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

Numerical 1

For the network shown in figure 1, determine

a) r_π

b) V_B & V_C

c) Z_i & $A_V = \dfrac{V_o}{V_i}$

Given: $\beta = 180$ & $r_o = 50k\Omega$

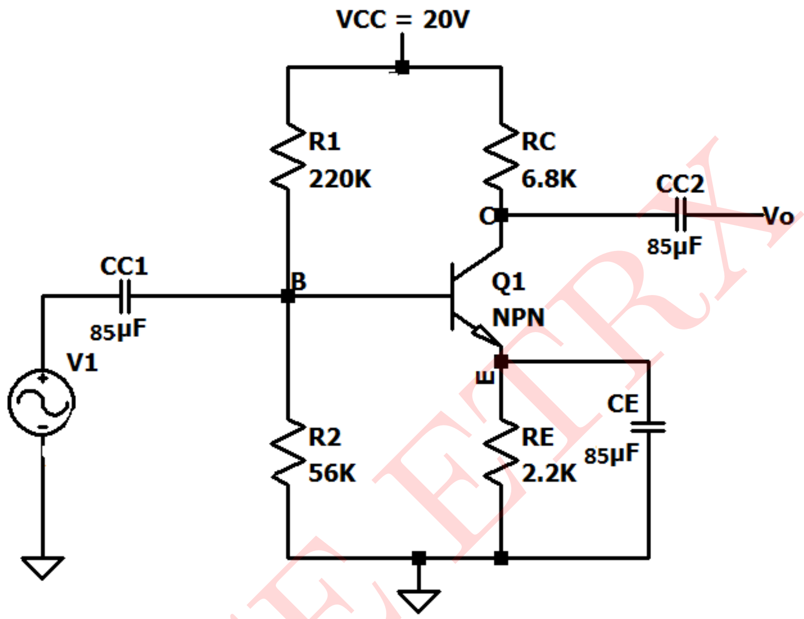

Figure 1: Circuit for Numerical 1

Solution:

Above circuit is a Common-Emitter BJT Amplifier.

DC Analysis:

During DC analysis, the capacitors become open circuit,

From figure 1 we get,

$R_{th} = R_1 \mid\mid R_2 = 220k \mid\mid 56k$

$\mathbf{R_{th} = 44.637k\Omega}$

We know that, $V_{th} = \dfrac{R_2}{R_1 + R_2} \times V_{CC} = \dfrac{56k}{56k + 220k} \times 20$

$\mathbf{V_B = V_{th} = 4.057V}$

The thevenin's equivalent circuit is shown in figure 2

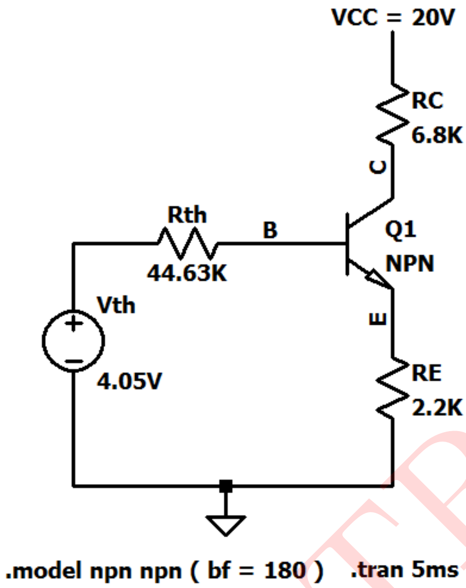

Figure 2: Thevenin's Equivalent Circuit

Applying KVL to B-E loop in figure 2 we get,

$V_{th} - I_B R_{th} - V_{BE_{ON}} - I_E R_E = 0$

$V_{th} - V_{BE_{ON}} = I_B R_{th} + (1+\beta) I_B R_E \qquad (\because I_E = (1+\beta) I_B)$

$$I_B = \frac{V_{th} - V_{BE_{ON}}}{R_{th} + (1+\beta)R_E} = \frac{4.057V - 0.7V}{44.637k + (181)2.2} \qquad (\text{Assuming } V_{BE_{ON}} = 0.7V)$$

$\mathbf{I_B = 7.580\mu A}$

$I_C = \beta I_B = 180 \times 7.580\mu A$

$\mathbf{I_C = 1.364mA}$

Applying KVL to output C-E loop in figure 2 we get,

$V_C = V_{CC} - I_C R_C = 20 - (1.364mA \times 6.8k\Omega)$

$\mathbf{V_C = 10.725V}$

AC Analysis:

Small Signal Parameter Calculation is given below

$$g_m = \frac{I_{C_Q}}{V_T} = \frac{1.364mA}{0.026} = \mathbf{52.46mA/V}$$

$$r_\pi = \frac{V_T}{I_{B_Q}} = \mathbf{3.43k\Omega}$$

$r_o = \mathbf{50k\Omega} \qquad$ (Given)

The small signal hybrid pi model is shown in figure 3

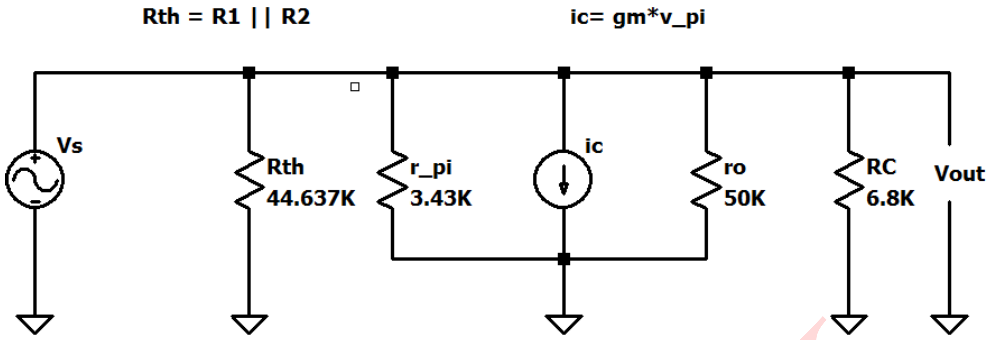

Figure 3: Small Signal Hybrid Pi Model

Calculation of $\mathbf{A_V}$:

$$A_V = \frac{V_{out}}{V_{in}} = -g_m(r_o \mid\mid R_C) = -52.46(50k \mid\mid 6.8k)$$

$$\mathbf{A_V = -314.021}$$

Calculation of $\mathbf{Z_i}$:

$$Z_i = R_1 \mid\mid R_2 = 220k \mid\mid 56k$$

$$\mathbf{Z_i = 44.63k\Omega}$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows:

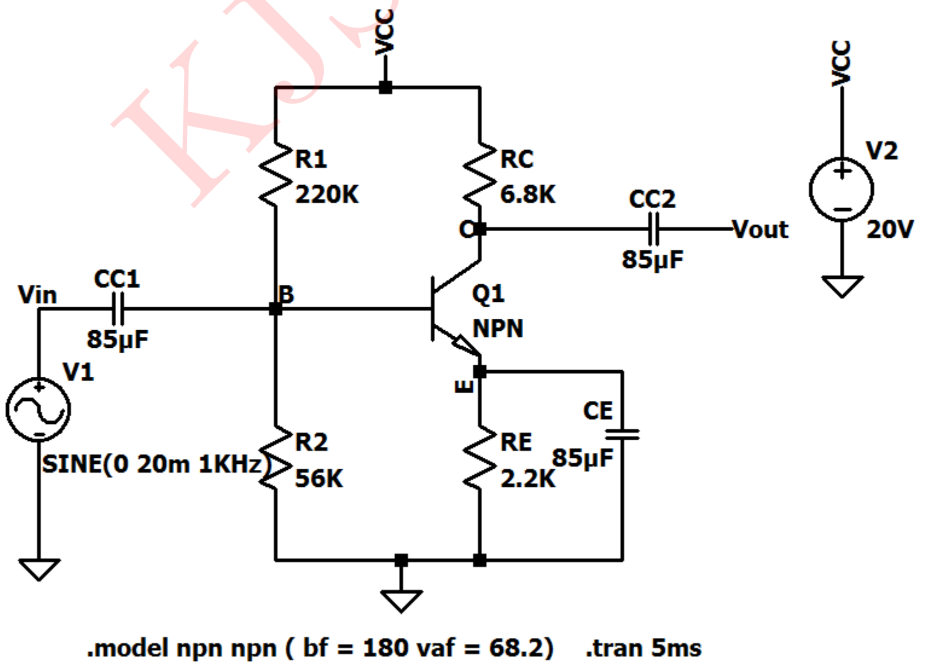

Figure 4: Circuit Schematic: Results

The input and output waveforms are shown in figure 5

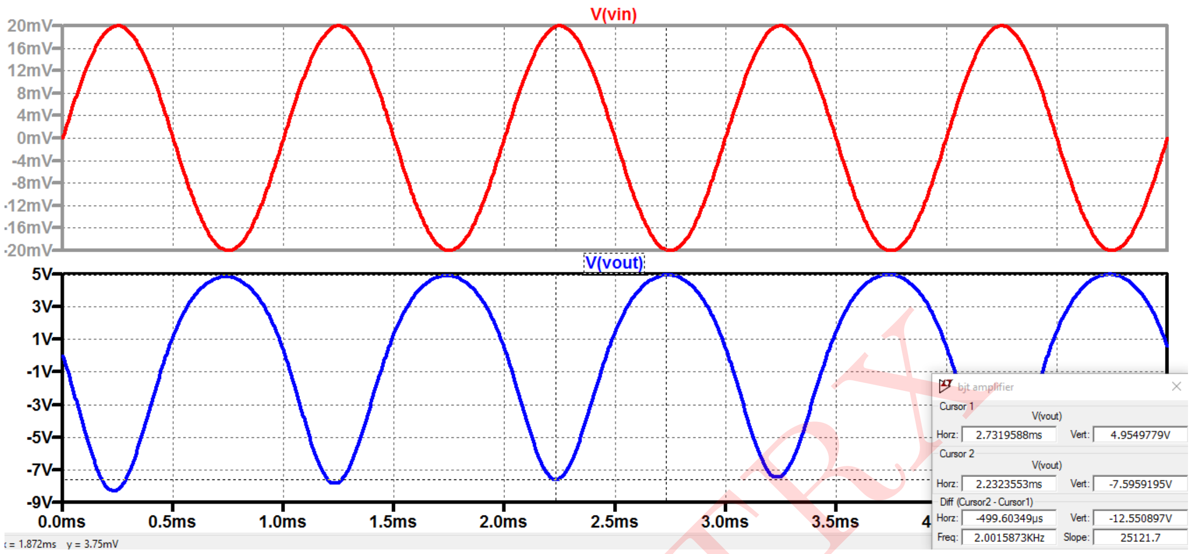

Figure 5: Input and Output Waveforms

Comparison between theoretical and simulated values is given below:

Parameters	Simulated Values	Theoretical Values
V_B	3.72V	4.0V
V_C	10.94V	10.72V
I_C	1.3mA	1.3mA
A_v	-313.75	-314.021

Table 1: Numerical 1

Numerical 2

For the emitter follower network shown in figure 1, calculate

a) r_π

b) Z_i

c) Z_o

d) A_V

e) Repeat parts (b) through (d) with $r_o = 25k\Omega$ and compare results

Given: $\beta = 100$

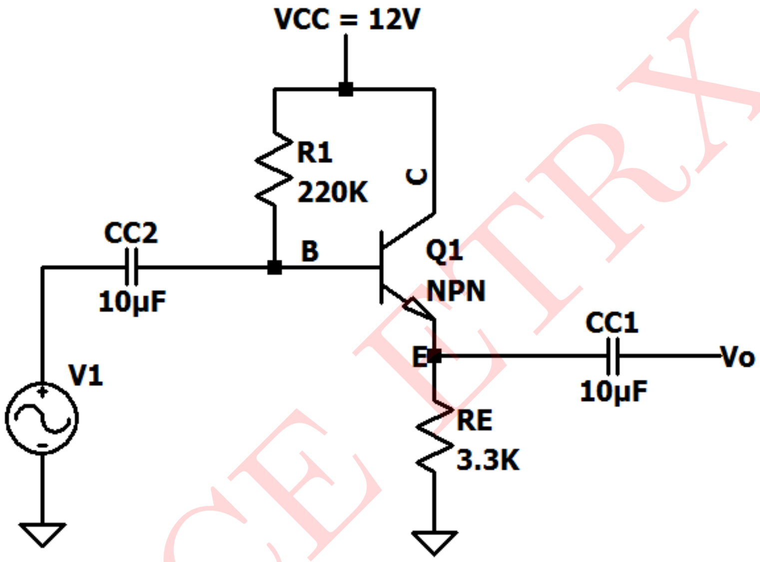

Figure 6: Circuit for Numerical 2

Solution: Given is a Emitter-Follower BJT Network.

DC Analysis:

In DC analysis, the capacitors become open circuit.

The DC equivalent circuit is shown in figure 7.

Applying KVL to B-E loop in figure 7 we get,

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

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_E} = \frac{12V - 0.7V}{220k + (100+1)3.3k} \qquad \text{(Assuming } V_{BE} = 0.7V\text{)}$$

$\mathbf{I_B = 20.423\mu A}$

$I_C = \beta I_B = 100 \times 20.423\mu A$

$\mathbf{I_C = 2.0423mA}$

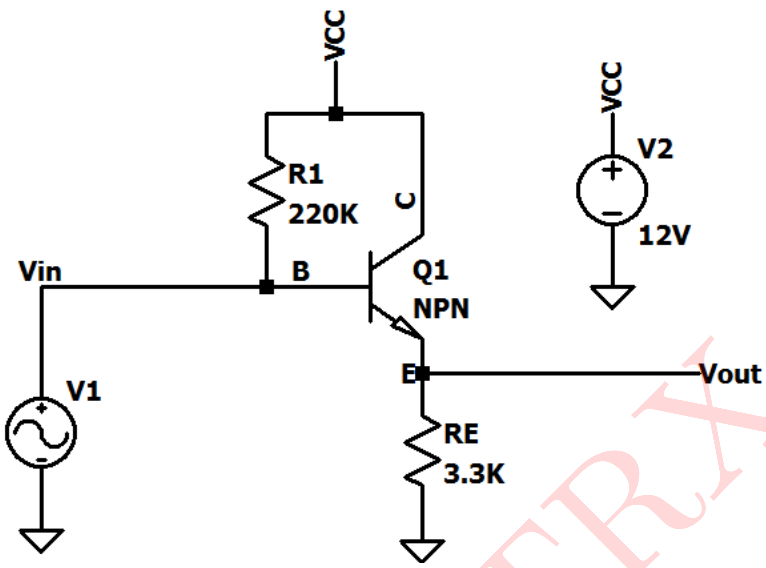

Figure 7: DC Equivalent Circuit

AC Analysis:

Small Signal Parameter Calculation is given below

$$r_\pi = \frac{V_T}{I_{B_Q}} = \frac{26mV}{20.423\mu A}$$

$$\mathbf{r_\pi = 1.273k\Omega}$$

$$g_m = \frac{\beta I_B}{V_T} = \frac{100 \times 20.423\mu A}{26mV}$$

$$\mathbf{g_m = 78.55mA/V}$$

The small signal equivalent circuit is shown in figure 8

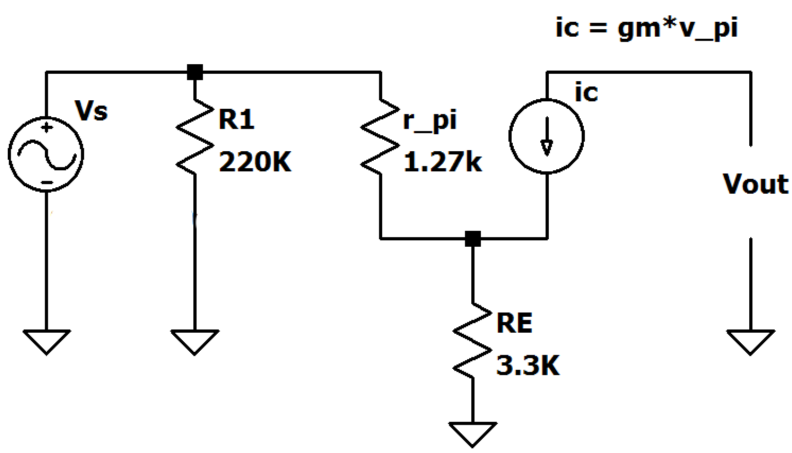

Figure 8: Small Signal Equivalent Circuit

Calculation of $\mathbf{A_v}$:

$$A_V = \frac{R_E}{\frac{1}{g_m} + R_E} = \frac{3.3k}{\frac{10^3}{78.55} + 3.3k}$$

$\mathbf{A_V = 0.996}$

Calculation of $\mathbf{Z_i}$ & $\mathbf{Z_o}$:

$$Z_i = R_B \,||\, [r_\pi + (1+\beta)R_E] = 220k \,||\, [1.273k + (1+100)3.3k]$$

$\mathbf{Z_i = 132.725k\Omega}$

$$Z_o = \frac{1}{g_m} \parallel R_E = \frac{10^3}{78.55} \parallel 3.3k$$

$\mathbf{Z_o = 12.682\Omega}$

<u>**Case: $\mathbf{r_o = 25k\Omega}$**</u>

The small signal equivalent circuit is shown in figure 9

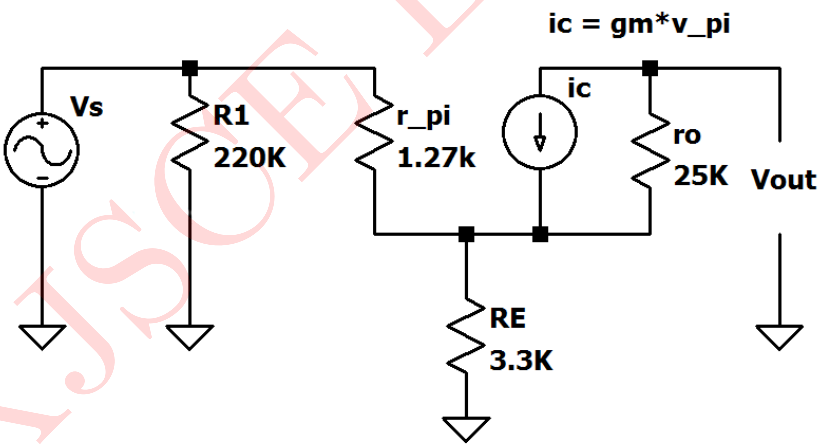

Figure 9: Small Signal Equivalent Circuit

Calculation of $\mathbf{Z_i}$ & $\mathbf{Z_o}$:

$$Z_i = R_B \,||\, [r_\pi + (1+\beta)(R_E \,||\, r_o)] = 220k \,||\, [1.273k + (1+100)(3.3k \,||\, 25k)]$$

$\mathbf{Z_i = 126.131k\Omega}$

$$Z_o = R_E \,||\, \frac{1}{g_m} \,||\, r_o$$

$\mathbf{Z_o = 12.675\Omega}$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows:

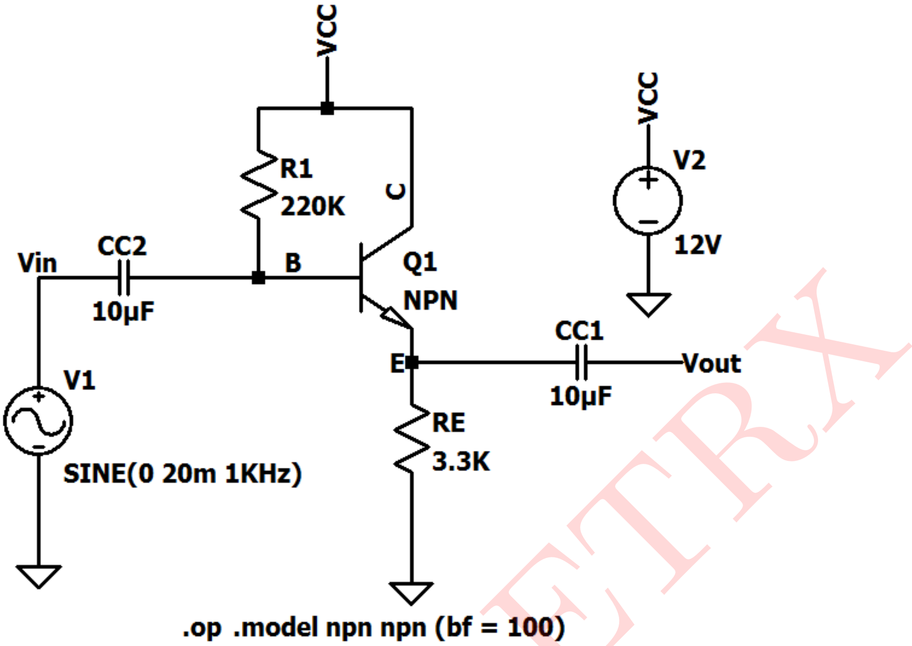

Figure 10: Circuit Schematic: Results

The input and output waveforms are shown in figure 11

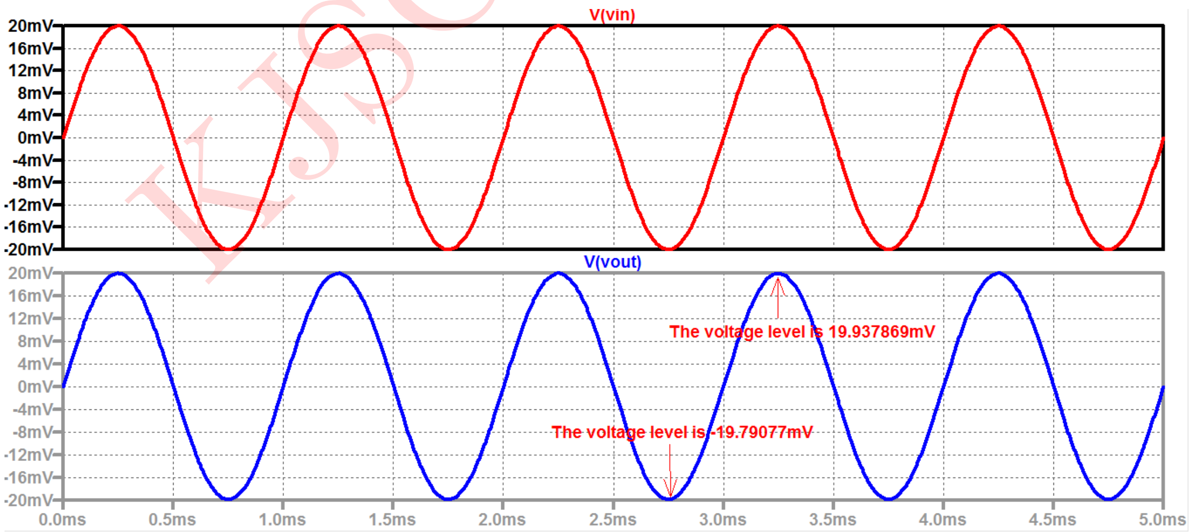

Figure 11: Input and Output Waveforms

Comparison between theoretical and simulated values is given below:

Parameters	Simulated Values	Theoretical Values
I_B	20.25μA	20.42μA
I_C	2.02mA	2.0mA
A_v	0.993	0.996

Table 2: Numerical 2

Comparison between $\mathbf{Z_i}$ and $\mathbf{Z_o}$ values after and before $\mathbf{r_o}$ is given below:

Parameters	with $\mathbf{r_o}$	without $\mathbf{r_o}$
Z_i	126.131$k\Omega$	132.725$k\Omega$
Z_o	12.68$k\Omega$	12.67$k\Omega$

Table 3: Numerical 2

Numerical 3

The transistor parameters for the circuit shown in figure 1 are $\beta = 180$ & $V_A = \infty$

a) Find I_{CQ} & V_{CEQ}

b) Calculate the small signal voltage gain

c) Determine the input-output resistances R_i & R_o

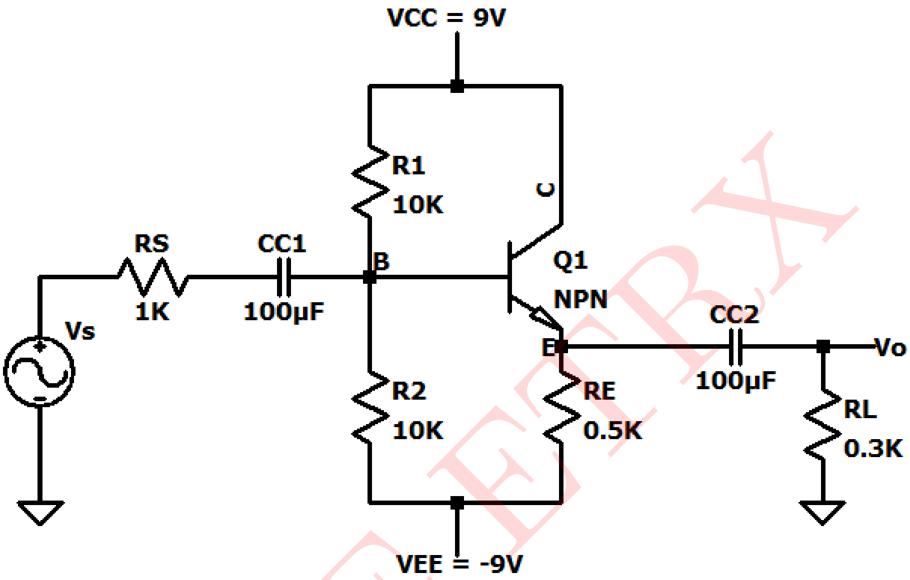

Figure 12: Circuit for Numerical 3

Solution:

The given circuit is an Emitter-Follower amplifier.

DC Analysis:

In DC analysis, the capacitors become open circuit.

We know that $V_{th} = \dfrac{R_2}{R_1 + R_2} \times (V_{CC} - V_{EE}) + V_{EE}$

$$V_{th} = \left(\frac{10k}{10k + 10k}\right) \times [9V - (-9V)] + (-9V) = 0.5 \times (18V) - 9V$$

$$\mathbf{V_B = V_{th} = 0V}$$

$$R_{th} = R_1 \mid\mid R_2 = 10k \mid\mid 10k$$

$$\mathbf{R_B = R_{th} = 5k\Omega}$$

Applying KVL to the Base-Emitter loop we get,

$$V_B - I_{BQ}R_B - V_{BE} - I_E R_E - V_{EE} = 0$$

$$V_B - I_{BQ}R_B - V_{BE} - (1+\beta)I_{BQ}R_E - V_{EE} = 0 \qquad (\because I_E = (1+\beta)I_B)$$

$$I_{BQ} = \frac{V_B - V_{BE} - V_{EE}}{R_B + (1+\beta)R_E} = \frac{0 - 0.7 - (-9V)}{5k + (1+180)0.5k}$$

$\mathbf{I_{BQ} = 86.9\mu A}$

$I_{CQ} = \beta \times I_{BQ} = 180 \times 86.91\mu A$

$\mathbf{I_{CQ} = 15.64mA}$

Applying KVL to Collector-Emitter loop we get,

$V_{CC} - V_{CEQ} - I_E R_E - V_{EE} = 0$

$V_{CEQ} = V_{CC} - (I_C + I_B)R_E - V_{EE} \qquad (\because I_E = I_B + I_C)$

$\mathbf{V_{CEQ} = 10.178V}$

AC Analysis:

The small signal parameters calculations are shown below

$$g_m = \frac{I_C}{V_T} = \frac{15.64mA}{0.026V}$$

$\mathbf{g_m = 601.69mA/V}$

$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{26mV}{86.91\mu A}$$

$\mathbf{r_\pi = 0.3k\Omega}$

The small signal equivalent circuit is shown in figure 2

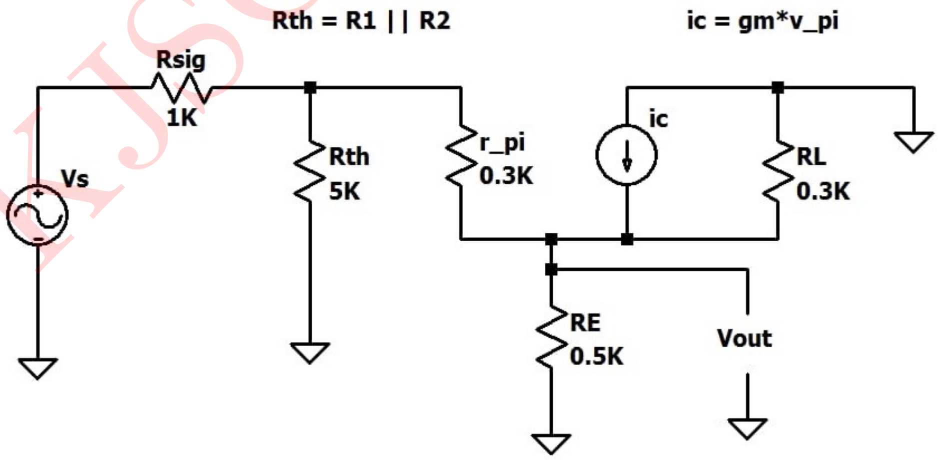

Figure 13: Small Signal Equivalent Circuit

Calculation of A_V

$$A_V = \frac{R_E \parallel R_L}{\frac{1}{g_m} + [R_E \parallel R_L]} = \frac{0.5k \parallel 0.3k}{\frac{10^3}{601.69} + (0.5k \parallel 0.3k)}$$

$\mathbf{A_V = 0.991}$

$$A_{VS} = \frac{V_{out}}{V_{in}} \times \frac{V_{in}}{V_S} = A_V \times \frac{V_{in}}{V_S} \qquad \left(\because A_V = \frac{V_{out}}{V_{in}}\right)$$

$$A_{VS} = A_V \times \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_{sig}} = 0.991 \times \frac{10k \parallel 10k}{10k \parallel 10k + 1k}$$

$$\mathbf{A_{VS} = 0.825}$$

Calculation of R_i & R_o

$$R_i = R_1 \parallel R_2 \parallel [r_\pi + (1+\beta)R_E \parallel R_L]$$

$$R_i = 10k \parallel 10k \parallel [0.3k + (1+181)0.5k \parallel 0.3k]$$

$$\mathbf{R_i = 4.36k\Omega}$$

$$R_o = R_L \parallel \frac{1}{g_m} \parallel R_E$$

$$R_o = 0.3k \parallel \frac{10^3}{601.69} \parallel 0.5k$$

$$\mathbf{R_o = 1.647\Omega}$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows:

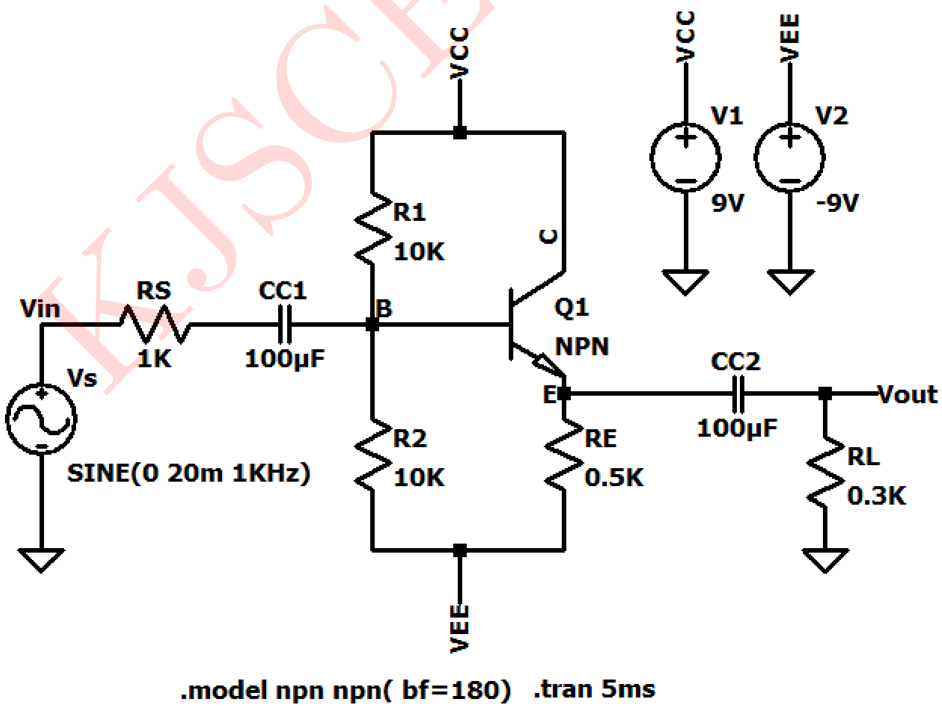

Figure 14: Circuit Schematic: Results

The input and output waveforms are shown in figure 4

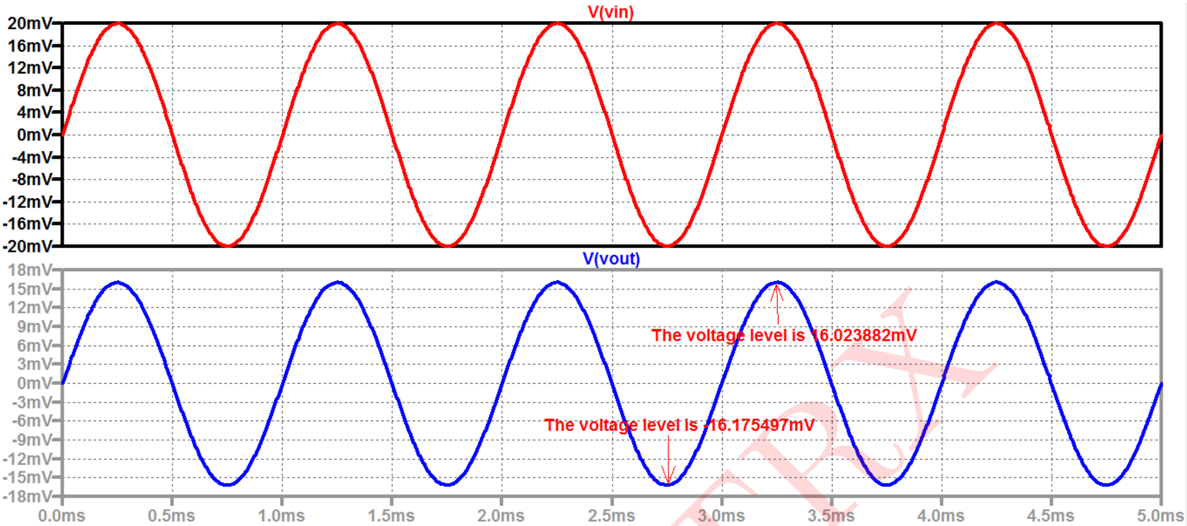

Figure 15: Input and Output Waveforms

Comparison between theoretical and simulated values is given below:

Parameters	Simulated Values	Theoretical Values
I_{BQ}	85.391μA	86.91μA
V_{CEQ}	10.27V	10.17V
A_{VS}	0.804	0.825

Table 4: Numerical 3

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