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
   Find: a) Determine Z_i and Z_o
   b) Find A_v
   c) Repeat a) with $r_o = 20\text{k}\Omega$
   d) Repeat b) with $r_o = 20\text{k}\Omega$
   Given: $\beta = 60$, $R_B = 220\text{k}\Omega$, $R_C = 2.2\text{k}\Omega$, $r_o = 40\text{k}\Omega$, $C_{C1} = C_{C2} = 10\ \mu\text{F}$

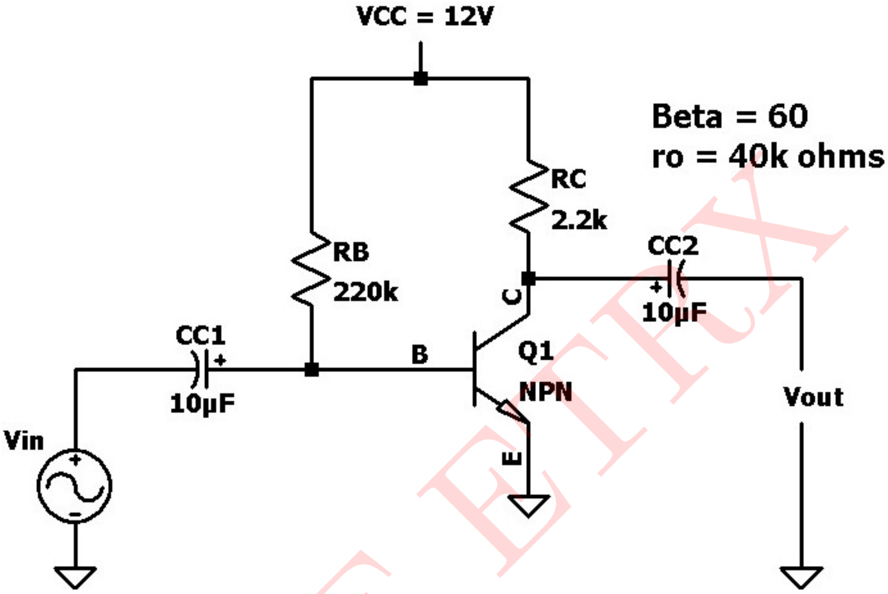

Figure 1: Circuit 1

Solution:

Above circuit is common emitter fixed biased BJT Amplifier

DC Analysis:

Applying KVL to input loop : $V_{BE} - V_{CC} - I_B R_B = 0$

$I_B = \dfrac{V_{CC} - V_{BE}}{R_B}$

$I_B = \dfrac{12 - 0.7}{220 \times 10^3}$

$I_B = \mathbf{51.3636}\mu\mathbf{A}$

$I_C = \beta I_B$

$I_C = \mathbf{3.0818mA}$

$V_{CE} = V_C - V_E$ (put $V_E = 0$)

$V_{CE} = V_C$

$V_C = V_{CC} - I_C R_C = 12 - 3.0818 \times 10^{-3} \times 2.2 \times 10^3$

$V_C = \mathbf{5.2V}$

Small signal parameters:

$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{26 \times 10^{-3}}{51.3636 \times 10^{-6}} = \mathbf{506.1950\ \Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{3.0818 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{118.53\ mA/V}$$

Small signal equivalent circuit:

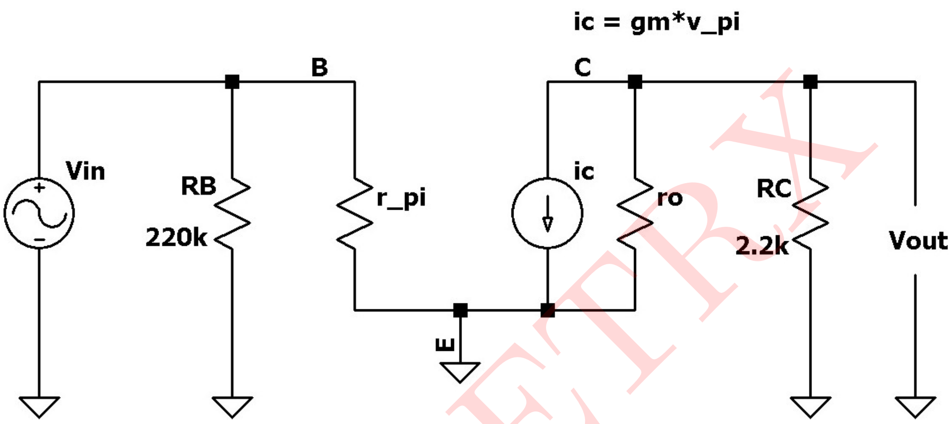

Figure 2: Small signal equivalent circuit

Input impedence $Z_i = R_B \mid\mid r_\pi$

$Z_i = 505.032\Omega$

With $r_o = 20\ \mathrm{k}\Omega$

$Z_i = 505.032\Omega$

$Z_o = r_o \mid\mid R_C = \mathbf{1981.981}\Omega$

$A_v = -g_m(r_o \mid\mid R_C)$

$A_v = \mathbf{-234.924}$ (Negative sign indicates 180 out of phase between input and output)

With $r_o = 40\ \mathrm{k}\Omega$

$Z_o = r_o \mid\mid R_C$

$Z_o = 40 \times 10^3 \mid\mid 2.2 \times 10^3$

$Z_o = \mathbf{2085.308}\Omega$

$$A_v = \frac{V_o}{V_{in}} = -g_m(r_o \mid\mid R_C)$$

$A_v = \mathbf{-247.171}$ (Negative sign indicates 180 out of phase between input and output)

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

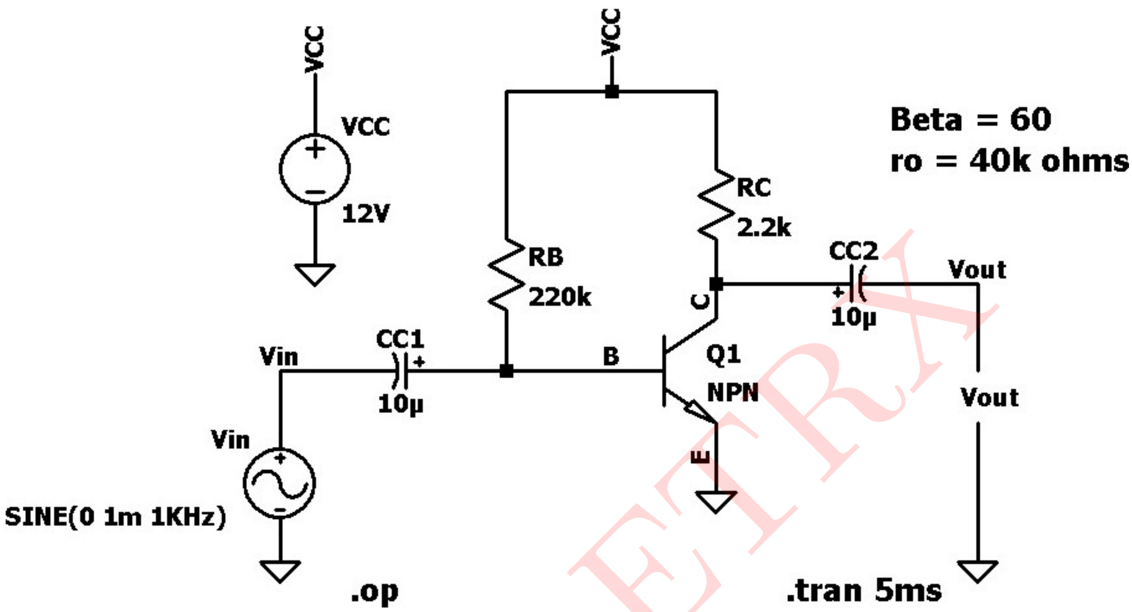

Figure 3: Circuit Schematic

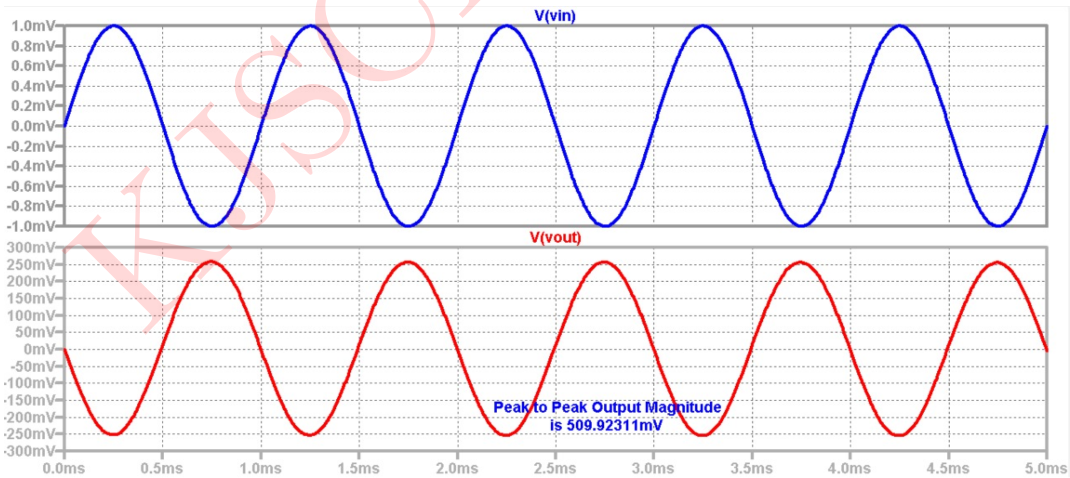

Figure 4: Input Output Waveform

Comparsion between simulated and theoretical values :

Parameters	Simulated	Observed
I_{BQ}	51.3636μA	51.1651μA
I_{CQ}	3.0818mA	3.1762mA
A_v	-247.171	-229.006
V_{CE}	5.2V	5.012V

Table 1: Numerical 1

2. For the network of figure 5
   Find: a) Determine Z_i and Z_o $\quad (r_o = \infty\Omega)$
   b) A_v $\quad (r_o = \infty\Omega)$
   c) Repeat a) with $r_o = 50\text{k}\Omega$
   d) Repeat b) with $r_o = 50\text{k}\Omega$

   Given: $\beta = 100$, $R_B = 470\text{k}\Omega$, $R_C = 3\text{k}\Omega$, $V_{CC} = 12\text{V}$, $C_{C1} = C_{C2} = 10\ \mu\text{F}$

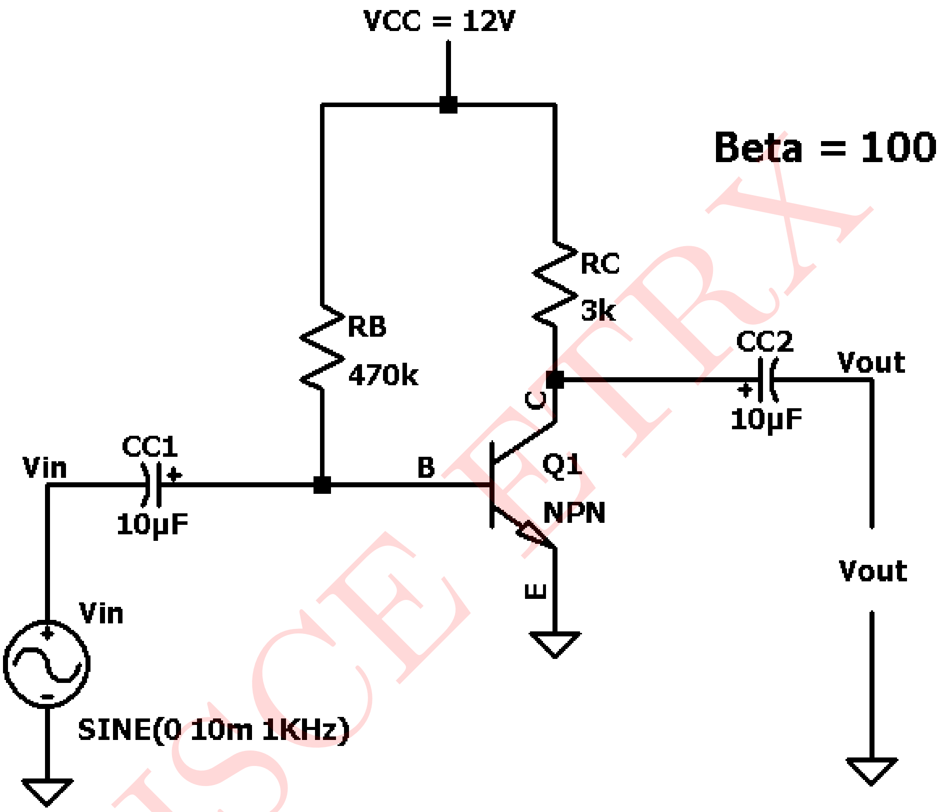

Figure 5: Circuit 2

Solution:

Above circuit is common emitter fixed biased BJT Amplifier

DC Analysis:

Applying KVL to input loop of circuit 2:

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

$I_B = \dfrac{V_{CC} - V_{BE}}{R_B}$

$I_B = \dfrac{12 - 0.7}{470 \times 10^3}$

$I_B = \mathbf{24.0425}\boldsymbol{\mu}\mathbf{A}$

$I_C = \beta I_B$

$I_C = \mathbf{2.4042mA}$

$V_{CE} = V_C - V_E \qquad (\text{ bur } V_E = 0)$

$V_{CE} = V_C$

$V_C = V_{CC} - I_C R_C$ $=12 - 2.4042 \times 10^{-3} \times 3 \times 10^3$

V_C = **4.7874V**

Small signal parameters:

$r_\pi = \dfrac{V_T}{I_{BQ}} = \dfrac{26 \times 10^{-3}}{24.0425 \times 10^{-6}} = \mathbf{1081.418\ \Omega}$

$g_m = \dfrac{I_{CQ}}{V_T} = \dfrac{2.4042 \times 10^{-3}}{26 \times 10^{-3}}$ =**92.4692 mA/V**

Small signal equivalent circuit:

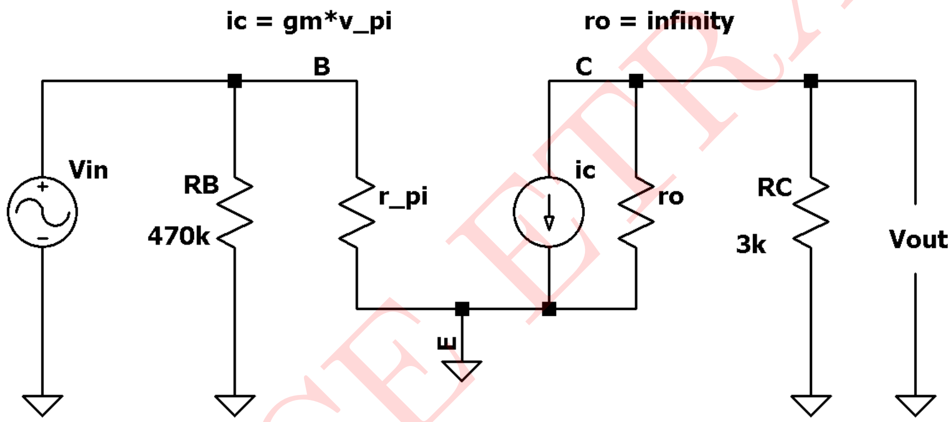

Figure 6: Small signal equivalent circuit

Input impedence

$Z_i = R_B \mid\mid r_\pi$

$Z_i = 2470 \times 10^3 \mid\mid 1081.418$

$Z_i = 1078.935\Omega$

$Z_o = R_c \quad (r_o = \infty)$

$Z_o = 3\text{k}\Omega$

$A_v = \dfrac{V_o}{V_{in}} = -g_m(R_C)$

$A_v = \mathbf{-277.4076}$ (Negative sign indicates 180 out of phase between input and output)

With $r_o = 50\ \text{k}\Omega$

$Z_o = r_o \mid\mid R_C = \mathbf{2830.1886}\Omega$

$A_v = -g_m(r_o \mid\mid R_C)$

$A_v = \mathbf{-261.7052}$ (Negative sign indicates 180 out of phase between input and output)

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

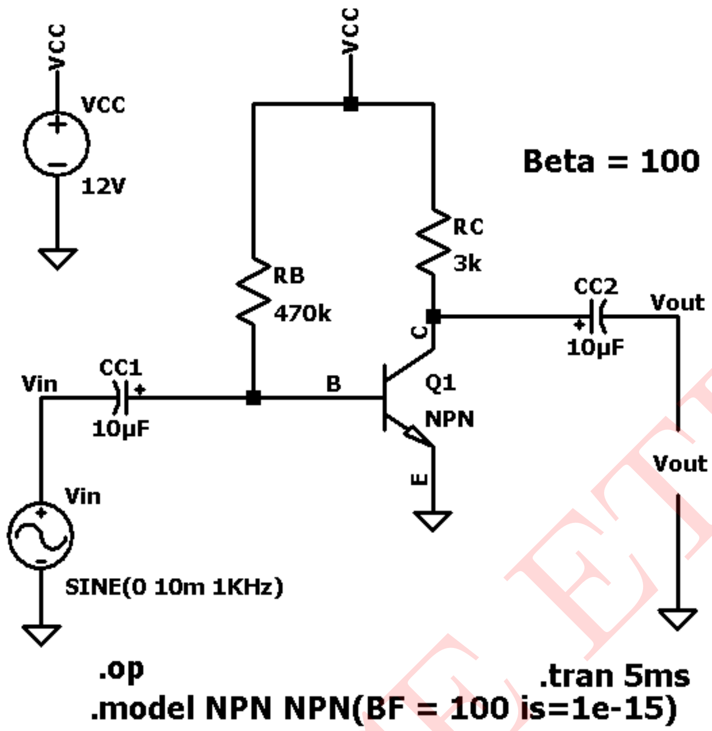

Figure 7: Circuit Schematic

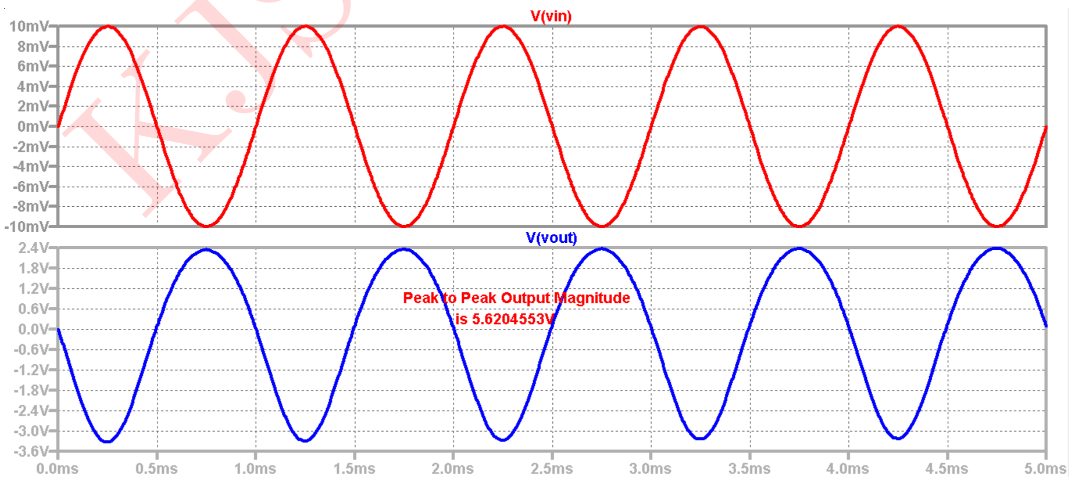

Figure 8: Input Output Waveforms

Comparsion between simulated and theoretical values :

Parameters	Simulated	Theoretical
I_{BQ}	23.9635μA	24.0425μA
I_{CQ}	2.3963mA	2.4042mA
$A_v(r_o = \infty)$	-281.45	-277.407
$A_v(r_o = 50k\Omega)$	-272.35V	-261.705V

Table 2: Numerical 2

3. For the network shown in figure 9
   Find: a) Find the Q point
   b) Find A_v
   c) Determine range in A_v if R_1 and R_2 vary by $\pm$ 5 percent

   Given: β = 100, R_1 = 33kΩ, R_2 = 50kΩ, V_{EE} = 3.3V, R_C = 2kΩ, R_E= 1kΩ, V_A = ∞

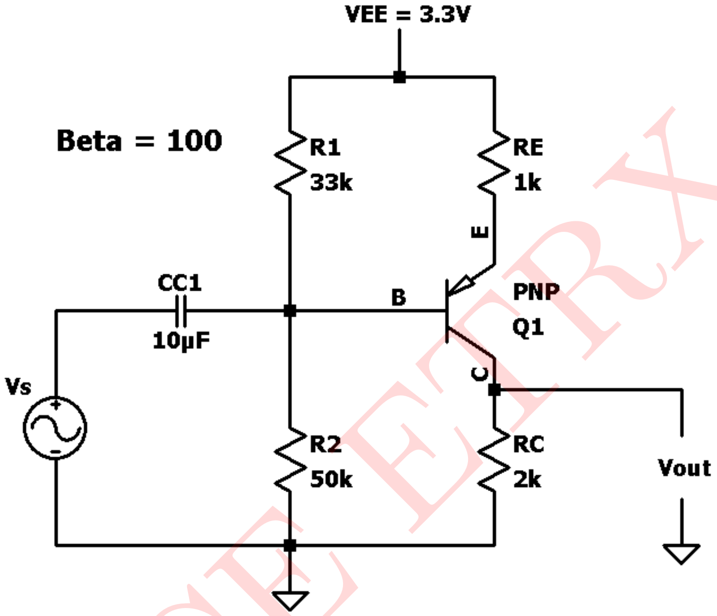

Figure 9: Circuit 3

Solution:

Above circuit is common emitter voltage divider BJT Amplifier

DC Analysis:

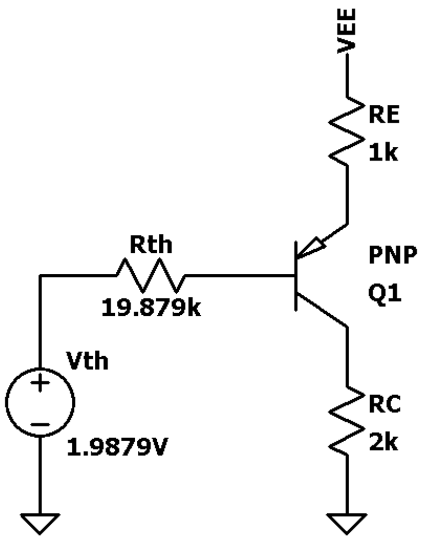

Figure 10: Thevenins equivalent circuit

$R_{TH} = R_1 \mid\mid R_2$

$R_{TH} = 33 \times 10^3 \mid\mid 50 \times 10^3$

$R_{TH} = \mathbf{19879.51\Omega}$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) \times V_{CC}$$

$$V_{TH} = \frac{50 \times 10^3}{50 \times 10^3 + 33 \times 10^3}$$

$V_{TH} = \mathbf{1.9879V}$

Applying KVL to the input loop

$V_{TH} - V_{EE} + V_{EB} - I_B R_{TH} + I_E R_E = 0$

$$I_B = \frac{V_{EE} - V_{BE} - V_{TH}}{R_{TH} + (1 + \beta)R_E}$$

$$I_B = \frac{12 - 0.7 - 1.9879}{19879.51 + 101 \times 10^3}$$

$I_B = \mathbf{5.0637\mu A}$

$I_C = \beta I_B$

$I_C = \mathbf{0.5063mA}$

$I_E = I_B + I_C$

$I_E = \mathbf{0.5113mA}$

Applying KVL to output loop

$V_{ECQ} = V_{EE} - I_E Q R_E Q - I_C Q R_C Q$

$V_{ECQ} = 3.3 - 0.5113 - 0.5063 \times 2$

$V_{ECQ} = \mathbf{1.7759V}$

Q point $= (V_C EQ, I_C Q)$

Q point $=$ **(1.77V , 0.506mA)**

Small signal parameters:

$$r_o = 0 \; r_\pi = \frac{V_T}{I_{BQ}} = \frac{26 \times 10^{-3}}{5.0637 \times 10^{-6}} = \mathbf{5134.58\ \Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.5063 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{19.473\ mA/V}$$

Small signal equivalent circuit:

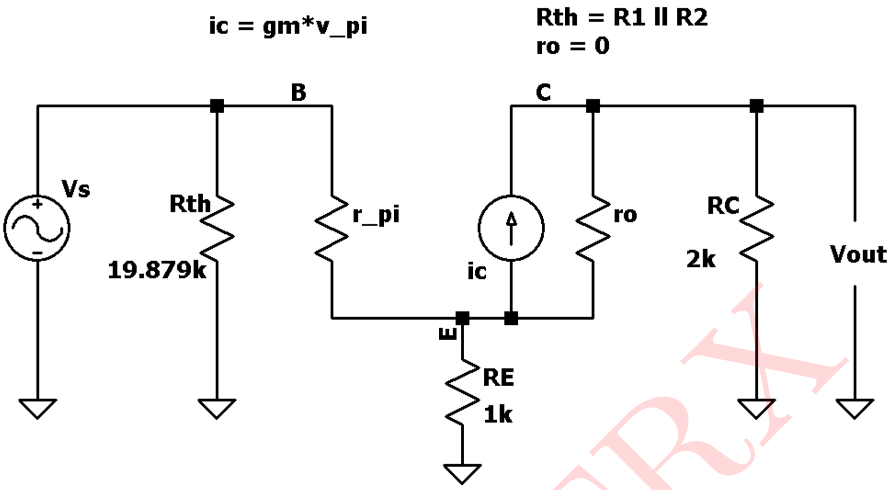

Figure 11: Small signal equivalent circuit

$$A_v = \frac{V_o}{V_{in}} = -g_m V_\pi (R_C)$$

$V_{in} = V_S = V_\pi +$ voltage drop at R_E

$$V_{in} = V_\pi \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) \times R_E$$

$$V_{in} = V_\pi \left(1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{-g_m V_\pi R_c}{V_\pi \left(1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right)}$$

$$A_v = \frac{-R_C}{\frac{1}{g_m} + R_E}$$

$A_v = -1.9023$ (Negative sign indicates $\angle 180$ out of phase between input and output)

Approximate:

$R_C = 2k\Omega \pm 5\% = 2.1k\Omega$ or $1.9k\Omega$

$R_E = 1k\Omega \pm 5\% = 1.051k\Omega$ or $0.95k\Omega$

To find range of A_v :

For $R_{C(max)} = 2.1k\Omega + R_{E(min)} = 0.95k\Omega$

$$A_v = \frac{-R_{C(max)}}{\frac{1}{g_m} + R_{E(min)}} = \frac{-2.1 \times 10^3}{\frac{1}{19.473} + 0.95 \times 10^3}$$

$A_v = -2.0971$

For $R_{C(min)} = 1.9k\Omega + R_{E(max)} = 1.05k\Omega$

$$A_v = \frac{-R_{C(min)}}{\frac{1}{g_m} + R_{E(max)}} = \frac{-1.9 \times 10^3}{\frac{1}{19.473} + 1.05 \times 10^3}$$

$A_v = -1.7251$

Range is of A_v $1.725 \leq A_v \leq 2.097$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

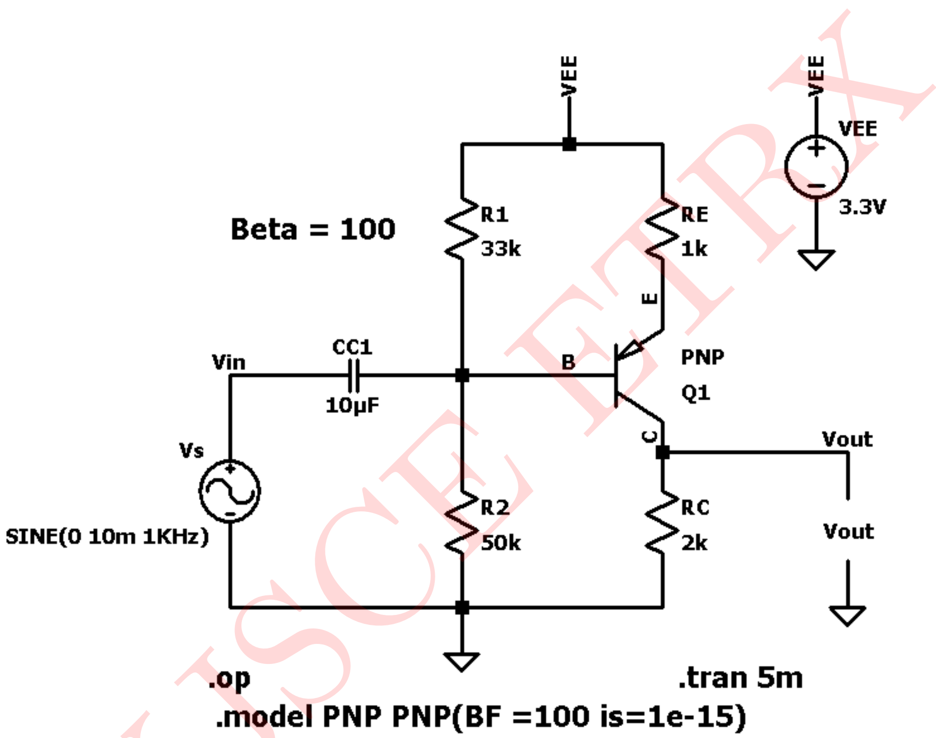

Figure 12: Circuit Schematic

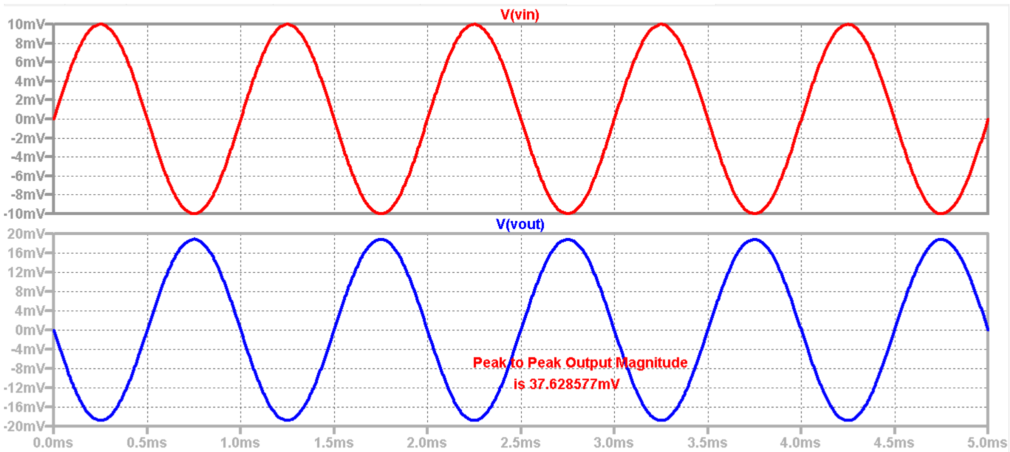

Figure 13: Circuit Schematic: Input Output Waveform

Comparsion between simulated and theoretical values :

Parameters	Simulated	Theoretical
I_{BQ}	5.0865μA	5.0637μA
I_{CQ}	0.5086mA	0.5063mA
I_{EQ}	0.5137mA	0.5113mA
A_v	-1.8814	-1.9023
V_{ECQ}	1.7689V	1.7759mA

Table 3: Numerical 3

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