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

Numerical 1:

For the network shown below in figure 1,

a) Determine r_π

b) Find Z_i and Z_o

c) Calculate A_V

d) Repeat parts (b) and (c) with $r_o = 20\text{k}\Omega$

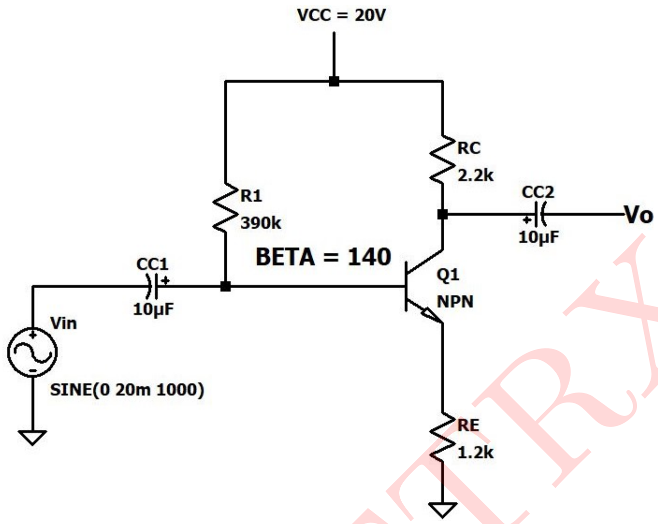

Figure 1: Circuit 1

Solution:

Above circuit is common emitter-bias configuration consisting of a BJT amplifier.

DC analysis:

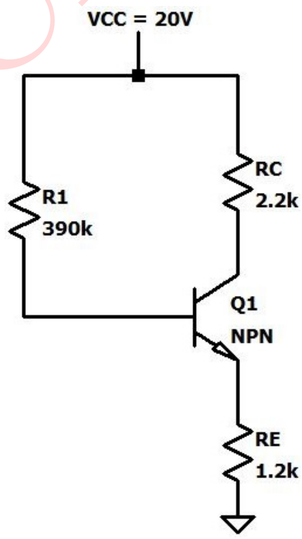

Figure 2: DC equivalent circuit

Applying KVL to base-emitter loop,

$V_{CC} - I_B R_1 - V_{BE} - I_E R_E = 0$

20V - I_B(390kΩ) - 0.7V - $(\beta + 1)I_B$(1.2kΩ) = 0

19.3V - I_B[(141)(1.2kΩ) + 390kΩ] = 0

$I_B = \dfrac{19.3}{559.2k} = 0.03451\text{mA} = \mathbf{34.51\mu A}$

$\because I_C = \beta I_B = (140)(0.03451\text{mA}) = \mathbf{4.831mA}$

$\because I_E = (\beta + 1)I_B = (141)(0.3451\text{mA}) = \mathbf{4.865mA}$

Small signal parameters

i) $g_m = \dfrac{I_C}{V_T} = \dfrac{4.331mA}{26mV} = \mathbf{185.80mA/V}$

ii) $r_o = \dfrac{V_A}{I_C}$

$\therefore V_A = r_o \times I_C = 100\text{k}\Omega \times 4.831\text{mA} = \mathbf{4.831V}$

iii) $r_\pi = \dfrac{V_T}{I_B} = \dfrac{26mV}{0.03451mA} = \mathbf{753.40\Omega}$

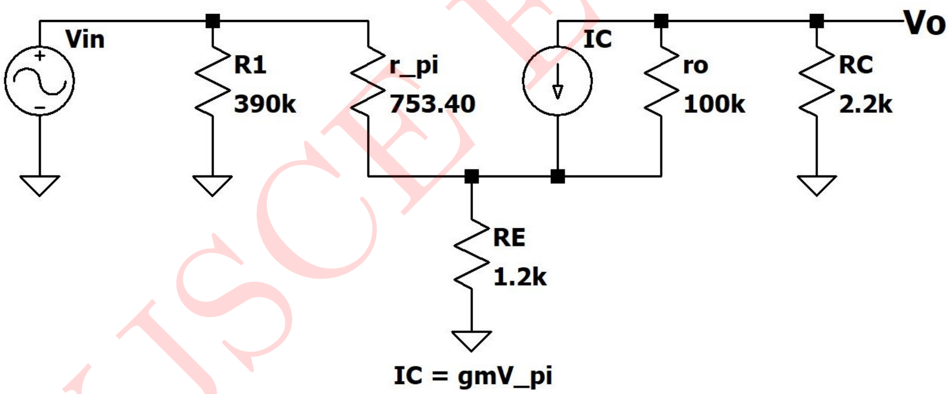

Figure 3: Small signal equivalent circuit for $r_o = 100\text{k}\Omega$

Input impedance,

$Z_i = R_1 \parallel (r_\pi + (1+\beta)R_E)$

$= 390k\Omega \parallel (753.40\Omega + (141)1.2k\Omega)$

$= 390k\Omega \parallel (753.40\Omega + 169200\Omega)$

$= 390k\Omega \parallel 169.953$

$= \dfrac{390k\Omega \times 169.953k\Omega}{390k\Omega + 169.953k\Omega} = \mathbf{118.370k\Omega}$

Output impedance,

$Z_o = r_o \parallel R_C$

$= \dfrac{r_o \times R_C}{r_o + R_C} = \dfrac{100k\Omega \times 2.2k\Omega}{100k\Omega + 2.2k\Omega} = \mathbf{2.152k\Omega}$

Voltage gain,

$$A_V = \frac{V_o}{V_{in}}$$

$$= \frac{-g_m V\pi \times Z_o}{V\pi + V_E}$$

$$= \frac{-I_C \times Z_o}{I_B[r_\pi + (\beta+1)R_E]}$$

$$= \frac{-\beta I_B Z_o}{I_B[r_\pi + (\beta+1)R_E]}$$

$$= \frac{-\beta Z_o}{r_\pi + (\beta+1)R_E} = \frac{-140 \times 2.152k\Omega}{753.40 + [(141)(1.2k\Omega)]} = \mathbf{-1.7727}$$

SIMULATED RESULTS:

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

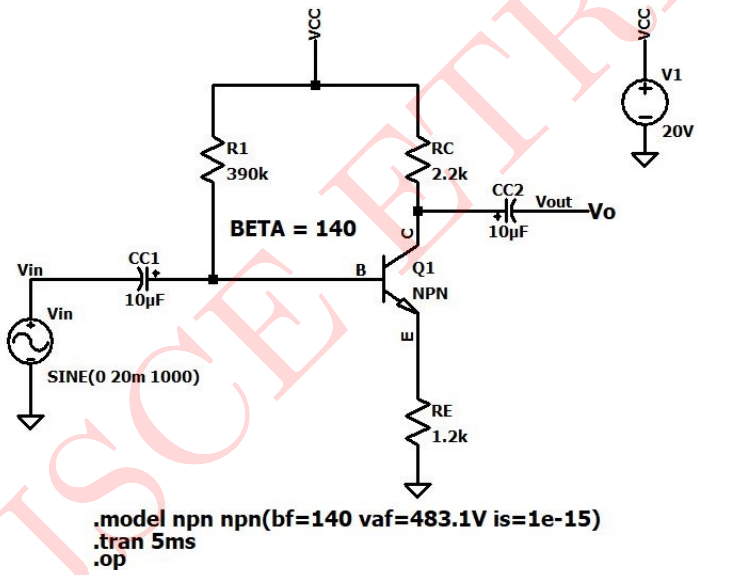

Figure 4: Circuit Schematic 1

The input and output waveforms are shown in figure 5.

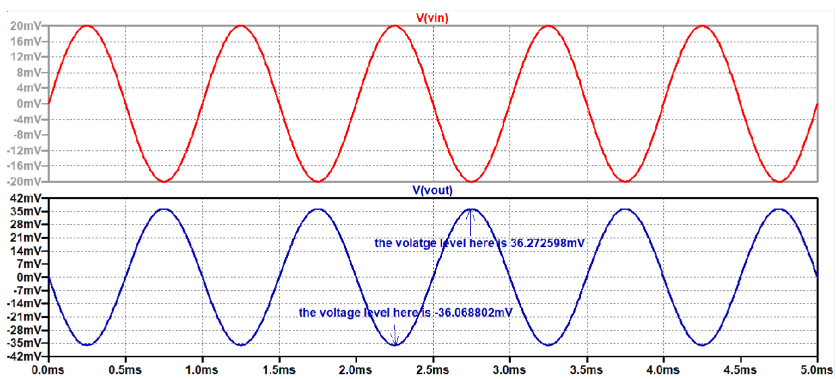

Figure 5: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_C	4.831mA	4.8372mA
I_B	0.03451mA	0.034355mA
Voltage gaine(A_V)	-1.7727	-1.8085

Table 1: Numerical 1

For $r_o = 20\text{k}\Omega$,

Small signal parameters

i) $g_m = \dfrac{I_C}{V_T} = \dfrac{4.331mA}{26mV} = \mathbf{185.80mA/V}$

ii) $r_o = \dfrac{V_A}{I_C}$

$\therefore V_A = r_o \times I_C = 20\text{k}\Omega \times 4.831\text{mA} = \mathbf{96.62V}$

iii) $r_\pi = \dfrac{V_T}{I_B} = \dfrac{26mV}{0.03451mA} = \mathbf{753.40\Omega}$

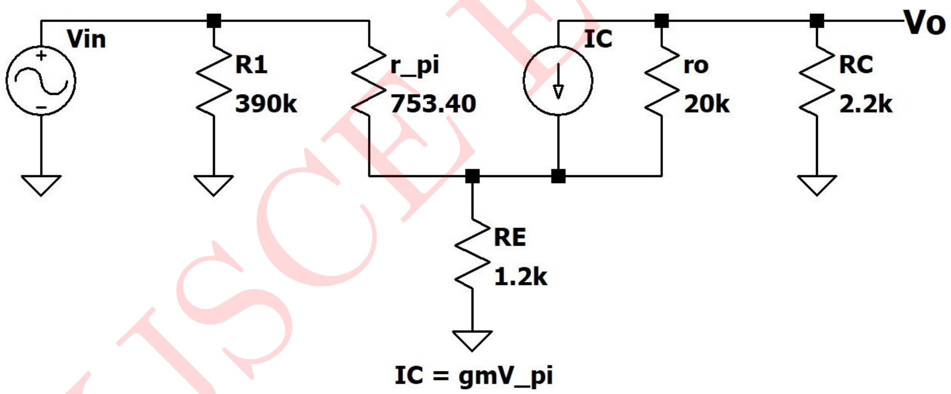

Figure 6: Small signal equivalent circuit for $r_o = 20\text{k}\Omega$

Input impedance,

$$Z_i = R_1 \parallel (r_\pi + (1+\beta)R_E)$$

$$= 390k\Omega \parallel 169.9482k\Omega$$

$$= \frac{390k\Omega \times 169.9482k\Omega}{390k\Omega + 169.9482k\Omega} = \mathbf{118.367k\Omega}$$

Output impedance,

$$Z_o = r_o \parallel R_C$$

$$= \frac{r_o \times R_C}{r_o + R_C} = \frac{20k\Omega \times 2.2k\Omega}{20k\Omega + 2.2k\Omega} = \mathbf{1.981k\Omega}$$

Voltage gain,

$$A_V = \frac{V_o}{V_{in}}$$

$$= \frac{-g_m V\pi \times Z_o}{V\pi + V_E}$$

$$= \frac{-I_C \times Z_o}{I_B[r_\pi + (\beta+1)R_E]}$$

$$= \frac{-\beta I_B Z_o}{I_B[r_\pi + (\beta+1)R_E]}$$

$$= \frac{-\beta Z_o}{r_\pi + (\beta+1)R_E} = \frac{-140 \times 1.981k\Omega}{753.40 + [(141)(1.2k\Omega)]} = \mathbf{-1.631}$$

SIMULATED RESULTS:

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

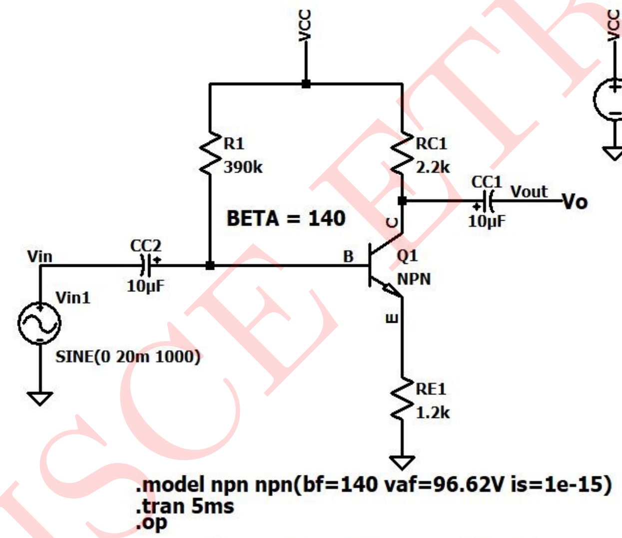

Figure 7: Circuit Schematic

The input and output waveforms are shown in figure 8.

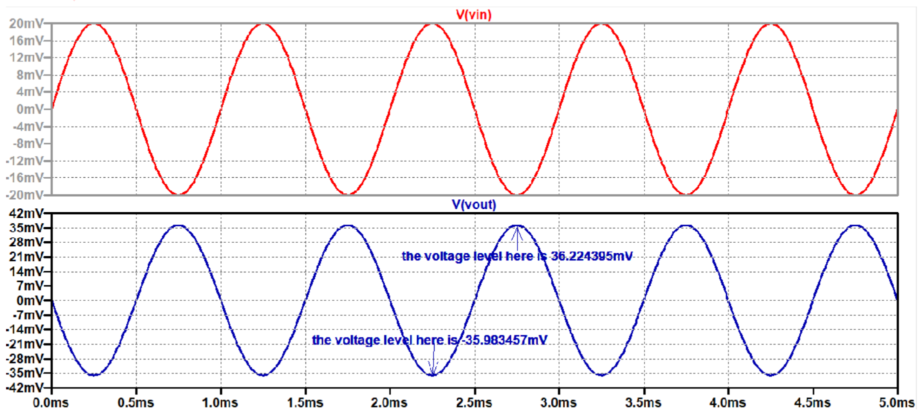

Figure 8: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_C	4.831mA	4.9055mA
I_B	0.03451mA	0.03414mA
Voltage gaine(A_V)	-1.631	-1.805

Table 2: Numerical 1

Numerical 2:
For the network shown below in figure 9, determine
a) r_π
b) Z_i
c) Z_o
d) A_V

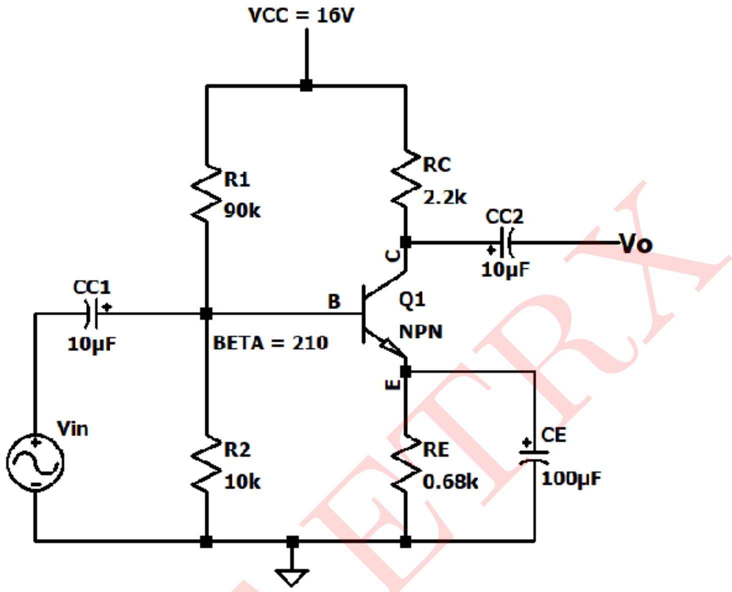

Figure 9: Circuit 2

Solution:

The above circuit is common emitter BJT amplifier.

DC analysis:

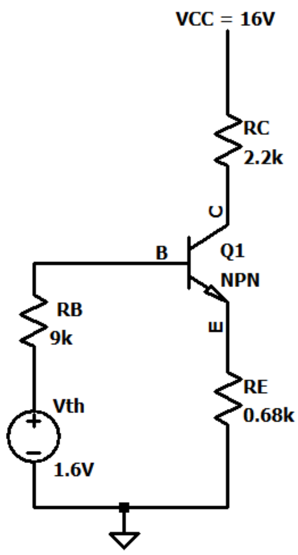

Figure 10: DC equivalent circuit

$$V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{10k\Omega}{90k\Omega + 10k\Omega} \times 16V = \mathbf{1.6V}$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = \frac{10k\Omega \times 90k\Omega}{10k\Omega \times 90k\Omega} = \mathbf{9k\Omega}$$

Applying KVL to base-emitter loop,

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

V_{TH} - $I_B R_B$ - V_{BE} - $(\beta + 1) I_B R_E = 0$ ....$(I_E = (\beta + 1) I_B)$

1.6V - $I_B(9k\Omega)$ - 0.7V - $(211) I_B (0.68k\Omega) = 0$ ....$(V_{BE} = 0.7V)$

0.9V - I_B[9kΩ + (211)(0.68kΩ)] = 0

$$I_B = \frac{0.9V}{9k\Omega + 143.48k\Omega} = \mathbf{5.902\mu A}$$

$\because I_C = \beta I_B = (210)(5.90\mu\text{A}) = \mathbf{1.239mA}$

Small signal parameters

i) $g_m = \frac{I_C}{V_T} = \frac{1.239mA}{26mV} = \mathbf{47.67mA/V}$

ii) $r_o = \frac{V_A}{I_C}$

$\therefore V_A = r_o \times I_C$ = 50kΩ×1.239mA = **61.95V**

iii) $r_\pi = \frac{V_T}{I_B} = \frac{26mV}{5.902\mu A} = \mathbf{4.405k\Omega}$

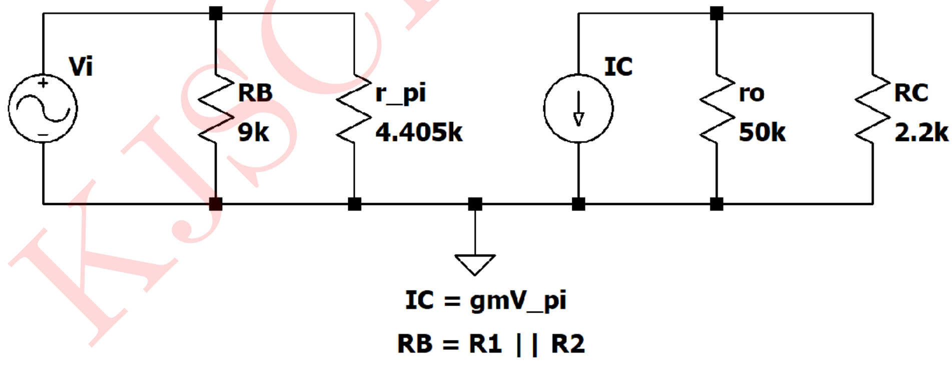

Figure 11: Small signal equivalent circuit for $r_o = 100\text{k}\Omega$

Input impedance,

$Z_i = R_B$

$= R_1 \parallel R_2$

$= 90k\Omega \parallel 10k\Omega$

$$= \frac{90k\Omega \times 10k\Omega}{90k\Omega + 10k\Omega} = \mathbf{9k\Omega}$$

Output impedance,

$$
\begin{aligned}
Z_o &= R_C \parallel r_o \\
&= 2.2k\Omega \parallel 50k\Omega \\
&= \frac{2.2k\Omega \times 50k\Omega}{2.2k\Omega + 50k\Omega} = \mathbf{2.10k\Omega}
\end{aligned}
$$

Voltage gain,

$$
\begin{aligned}
A_V &= \frac{V_o}{V_{in}} \\
&= \frac{-g_m V\pi(r_0 \parallel R_C)}{V\pi} \\
&= -g_m(r_0 \parallel R_C) \\
&= -47.67mA/V(2.10k\Omega) = \mathbf{-100.107}
\end{aligned}
$$

SIMULATED RESULTS:

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

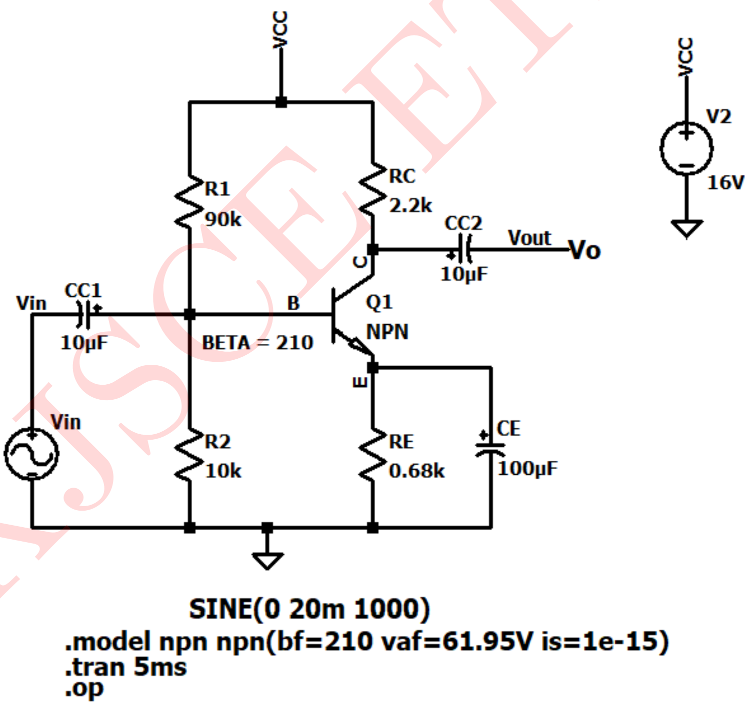

Figure 12: Circuit Schematic 1

The input and output waveforms are shown in figure 13.

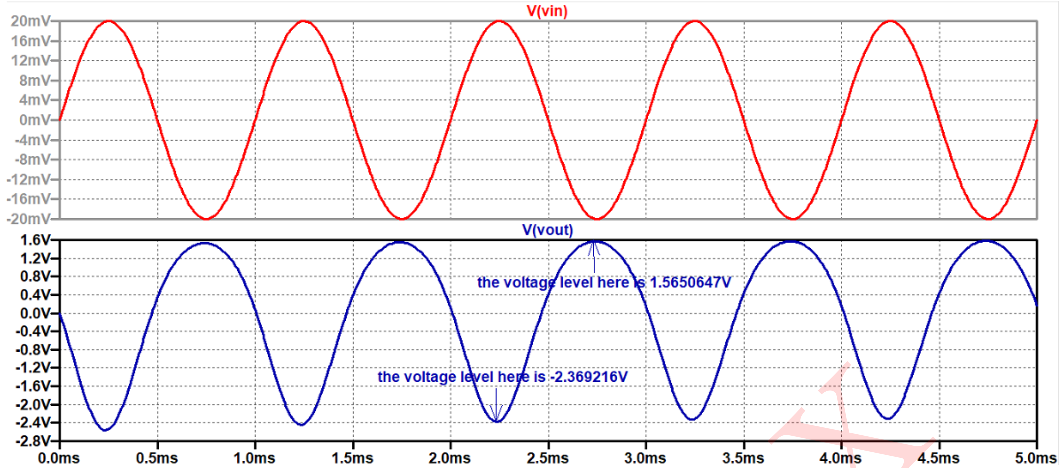

Figure 13: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_C	1.239mA	1.3823mA
I_B	5.902μA	5.3944μA
Voltage gaine(A_V)	-100.107	-98.3750

Table 3: Numerical 2

Numerical 3:
In the circuit shown below in figure 14, determine the range in small signal voltage gain $A_{V_S} = V_o/V_S$ if β is in the range $75 \leq \beta \leq 150$.

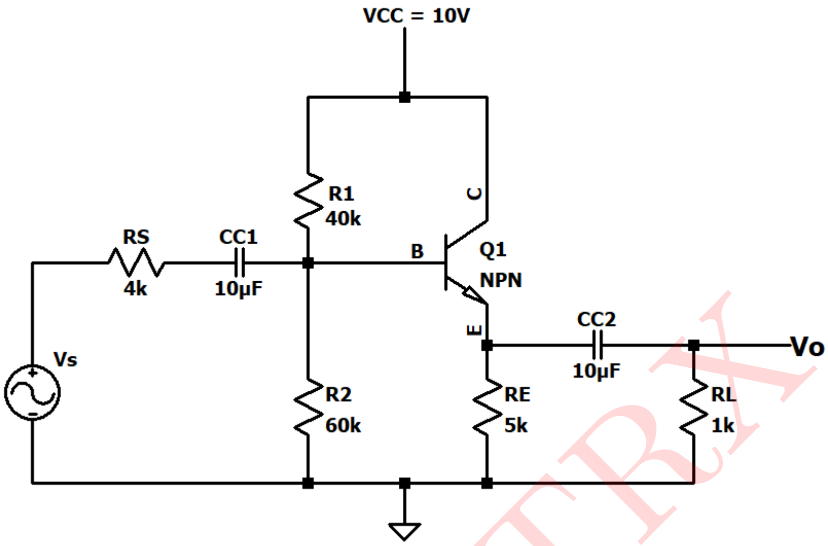

Figure 14: Circuit 3

Solution:

The above circuit is common collector amplifier consisting of npn BJT.

DC analysis:

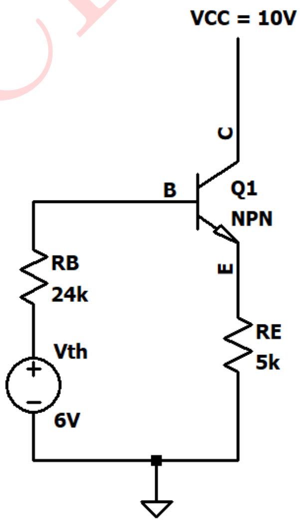

Figure 15: Thevenin's equivalent circuit

$$V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{60k\Omega}{40k\Omega + 60k\Omega} \times 10V = \mathbf{6V}$$

$$R_B = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} = \frac{40k\Omega \times 60k\Omega}{40k\Omega + 60k\Omega} = \mathbf{24k\Omega}$$

Applying KVL to base-emitter loop,

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

$V_{TH} - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0 \qquad ....(I_E = (\beta + 1) I_B)$

$6V - I_B(24k\Omega) - 0.7V - (75 + 1) I_B(5k\Omega) = 0$

$6V - I_B(24k\Omega) - 0.7V - (76) I_B(5k\Omega) = 0$

$5.3V - I_B(24k\Omega + 76(5k\Omega)) = 0$

$$I_B = \frac{5.3V}{24k\Omega + 380k\Omega} = \mathbf{13.14\mu A}$$

$\because I_C = \beta I_B = (75)(13.11\mu\text{A}) = \mathbf{0.983mA}$

Small signal parameters(for $\beta = 75$):

i) $g_m = \frac{I_C}{V_T} = \frac{0.983mA}{26mV} = \mathbf{37.80mA/V}$

ii) $r_o = \frac{V_A}{I_C} = \infty$

iii) $r_\pi = \frac{V_T}{I_B} = \frac{26mV}{13.11\mu A} = \mathbf{1.983k\Omega}$

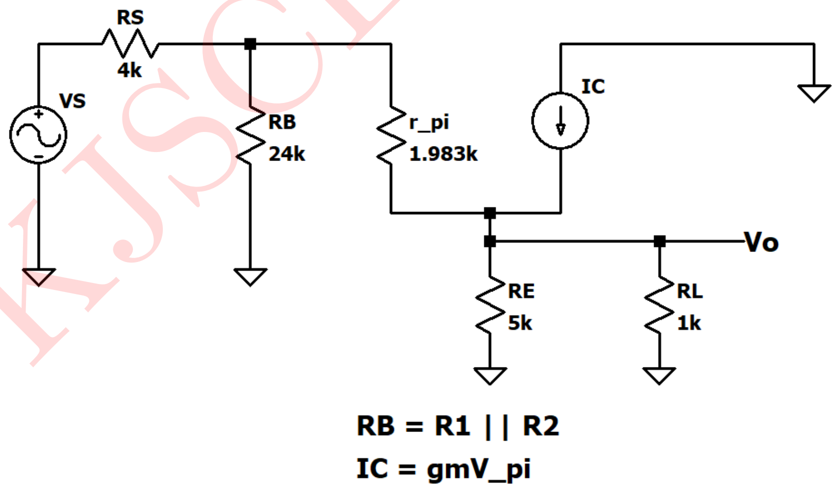

Figure 16: Small signal equivalent circuit for $\beta = 75$

Input impedance(for $\beta = 75$),

$Z_i = R_B \parallel [r_\pi + (1 + \beta)(R_E \parallel R_L)]$

$\quad = 24k\Omega \parallel [1.983k\Omega + (76)(5k\Omega \parallel 1k\Omega)]$

$$\quad = 24k\Omega \parallel \left[1.983k\Omega + 76\left(\frac{5k\Omega \times 1k\Omega}{5k\Omega + 1k\Omega}\right)\right]$$

$\quad = 24k\Omega \parallel [1.983k\Omega + 76(0.83k\Omega)]$

$$= 24k\Omega \parallel [65.063k\Omega]$$

$$= \frac{24k\Omega \times 65.063k\Omega}{24k\Omega + 65.063k\Omega} = \mathbf{17.53k\Omega}$$

Output impedance(for $\beta = 75$),

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

$$= 5k\Omega \parallel 1k\Omega \parallel \frac{1}{37.80mA/V}$$

$$= \frac{5k\Omega \times 1k\Omega}{5k\Omega + 1k\Omega} \parallel 0.026k\Omega$$

$$= 0.83k\Omega \parallel 0.026k\Omega$$

$$= \frac{0.83k\Omega \times 0.026k\Omega}{0.83k\Omega + 0.026k\Omega} = \mathbf{0.025k\Omega}$$

Small signal voltage gain(for $\beta = 75$),

$$A_{V_S} = \frac{V_o}{V_S} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_S} = A_V \times \frac{V_{in}}{V_S} = A_V \times \frac{Z_{in}}{Z_{in} + R_S}$$

$$\because A_V = \frac{V_o}{V_{in}}$$

$$= \frac{I_E(R_E \parallel R_L)}{I_B Z_B}$$

$$= \frac{(\beta+1)I_B(R_E \parallel R_L)}{I_B Z_B}$$

$$= \frac{(\beta+1)(R_E \parallel R_L)}{r_\pi + (1+\beta)(R_E \parallel R_L)}$$

$$= \frac{(75+1)(5k\Omega \parallel 1k\Omega)}{1.983k\Omega + (1+75)(5k\Omega \parallel 1k\Omega)}$$

$$= \frac{76(0.83k\Omega)}{1.983k\Omega + 76(0.83k\Omega)} = \mathbf{0.9695}$$

$$\because A_{V_S} = A_V \times \frac{Z_{in}}{Z_{in} + R_S}$$

$$= 0.9695 \times \frac{17.53k}{(17.53+4)k} = 0.9695 \times 0.8142 = \mathbf{0.789}$$

SIMULATED RESULTS:

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

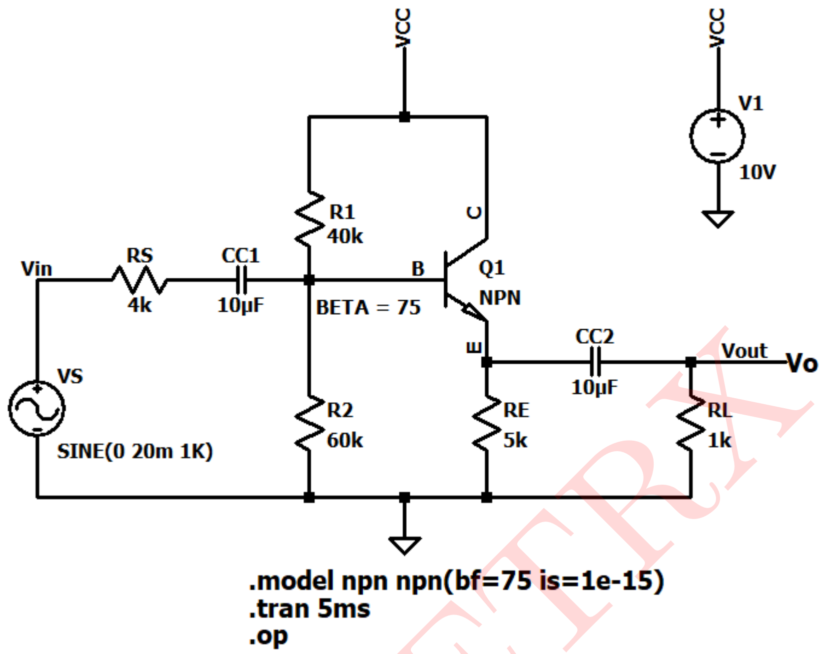

Figure 17: Circuit Schematic

The input and output waveforms are shown in figure 18.

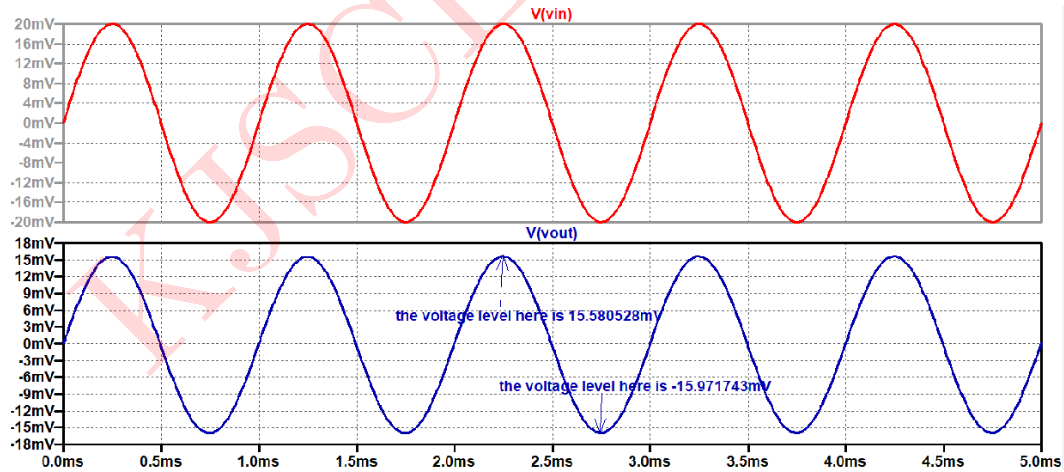

Figure 18: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_C	0.983mA	0.9702mA
I_B	13.11μA	12.937μA
A_{V_S}	0.789	0.788

Table 4: Numerical 3

For $\beta = 150$,
We will get different values for I_B, I_C etc.

Applying KVL to base-emitter loop of Thevenin's equivalent cicuit,

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

$V_{TH} - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0 \qquad ....(I_E = (\beta + 1) I_B)$

$6V - I_B(24k\Omega) - 0.7V - (151) I_B(5k\Omega) = 0$

$5.3V - I_B(24k\Omega + 151(5k\Omega)) = 0$

$I_B = \dfrac{5.3V}{24k\Omega + 755k\Omega} = \mathbf{6.80\mu A}$

$\because I_C = \beta I_B = (150)(6.30\mu\text{A}) = \mathbf{1.0205mA}$

Small signal parameters(for $\beta = 75$):

i) $g_m = \dfrac{I_C}{V_T} = \dfrac{1.0205mA}{26mV} = \mathbf{39.25mA/V}$

ii) $r_o = \dfrac{V_A}{I_C} = \infty$

iii) $r_\pi = \dfrac{V_T}{I_B} = \dfrac{26mV}{6.80\mu A} = \mathbf{3.823k\Omega}$

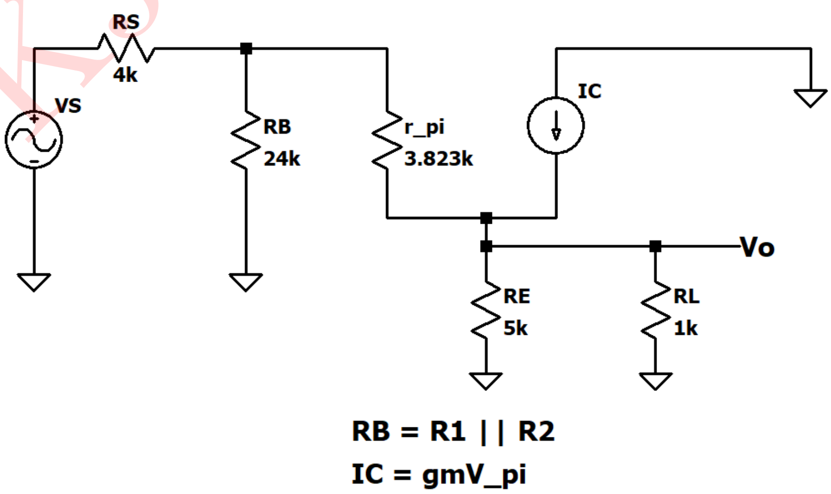

Figure 19: Small signal equivalent circuit for $\beta = 150$

Input impedance(for $\beta = 150$),

$$Z_i = R_B \parallel [r_\pi + (1+\beta)(R_E \parallel R_L)]$$
$$= 24k\Omega \parallel [3.823k\Omega + (151)(5k\Omega \parallel 1k\Omega)]$$
$$= 24k\Omega \parallel [3.823k\Omega + 125.33k\Omega)]$$
$$= 24k\Omega \parallel [3.823k\Omega + 151(0.83k\Omega)]$$
$$= 24k\Omega \parallel [129.153k\Omega]$$
$$= \frac{24k\Omega \times 129.153k\Omega}{24k\Omega + 129.153k\Omega} = \mathbf{20.23k\Omega}$$

Output impedance(for $\beta = 150$),

$$Z_o = R_E \parallel R_L \parallel \frac{1}{g_m}$$
$$= 5k\Omega \parallel 1k\Omega \parallel \frac{1}{39.25mA/V}$$
$$= 0.83k\Omega \parallel 0.025k\Omega$$
$$= \frac{0.83k\Omega \times 0.025k\Omega}{0.83k\Omega + 0.025k\Omega} = \mathbf{0.024k\Omega}$$

Small signal voltage gain(for $\beta = 150$),

$$A_{V_S} = \frac{V_o}{V_S} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_S} = A_V \times \frac{V_{in}}{V_S} = A_V \times \frac{Z_{in}}{Z_{in} + R_S}$$

$$\because A_V = \frac{V_o}{V_{in}}$$
$$= \frac{I_E(R_E \parallel R_L)}{I_B Z_B}$$
$$= \frac{(\beta+1)I_B(R_E \parallel R_L)}{I_B Z_B}$$
$$= \frac{(\beta+1)(R_E \parallel R_L)}{r_\pi + (1+\beta)(R_E \parallel R_L)}$$
$$= \frac{(150+1)(5k\Omega \parallel 1k\Omega)}{3.823k\Omega + (1+150)(5k\Omega \parallel 1k\Omega)}$$
$$= \frac{151(0.83k\Omega)}{3.823k\Omega + 151(0.83k\Omega)} = \mathbf{0.9703}$$

$$\because A_{V_S} = A_V \times \frac{Z_{in}}{Z_{in} + R_S}$$
$$= 0.9703 \times \frac{20.23k}{(20.23+4)k} = 0.9703 \times 0.8349 = \mathbf{0.8101}$$

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

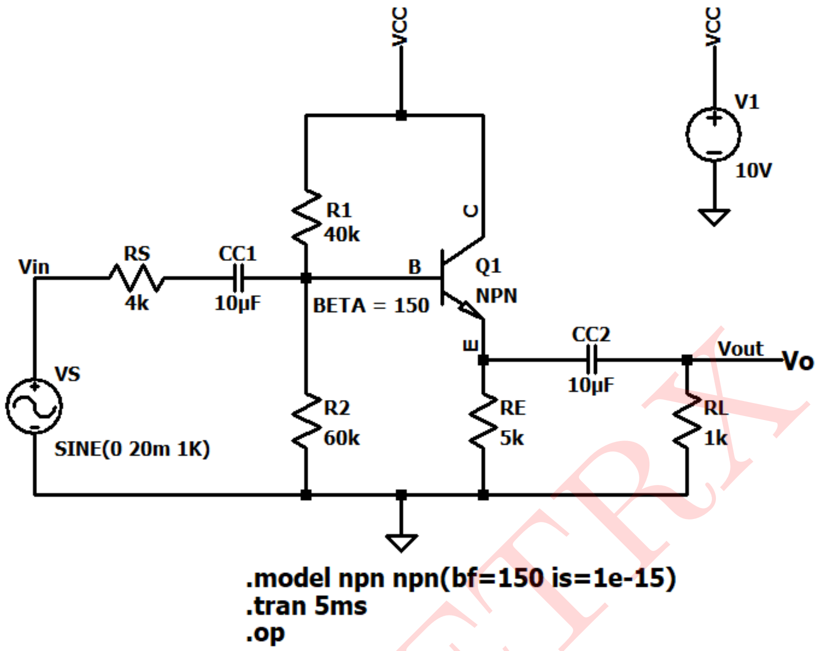

Figure 20: Circuit Schematic

The input and output waveforms are shown in figure 21.

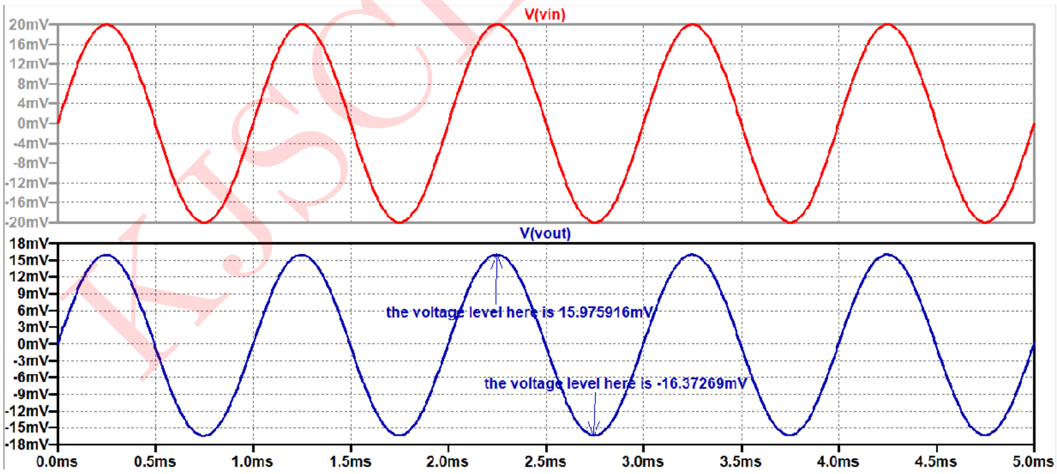

Figure 21: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_C	1.0205mA	1.01763mA
I_B	6.80μA	6.7842μA
A_{V_S}	0.8101	0.8087

Table 5: Numerical 3

For $75 \leq \beta \leq 150$, small signal voltage gain $A_{V_S} = V_o/V_S$ is in the range $0.789 \leq A_{V_S} \leq 0.8101$

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