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DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Design of single-stage Amplifier

Design 1:

Design a single stage RC coupled BJT amplifier for the following specifications:

$V_{o_{rms}} = 3V$, $f_L \leq 15Hz$, $S \leq 10$, $|A_V| \geq 120$

Calculate A_V, Z_i & Z_o of the amplifier you have designed.

Solution:

1. Given Data:

$|A_V| \geq 120$, $S \leq 10$, $V_{o_{rms}} = 3V$, $f_L \leq 15Hz$

2. Circuit Diagram and Selection of Transistor:

Transistor BC147B is selected with following specifications:

$h_{FE(min)} = 200$, $h_{FE(typ)} = 290$, $h_{FE(max)} = 450$

$h_{ie} = 4.5k\Omega$, $V_{CE(sat)} = 0.25V$

$h_{fe(min)} = 240$, $h_{fe(typ)} = 330$, $h_{fe(max)} = 500$

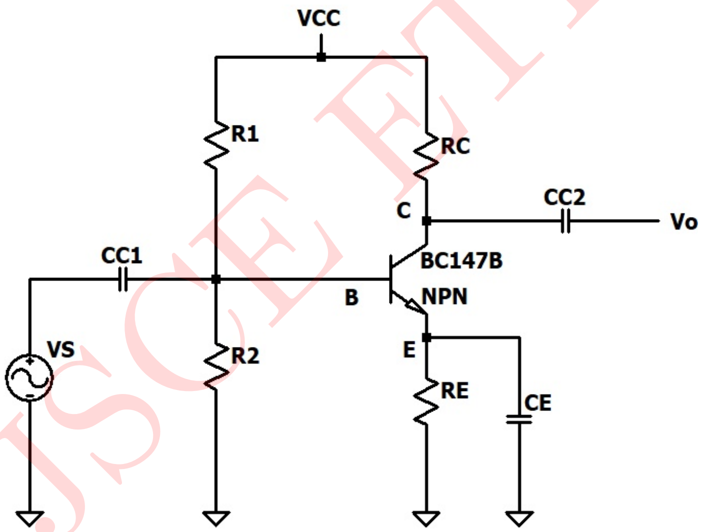

Figure 1: Circuit 1

3. Selection of $\mathbf{R_C}$

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

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

$R_C = \mathbf{2.25k\Omega}$

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

$\therefore$ Select $R_C = 2.4k\Omega$, $\frac{1}{4}W$

4. Selection of Qpoint ($\mathbf{V_{CE}}$ & $\mathbf{I_C}$)

$V_{o_{peak}} = V_{o_{rms}} \times \sqrt{2} = 3 \times \sqrt{2} = \mathbf{4.2426V}$
$V_{CE} = 1.5 \quad [V_{o_{peak}} + V_{CE_{(sat)}}]$

The value is multiplied by 1.5 to take care of saturation voltages, variation in resistance, variation in supply voltage an device parameter variation.

$V_{CE} = 1.5(4.2426 + 0.25) = \mathbf{6.74V}$

$$I_{o_{peak}} = \frac{V_{o_{peak}}}{R_C} = \frac{4.2426V}{2.4k\Omega} = \mathbf{1.767mA}$$

$I_C \geq I_{o_{peak}}$ [For undistorted output signal]
Select $I_C = \mathbf{2mA}$

$V_{CC} \geq 2V_{CE}$ [Selecting Qpoint at the center of DC load line for maximum output swing]
$V_{CC} \geq 2 \times 4.2426V$
$V_{CC} \geq 8.4852V$
Select $V_{CC} = \mathbf{9V}$

5. Selection of $\mathbf{R_E}$

For proper operation,
$V_{RE} = 10\%$ of V_{CC}
$V_{RE} = 0.1V_{CC} = 0.1 \times 9 = \mathbf{0.9V}$

Now,
$V_{RE} = R_E \times I_E$

$$R_E = \frac{V_{RE}}{I_E} \approx \frac{V_{RE}}{I_C}$$

$$R_E \approx \frac{0.9V}{2mA}$$

$R_E \approx 450\Omega$

Selecting a lower standard value

Select $R_E = \mathbf{420\Omega, \frac{1}{4}W}$

6. Selection of $\mathbf{R_1}$ & $\mathbf{R_2}$

$$\text{S} = \frac{1 + h_{FE(max)}}{1 + h_{FE(max)}\left[\dfrac{R_E}{R_E + R_B}\right]}$$

$\beta = h_{FE(max)} = 450$ & $R_B = R_1 \parallel R_2$

$$10 = \frac{1 + 450}{1 + 500\left[\dfrac{420}{420 + R_B}\right]}$$

$$R_{TH} = R_B = 3.8657k\Omega = \frac{R_1R_2}{R_1 + R_2} \qquad .....(1)$$

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

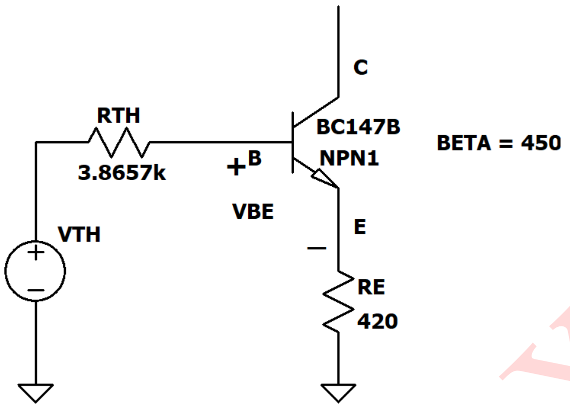

Figure 2: Thevenin's Equivalent Circuit

Applying KVL at B-E loop,

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

$V_B - I_B R_B - V_{BE} - I_E R_E = 0$

$V_B = V_{BE} + \frac{I_C}{\beta} R_B + I_C R_E$

$= 0.7 + \frac{2mA}{500} \times 3.8657k\Omega + 2mA \times 420\Omega$

$= \mathbf{1.557V}$

From equation (2),

$V_B = 1.557 = \frac{R_2}{R_1 + R_2} \times 9V$

$$\frac{R_2}{R_1 + R_2} = 0.173 \qquad .....(3)$$

Substituting equation (3) in equation (1),

$R_1 \times (0.173) = 3.8657k\Omega$

$R_1 = 22.345k\Omega$

Selecting a higher standard value so that circuit draws minimum current,

Select $R_1 = \mathbf{24k\Omega, \frac{1}{4}W}$

From equation (3),

$\frac{R_2}{24k\Omega + R_2} = 0.173$

$R_2 = 5.02k\Omega$

Selecting a lower standard value,

Select $R_2 = \mathbf{4.7k\Omega, \frac{1}{4}W}$

7. Selection of C_E

To ensure complete bypass of R_E

$X_{CE} < R_E$

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

i.e $\frac{1}{2\pi f_L C_E} = 0.1R_E$

$$C_E = \frac{1}{2\pi f_L \times 0.1R_E}$$
$$= \frac{1}{2\pi \times 15 \times 0.1 \times 420}$$
$$= 252.62\mu F$$

Selecting a higher standard value

Select C_E = **270μF/18V**

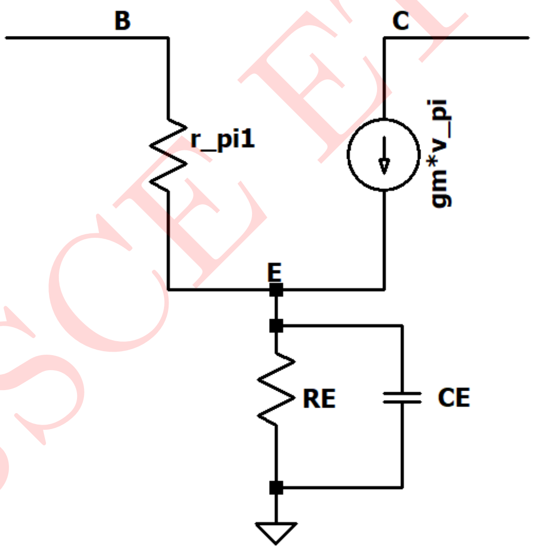

Figure 3: Small Signal Equivalent Circuit for CE

8.Selection of C_{C_1}

$C_{C_1} = \frac{1}{2\pi R_{eq} f_L}$

$R_{eq} = R_1 \parallel R_2 \parallel h_{ie}$ $\qquad [h_{ie} = r_\pi]$

$$= 24k\Omega \parallel 4.7k\Omega \parallel 4.5k\Omega$$
$$= 3.93k\Omega \parallel 4.5k\Omega$$
$$= 2.097k\Omega$$

$$C_{C_1} = \frac{1}{2\pi \times 2.097k\Omega \times 15Hz} = 5.059\mu F$$

Selecting a higher standard value

Select $C_{C_1} = \mathbf{5.6\mu F/18V}$

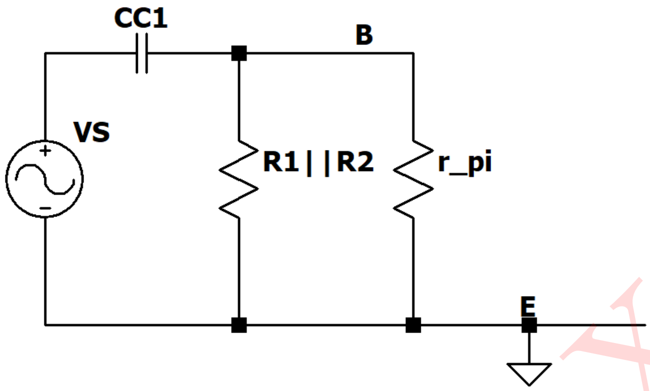

Figure 4: Small Signal Equivalent Circuit for C_{C_1}

9. Selection of $\mathbf{C_{C_2}}$

$$\begin{aligned} C_{C_2} &= \frac{1}{2\pi R_{eq} f_L} \\ &= \frac{1}{2\pi R_C f_L} && \text{[Since, } R_{eq} = R_C\text{]} \\ &= \frac{1}{2\pi \times 2.4k\Omega \times 15Hz} \\ &= 4.42\mu F \end{aligned}$$

Selecting a higher standard value,

Select $C_{C_2} = \mathbf{4.7\mu F/18V}$

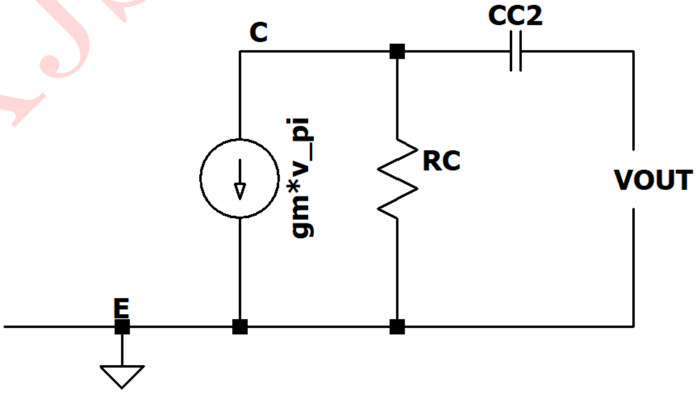

Figure 5: Small Signal Equivalent Circuit for C_{C_2}

10. Complete Designed Circuit:

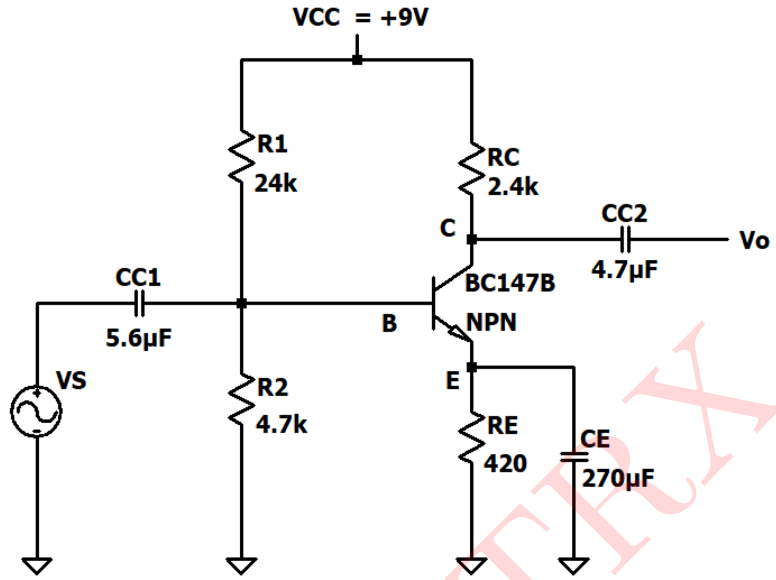

Figure 6: Designed Circuit

11. Calculation of A_V, Z_i & Z_o

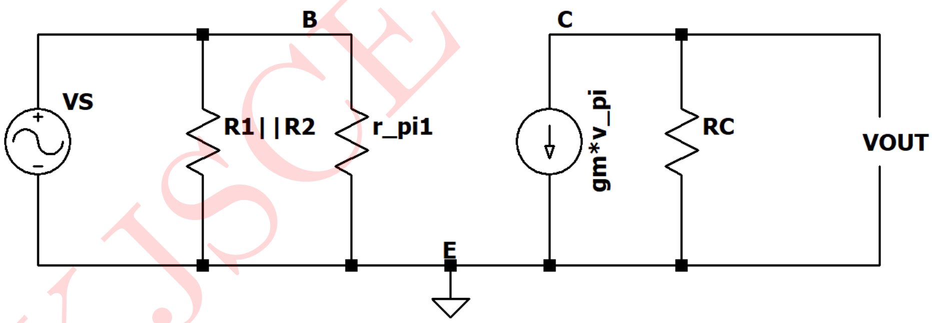

Figure 7: Small Signal Equivalent Circuit

Small Signal Voltage Gain $(A_V) = -g_m R_C$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2mA}{0.026V} = 76.923mA/V$$

$$\therefore A_V = -(76.923mA/V) \times (2.4k\Omega) = \mathbf{-184.615}$$

Input Impedance (Z_i):

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

$$r_\pi = \frac{\beta \times V_T}{I_{CQ}}$$

$$= \frac{450 \times 0.026V}{2mA}$$

$$= 5.85k\Omega$$

$Z_i = 24k\Omega \parallel 4.7k\Omega \parallel 5.85k\Omega = \mathbf{2.35k\Omega}$

Output Impedance (Z_o):

$Z_o = R_C$

$\therefore Z_o = \mathbf{2.4k\Omega}$

SIMULATED RESULTS

The above circuit is simulated in LTspice and results are presented below:

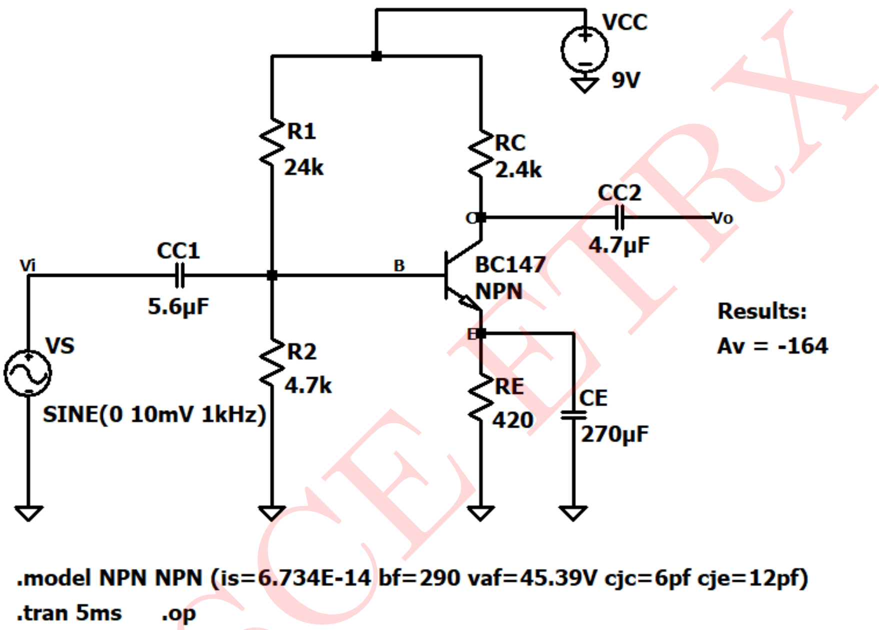

Figure 8: Circuit Schematic

The input and output waveform are shown in figure 8

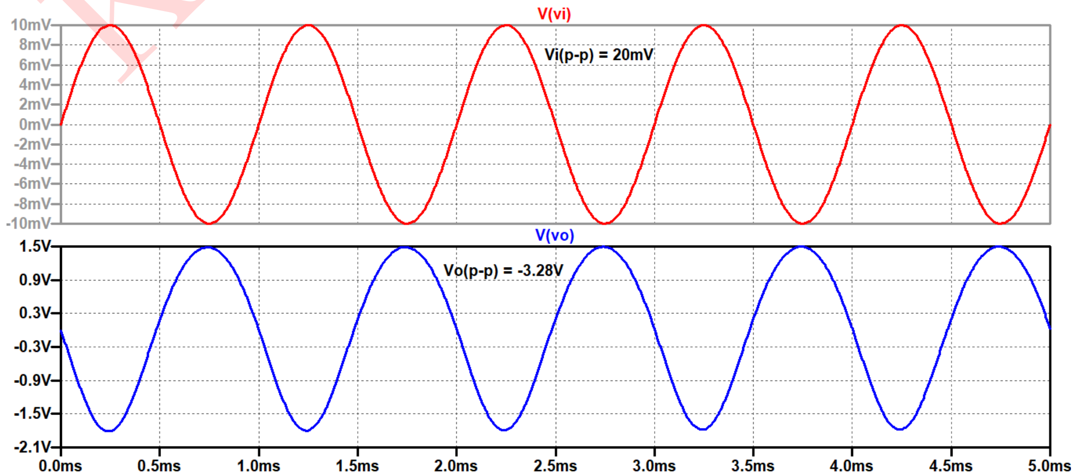

Figure 9: $V_{IN}(t)$ & $V_{OUT}(t)$

Comparison of Theoretical and Simulated results:

Parameters	Theoretical	Simulated
$\lvert A_V \rvert$	> 120	164
I_{CQ}	$2mA$	$1.96315mA$

Table 1: Design 1

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