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, a) Determine r_π, b) Calculate Z_i and Z_o c) Find A_V d) Repeat parts b) and c) with $r_o = 25k\Omega$
Given: $\beta = 100$

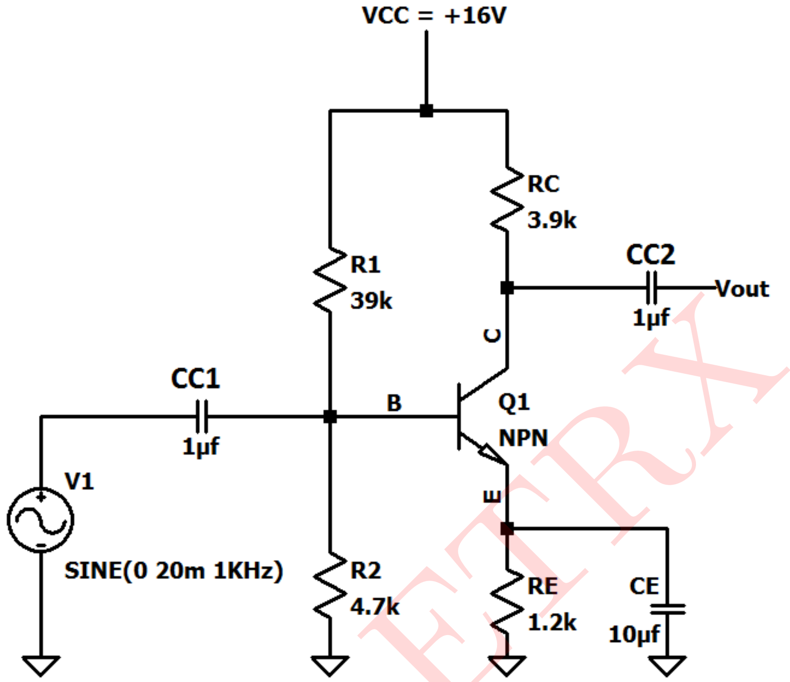

Figure 1: Circuit 1

Solution:

Above circuit 1 is a common-emitter BJT amplifier

DC Analysis:-

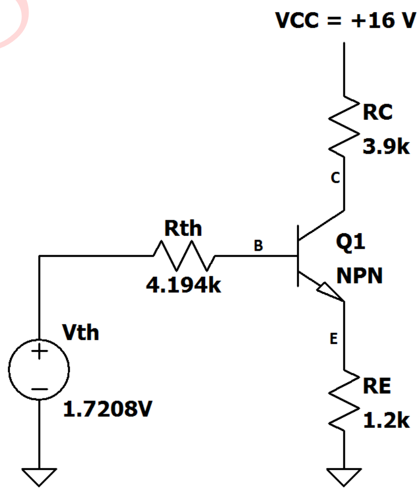

Figure 2: DC Equivalent circuit

$V_B = V_{th} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{4.7k\Omega}{4.7k\Omega + 3.9k\Omega} \times 1.6 = 1.72V$

$\boldsymbol{V_{th} = 1.72V}$

$R_{th} = R1||R2 = 4.194k\Omega$

$\boldsymbol{R_{th} = 4.194k\Omega}$

Applying KVL to the base-emitter loop:-

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

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

Assume $V_{BE(ON)} = 0.7V$

$V_{th} - I_B R_{th} - 0.7V - (\beta + 1)I_B R_E = 0$

$I_B = \frac{V_{th} - 0.7V}{R_{th} + ((\beta + 1)R_E)} = \frac{1.72 - 0.7}{4.194k\Omega + (101 \times 1.2k\Omega)} = 8.13\mu A$

$\boldsymbol{I_B = 8.13\mu A}$

$I_C = \beta I_B = 100 \times 8.13\mu A = 0.813mA$

$\boldsymbol{I_C = 0.813mA}$

Applying KVL to the collector emiiter loop:-

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

$V_{CE} = V_{CC} - I_C R_C - (\beta + 1)I_B R_E$

$V_{CE} = 16 - (0.813 \times 3.9) - (101 \times 8.13 \times 1.2 \times 10^{-3}) = 11.84V$

$\boldsymbol{V_{CE} = 11.84V}$

Small-Signal parameters:-

$g_m = \frac{I_C}{V_T} = \frac{0.813mA}{26mV} = 31.27\frac{mA}{V}$

$\boldsymbol{g_m = 31.27\frac{mA}{V}}$

$r_o = 50k\Omega(\text{given})$

$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{8.13\mu A} = 3.198k\Omega$

$\boldsymbol{r_\pi = 3.198k\Omega}$

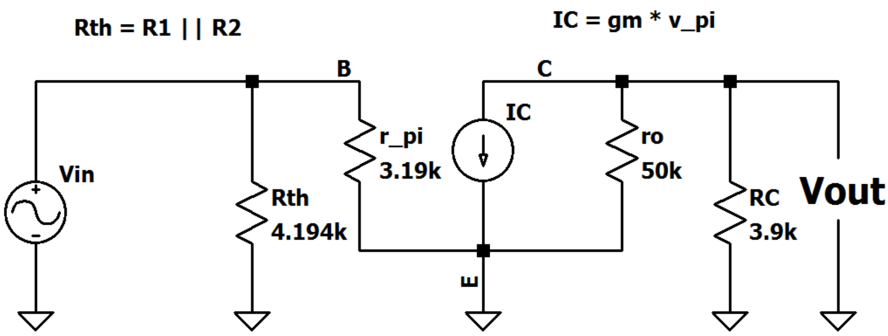

Figure 3: Small Signal Equivalent Circuit

Input Impedance $= Z_i = R_{th} = 4.194k\Omega$

$\boldsymbol{Z_i = 4.194k\Omega}$

Output Impedance $= Z_o = r_o||R_C = 50k\Omega||3.9k\Omega = 3.617k\Omega$

$\boldsymbol{Z_o = 3.167k\Omega}$

Applying KCL at the collector terminal:-

$$g_m V_\pi + \frac{V_{out}}{r_o} + \frac{V_{out}}{R_C} = 0$$

$$g_m V_{in} = -V_{out}\left(\frac{1}{r_o} + \frac{1}{R_C}\right) \qquad \text{.........(1)}$$

$$A_V = \frac{V_o}{V_{in}} = -g_m(r_o||R_C) \qquad \text{.........(2)}$$

$$A_V = -31.27\frac{mA}{V}(50k\Omega||3.9\Omega) = -113.10$$

$\boldsymbol{A_V = -113.10}$

Negative sign indicated 180 out of phase between input and output signal

<u>When $r_o = 25k\Omega$</u>

Input Impedance $= Z_i = R_{th} = 4.194k\Omega$

$\boldsymbol{Z_i = 4.194k\Omega}$

Output Impedance $= Z_o = r_o||R_C = 25k\Omega||3.9k\Omega = 3.3737k\Omega$

$\boldsymbol{Z_o = 3.3737k\Omega}$

$$A_V = \frac{V_o}{V_{in}} = -g_m(r_o||R_C)$$

$$A_V = -31.27\frac{mA}{V}(25k\Omega||3.9\Omega) = -105.495$$

$\boldsymbol{A_V = -105.495}$

SIMULATED RESULTS:
Above circuit was simulated in LTSpice and results are presented below:

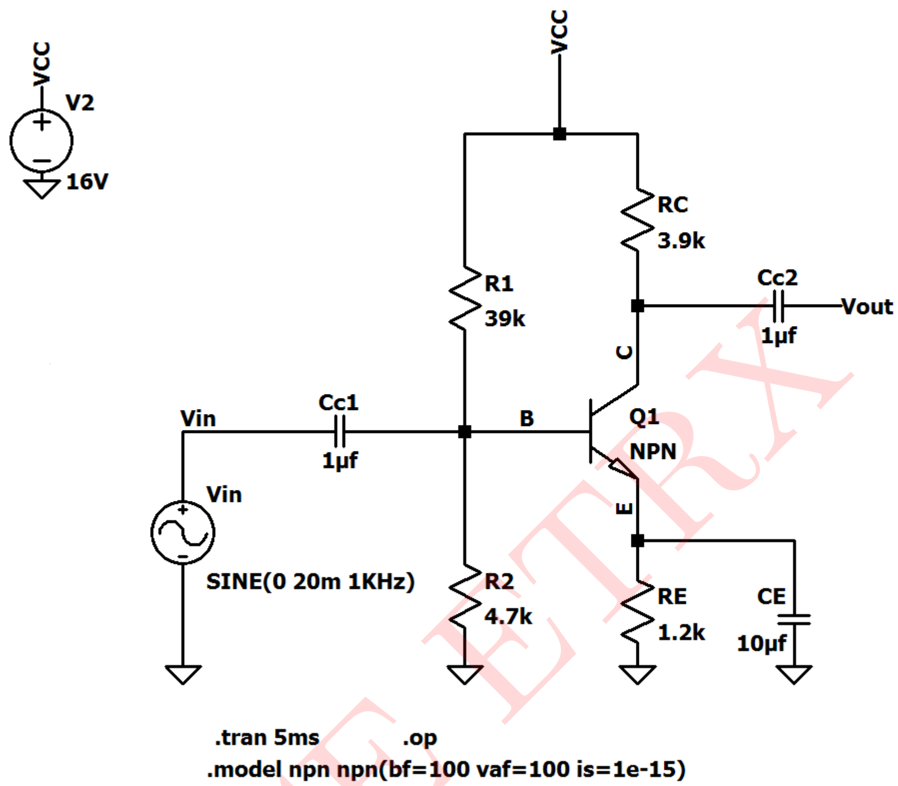

Figure 4: Circuit Schematic 1

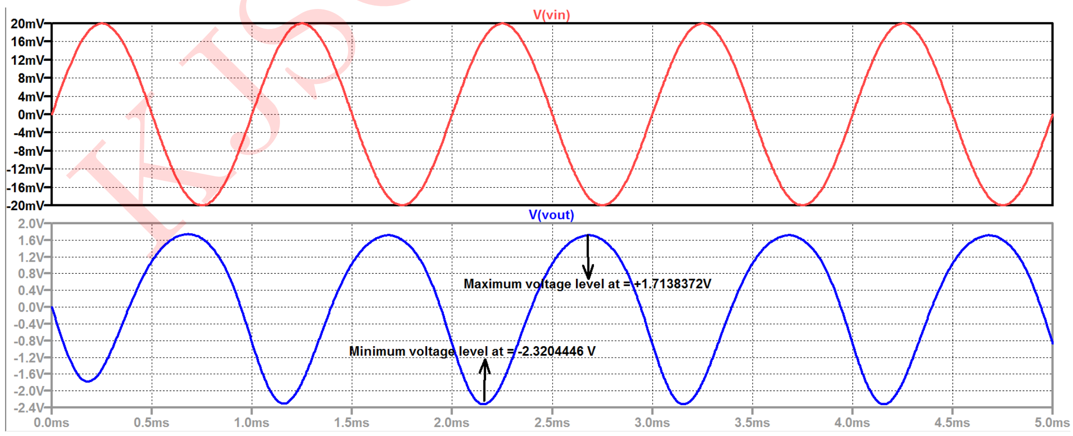

Figure 5: Input & Output waveform

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
V_{th}	$1.72V$	$1.69V$
I_C	$0.813mA$	$0.812mAV$
V_{CE}	$11.84V$	$11.84V$
$A_V(r_o = 50k\Omega)$	-113.10	-100.85
$A_V(r_o = 25k\Omega)$	-105.498	$-100.74V$

Table 1: Numerical 1

Numerical 2:

For the circuit shown in figure 6, a) Determine r_π b) Calculate Z_i c) Calculate Z_o d) Find A_V

Given: $\beta = 120$

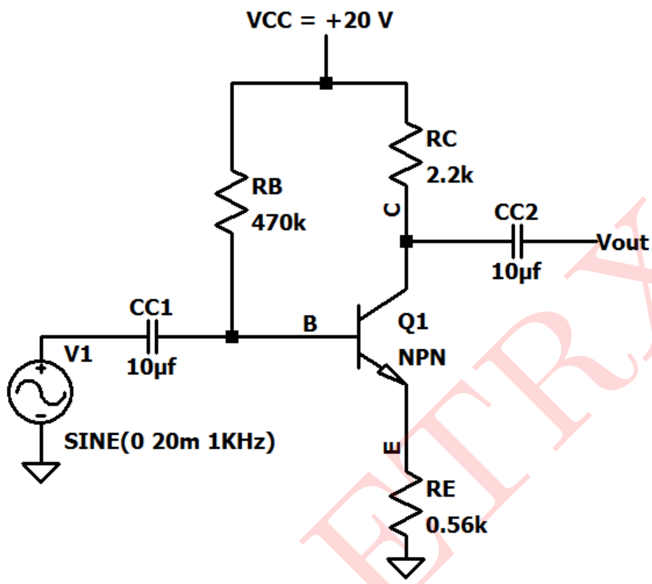

Figure 6: Circuit 2

Solution:

Above circuit 2 is a common-emitter(unbypassed) BJT amplifier

DC Analysis:-

Applying KVL to the base-emitter loop:-

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

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

Assume $V_{BE(ON)} = 0.7V$

$V_{CC} - I_B R_B - 0.7V - (\beta + 1)I_B R_E = 0$

$$I_B = \frac{V_{CC} - 0.7V}{R_B + ((\beta + 1)R_E)} = \frac{20 - 0.7}{470k\Omega + (121 \times 0.56k\Omega)} = 35.88\mu A$$

$\boldsymbol{I_B = 35.88\mu A}$

$I_C = \beta I_B = 120 \times 35.88\mu A = 4.306mA$

$\boldsymbol{I_C = 4.306mA}$

Applying KVL to the collector emiiter loop:-

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

$V_{CE} = V_{CC} - I_C R_C - (\beta + 1)I_B R_E$

$V_{CE} = 20 - (4.306 \times 2.2) - (121 \times 35.88 \times 560 \times 10^{-3}) = 8.095V$

$\boldsymbol{V_{CE} = 8.095V}$

Small-Signal parameters:-

$g_m = \frac{I_C}{V_T} = \frac{4.306mA}{26mV} = 165.6\frac{mA}{V}$

$\boldsymbol{g_m = 165.6\frac{mA}{V}}$

$r_o = 40k\Omega(\text{given})$

$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{35.88\mu A} = 0.724k\Omega$

$\boldsymbol{r_\pi = 0.724k\Omega}$

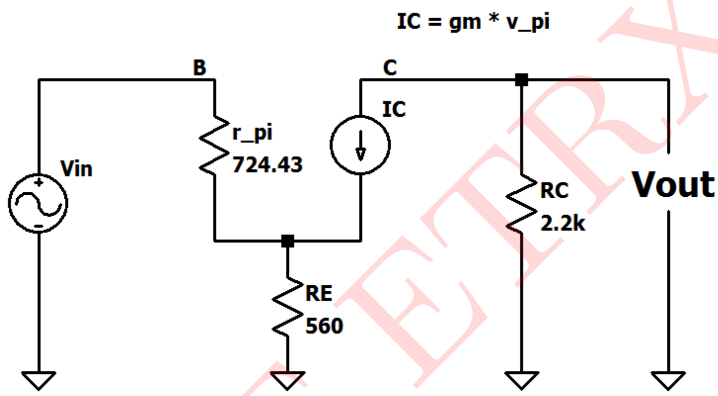

Figure 7: Small Signal Equivalent Circuit

<u>Input Impedance</u>

$V_{in} = V_\pi + V_{RE}$

$V_{in} = i_x r_\pi + I_E R_E = i_x r_\pi + (\beta+1)i_x R_E$

$V_{in} = i_x[r_\pi + (\beta+1)R_E]$

$Z_i = \frac{V_{in}}{i_x} = r_\pi + (\beta+1)R_E = 724.63 + (121 \times 560) = 68.484k\Omega$

$\boldsymbol{Z_i = 68.484k\Omega}$

<u>Output Impedance</u>

Applying KCL at emitter node,

$\frac{V_\pi}{r_\pi} + g_m V_\pi = \frac{-V_\pi}{R_E} \quad [V_{RE} = -V_\pi]$

This implies $V_\pi = 0$

If, $V_\pi = 0$; then $g_m V_\pi = 0$

i.e. current source is zero, it is open circuit

$\therefore Z_o = R_C = 2.2k\Omega$

$\boldsymbol{Z_o = 2.2k\Omega}$

Applying KCL at the collector terminal:-

$$g_m V_\pi + \frac{V_{out}}{R_C} = 0$$

$$V_\pi = -\frac{V_{out}}{g_m R_C} \qquad \text{.........(1)}$$

Applying KCL at emitter node,

$$\left(\frac{V_\pi}{r_\pi} + g_M V_\pi\right) R_E = \text{Voltage drop on } R_E$$

$$\left[\frac{-V_{out}}{g_m R_C} \times \frac{1}{r_\pi} + g_m \left(\frac{-V_{out}}{g_m R_C}\right)\right] R_E = \text{Voltage drop on } R_E \qquad \text{.........(2)}$$

Applying KVL at the base-emitter loop:-

$$V_{in} = V_\pi + \text{Voltage drop on } R_E$$

From (1) & (2)

$$V_{in} = \frac{-V_{out}}{g_m R_C} - \frac{V_{out}}{g_m r_\pi R_C} R_E - \frac{V_{out}}{R_C} R_E$$

$$V_{in} = \frac{-V_{out}}{g_m R_C} - \frac{V_{out}}{\beta R_C} R_E - \frac{V_{out}}{R_C} R_E \qquad [\because g_m R_\pi = \beta]$$

$$V_{in} = \frac{-V_{out}\beta + g_m R_E V_{out} + \beta g_m R_E V_{out}}{\beta(g_m R_C)}$$

$$\frac{V_{out}}{V_{in}} = \frac{-\beta g_m R_C}{\beta + (\beta+1) g_m R_E}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-120 \times 0.1656 \times 2.2k\Omega}{120 + (121 \times 0.1656 \times 560)} = -3.854$$

$$\boldsymbol{A_V = -3.854}$$

SIMULATED RESULTS:
Above circuit was simulated in LTSpice and results are presented below:

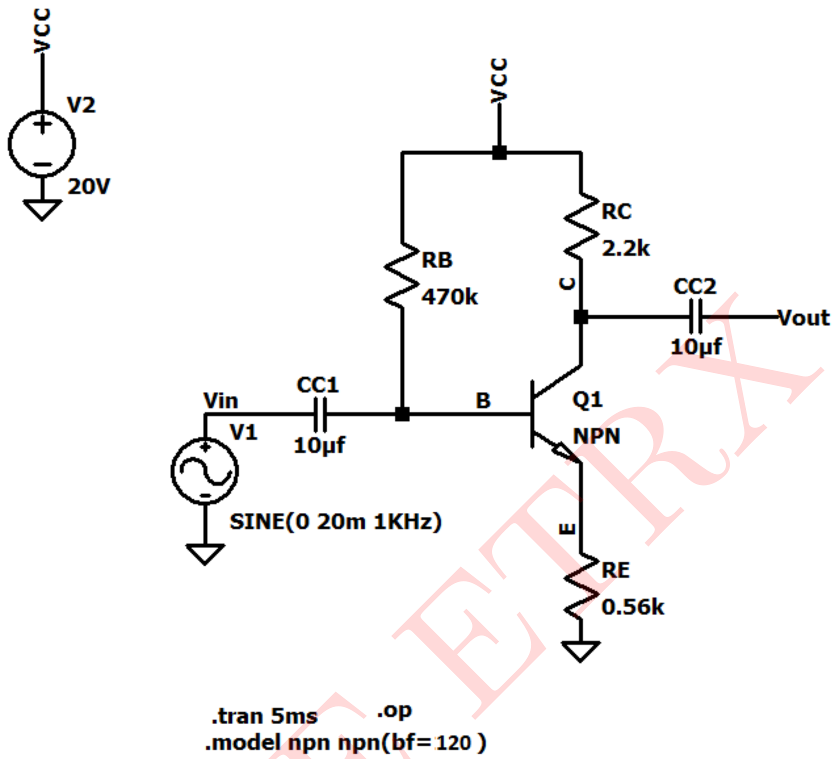

Figure 8: Circuit Schematic 2

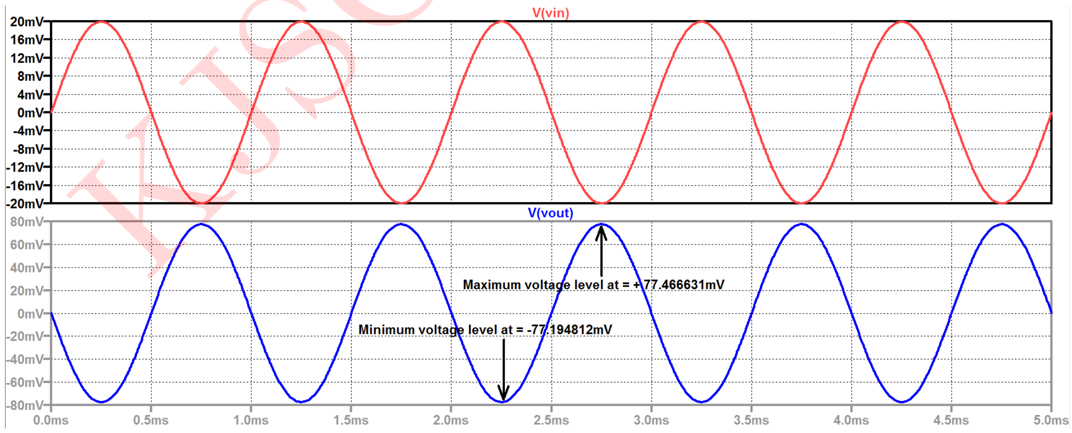

Figure 9: Input & Output waveform

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_B	$35.88\mu A$	$35.68\mu A$
I_C	$4.306mA$	$4.28mAV$
V_{CE}	$8.095V$	$8.162V$
A_V	-3.854	-3.866

Table 2: Numerical 2

Numerical 3:
For the circuit shown in figure 10, $\beta = 180$ and $r_o = \infty$ a) Determine Q-point values b) Small Signal hyprid-π parameters c) Small Signal Voltage gain $A_V = \frac{V_{out}}{V_S}$

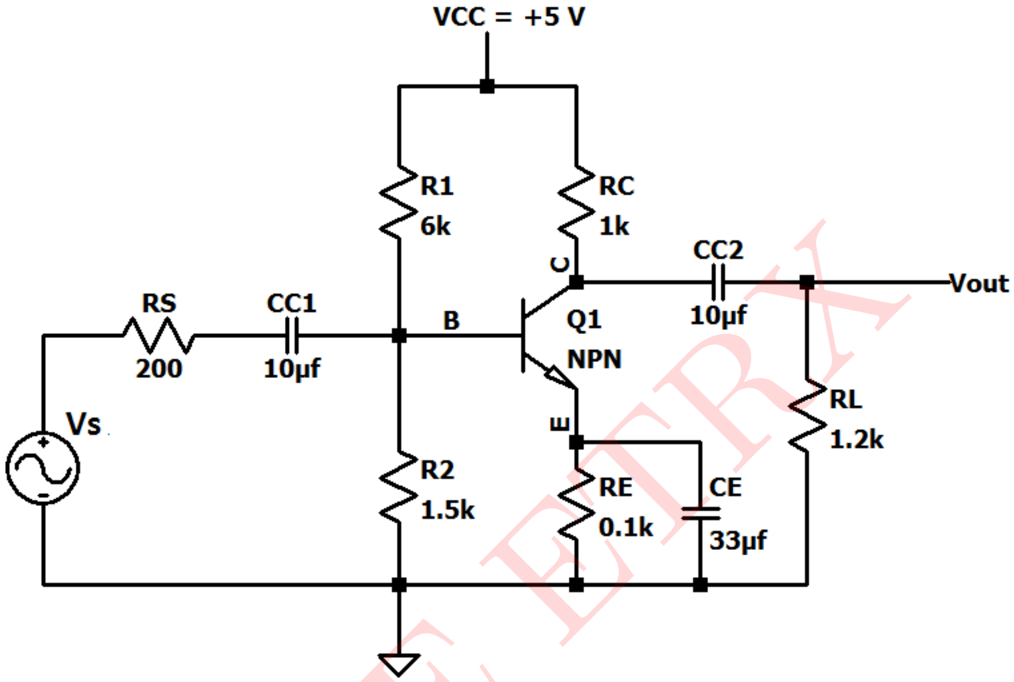

Figure 10: Circuit 3

Solution:

Above circuit 3 is a common-emitter(unbypassed) BJT amplifier

DC Analysis:-

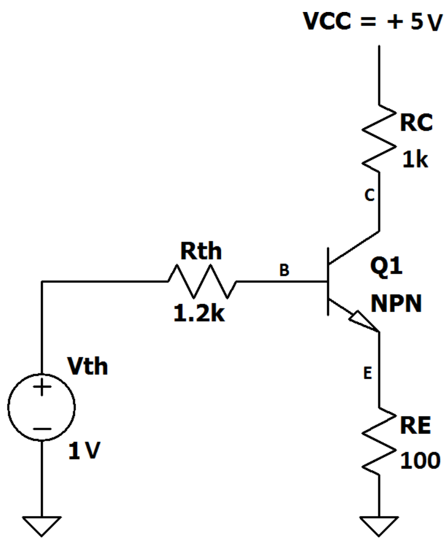

Figure 11: DC Equivalent circuit

$$V_B = V_{th} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{1.5k\Omega}{6k\Omega + 1.5k\Omega} \times 5 = 1V$$

$\boldsymbol{V_{th} = 1V}$

$R_{th} = R1||R2 = 1.2k\Omega$

$\boldsymbol{R_{th} = 1.2k\Omega}$

Applying KVL to the base-emitter loop:-

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

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

Assume $V_{BE(ON)} = 0.7V$

$V_{th} - I_B R_{th} - 0.7V - (\beta + 1) I_B R_E = 0$

$$I_B = \frac{V_{th} - 0.7V}{R_{th} + ((\beta + 1)R_E)} = \frac{1 - 0.7}{1.2k\Omega + (181 \times 0.1k\Omega)} = 15.54\mu A$$

$\boldsymbol{I_B = 15.54\mu A}$

$I_C = \beta I_B = 180 \times 15.54\mu A = 2.74mA$

$\boldsymbol{I_C = 2.74mA}$

Applying KVL to the collector emiiter loop:-

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

$V_{CE} = V_{CC} - I_C R_C - (\beta + 1) I_B R_E$

$V_{CE} = 5 - (2.74mA \times 1k\Omega) - (181 \times 15.54 \times 0.1 \times 10^{-3}) = 1.99V$

$\boldsymbol{V_{CE} = 1.99V}$

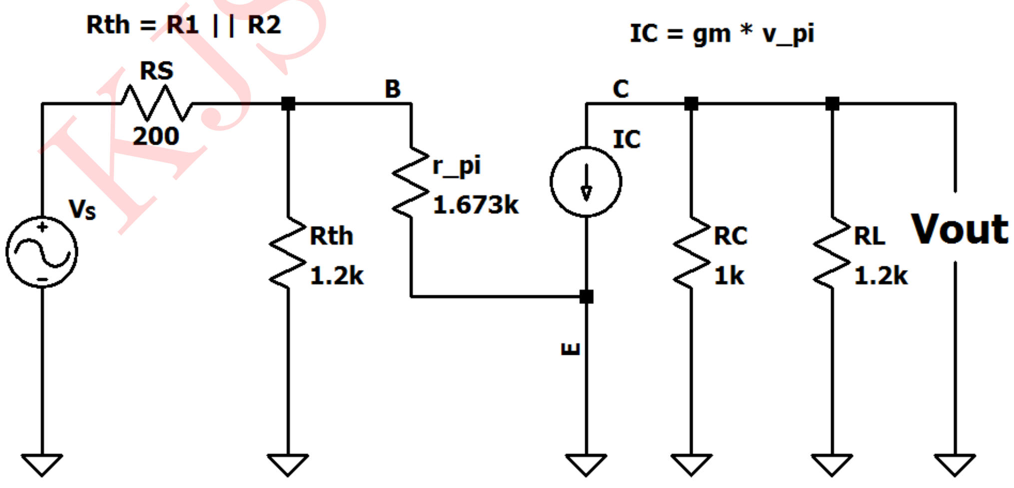

Figure 12: Small Signal Equivalent Circuit

Small-Signal parameters:-

$$g_m = \frac{I_C}{V_T} = \frac{2.74mA}{26mV} = 105.38\frac{mA}{V}$$

$$\boldsymbol{g_m = 105.38\frac{mA}{V}}$$

$r_o = \infty$(given)

$$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{15.54\mu A} = 1.673k\Omega$$

$$\boldsymbol{r_\pi = 1.673k\Omega}$$

Applying KCL at the collector terminal:-

$$g_m V_\pi + \frac{V_{out}}{R_L} + \frac{V_{out}}{R_C} = 0$$

$$g_m V_{in} = -V_{out}\left(\frac{1}{R_L} + \frac{1}{R_C}\right) \quad ....(1)$$

$$A_{V_S} = \frac{V_{out}}{V_S} = \frac{V_{out}}{V_{in}} \times \frac{V_{in}}{V_S} = A_V \times \frac{V_{in}}{V_S}$$

$$A_V = -g_m(R_C \times R_L) \qquad \text{[Using equation 1]}$$

$$A_V = -0.185 \times \frac{1000 \times 1200}{2200} = -57.272$$

$$\boldsymbol{A_V = -57.272}$$

$$A_{V_S} = A_V \times \frac{V_{in}}{V_S} = A_V \times \frac{R_1||R_2||r_\pi}{(R_1||R_2||r_\pi) + R_S} = -57.272 \times \frac{698.78}{898.78} = -44.52$$

$$\boldsymbol{A_{V_S} = -44.52}$$

SIMULATED RESULTS:

Above circuit was simulated in LTSpice and results are presented below:

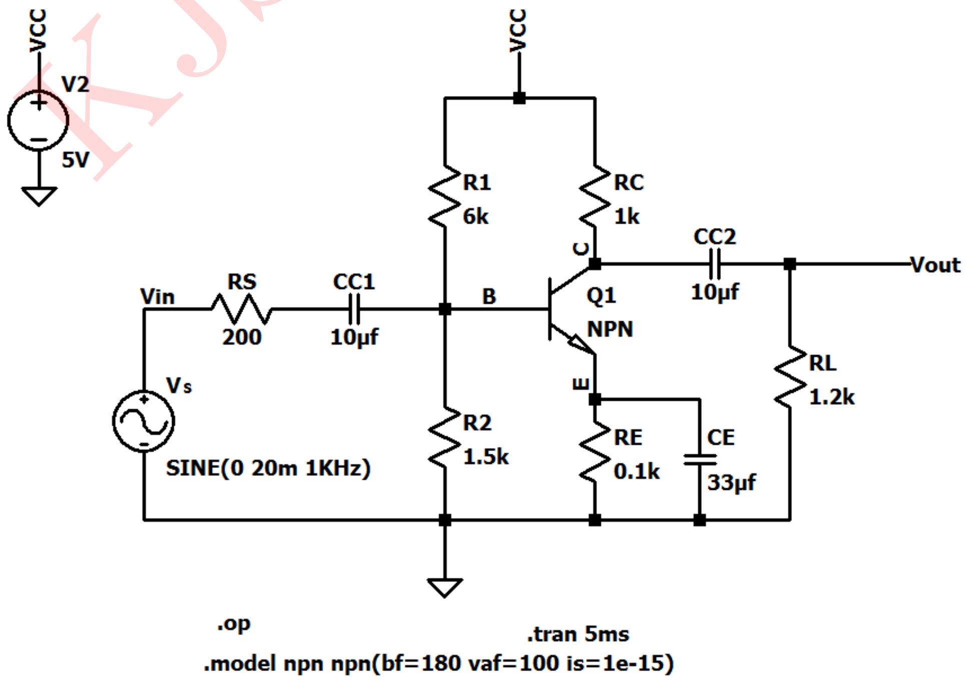

Figure 13: Circuit Schematic 3

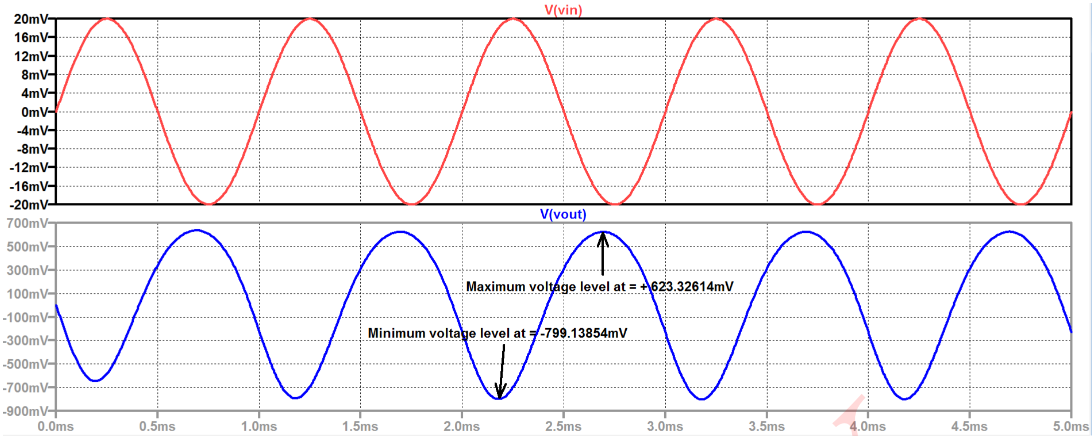

Figure 14: Input & Output waveform

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_B	$15.54\mu A$	$13.40\mu A$
I_C	$2.74mA$	$2.51mA$
V_{CE}	$1.99V$	$2.25V$
A_{V_S}	-44.52	-35.61

Table 3: Numerical 3

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