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

11^{th} **July, 2020**

Numerical 1:
For the network shown in figure 1, determine A_V, Z_i and Z_O
Given: $\beta = 210$, $V_A = 100V$

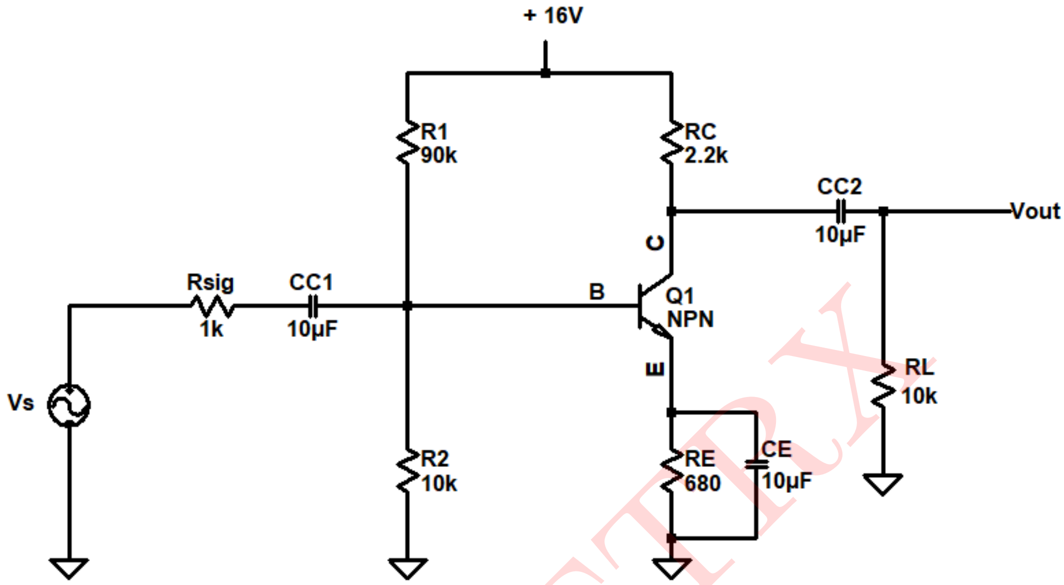

Figure 1: Circuit Diagram

Solution: Circuit shown in figure 1 is a common emitter BJT amplifier.

DC equivalent circuit is shown in figure 2:

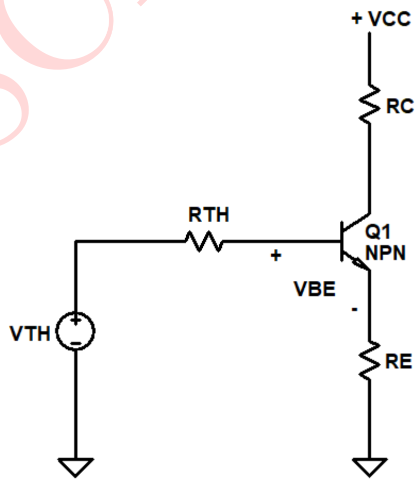

Figure 2: DC equivalent circuit

Thevenin's voltage, $V_{TH} = \dfrac{R_2}{R_1 + R_2} \times V_{CC} = \dfrac{10k\Omega}{10k\Omega + 90k\Omega} = 1.6\text{V}$

Thevenin's equivalent resistance, $R_{TH} = R_1 \parallel R_2 = 10\text{k}\Omega \parallel 90\text{k}\Omega = 9\text{k}\Omega$

Applying KVL to the B-E loop:

$V_{TH} - I_B R_{TH} - V_{BE(ON)} - I_E R_E = 0$

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

$$\therefore I_{BQ} = \frac{V_{TH} - V_{BE(ON)}}{R_{TH} + (1+\beta)R_E} = \frac{1.6 - 0.7}{9k\Omega + 211 \times 680} = \mathbf{5.9024\mu A}$$

$\therefore I_{CQ} = \beta I_{BQ} = 210 \times 5.9024\mu A = \mathbf{1.2395\ mA}$

$I_{EQ} = I_{CQ} + I_{BQ} = \mathbf{1.2454mA}$

Applying KVL to C-E loop:

$V_{CEQ} = V_{CC} - I_C R_C - I_E R_E = 16 - (1.2395mA)(2.2k\Omega) - (1.2454mA)(680)$

$\therefore V_{CEQ} = \mathbf{12.462V}$

Small signal equivalent parameters:

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.2395mA}{26mV} = 47.673 \text{ mA/V}$$
$$r_o = \frac{V_A}{I_{CQ}} = \frac{100}{1.2395mA} = 80.677\text{k}\Omega$$
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{210 \times 26mV}{1.2395mA} = 4.405\text{k}\Omega$$

Figure 3 shows Small signal equivalent circuit:

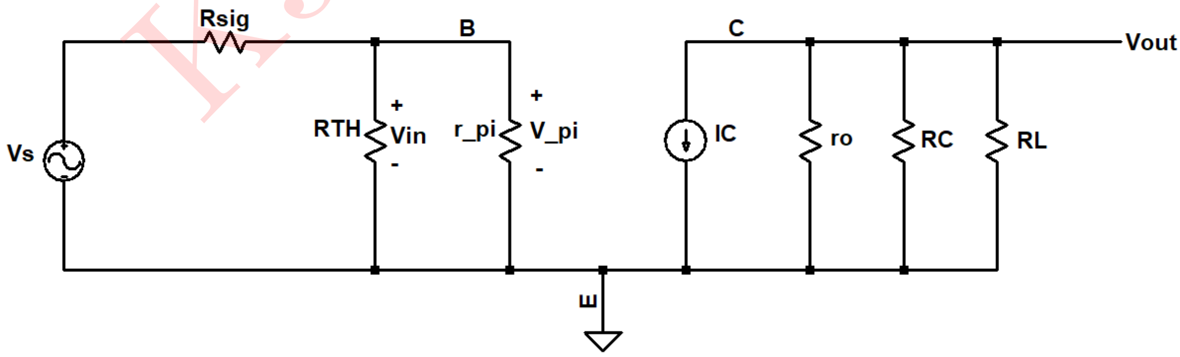

Figure 3: Small signal equivalent circuit

For mid-band analysis, all the capacitors are short-circuited.
Collector current is represented using small signal parameters as: $I_C = g_m V_\pi$

The impedance seen by looking from the input side gives input impedance, which is:

$Z_i = R_1 \parallel R_2 = 90\text{k}\Omega \parallel 10\text{k}\Omega = \mathbf{9k\Omega}$

The output impedance is given as:

$Z_o = r_o \parallel R_C \parallel R_L = 80.677k\Omega \parallel 2.2k\Omega \parallel 10k\Omega = \mathbf{1.7639k\Omega}$

$$\text{Voltage gain: } A_V = \frac{V_{out}}{V_S} \qquad \text{...(1)}$$

$$\text{We know, } V_{in} = \frac{R_1 \parallel R_2}{R_{sig} + (R_1 \parallel R_2)} \times V_S$$

$$\therefore \frac{1}{V_S} = \frac{R_1 \parallel R_2}{R_{sig} + (R_1 \parallel R_2)} \times \frac{1}{V_{in}} \qquad \text{...(2)}$$

$$\text{Also, } V_{out} = -g_m V_\pi (r_o \parallel R_C \parallel R_L) \qquad \text{...(3)}$$

From (1), (2) & (3),

$$A_V = \frac{V_{out}}{V_S} = \frac{-g_m (R_1 \parallel R_2)(r_O \parallel R_C \parallel R_L)}{R_{sig} + (R_1 \parallel R_2)} \qquad \text{...}(\because V_{in} = V_\pi)$$

$$\therefore A_V = \frac{-47.673 \times 10^{-3} \times 9 \times 10^3 \times 1.7639 \times 10^3}{1 \times 10^3 + 9 \times 10^3}$$

$\mathbf{A_V = -75.6814}$

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

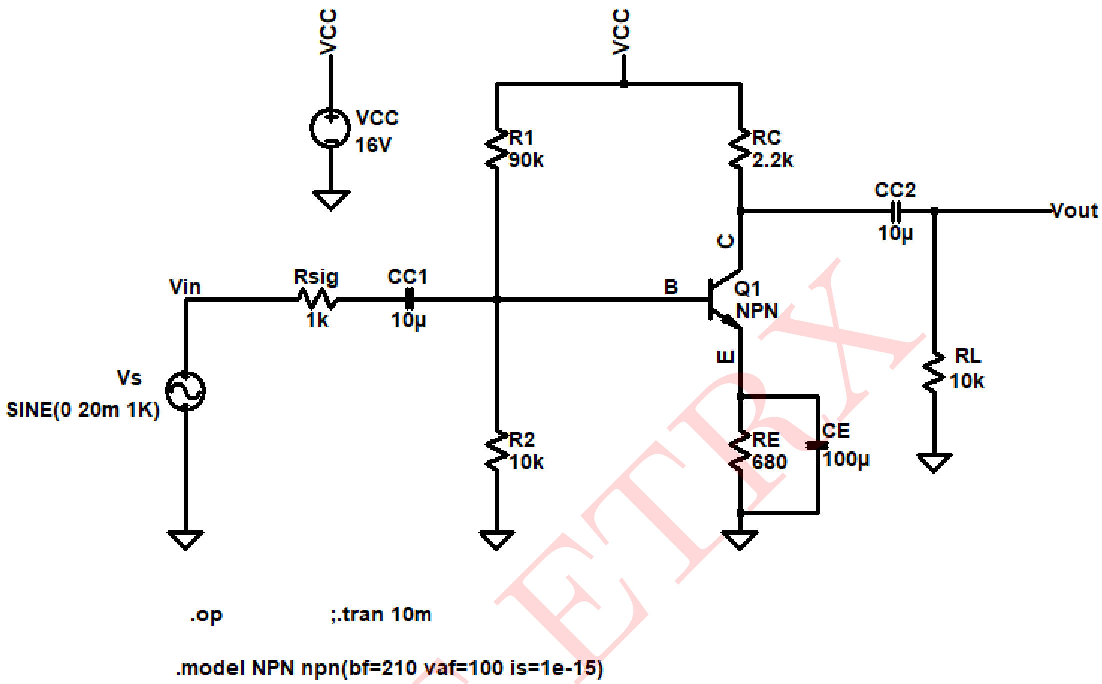

Figure 4: Circuit Schematic: Results

Input and Output waveforms are shown in figure 5:

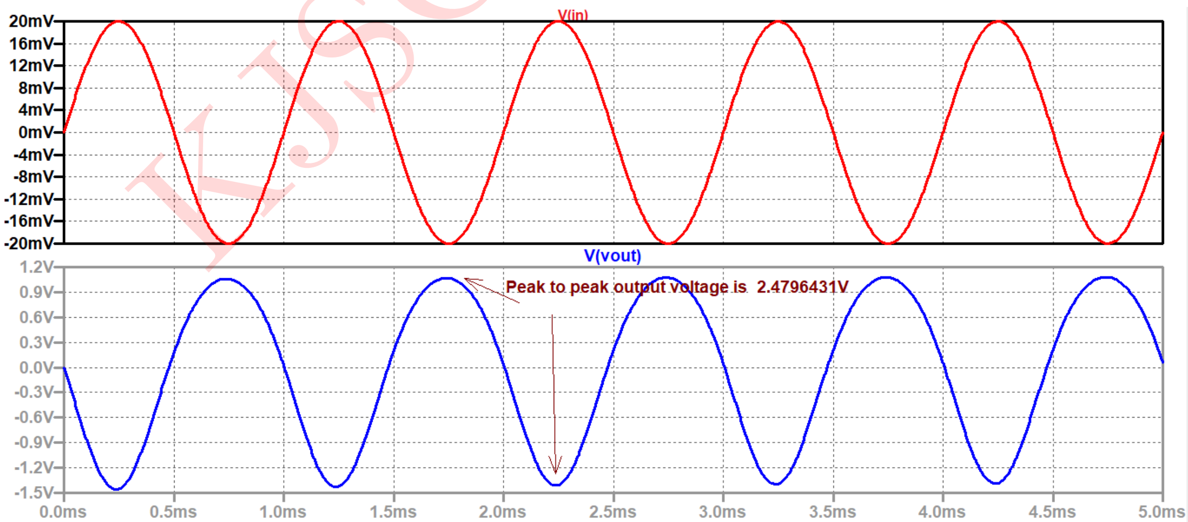

Figure 5: Input and output waveforms

Comparsion between theoretical and simulated values:

Parameter	Theoretical value	Simulated value
I_{CQ}	1.2395mA	1.2242mA
V_{CEQ}	12.4262V	12.4707V
I_{BQ}	5.9024uA	5.2164uA
V_{TH}	1.6V	1.5531V
A_V	-75.6814	-61.6075

Table 1: Numerical 1

Numerical 2:
For the network shown in figure 6, $\beta = 90$, determine:
a. r_π
b. Z_i
c. $Z_o(r_o = \infty)$
d. $A_V(r_o = \infty)$
e. The parameters of parts (b) to (d) if $r_o = 50k\Omega$ and compare results.

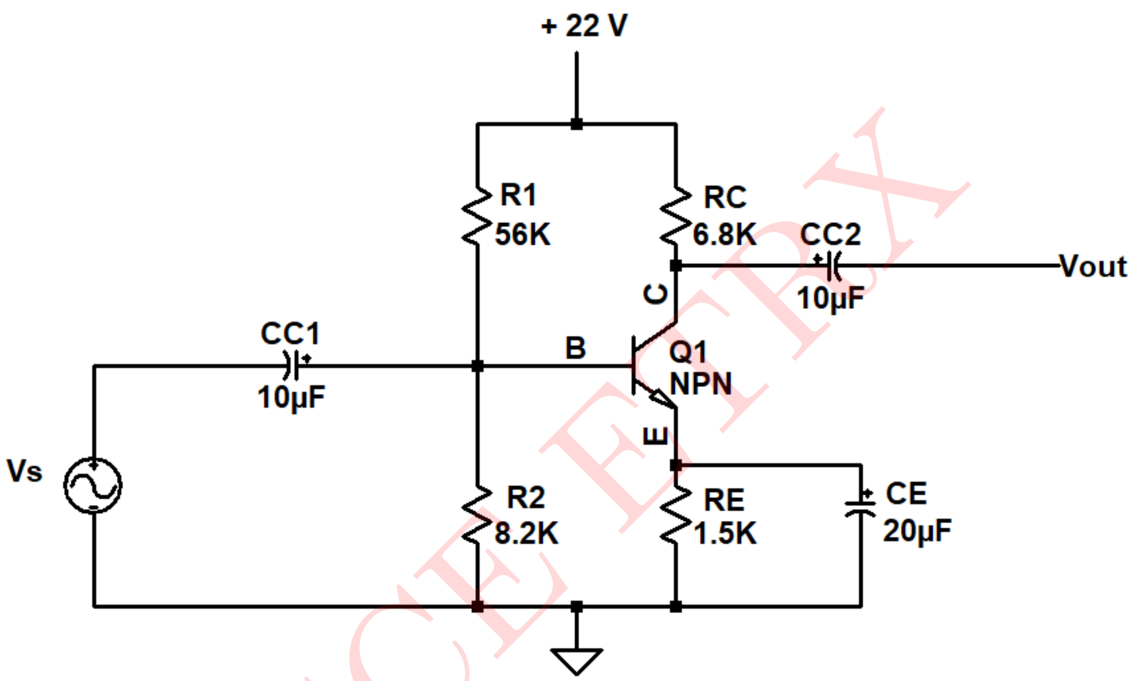

Figure 6: Circuit Diagram

Solution: The circuit shown in figure 6 is common emitter BJT amplifier.

Using Thevenin's theorem:

$$V_{TH} = \frac{R_2 \times 22}{R_1 + R_2} = \frac{8.2 \times 22}{56 + 8.2} = 2.81\text{V}$$

$$R_{TH} = R_1 \parallel R_2 = 56k\Omega \parallel 8.2k\Omega = 7.1526\text{k}\Omega$$

Thevenin's equivalent circuit is shown in figure 7:

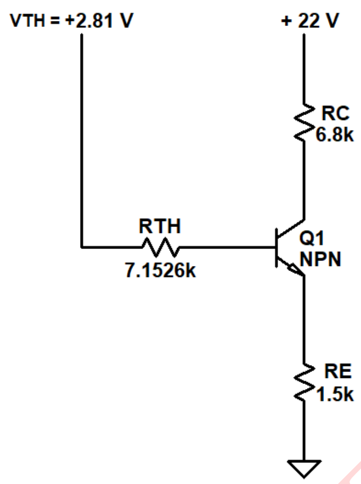

Figure 7: Thevenin's equivalent circuit

Applying KVL to B-E loop:

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

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

$$I_{BQ} = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)R_E} = \frac{2.81 - 0.7}{7.1526k\Omega + 91 \times 1.5k\Omega}$$

$$\therefore I_{BQ} = 14.690\mu\text{A}$$

$$I_{CQ} = \beta I_{BQ} = (90)(14.690\mu\text{A})$$

$$\therefore I_{CQ} = 1.3221mA$$

$$I_{EQ} = (\beta+1)I_{BQ} = (91)(14.69\mu\text{A})$$

$$\therefore I_{EQ} = 1.3368\text{mA}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{90 \times 26mV}{1.3221mA} = \mathbf{1.770k\Omega} \quad ...V_T \text{ is thermal voltage which is 26mV at 27°C}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.3221mA}{26mV} = \mathbf{50.85mA/V}$$

Applying KVL to C-E loop:

$V_{CEQ} = 22 - I_C R_C - I_E R_E$

$\therefore V_{CEQ} = 22 - (1.3221mA)(6.8k\Omega) - (1.3368mA)(1.5k\Omega)$

$\therefore V_{CEQ} = 11V$

Figure 8 shows Small signal equivalent circuit:

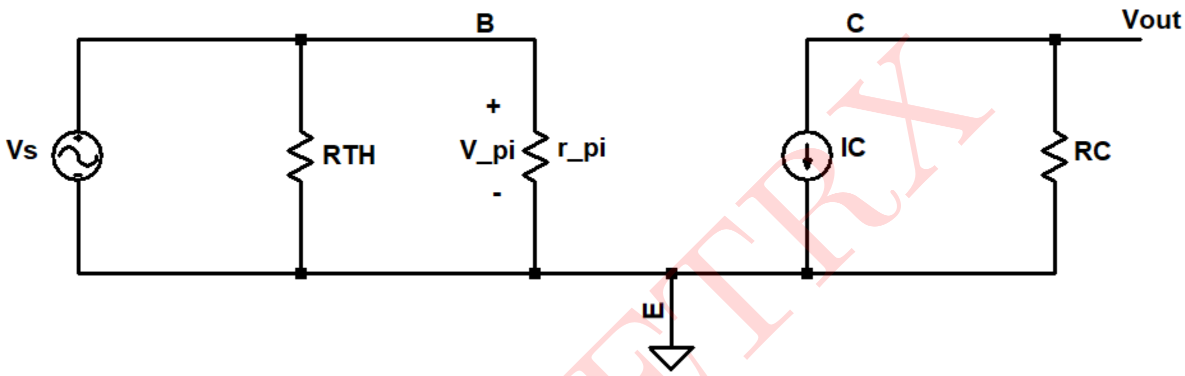

Figure 8: Small signal equivalent circuit

Here $r_o = \infty$ hence open-circuited

For mid-band analysis, all the capacitors are short-circuited.
Collector current is represented using small signal parameters as: $I_C = g_m V_\pi$

The impedance seen by looking from the input side gives input impedance, which is:

$Z_i = R_1 \parallel R_2 \parallel r_\pi = 56k\Omega \parallel 8.2k\Omega \parallel 1.77k\Omega$

$\therefore \mathbf{Z_i = 1.4189k\Omega}$

Output impedance is given as:

$Z_o = R_C$

$\therefore \mathbf{Z_o = 6.8k\Omega}$

Voltage gain, $A_V = \dfrac{V_{out}}{V_{in}}$ ...(1)

$V_{out} = -g_m V_\pi R_C$ ...(2)

As seen from small signal equivalent circuit:

$V_{in} = V_\pi$ ...(3)

From (1), (2) & (3), we get:

$A_V = \dfrac{-g_m \times V_\pi \times R_C}{V_\pi}$

$\therefore A_V = -g_m R_C$

$\therefore A_V = -50.85mA \times 6.8k\Omega$

$\mathbf{A_V = -345.75}$

Small signal equivalent circuit with r_o is shown in figure 9:

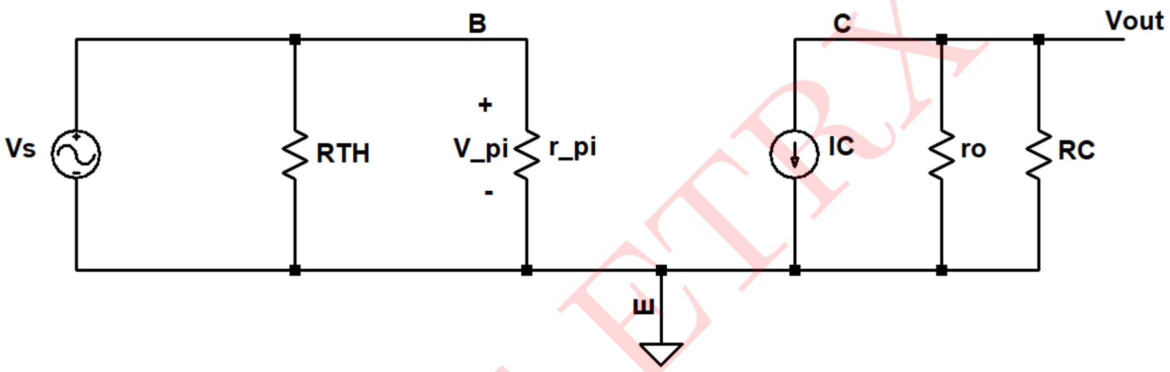

Figure 9: Small signal equivalent circuit with r_o

Input impedance remains unchanged,

$Z_i = R_1 \parallel R_2 \parallel r_\pi$

$\mathbf{Z_i = 1.4189k\Omega}$

Output impedance is given as:

$Z_o = R_C \parallel r_o = 6.8k\Omega \parallel 50k\Omega$

$\mathbf{Z_o = 5.9859k\Omega}$

Also voltage gain, $A_V = \dfrac{V_{out}}{V_{in}}$

$V_{out} = -g_m V_\pi (R_C \parallel r_o) \qquad ...(V_{in} = V_\pi)$

$\therefore A_V = -g_m (R_C \parallel r_o)$

$A_V = -(50.85mA)(6.8k\Omega \parallel 50k\Omega)$

$\mathbf{A_V = -304.38}$

Comparing results with and without r_o :

Parameter	ro = 50kΩ	ro = ∞
Z_i	1.4189kΩ	1.4189kΩ
Z_o	5.9859kΩ	6.8kΩ
A_V	−304.38	−345.75

Table 2: Numerical 2

Output impedance decreases and r_o changes from ∞ to 50kΩ

Also, the voltage gain of the amplifier decreases from ∞ to 50kΩ which means that early voltage V_A is no more ∞ ($\because r_o \propto V_A$). Hence, BJT deviates from it's ideal characteristics.

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

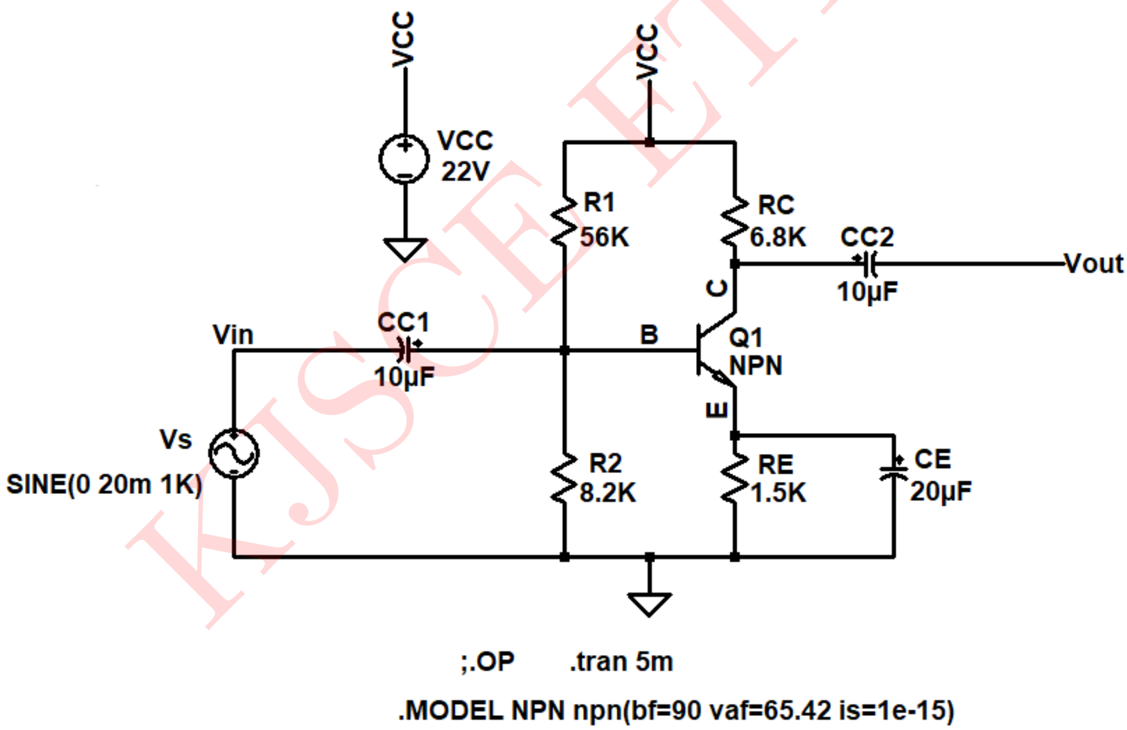

Figure 10: Circuit Schematic: Results

The input and output waveforms for both the cases are shown in figure 11 and 12 respectively:

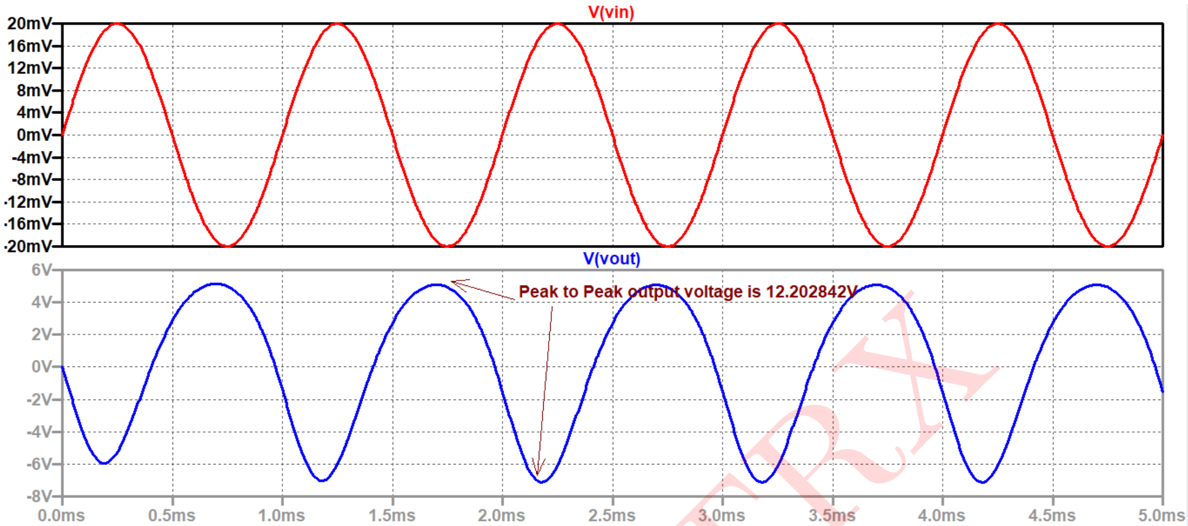

Figure 11: Input and output waveform for $r_o = \infty$

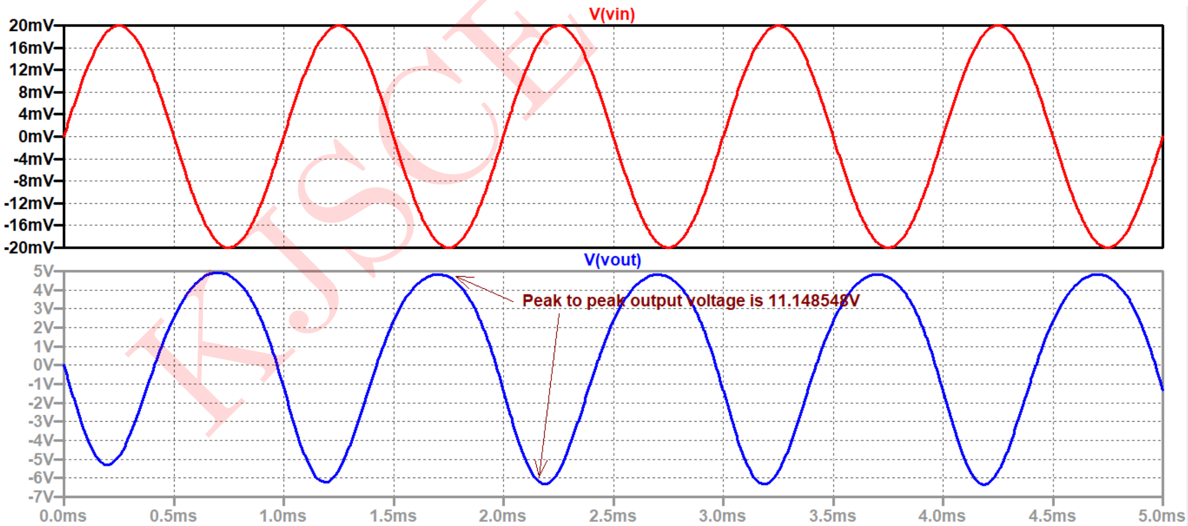

Figure 12: Input and output waveform for $r_o = 50k\Omega$

Comparsion between theoretical and simulated values:

Parameter	Theoretical value	Simulated value
I_{CQ}	1.3221mA	1.3084mA
I_{BQ}	14.690μA	14.5374μA
V_{CEQ}	11.0V	11.1187V
V_{TH}	2.81V	2.706V
A_V (with r_o)	-304.38	-278.71
A_V (without r_o)	-345.75	-305.71

Table 3: Numerical 2

Numerical 3:
For the network shown in figure 13, the transistor parameters are $\beta = 100$ and $V_A = 100$V Determine R_i and $A_V = V_{out}/V_s$

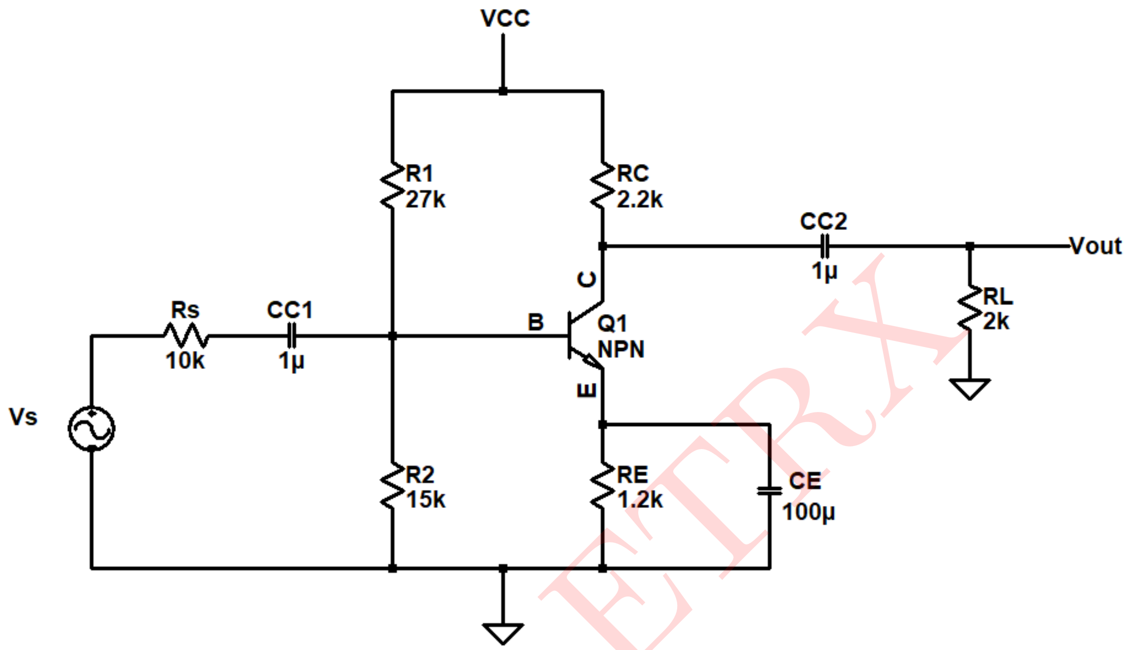

Figure 13: Circuit Diagram

Solution: The circuit shown in figure 13 is a common emitter BJT Amplifier.

$$V_{TH} = \frac{15k\Omega \times 9}{27k\Omega + 15k\Omega} = 3.2143\text{V}$$

$$R_{TH} = R_1 \parallel R_2 = 27\text{k}\Omega \parallel 15\text{k}\Omega = 9.6429\text{k}\Omega$$

Thevenin's equivalent circuit is shown in figure 14:

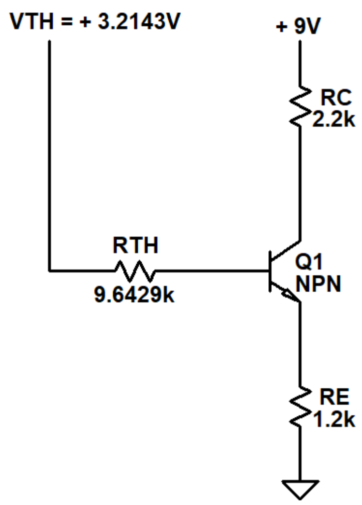

Figure 14: Thevenin's equivalent circuit

Applying KVL to B-E loop:

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

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

$\therefore I_{BQ} = \dfrac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1) R_E} = \dfrac{3.2143 - 0.7}{9.6429 k\Omega + 101 \times 1.2 k\Omega}$

$\therefore I_{BQ} = \mathbf{19.2162\mu A}$

We know, $I_{CQ} = \beta I_{BQ}$ and $I_{EQ} = (\beta + 1) I_{BQ}$

$\therefore I_{CQ} = 100 \times 19.2162\mu A = 1.9216\text{mA}$

$I_{EQ} = (100 + 1) 19.2162\mu A = 1.9408 mA$

Small signal parameters:

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{100 \times 26mV}{1.9216mA}$

$\therefore r_\pi = 1.353 k\Omega$, where V_T is thermal voltage which is 26mV at 27°C

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{1.9216mA}{26mV} = 73.9077$ mA/V

Applying KVL to C-E loop:

$V_{CEQ} = 9 - I_C R_C - I_E R_E$

$\therefore V_{CEQ} = 9 - (1.9216mA)(2.2k\Omega) - (1.9408mA)(1.2k\Omega)$

$\therefore V_{CEQ} = 2.4435$V

Figure 15 shows Small signal equivalent circuit:

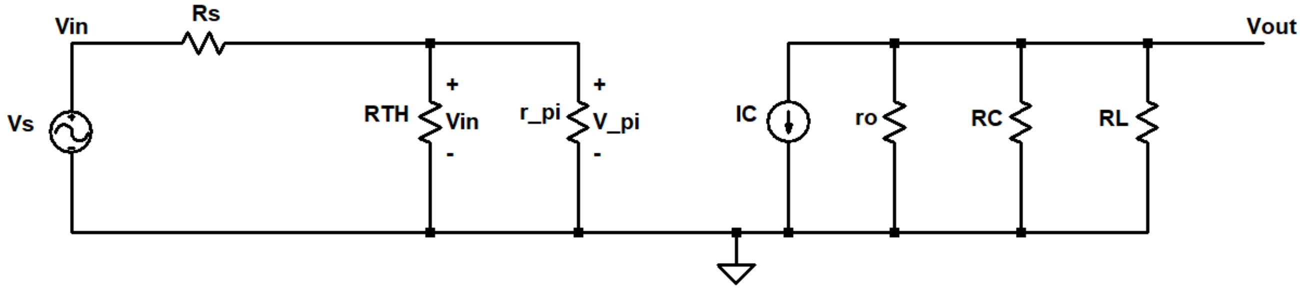

Figure 15: Small signal equivalent circuit

All capacitors are short-circuited.

Input resistance, $R_i = R_1 \parallel R_2 \parallel r_\pi$

$\therefore R_i = 27k\Omega \parallel 15k\Omega \parallel 1.353k\Omega = 1.1865\text{k}$

$\therefore \mathbf{R_i = 1.1865k\Omega}$

Voltage gain: $A_V = \dfrac{V_{out}}{V_s} = \dfrac{V_{out}}{V_{in}} \times \dfrac{V_{in}}{V_s}$ ...(1)

From small signal equivalent circuit, $V_{in} = V_\pi$

$\therefore V_{out} = -g_m V_\pi (R_C \parallel r_o \parallel R_L)$ ...(2)

Also, $V_{in} = \dfrac{R_1 \parallel R_2 \parallel r_\pi}{R_s + (R_1 \parallel R_2 \parallel r_\pi)} \times V_s$

$\therefore \dfrac{1}{V_s} = \dfrac{R_1 \parallel R_2 \parallel r_\pi}{R_s + (R_1 \parallel R_2 \parallel r_\pi)} \times \dfrac{1}{V_\pi}$ ...(3)

From (1), (2) and (3):

$$A_V = \frac{-g_m V_\pi (R_C \parallel r_o \parallel R_L)}{V_\pi} \times V_\pi \times \frac{R_1 \parallel R_2 \parallel r_\pi}{R_s + (R_1 \parallel R_2 \parallel r_\pi)} \times \frac{1}{V_\pi}$$

$$\therefore A_V = \frac{-g_m (R_C \parallel r_o \parallel R_L)(R_1 \parallel R_2 \parallel r_\pi)}{R_s + (R_1 \parallel R_2 \parallel r_\pi)}$$

$$\therefore A_V = \frac{(-73.9077 \times 10^{-3})(1.0269 \times 10^3)(1.1855 \times 10^3)}{(10 + 1.1865) \times 10^3}$$

$\mathbf{A_V = -8.05}$

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

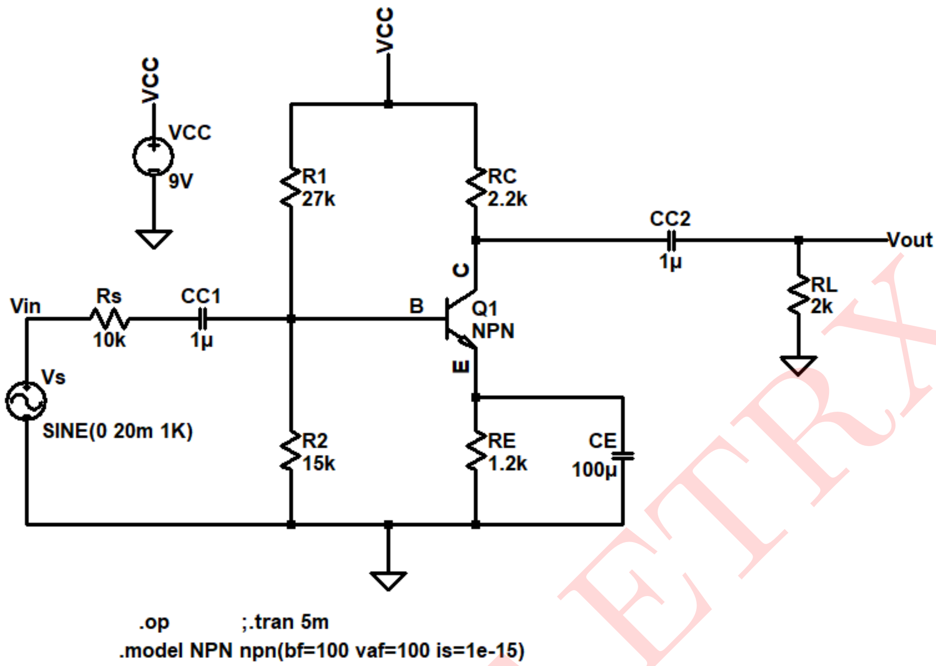

Figure 16: Circuit Schematic: Results

The input and output waveform is shown in figure 17:

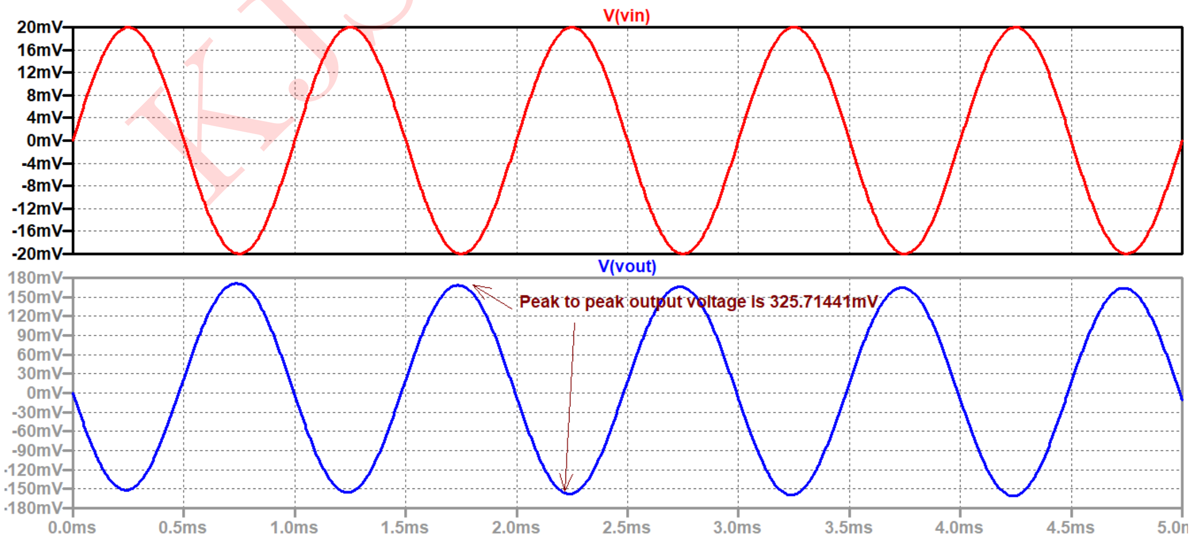

Figure 17: Input and output waveform

Comparsion between theoretical and simulated values:

Parameter	Theoretical value	Simulated value
I_{CQ}	1.9216mA	1.9mA
I_{BQ}	19.2162μA	18.6749μA
V_{TH}	3.2143V	3.0342V
V_{CEQ}	2.4435V	2.5149V
A_V	-8.05	-8.15

Table 4: Numerical 3