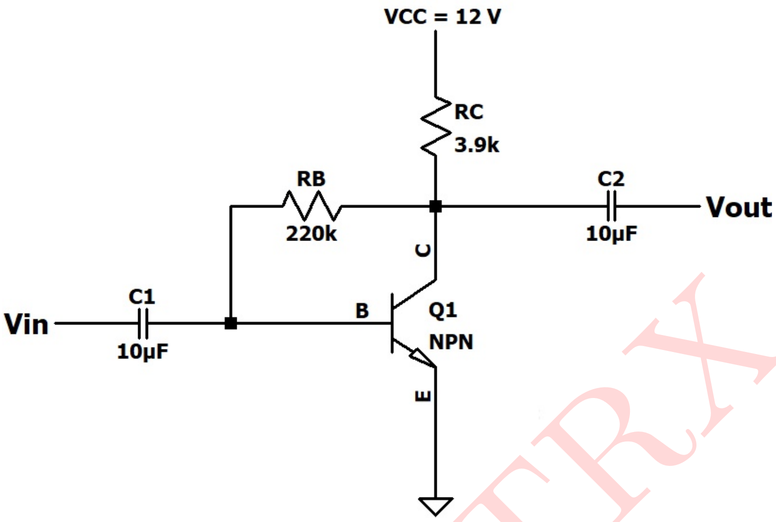

Figure 6: Circuit 2

Solution:

The given circuit 2 is a collector feedback configuration.

For DC biasing, the capacitors will act as an open source.

DC Analysis:

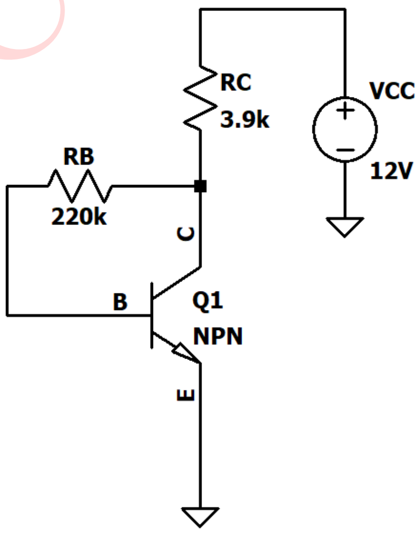

Figure 7: DC Biasing Circuit

I_B can be calculated by applying KVL to the base-emitter loop,

$V_{CC} - (I_C + I_B)R_C - I_B R_B - V_{BE} = 0$

$I_B R_B + (I_C + I_B)R_C = V_{CC} - V_{BE}$

$I_B R_B + (1 + \beta)I_B R_C = V_{CC} - V_{BE} \qquad ...(\because I_C = \beta I_B)$

$I_B(R_B + (1 + \beta)R_C) = V_{CC} - V_{BE}$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1 + \beta)R_C}$$

$$I_B = \frac{12 - 0.7}{220 \times 10^3 + (1 + 120) \times 3.9 \times 10^3} = \mathbf{16.33\ \mu A}$$

$I_{CQ} = \beta I_B$

$I_{CQ} = 120 \times 16.33 \times 10^{-6} = \mathbf{1.96\ mA}$

V_{CEQ} can be calculated by applying KVL to the collector-emitter loop,

$V_{CC} - (I_C + I_B)R_C - V_{CE} = 0$

$V_{CE} = V_{CC} - (I_C + I_B)R_C$

$V_{CE} = 12 - (1.96 \times 10^{-3} + 16.33 \times 10^{-6})3.9 \times 10^3 = \mathbf{4.29\ V}$

AC Analysis:

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r_\pi = \frac{120 \times 26 \times 10^{-3}}{1.96 \times 10^{-3}} = \mathbf{1.59\ k\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$g_m = \frac{1.96 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{75.38\ mA/V}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

$V_A = r_o I_{CQ}$

$V_A = 40 \times 10^3 \times 1.96 \times 10^{-3} = \mathbf{78.4\ V}$

Small Signal Equivalent Circuit,

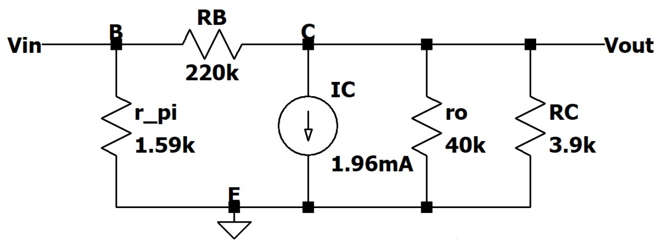

Figure 8: Small Signal Equivalent Circuit

Simplifying the above circuit with miller's theorem,

$R_1 = \dfrac{R_B}{1 - A_V}$ and $R_2 = \dfrac{A_V}{A_V - 1} R_B$

The voltage gain is much greater than 1.

$\therefore R_2 \simeq R_B$ ...(1)

Small signal equivalent circuit after miller's theorem,

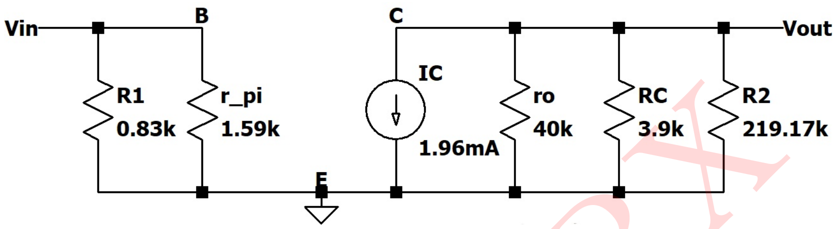

Figure 9: Small Signal Equivalent Circuit after Miller's Theorem

Voltage Gain:

$$A_V = \frac{V_o}{V_i}$$

$$A_V = \frac{-g_m V_\pi (r_o \,||\, R_C \,||\, R_2)}{V_\pi}$$

$$A_V = -g_m (r_o \,||\, R_C \,||\, R_2) \quad \text{...(from 1)}$$

$$A_V = -75.38 \times 10^{-3} (40 \times 10^3 \,||\, 3.9 \times 10^3 \,||\, 220 \times 10^3)$$

$$A_V = -75.38 \times 10^{-3} \times 3.497 \times 10^3 = \mathbf{-263.6\ V}$$

Negative sign indicates that input and output are out of phase.

$$R_1 = \frac{R_B}{1 - A_V}$$

$$R_1 = \frac{220 \times 10^3}{1 + 263.6} = \mathbf{10.83\ k\Omega}$$

$$R_2 = \frac{A_V}{A_V - 1} R_B$$

$$R_2 = \frac{-263.6}{-263.6 - 1} \times 220 \times 10^3 = \mathbf{219.17\ k\Omega} \simeq R_B$$

$$Z_i = R_1 \,||\, r_\pi$$

$$Z_i = 0.83 \times 10^3 \,||\, 1.59 \times 10^3 = \mathbf{0.54\ k\Omega}$$

$$Z_o = r_o \,||\, R_C \,||\, R_2$$

$$Z_o = 40 \times 10^3 \,||\, 3.9 \times 10^3 \,||\, 219.17 \times 10^3 = \mathbf{3.496\ k\Omega}$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice. The results are presented below:

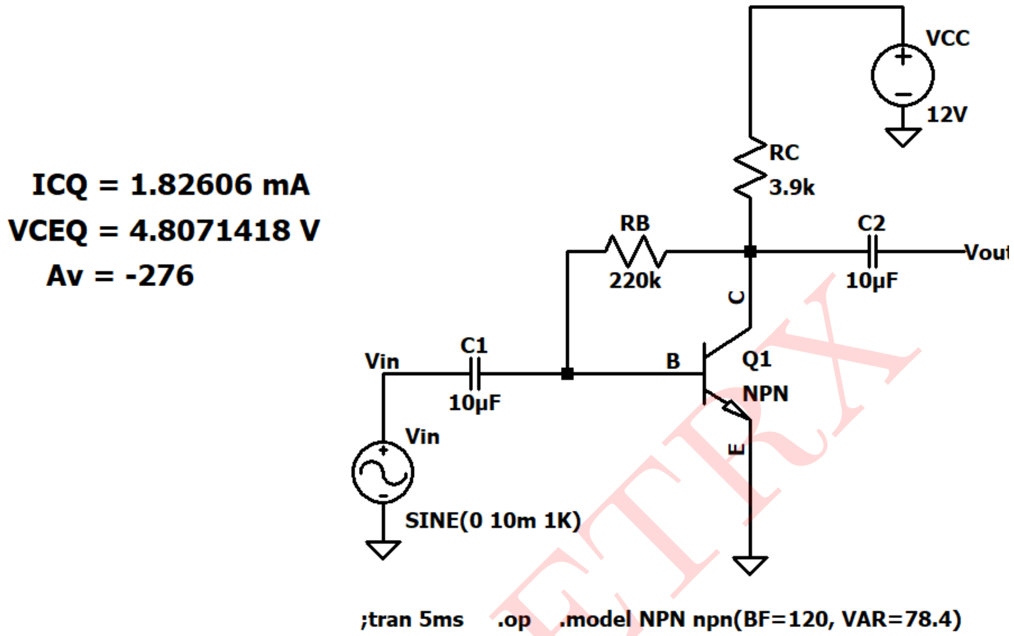

Figure 10: Circuit Schematic 2: Results

The input and output waveforms are shown in figure 11.

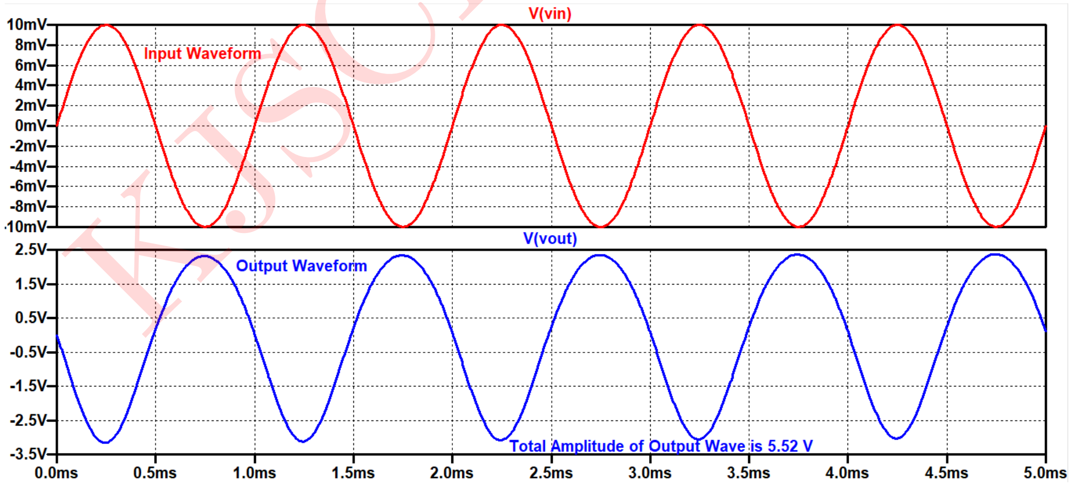

Figure 11: Input & Output waveforms

Comparison of theoretical and simulated values:

Parameters	Theoretical Values	Simulated Values
I_{CQ}	1.96 mA	1.826 mA
V_{CEQ}	4.29 V	4.8071 V
A_V	-263.6	-276

Table 2: Numerical 2

Numerical 3: The emitter follower has $R_B = 74$ kΩ, $R_E = 750$ Ω, $R_L = 5$ kΩ, $R_S = 200$ Ω, $V_{CC} = 18$ V and $V_{BE} = 0.7$ V. Assume $\beta = 100$, $V_A = 200$ V, $C_1 = C_2 = 10$ μF
a) Find the Q-point defined by I_B, I_C and V_{CE}.
b) Calculate the small-signal parameters g_m, r_π and r_o of the transistor.
c) Calculate the input resistance $R_{in} = V_S/i_S$, the no-load voltage gain $A_{VO} = V_o/V_b$, the output resistance R_o, the overall voltage gain $A_V = V_L/V_S$

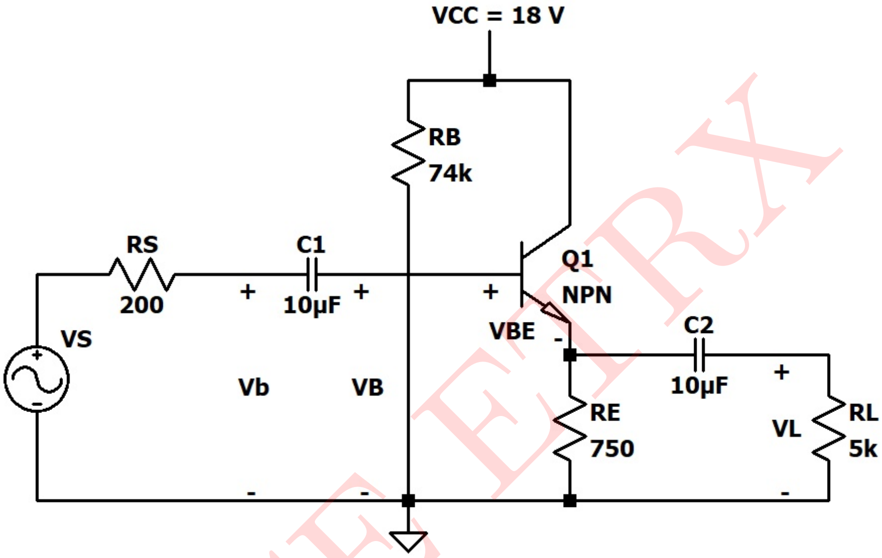

Figure 12: Circuit 3

Solution:
The given circuit 3 is a emitter-follower configuration.
For DC biasing, the capacitors will act as an open source.
DC Analysis:

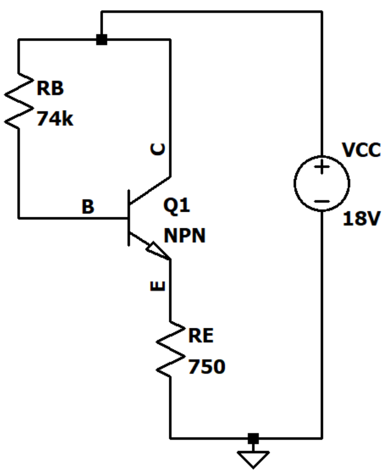

Figure 13: DC Biasing Circuit

a) I_{BQ} can be calculated by applying KVL to the base-emitter loop,

$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$

$I_B R_B + (1+\beta) I_B R_E = V_{CC} - V_{BE}$ ...($\because I_E = (1+\beta) I_B$)

$I_B (R_B + (1+\beta) R_E) = V_{CC} - V_{BE}$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

$$I_B = \frac{18 - 0.7}{74 \times 10^3 + (1+100) \times 750} = \mathbf{115.52\ \mu A}$$

$I_{CQ} = \beta I_B$

$I_{CQ} = 100 \times 115.52 \times 10^{-6} = \mathbf{11.55\ mA}$

$I_E = (1+\beta) I_B$

$I_E = (1+100) \times 115.52 \times 10^{-6} = \mathbf{11.66\ mA}$

V_{CEQ} can be caluclated ny applying KVL to the collector-emitter loop,

$V_{CC} - V_{CE} - I_E R_E = 0$

$V_{CE} = V_{CC} - I_E R_E$

$V_{CE} = 18 - 11.66 \times 10^{-3} \times 750 = \mathbf{9.255\ V}$

$I_B = \mathbf{115.52\ \mu A}$, I_{CQ} =**11.55 mA** & $V_{CEQ} = \mathbf{9.255\ V}$

AC Analysis:

b) $g_m = \dfrac{I_{CQ}}{V_T}$

$$g_m = \frac{11.55 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{444\ mA/V}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

$$r_o = \frac{200}{11.55 \times 10^{-3}} = \mathbf{17.32\ k\Omega}$$

$$r_\pi = \frac{\beta V_T}{I_E}$$

$$r_\pi = \frac{100 \times 26 \times 10^{-3}}{11.66 \times 10^{-3}} = \mathbf{222.98\ \Omega}$$

$g_m = \mathbf{444\ mA/V}$, $r_o = \mathbf{17.32\ k\Omega}$ and $r_\pi = \mathbf{222.98\ \Omega}$

c) Small Signal Equivalent Circuit,

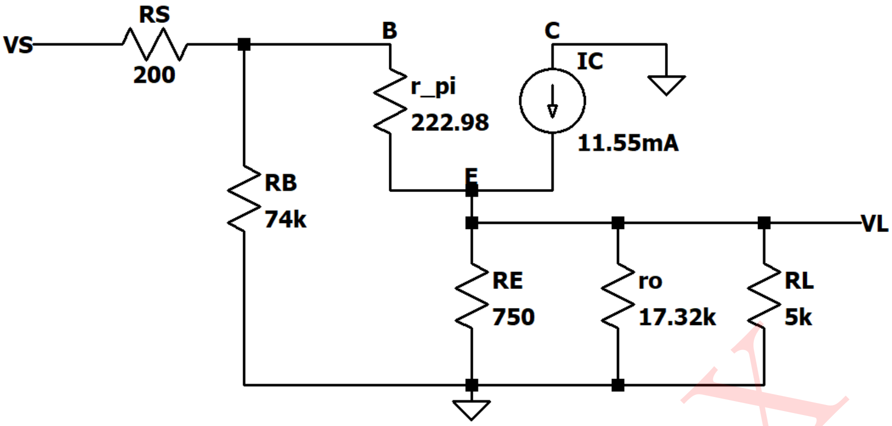

Figure 14: Small Signal Equivalent Circuit

Input Resistance:

Applying KVL to the input loop,

$V_b = I_b r_\pi + (1+\beta) I_b R_E$

$\dfrac{V_b}{I_b} = r_\pi + (1+\beta) R_E$

$R^{'} = r_\pi + (1+\beta) R_E$

We know, $R_i = R_B \ || \ R^{'}$

$R_i = R_B \ || \ [r_\pi + (1+\beta) R_E]$

$R_i = 74 \times 10^3 \ || \ [222.98 + (1+100) \times 750]$

$R_i = 74 \times 10^3 \ || \ 75.97 \times 10^3 = \mathbf{37.48 \ k\Omega}$

Output Resistance:

Let, $V_S = 0$

$\therefore R^{'} = (R_S \ || \ R_B) + r_\pi$

$R_o = \dfrac{R^{'}}{(1+\beta)} \ || \ (r_o \ || \ R_E)$

$R_o = \dfrac{(R_S \ || \ R_B) + r_\pi}{(1+\beta)} \ || \ (r_o \ || \ R_E)$

$R_o = \dfrac{(200 \ || \ 74 \times 10^3) + 222.98}{1+100} \ || \ (17.32 \times 10^3 \ || \ 750)$

$R_o = 4.18 \ || \ 718.87 = \mathbf{4.15} \ \Omega$

No-load voltage gain:

Output voltage V_o= voltage developed across $(r_0 \ || \ R_E)$

$V_o = I_b(r_o \ || \ R_E) + I_C(r_0 \ || \ R_E)$

$V_o = I_b(r_o \ || \ R_E) + \beta I_b(r_0 \ || \ R_E)$

$V_o = (1+\beta) I_b (r_0 \ || \ R_E)$ ...(1)

I_b can be written as,

$$I_b = \frac{V_\pi}{r_\pi}$$

$$I_b = \frac{V_b - V_e}{r_\pi}$$

but $V_e = V_o$,

$$I_b = \frac{V_b - V_o}{r_\pi}$$

Subsituting this in equation 1,

$$V_o = (1+\beta)\left(\frac{V_b - V_o}{r_\pi}\right)(r_0 \mid\mid R_E)$$

$$V_o = \frac{(1+\beta)V_b(r_0 \mid\mid R_E)}{r_\pi} - \frac{(1+\beta)V_o(r_0 \mid\mid R_E)}{r_\pi}$$

$$V_o + \frac{(1+\beta)V_o(r_0 \mid\mid R_E)}{r_\pi} = \frac{(1+\beta)V_b(r_0 \mid\mid R_E)}{r_\pi}$$

$$V_o\left[1 + \frac{(1+\beta)(r_0 \mid\mid R_E)}{r_\pi}\right] = \frac{(1+\beta)V_b(r_0 \mid\mid R_E)}{r_\pi}$$

$$V_o\left[\frac{r_\pi + (1+\beta)(r_0 \mid\mid R_E)}{r_\pi}\right] = \frac{(1+\beta)V_b(r_0 \mid\mid R_E)}{r_\pi}$$

$$\frac{V_o}{V_b} = \frac{(1+\beta)(r_0 \mid\mid R_E)}{r_\pi} \times \frac{r_\pi}{r_\pi + (1+\beta)(r_0 \mid\mid R_E)}$$

$$A_{VO} = \frac{(1+\beta)(r_0 \mid\mid R_E)}{r_\pi + (1+\beta)(r_0 \mid\mid R_E)}$$

$$A_{VO} = \frac{(1+100)(17.32 \times 10^3 \mid\mid 750)}{222.98 + (1+100)(17.32 \times 10^3 \mid\mid 750)}$$

$$A_{VO} = \frac{(101)(718.87)}{222.98 + (101)(718.87)} = \mathbf{0.9969}$$

Overall Voltage Gain:

Output voltage V_o = voltage developed across $(r_o \mid\mid R_E \mid\mid R_L)$

$$V_L = I_e(r_o \mid\mid R_E \mid\mid R_L)$$

$$V_L = (1+\beta)I_b(r_o \mid\mid R_E \mid\mid R_L) \qquad ...(2)$$

I_b can be written as,

$$I_b = \frac{V_\pi}{r_\pi} = \frac{V_b - V_e}{r_\pi}$$

but $V_e = V_L$,

$$I_b = \frac{V_b - V_L}{r_\pi}$$

Subsituting this in equation 2,

$$V_L = (1+\beta)\left(\frac{V_b - V_L}{r_\pi}\right)(r_o \mid\mid R_E \mid\mid R_L)$$

$$V_L = \frac{(1+\beta)V_b}{r_\pi}(r_o \mid\mid R_E \mid\mid R_L) - \frac{(1+\beta)V_L}{r_\pi}(r_o \mid\mid R_E \mid\mid R_L)$$

$$V_L\left[1+\frac{(1+\beta)}{r_\pi}(r_o \parallel R_E \parallel R_L)\right] = \frac{(1+\beta)V_b}{r_\pi}(r_o \parallel R_E \parallel R_L)$$

$$V_L[r_\pi + (1+\beta)(r_o \parallel R_E \parallel R_L)] = (1+\beta)V_b(r_o \parallel R_E \parallel R_L) \qquad ...(3)$$

but by voltage divider we get,

$$V_b = \left(\frac{R_i}{R_i + R_S}\right) V_S$$

Where, $R_i = R_B \parallel [r_\pi + (1+\beta)R_E]$

Substituting V_b in equation 3,

$$V_L[r_\pi + (1+\beta)(r_o \parallel R_E \parallel R_L)] = (1+\beta)(r_o \parallel R_E \parallel R_L)\left(\frac{R_i}{R_i + R_S}\right) V_S$$

$$\frac{V_L}{V_S} = \frac{(1+\beta)(r_o \parallel R_E \parallel R_L)}{r_\pi + (1+\beta)(r_o \parallel R_E \parallel R_L)} \times \left(\frac{R_i}{R_i + R_S}\right)$$

$$A_V = \frac{(1+100)(17.32\times10^3 \parallel 750 \parallel 5\times10^3)}{222.98 + (1+100)(17.32\times10^3 \parallel 750 \parallel 5\times10^3)} \times \left(\frac{37.48\times10^3}{37.48\times10^3 + 200}\right)$$

$$A_V = \frac{(101)(628.5)}{222.98 + (101)(628.5)} \times 0.9945 = 0.991$$

R_i = **37.48 kΩ**, R_o = **4.15 Ω**, A_{VO} = **0.9969** & A_V = **0.991**

SIMULATED RESULTS:

Above circuit is simulated in LTspice. The results are presented below:

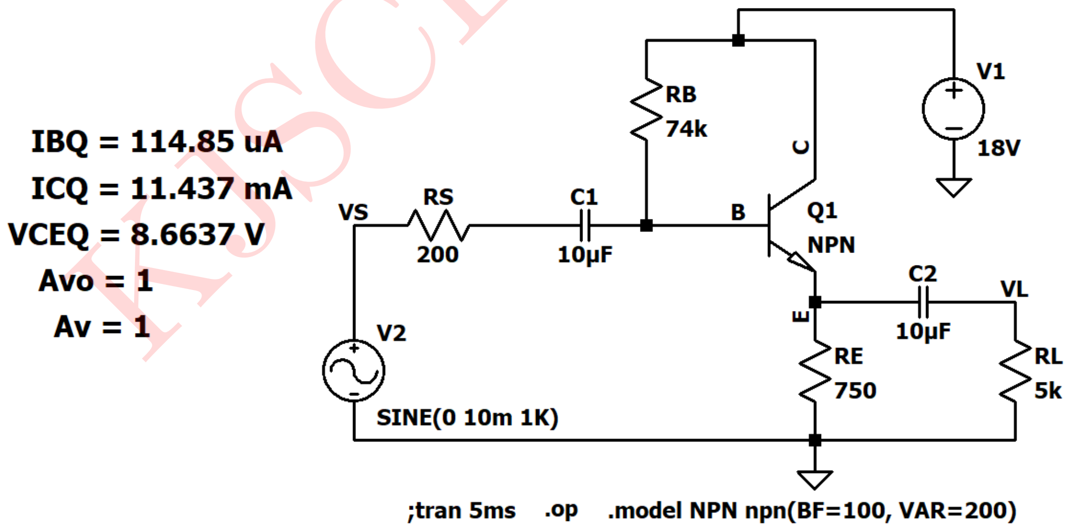

Figure 15: Circuit Schematic 3: Results

The input and output waveforms are shown in figure 16.

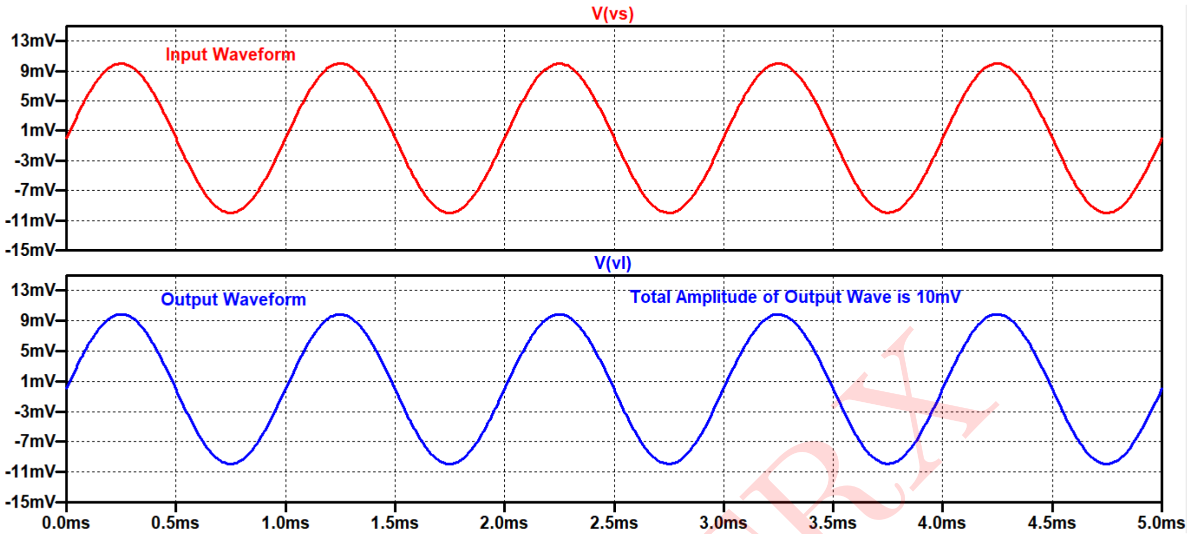

Figure 16: Input & Output waveforms

Comparison of theoretical and simulated values:

Parameters	Theoretical Values	Simulated Values
I_{BQ}	115.52 μA	114.85 μA
I_{CQ}	11.55 mA	11.437 mA
V_{CEQ}	9.255 V	8.6637 V
A_{VO}	0.9969	1
A_V	0.991	1

Table 3: Numerical 3

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