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DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
DESIGN OF SINGLE STAGE AMPLIFIER

25^{th} **June, 2020** **Numerical**

1. Design a single stage RC coupled BJT amplifier for following specifications:
   $V_{o_{rms}} = 5$ V, $f_L \leq 20$ Hz, S ≤ 10, $|A_V| \geq 120$
   Calculate A_V, Z_i and Z_o of the amplifier you have designed

   Solution:
   Step 1: Given data
   $V_{o_{rms}} = 5$ V, $f_L \leq 20$ Hz, S ≤ 10, $|A_V| \geq 120$

   Step 2: Selection of transistor
   Transistor selected is BC147B with following specifications:
   $h_{FE}(min) = 200$
   $h_{FE}(typ) = 290$
   $h_{FE}(max) = 450$
   $h_{ie} = 4.5$ kΩ
   $h_{fe}(min) = 240$
   $h_{fe}(typ) = 330$
   $h_{fe}(max) = 500$
   $V_{CE}(sat) = 0.25$ V

   Step 3: Selection of biasing network

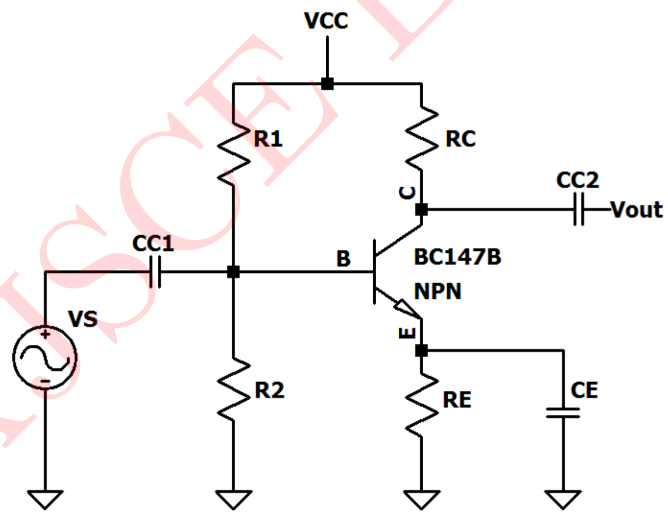

Figure 1: Circuit 1

   Step 4: Selection of R_L

$$|A_V| = \frac{h_{fe}(min) \times R_C}{h_{ie}}$$

$$\therefore 120 = \frac{240 \times R_C}{4.5k}$$

$$\therefore R_C = 2.25 \text{ k}\Omega$$

We select a higher standard value of R_C to increase the gain.

Hence, we select $R_C = 2.4\ \text{k}\Omega,\ \frac{1}{4}W$

Step 5: Selection of Q-point (V_{CEQ}, I_{CQ})

If V_{CC} is not given, we take $V_{CEQ} \geq 1.5 \times [V_{o_{peak}} + V_{CE}(sat)]$

$\therefore V_{o_{peak}} = V_{o_{rms}} \times \sqrt{2} = 5\sqrt{2} = 7.07106$ V

$V_{CEQ} \geq 1.5 \times [7.07106 + 0.25]$

$\therefore V_{CEQ} \geq 10.98159$ V, i.e. $V_{CEQ} = 11$ V

$$I_{o_{peak}} = \frac{V_{o_{peak}}}{R_C} = \frac{7.07106}{2.4k} = 2.946 \text{ mA}$$

$I_{CQ} \geq I_{o_{peak}}$ (for undistorted output signal)

$I_{CQ} \geq 2.946$ mA, $\therefore I_{CQ} = 3$ mA

Step 6: Selection of DC power supply (V_{CC})

Selecting Q-point at center of DC load line for maximum output swing

$V_{CC} \geq 2V_{CEQ} \geq 2 \times 11$ V

$V_{CC} \geq 22$ V

Selecting HSV, $V_{CC} = 23$ V

Step 7: Calculation of R_E

For proper operation, $V_{RE} = 10\%$ of $V_{CC} = 0.1V_{CC}$

$\therefore V_{RE} = 2.3$ V

$V_{RE} = R_E \times I_{EQ}$

$$\therefore R_E = \frac{V_{RE}}{I_{EQ}} = \frac{V_{RE}}{I_{CQ}} = \frac{2.3}{3 \times 10^{-3}} = 766.667 \text{ k}\Omega$$

Step 8: Calculation of biasing resistors R_1 and R_2

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)}$$

$\beta = h_{fe}(max) = 450$

$$10 = \frac{1+450}{1+450\left(\frac{680}{680+R_B}\right)}$$

$$\therefore R_B = \frac{R_2 \times R_1}{R_1 + R_2} = 6258.7755\Omega \qquad \text{..........(1)}$$

$$V_{th} = V_B = \frac{R_2}{R_1 + R_2} \times V_{CC} \qquad \text{..........(2)}$$

Applying KVL at B-E loop of Q_1

$$V_B - I_{BQ}R_B - V_{BE} - I_{EQ}R_E = 0$$

$$V_B = V_{BE} + \left(\frac{I_{CQ}}{\beta} \times R_B\right) + I_{CQ}R_E$$

$$V_B = 0.7 + \frac{3 \times 10^{-3}}{450} \times 6258.775 + (3 \times 10^{-3} \times 680)$$

$$\therefore V_B = 2.781725 \text{ V}$$

From equation (2), $V_B = 2.7817 = \dfrac{R_2}{R_1 + R_2} \times 23$

$$\therefore \frac{R_2}{R_1 + R_2} = 0.12094$$

$\therefore$ Equation (1) becomes: $R_! \times 0.12094 = 6258.7755$

$$\therefore R_1 = 51.75 \text{ k}\Omega$$

Selecting HSV so that circuit draws minimum current

$$\therefore R_1 = 56 \text{ k}\Omega, \frac{1}{4}W$$

$$\therefore \frac{R_2}{56k + R_2} = 0.12094$$

$$\therefore R_2 = 7.704 \text{ k}\Omega$$

Selecting LSV, $R_2 = 7.5 \text{ k}\Omega, \dfrac{1}{4}W$

Step 9: Selection of bypass capacitor C_E

$$X_{CE} = \frac{R_E}{10} = 0.1R_E$$

$$\therefore \frac{1}{2\pi f_L C_E} = 0.1R_E$$

$$\therefore C_E = \frac{1}{2\pi f_L \times 0.1 \times R_E} = \frac{1}{2\pi \times 20 \times 0.1 \times 680} = 117.02569 \ \mu\text{F}$$

Selecting HSV, $C_E = 120 \ \mu\text{F} \ /25 \text{ V}$

Step 10: Selection of coupling capacitor

a) $C_{C1} = \dfrac{1}{2\pi R_{eq} f_L}$

$R_{eq} = R_1||R_2||h_{ie} = 56k||7.5k||4.5k$

$\therefore R_{eq} = 2.6779 \text{ k}\Omega$

$C_{C1} = \dfrac{1}{2\pi \times 2.6779 \times 10^3 \times 20} = 2.9716\mu\text{F}$

Selecting HSV, $C_{C1} = 3.3\mu\text{F}$ / 25 V

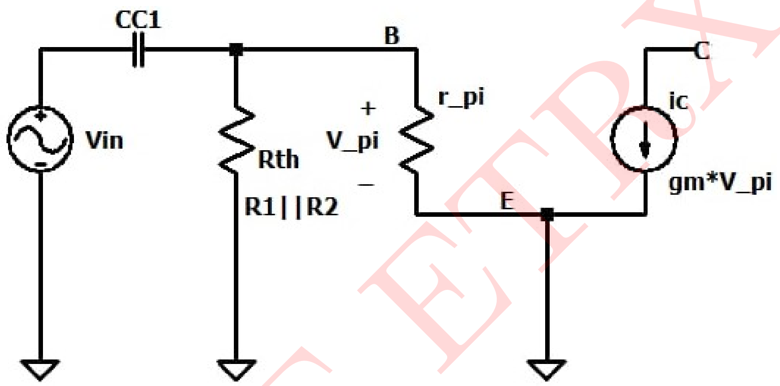

Figure 2: Low frequency equivalent circuit for C_{C1}

b) $C_{C2} = \dfrac{1}{2\pi R_{eq} f_L} = \dfrac{1}{2\pi R_C f_L}$

$\therefore C_{C2} = \dfrac{1}{2\pi \times 2.4 \times 10^3 \times 20} = 3.3157\mu\text{F}$

Selecting HSV, $C_{C2} = 3.9\mu\text{F}$ / 25 V

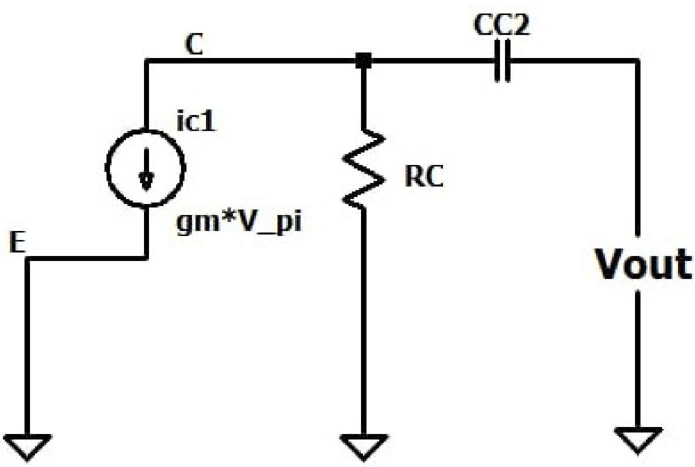

Figure 3: Low frequency equivalent circuit for C_{C2}

Small-signal analysis:

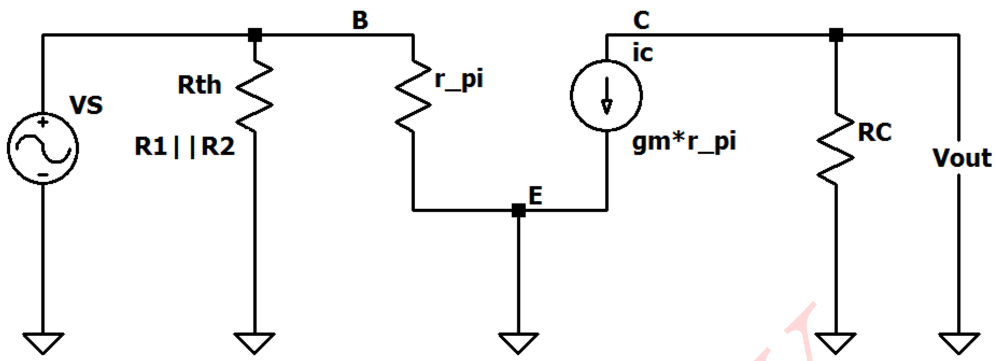

Figure 4: Small-signal equivalent circuit

Small-signal parameters:

$$g_m = \frac{I_{CQ}}{V_T} = \frac{3mA}{26mV} = 115.38\frac{mA}{V}$$

Verification of gain A_V:

$$A_V = -g_m R_C = -115.38\frac{mA}{V} \times 2.4\ \text{k}\Omega$$

$$\therefore A_V = -276.912$$

$$Z_i = R_1||R_2||r_\pi = 2.677\ \text{k}\Omega$$

$$Z_o = R_C = 2.4\ \text{k}\Omega$$

The complete designed circuit is shown in Figure 4.

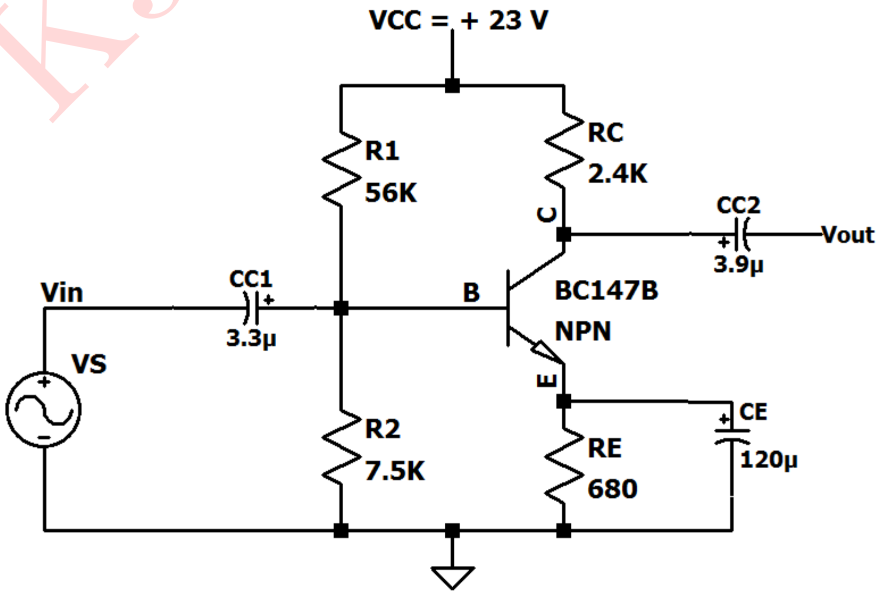

Figure 5: Designed circuit

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

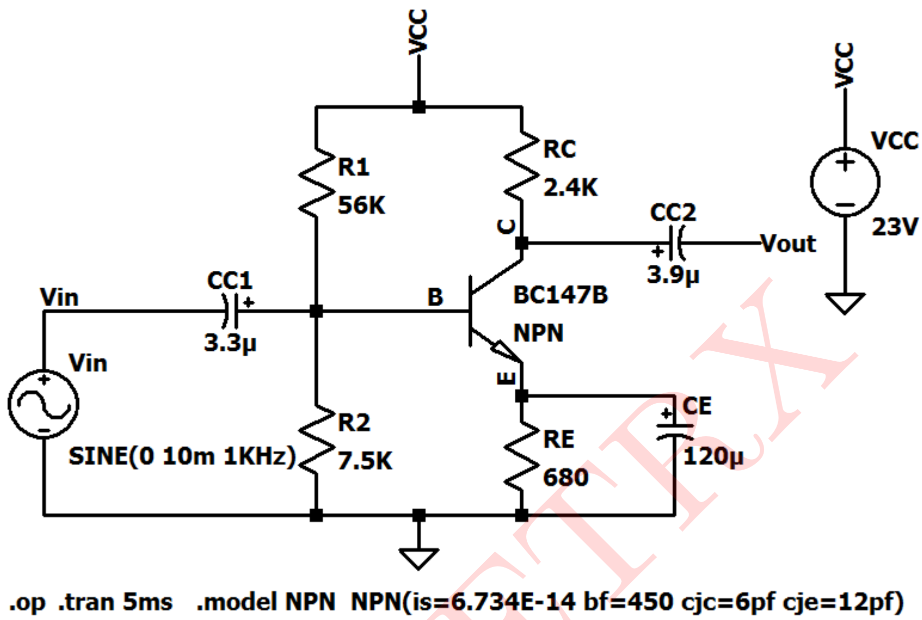

Figure 6: Circuit schematic

The input and output waveforms for are shown in Figure 7.

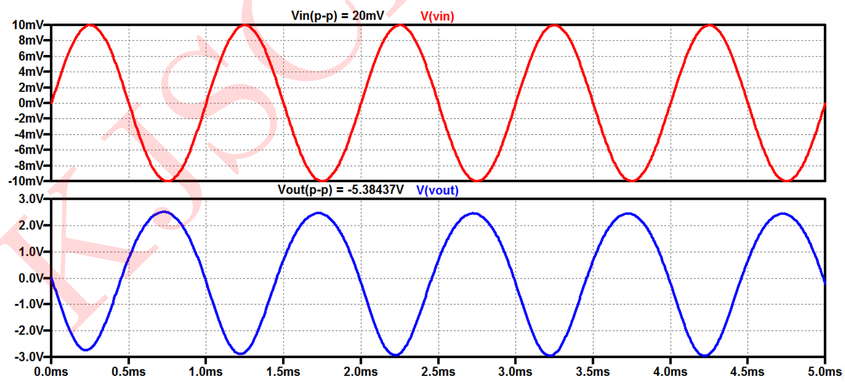

Figure 7: Circuit schematic

Comparison of theoretical and simulated values:

Parameters	Theoretical	Simulated
Voltage gain $\|A_V\|$	≥ 120	269.218
I_{CQ}	3 mA	2.8 mA

Table 1: Numerical 1