**K. J. SOMAIYA COLLEGE OF ENGINEERING**
**DEPARTMENT OF ELECTRONICS ENGINEERING**
**ELECTRONIC CIRCUITS**
**SINGLE STAGE BJT AMPLIFIER**

$18^{th}$ **June, 2020** **Numerical**

1. For the circuit shown in Figure 1,
   a) Calculate $I_B$ and $I_C$
   b) Determine $r_\pi$
   c) Determine $Z_i$ and $Z_o$
   d) Find $V_A$
   Given: $V_{BE(on)} = 0.7$ V, $\beta = 200$, $r_o = 40k\Omega$, $V_T = 26$mV

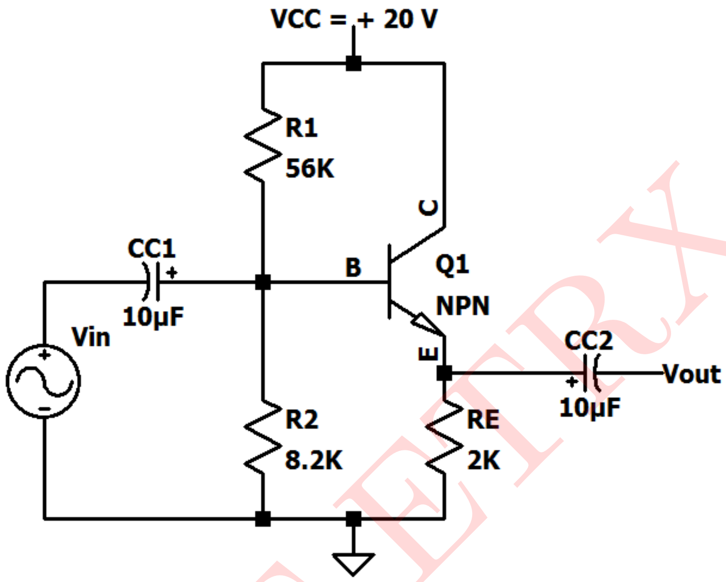


Figure 1: Circuit 1

**Solution:**
The above circuit is a common collector amplifier using npn BJT.

**DC Analysis:**
The capacitors act as open circuit.

$$f = 0, \qquad \therefore X_C = \frac{1}{2\pi f C} = \infty$$

Applying Thevenin's equivalent at base

$$V_{th} = \frac{R_2}{R_1 + R_2} \times V_{CC}$$

$$\therefore V_{th} = \frac{8.2k}{56k + 8.2k} \times 20 = 2.5545 \text{ V}$$

$$R_{th} = R_1 || R_2 = 56k || 8.2k = 7.1526k\Omega$$

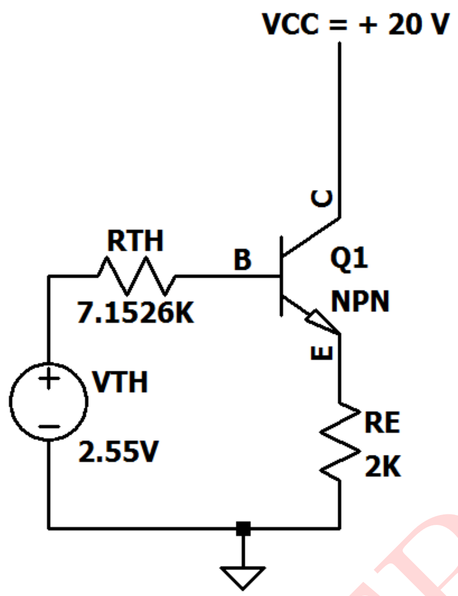


Figure 2: Thevenin equivalent circuit

Applying KVL to base-emitter loop

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

$$\therefore I_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta) I_B R_E} = 0$$

$$\therefore I_B = \frac{2.5545 - 0.7}{7.1526k + (201 \times 2k)} = \mathbf{4.5325\mu A}$$

$$I_{CQ} = \beta I_B = 200 \times 4.5325 \times 10^{-6} = \mathbf{0.906507\ mA}$$

Applying KVL to output collector-emitter loop

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

$$\therefore V_{CEQ} = V_{CC} - I_E R_E = 20 - (1+\beta) \times I_B \times 2k$$

$$\therefore V_{CEQ} = 18.177996 \text{ V}$$

**Small-signal model parameters:**

i) $r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{V_T}{I_B} = \mathbf{5.7363k\Omega}$

ii) $g_m = \dfrac{I_{CQ}}{V_T} = 34.86565 \dfrac{mA}{V}$

iii) $r_o = \dfrac{V_A}{I_{CQ}}$

$$\therefore V_A = r_o \times I_{CQ} = 40k \times 0.906507 \times 10^{-3}$$

$$\therefore V_A = \mathbf{36.26028\ V}$$

**Small-signal equivalent circuit:**

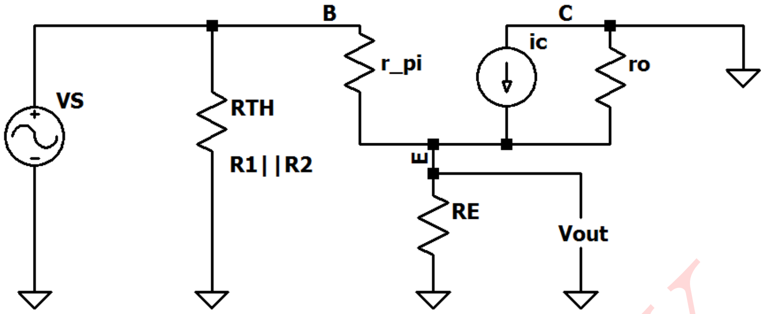


Figure 3: Small-signal equivalent circuit

Input impedence$(Z_i)$ = $R_1||R_2||[r_\pi + (1+\beta)(R_E + r_o)]$

$r_o||R_E = 1.90476k\Omega$

$\therefore r_\pi + (1+\beta)(r_o||R_E) = 388.59306k\Omega$

$\therefore Z_i = R_1||R_2||388.59306k = \mathbf{7.0233k\Omega}$

Output resistance$(Z_o)$ = $R_E||\frac{1}{g_m}||r_o$

$\therefore Z_o = (R_E||r_o)||\frac{1}{g_m} = 1.90476k||28.68152$

$\therefore Z_o = \mathbf{28.256\Omega}$

**Small-signal voltage gain($A_V$):**

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

$$A_V = \frac{R_E||r_o}{\frac{1}{g_m} + (R_E||r_o)}$$

$\therefore A_V = 0.9851655$

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

$$\frac{V_{in}}{V_S} = \frac{Z_i}{Z_i} = 1$$

$$\therefore A_{VS} = \frac{V_o}{v_S} = A_V \times \frac{V_{in}}{V_S} = A_V \times 1$$

$\therefore A_{VS} = \mathbf{0.9851655}$

**SIMULATED RESULTS:**
Above circuit is simulated using LTspice and the results are presented below:

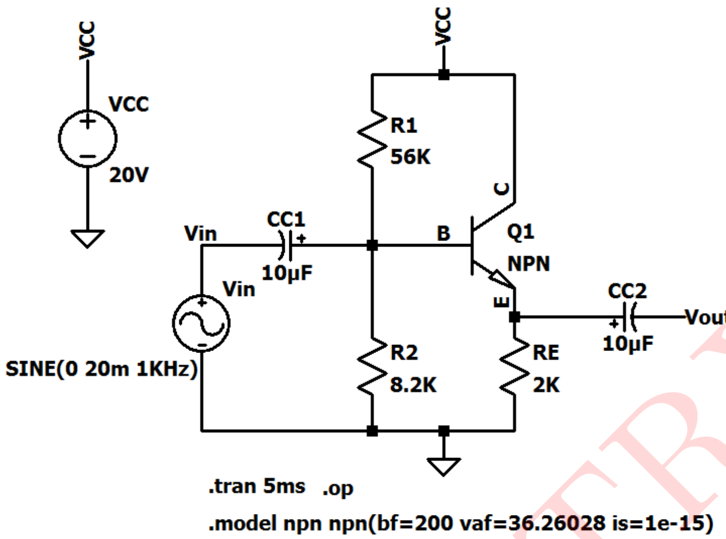


Figure 4: Circuit schematic

The input and output waveforms are shown in Figure 5.

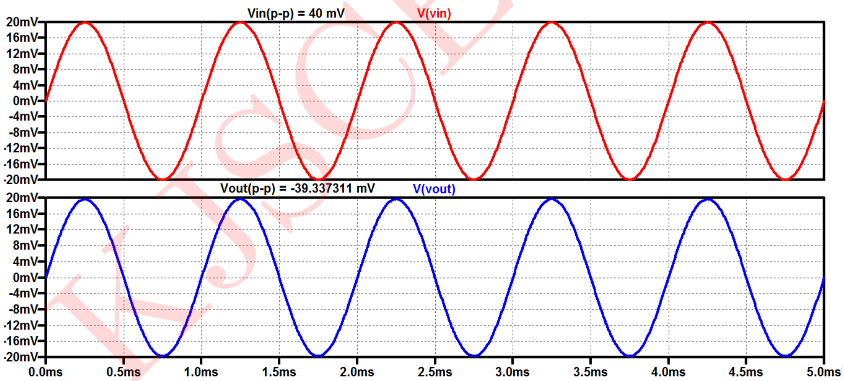


Figure 5: Input and output waveforms

**Comparison of theoretical and simulated values:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| $V_{th}$ | 2.5545 V | 2.5325 V |
| $I_{CQ}$ | 0.906507 mA | 0.912115 mA |
| $V_{CEQ}$ | 18.177996 V | 18.16962 V |
| $A_V$ | 0.9851655 V | 0.983432 V |

Table 1: Numerical 1

2. For the circuit shown in Figure 6, determine
   a) $r_\pi$
   b) $Z_i$
   c) $Z_o$
   d) $A_V$
   Repeat parts b) and d) with $r_o = 20k\Omega$ and compare the results
   Given: $\beta = 200$, $r_o = \infty\Omega$, $V_T = 26$ mV

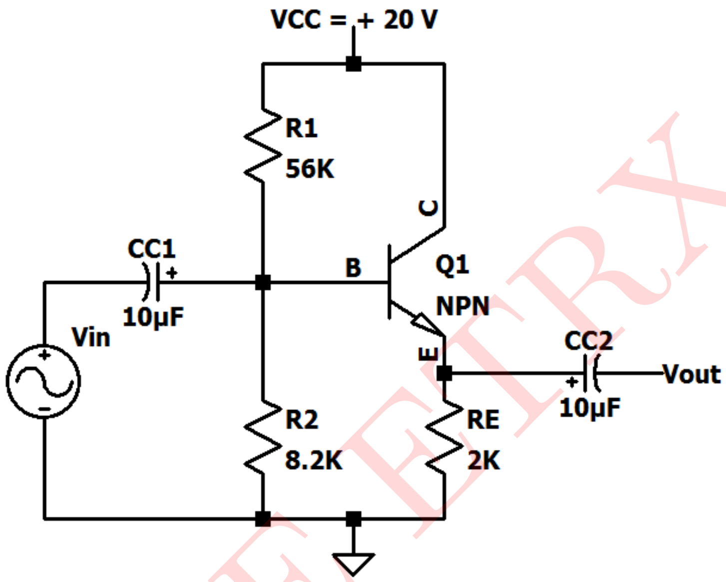


Figure 6: Circuit 2

**Solution:**
The above circuit is a collector feedback configuration.

**DC Analysis:**
The capacitors act as open circuit.

$$f = 0, \qquad \therefore X_C = \frac{1}{2\pi f C} = \infty$$

Applying KVL to input base-emitter loop

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_C} = \frac{9 - 0.7}{180k + (200 \times 2.7k)}$$

$\therefore I_B = 11.53\mu\text{A}$

$I_{CQ} = \beta I_B = 200 \times 11.53 \times 10^{-6}$

$\therefore I_{CQ} = 2.306$ mA

**Case 1:** For $r_o = \infty\Omega$

**Small-signal model parameters:**

i) $r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \mathbf{2.25498k\Omega}$

ii) $g_m = \dfrac{I_{CQ}}{V_T} = 88.69\dfrac{mA}{V}$

iii) $r_o = \infty$ (Given)

**Small-signal equivalent circuit:**

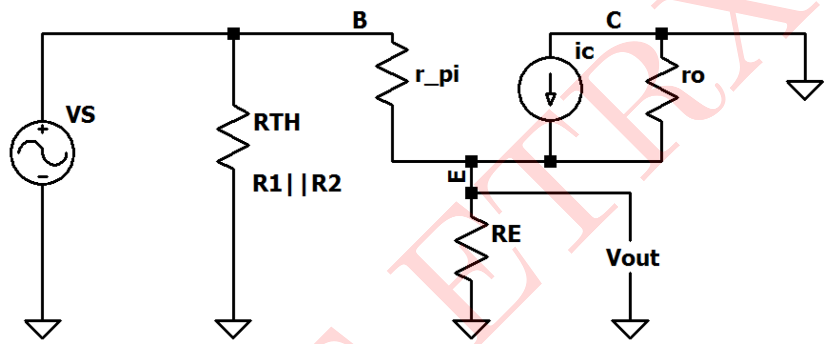


Figure 7: Small-signal equivalent circuit

Simplifying the above circuit using Miller's Theorem

By Miller's Theorem

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

$R_2 = \dfrac{A_V}{A_V - 1} \times R_B$

The voltage gain $(A_V)$ is much greater than 1

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

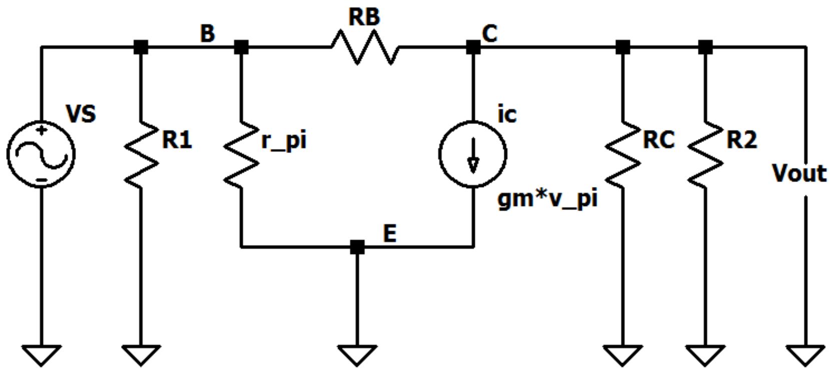


Figure 8: Miller's equivalent circuit

Voltage gain $(A_V) = \dfrac{V_o}{V_i} = \dfrac{-g_m V_\pi (R_C||R_2)}{V_\pi}$

From equation (1), $A_V = -g_m(R_C||R_B)$

$\therefore A_V = -88.69 \times 10^{-3} \times (2.7k||180k)$

$\therefore A_V = -235.924$

Now,

$$R_1 = \frac{R_B}{1 - A_V} = \frac{R_B}{1-(-A_V)} = \frac{R_B}{1 + A_V}$$

$$R_1 = \frac{180k}{1 + 235.924} = 0.759k\Omega$$

$$R_2 = \frac{-235.924}{-235.924 - 1} \times 180k = 179.2395k\Omega$$

$Z_i = R_1||r_\pi = 0.75k||2.25k$

$\therefore Z_i = \mathbf{562.5k\Omega}$

$Z_o = R_C||R_2 = \mathbf{2.66k\Omega}$

**Case 2:** For $r_o = 20k\Omega$

$V_A = r_o \times I_{CQ}$

$\therefore V_A = 46.12$ V

Small-signal analysis:

By Miller's Theorem

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

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

The voltage gain $(A_V)$ is much greater than 1

$\therefore R_2 \approx R_B$

Voltage gain $(A_V) = \frac{V_o}{V_i} = \frac{-g_m V_\pi (r_o||R_C||R_2)}{V_\pi}$

From equation (1), $A_V = -g_m(r_o||R_C||R_B)$

$\therefore A_V = -88.69 \times 10^{-3} \times (20k||2.7k||180k) = -\mathbf{208.22}$

Now,

$R_1 = \frac{R_B}{1 - A_V} = 0.86k\Omega$

$R_2 = \frac{A_V}{A_V - 1} \times R_B = 178.139k\Omega$

$Z_i = R_1||r_\pi = \mathbf{618.3k\Omega}$

$Z_o = r_o||R_C||R_2 = \mathbf{2.347k\Omega}$

**SIMULATED RESULTS:**
Above circuit is simulated using LTspice and the results are presented below:

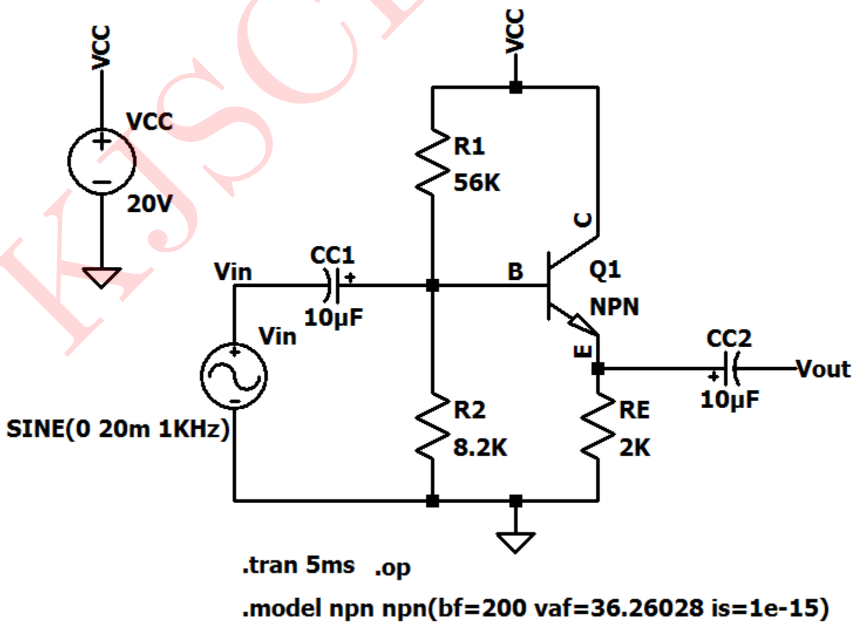


Figure 9: Circuit schematic

The input and output waveforms for $r_o = \infty$ are shown in Figure 10.

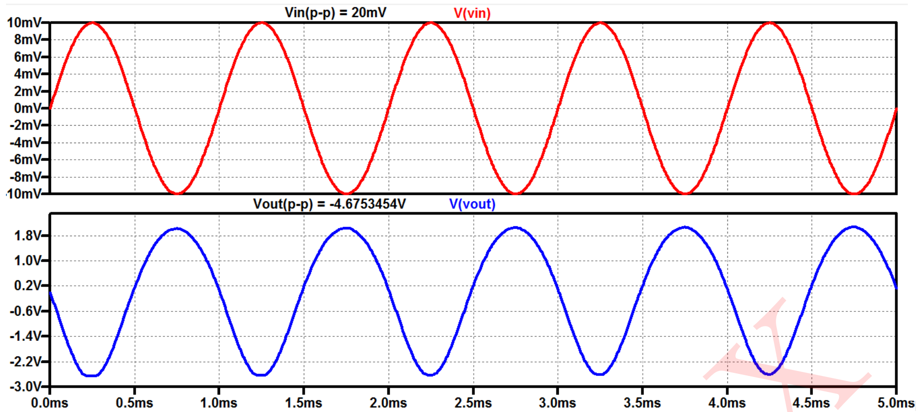


Figure 10: Input and output waveforms for $r_o = \infty$

The input and output waveforms for $r_o = 20k\Omega$ are shown in Figure 11.

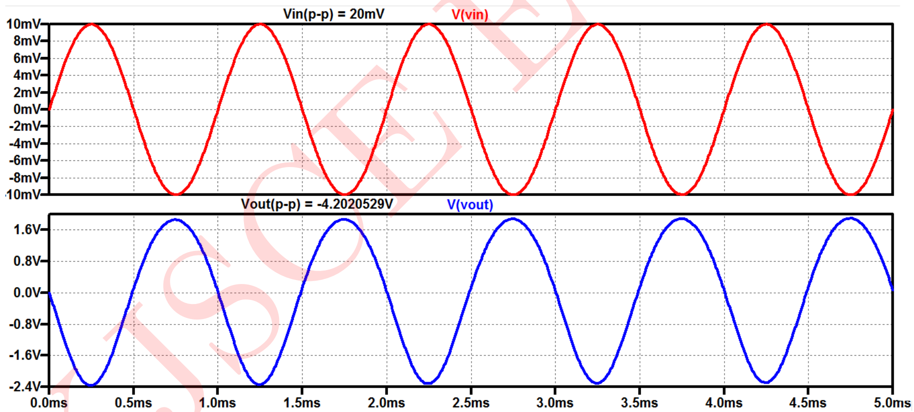


Figure 11: Input and output waveforms for $r_o = 20k\Omega$



**Comparison of theoretical and simulated values:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| $I_{CQ}$ | 2.306 mA | 2.287 mA |
| $I_B$ | 11.53 $\mu$A | 11.435 $\mu$A |
| $A_V$ (with $r_o = \infty$) | $-235.924$ | $-233.767$ |
| $A_V$ (with $r_o = 20k\Omega$) | $-208.22$ | $-210.1026$ |

Table 2: Numerical 2

3. For the circuit shown in Figure 12
   a) Find the Q-point defined by $I_B$, $I_C$ and $V_{CE}$
   b) Calculate small-signal parameters $g_m$, $r_\pi$ and $r_o$
   c) Calculate the input resistance, output resistance, overall voltage gain $A_V$ and no voltage gain $A_{V_o}$
   Given: $\beta = 100$, $V_A = 200$V

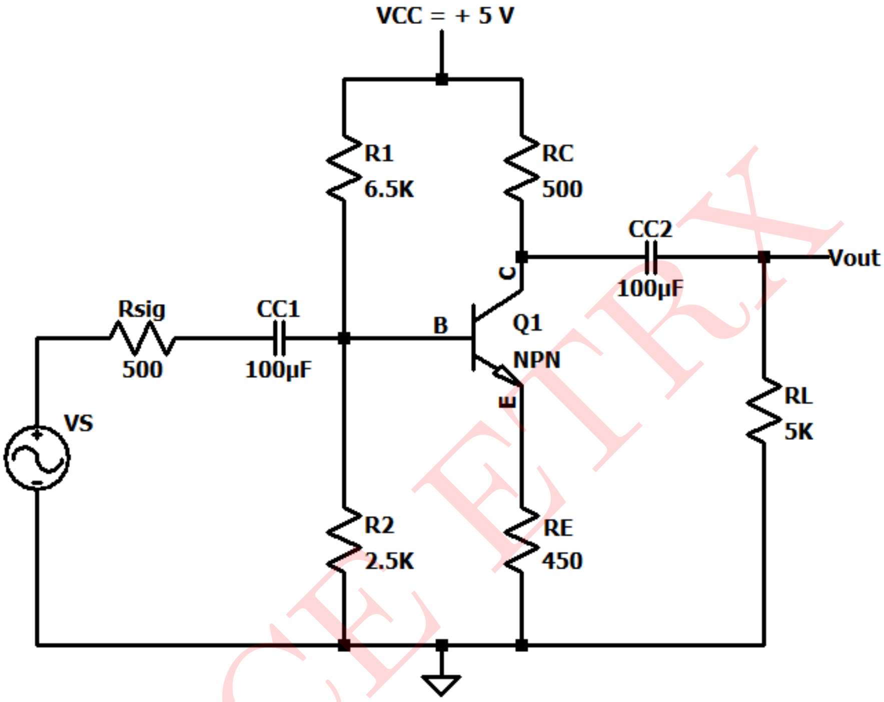


Figure 12: Circuit 3

**Solution:**

The above circuit is a common emitter configuration.

**DC Analysis:**
The capacitors act as open circuit.

$$f = 0, \quad \therefore X_C = \frac{1}{2\pi f C} = \infty$$

Applying Thevenin's equivalent at base

$$V_{th} = \frac{R_2}{R_1 + R_2} \times V_{CC}$$

$\therefore V_{th} = 1.3884$V

$R_{th} = R_1 || R_2 = 1.80556$ kΩ

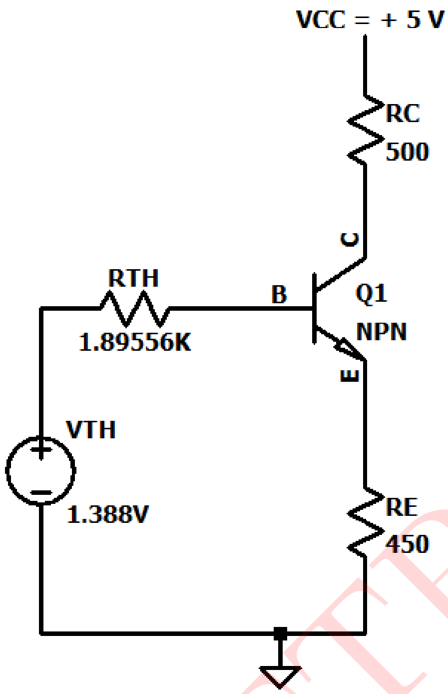


Figure 13: Thevenin's equivalent circuit

Applying KVL to input base-emitter loop

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta)R_E} = \frac{1.388 - 0.7}{1.80556k + (101 \times 450)}$$

$\therefore I_B = 14.559\mu\text{A}$

$I_{CQ} = \beta I_B = 100 \times 14.559 \times 10^{-6}$

$\therefore I_{CQ} = 1.4559$ mA

**Small-signal model parameters:**

i) $r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \mathbf{1.7858}$ **k$\Omega$**

ii) $g_m = \dfrac{I_{CQ}}{V_T} = 55.996mA/V$

iii) $r_o = \dfrac{V_A}{I_{CQ}} = 137.372$ k$\Omega$

Applying KVL to output loop

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

$\therefore V_{CE} = 3.610$ V

**Small-signal analysis(with load $R_L$)**

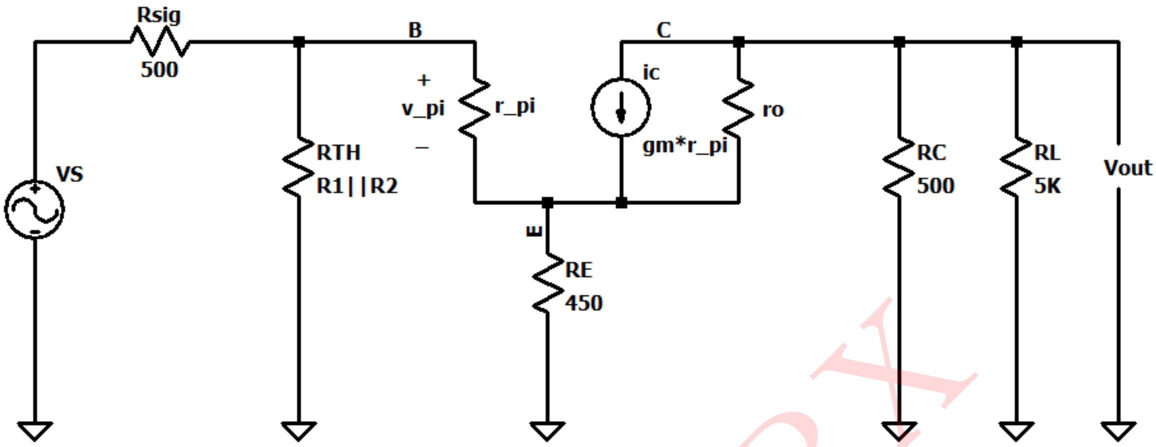


Figure 14: Small-signal equivalent circuit (with load $R_L$)

Input resistance $Z_i = R_1||R_2||[r_\pi + (+\beta)R_E] = 1.80556k[1.7858k + (101 \times 450)]$

$\therefore Z_i = \mathbf{1.739\ k\Omega}$

Output resistance $Z_o = r_o||R_C||R_L$

$\therefore Z_o = \mathbf{453.0459\ \Omega}$

Overall voltage gain $A_V = \dfrac{V_o}{V_S} = \dfrac{V_o}{V_i} \times \dfrac{V_i}{V_S}$

$$\frac{V_o}{V_i} = \frac{(-R_C||R_L||r_o)}{\left(\dfrac{1}{g_m} + R_E\right)}$$

$$\frac{V_o}{V_i} = -0.96834$$

$$\frac{V_i}{V_S} = \frac{Z_i}{Z_i + R_{sig}} = \frac{1.739k}{1.739k + 500} = 0.776686$$

$$\therefore A_V = \frac{V_o}{V_S} = \frac{V_o}{V_i} \times \frac{V_i}{V_S}$$

$A_V = -0.96834 \times 0.776686$

$\therefore A_V = \mathbf{-0.752096}$

**Small-signal analysis(without load $R_L$)**

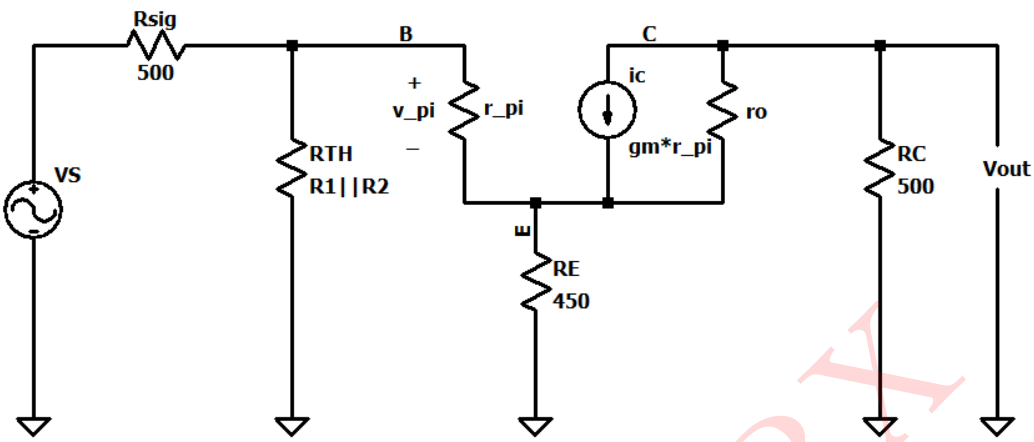


Figure 15: Small-signal equivalent circuit(without load $R_L$)



$Z_o = r_o||R_C = 498.1867\ \Omega$

No load voltage gain $A_{V_o} = \dfrac{V_o}{V_S} = \dfrac{V_o}{V_i} \times \dfrac{V_i}{V_S}$

$$\frac{V_o}{V_i} = \frac{(-R_C||r_o)}{\left(\dfrac{1}{g_m} + R_E\right)} = -1.0648$$

$$\frac{V_i}{V_S} = \frac{Z_i}{Z_i + R_{sig}} = 0.776686$$

$$\therefore A_{V_o} = \frac{V_o}{V_S} = \frac{V_o}{V_i} \times \frac{V_i}{V_S}$$

$A_V = -1.0648 \times 0.776686$

$\therefore A_{V_o} = \mathbf{-0.827027}$

**SIMULATED RESULTS:**
Above circuit is simulated using LTspice and the results are presented below:

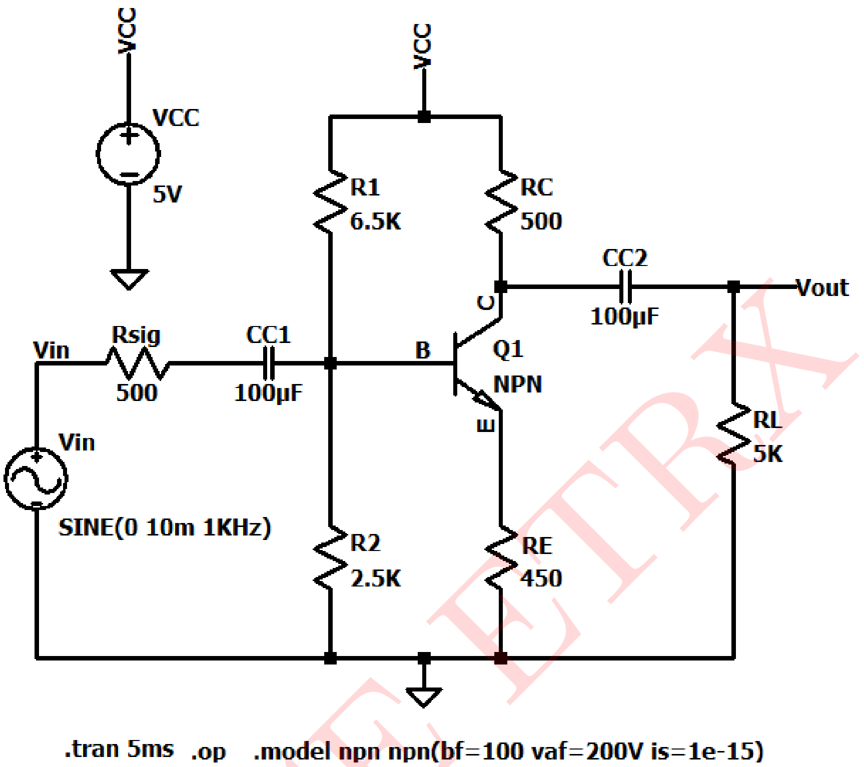


Figure 16: Circuit schematic

The waveforms for input and output voltage with load $R_L$ are shown in Figure 17.

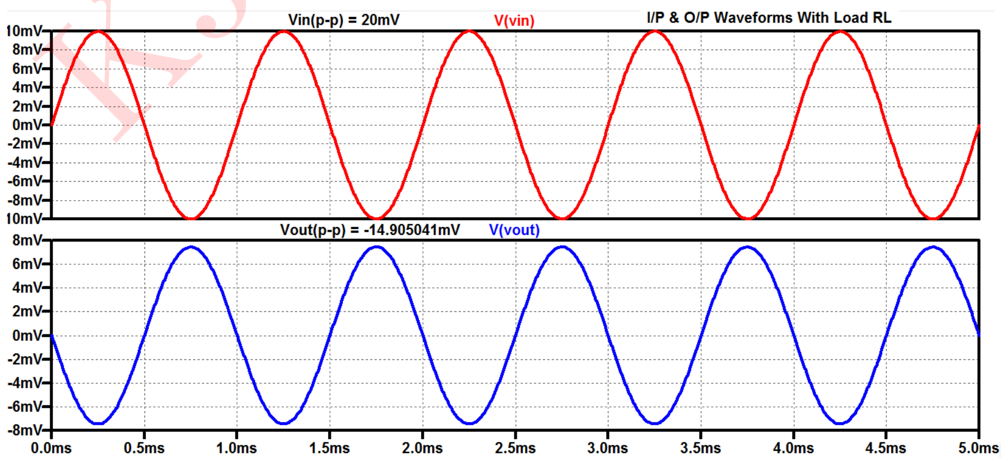


Figure 17: Input and output waveforms for $V_{in}$ and $V_{out}$(with load)

The waveforms for input and output voltage without load $R_L$ are shown in Figure 18.

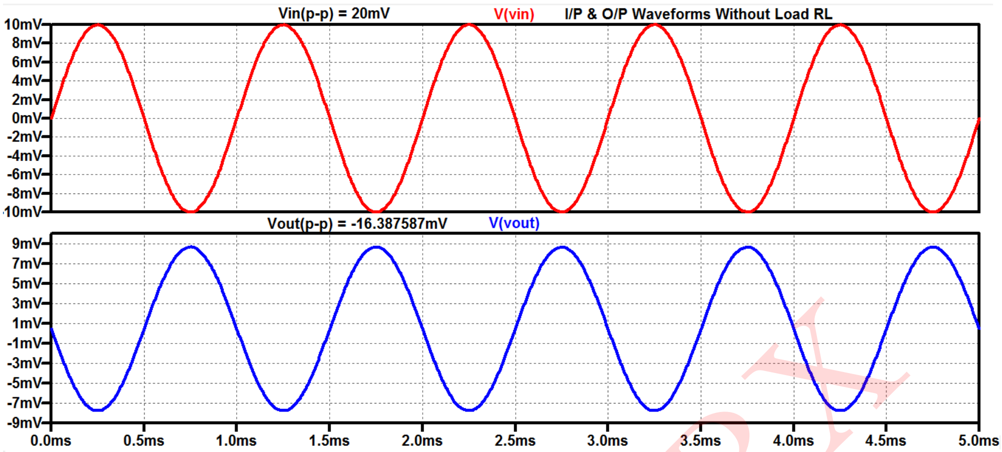


Figure 18: Input and output waveforms for $V_{in}$ and $V_{out}$(without load)

**Comparison of theoretical and simulated values:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| $I_{CQ}$ | 1.4559 mA | 1.40971 mA |
| $I_B$ | 14.559 $\mu$A | 13.8935 $\mu$A |
| $V_{CE}$ | 3.610 V | 3.654517 V |
| Overll voltage gain ($A_V$) | $-0.752096$ | $-0.74525$ |
| No load voltage gain ($A_{V_o}$) | $-0.827027$ | $-0.819379$ |

Table 3: Numerical 3