K. J. SOMAIYA COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Cascade Amplifier Design

Q1. Design a two stages RC coupled cascade amplifier for the following specifications:
$V_o = 3\text{V}$, $R_i \geq 1\text{M}\Omega$, $|A_v| \geq 220$
Calculate A_v, R_i, R_o

Solution:

1) For the above requirement we can use CS-CS self bais JFET amplifier:

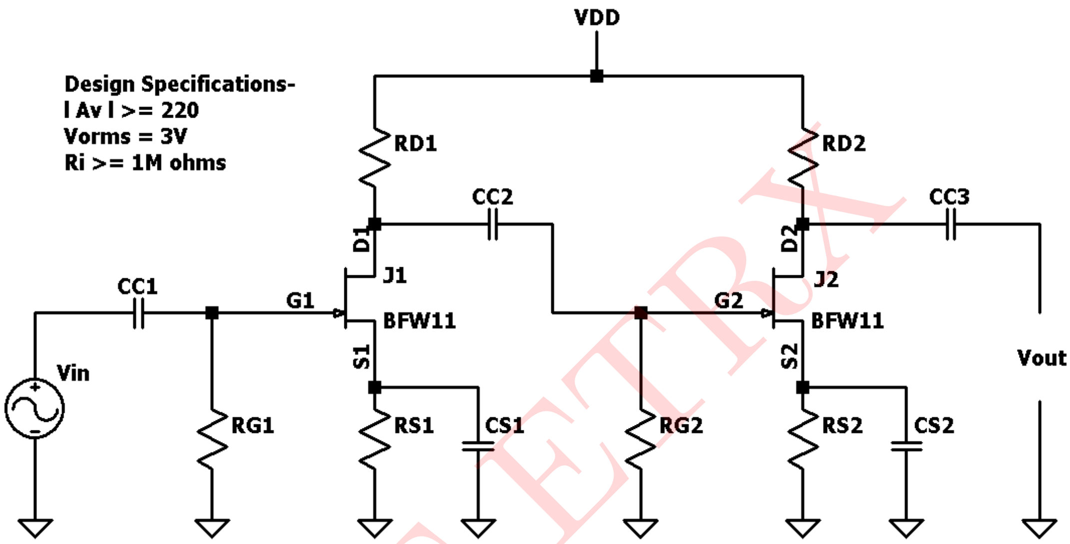

Figure 1: Self baised Circuit 1

We select n channel JFET BFW11 from the datasheet with the following specifications:
$g_{mo} = 5600\mu\mho, V_p = -2.5V, r_d = 50k\Omega, I_{DSS} = 7mA$

2) Selection of voltage gain:

$A_v \geq 220$

$let A_v = 240$ also, $let A_{V_1} = 0.6 A_{V_2}$

$A_{V_t} = A_{V_1} \times A_{V_2}$

$240 = 0.6 A_{V_1}^2$

$A_{V_1} = 12$ and $A_{V_2} = 20$

3) Selection of Q point:

a) For mid point baising: $I_D = \dfrac{I_{DSS}}{2} = \dfrac{7}{2} = 3.5\text{mA}$

b) $I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_p}\right)^2$

$$\frac{3.5}{7} = \left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$$0.5 = \left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$$V_{GS} = V_p\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

$$V_{GS} = -2.5\left(1 - \sqrt{\frac{1}{2}}\right)$$

$$V_{GS} = -0.732\text{V}$$

c) Calculation g_m:

$$g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_p}\right)$$

$$g_m = 5600 \times 10^{-6}\left(1 - \frac{-0.732}{-2.5}\right)$$

$$g_m = 3.96\text{m}℧$$

4) Selection of R_{S2}:

$V_{GS2} = V_G - V_S \qquad (V_G = 0 \because \text{self baised})$

$V_{GS2} = -V_S$

$V_{GS2} = -I_D R_{S2}$

$R_{S2} = -V_{GS2}/I_D = -(-0.732)/3.5mA = 209.142\Omega$, 1/4 W (H.S.V)

Select $R_S = 180\Omega$, 1/4 W (H.S.V)

5) Selection of R_{D2}:

$A_v = g_m(r_d||R_{D2})$

$20 = 3.96 \times 10^{-3}(50 \times 10^3||R_{D2})$

$R_{D2} = 5.617k\Omega$

Select $R_{D2} = 6.2k\Omega$, 1/4 W (H.S.V)

6) Selection of R_{G2}:

Select $R_{G2} = 1\text{M}\Omega$, 1/4 W (H.S.V)

7) Selection of V_{DD}:

Applying KVL at DS loop for JFET

$V_{DD} - I_{DQ2}R_{D2} - V_{DSQ2} - I_{DQ2}R_{S2} = 0$

$V_{DD} = I_{DQ2}(R_D2 + R_S2) + V_{DSQ2}$

$V_{DS} \geq V_{o(peak)} + |V_p|$

$V_{DS} = 1.5(V_{o(peak)} + 2.5)$

$V_{DS} = 1.5(2\sqrt{3} + 2.5)$

$V_{DS} \geq 10.113V$

$V_{DS} = 10.2V$

$V_{DD} = 3.5 \times 10^{-3}(6.2 \times 10^3 + 180) + 10.2$

$V_{DD} = 32.53V$

Select $V_{DD} = 34V$

8) Selection of R_{D1}:

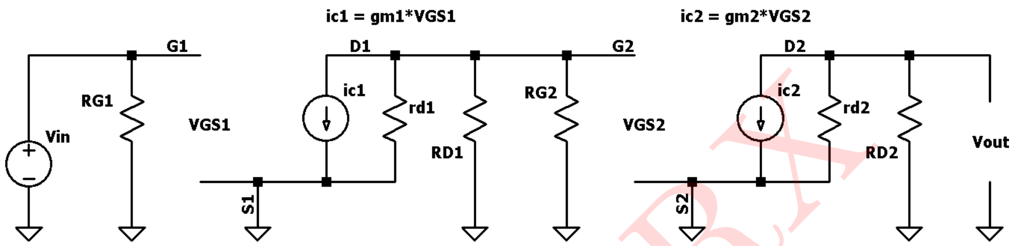

Figure 2: Mid Band AC equivalent circuit

$A_{V_2} = g_m(r_d||R_{D2}) = 3.96(50k||6.2k)$

$A_{V_2} = 21.8450$

$A_{V_1} = \dfrac{A_V}{A_{V_2}} = \dfrac{240}{21.8450} = 10.986$

$A_{V_1} = 11$

$A_{V_1} = g_m(r_{d1} \ || \ R_{D1} \ || \ R_{G2})$

$11 = 3.9063m(R_{D1} \ || \ 47.62k)$

$R_{D1} = 2.949\text{k}\Omega$ (select H.S.V)

Select $R_{D1} = 3.3\text{k}\Omega$, 1/4W

9) Selection of R_{S1}:

$V_{GS} = V_G - V_S \qquad (V_G = 0 \because$ self baised)

$V_{GS} = -V_S$

$V_{GS} = -I_D R_S$

$R_S = -V_{GS}/I_D = -(-0.732)/3.5mA = 209.142\Omega$, 1/4 W (H.S.V)

Select $R_S = 180\Omega$, 1/4 W (H.S.V)

10) Selection of R_{G1}:

To aviod the effect and fullfill requirement

$R_{G1} \geq 1\text{M}\Omega$

Select $R_{G1} \geq 1\text{M}\Omega$, 1/4 W (H.S.V)

11) Selection of C_{C1}, C_{C2}, C_{C3}:

a) Selection of C_{C1}:

$$C_{C1} = \frac{1}{2\pi \times f_{LCC1} R_{G1}} \qquad (f_{LCC1} = f_L \leq 20Hz)$$

$$R_{eq} = R_G = 1.2M\Omega$$

$$C_{C1} = \frac{1}{2\pi \times 20 \times 1.2 \times 10^6}$$

$$C_{C1} = 6.631 \text{ nF}$$

Small signal equivalent circuit:

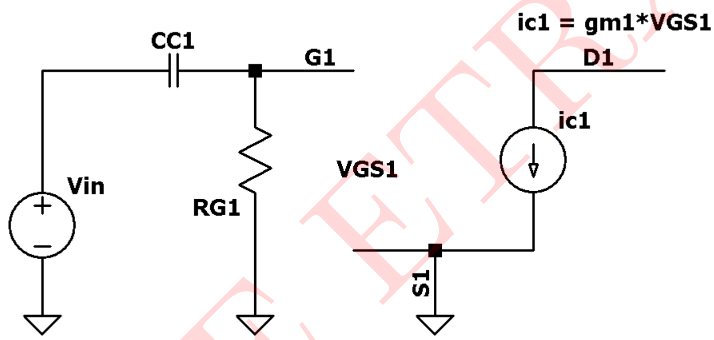

Figure 3: Small signal equivalent circuit for CC1

Select C_{C1} = 8.2 nF, 50V (H.S.V)

b) Selection of C_{C2}:

$$C_{C2} = \frac{1}{2\pi \times f_{LCC2} R_{eq}} \qquad (f_{LCC2} = f_L \leq 20Hz)$$

$$R_{eq} = (r_d || R_D) + R_{G2} = (2.7 \times 10^3 || 20 \times 10^3) 1.2 \times 10^6 = 1.00309M\Omega$$

$$C_{C2} = \frac{1}{2\pi \times 1.00309 \times 10^6 \times 20}$$

$$C_{C2} = 7.9332\text{nF}$$

Select C_{C2} = 8.2μF, 50V (H.S.V)

Small signal equivalent circuit:

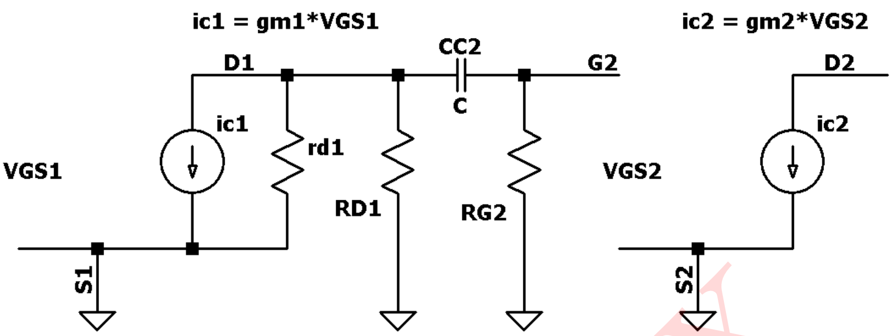

Figure 4: Small signal equivalent circuit for CC2

c) Selection of C_{C3}:

$C_{C3} = \dfrac{1}{2\pi \times f_{LCC2} R_{eq}} \qquad (f_{LCC3} = f_L \leq 20Hz)$

$R_{eq} = (r_{d2}||R_{D2}) == 5.516k\Omega$

$C_{C3} = \dfrac{1}{2\pi \times 5.516 \times 10^3 \times 20}$

$C_{C3} = 1.442$nF

Select $C_{C3} = 1.5\ \mu$F, 50V (H.S.V)

12) Selection of C_{S1}, C_{S2}:

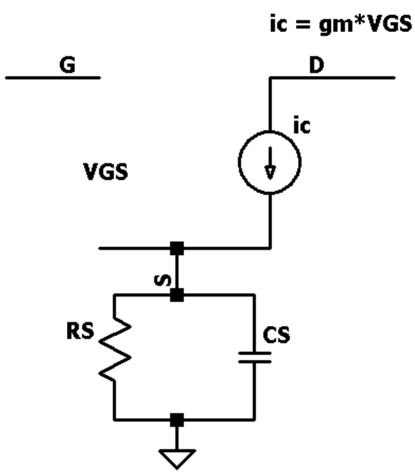

Figure 5: Small signal equivalent circuit for CS

$g_m = g_{m1} = g_{m2}$ and $R_{S1} = R_{S2} = 180\Omega$

$C_{S1} = C_{S2} = \dfrac{1}{2\pi \times f_{LCS} R_{eq}}$

$R_{eq} = \dfrac{1}{g_m}||R_S = \dfrac{1}{3.9603 \times 10^{-3}}||180 = 105.0887$

$C_{S1} = C_{S2} = \dfrac{1}{2\pi \times 105.0877 \times 20} = 75.724\mu F$

$C_S \geq 361.715\mu F$

Select $C_{S1} = C_{S2} = 82\mu$F, 50V (H.S.V)

13) Designed Circuit is:

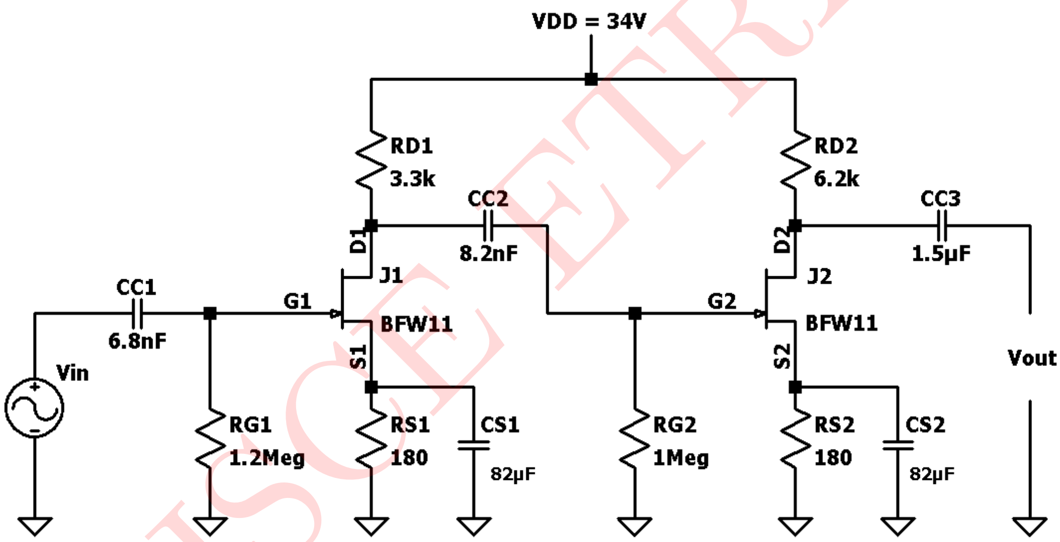

Figure 6: Designed circuit 1

Verification of overall gain:

$Z_i = R_g$

$Z_o = r_{d2}||R_{D2}$

$A_{V_2} = g_m(r_{d2}||R_{D2}) = 3.96m(50k||6.2k)$

$A_{V_2} = -21.8450$

$A_{V_1} = g_m(r_{d1} \; || \; R_{D1} \; || \; R_{G2}) = 3.96\text{m}(50\text{k} \; || \; 3.3\text{k} \; || \; 1.2\text{M})$

$A_{V_1} = -12.22$

$A_{V_T} = A_{V_2} \times A_{V_1} = -21.845 \times -12.22$

$A_{V_T} = \mathbf{266.94}$ ($\because A_V \geq 220$)

$A_{V_T} = 20\log_{10}(266.94)$

$A_{V_T} = \mathbf{48.528\ dB}$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

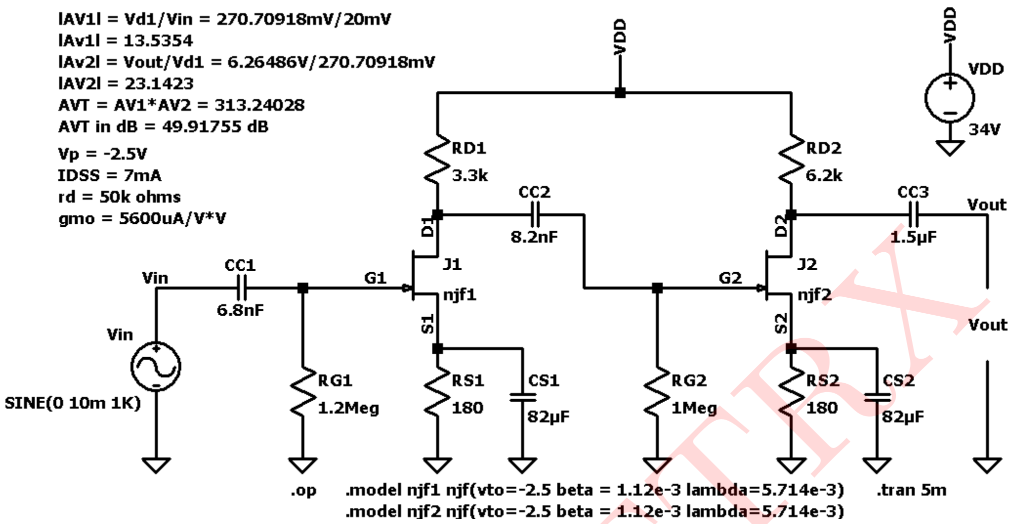

Figure 7: Circuit schematic 1

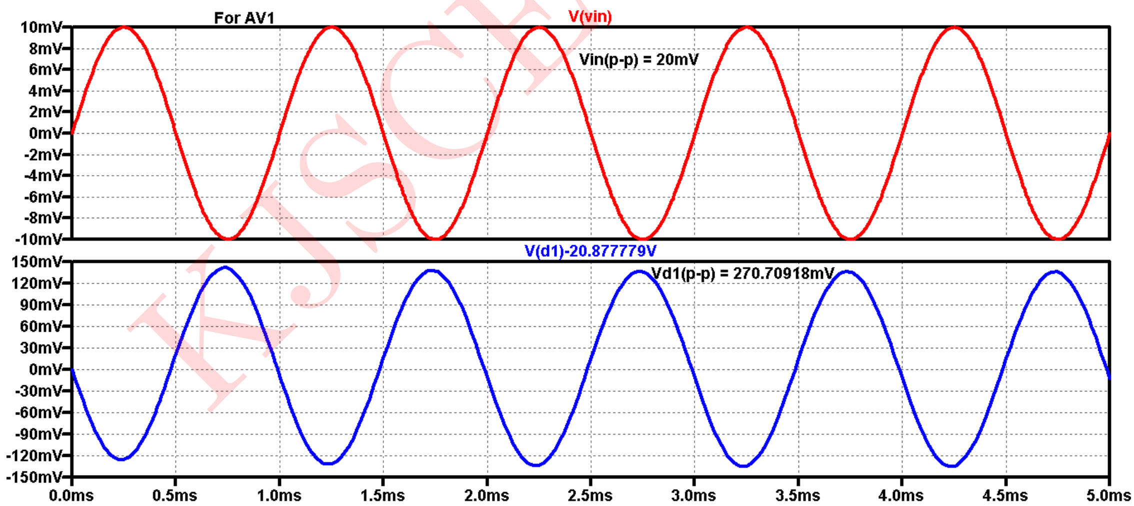

Figure 8: Circuit Schematic: Input Output Waveform A_{V_1}

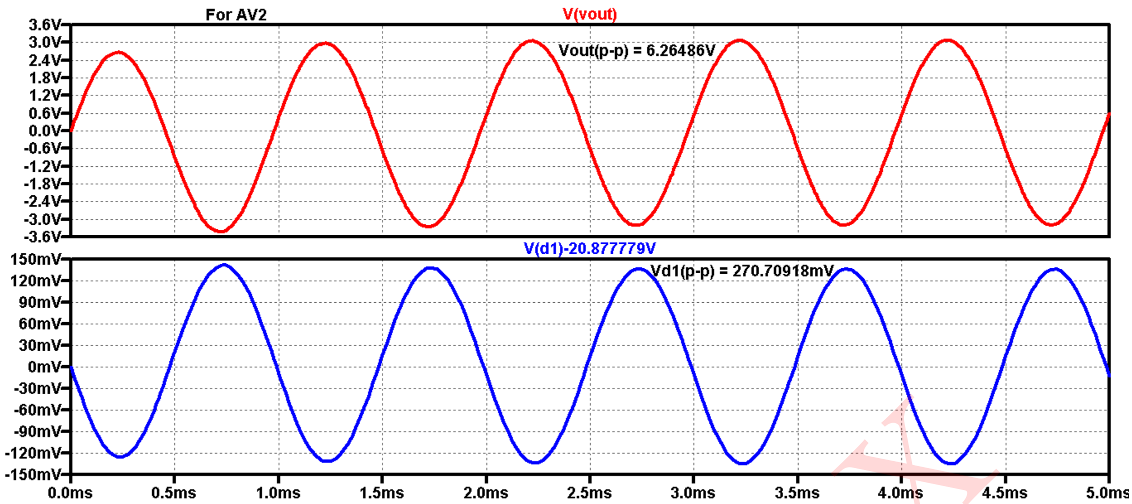

Figure 9: Circuit Schematic: Input Output Waveform A_{V_2}

Comparsion between observed and theoretical values :

Parameters	Observed	Theoretical
I_{DQ1}, V_{GSQ1}	3.738mA, −0.6729V	3.5mA, −0.732V
I_{DQ2}, V_{GSQ2}	3.738mA, −0.6729V	3.5mA, −0.732V
A_{V_1}	− 13.5354	− 12.22
A_{V_2}	− 23.1423	− 21.845
A_{V_T} in dB	49.9175	48.5284
Z_i	–	1.2MΩ
Z_o	–	5.516kΩ

Table 1: Numerical 1

Q2. Design a two stages RC coupled cascade amplifier for the following specifications:
$V_{CC} = 20\text{V}$, $R_i \geq 1\text{M}\Omega$, $|A_v| \geq 450$, $S \leq 8$
Calculate A_v, R_i, R_o

Solution:

1) For the above requirement we can use CS-CE self bais JFET amplifier:

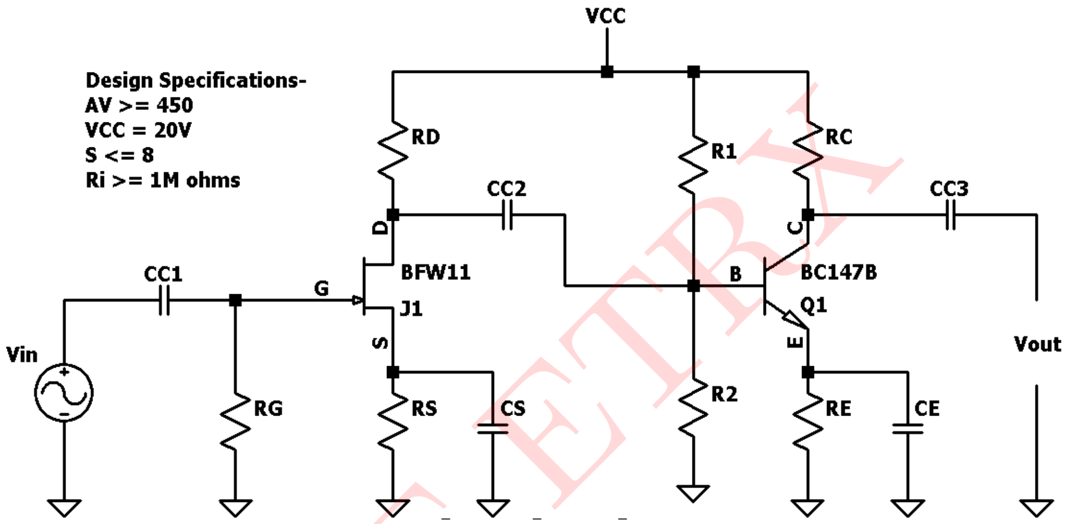

Figure 10: Self baised Circuit 2

We select n channel JFET BFW11 from the datasheet with the following specifications:

$g_{mo} = 5600\mu\mho, V_p = -2.5V, r_d = 50k\Omega, I_{DSS} = 7mA$

We select BC147B BJT amplifier from the datasheet with the following specifications:

$h_{fe(typ)} = 330$, $\beta = 290$, $V_{ce(sat)} = 0.25V$, $hie = 4.5k\Omega$

2) Selection of voltage gain:

$A_v \geq 450$

let $A_v = 450$ also, let$A_{V_1} = 4$, $A_{V_2} = 450/4 = 112.2 \approx 120$

$A_{V_1} = 4$ and $A_{V_2} = 120$

Design of 2^{nd} Stage:

3) Selection of R_C:

$$A_{V_2} = \frac{h_{fe(typ)R_C}}{h_{ie}}$$

$$120 = \frac{330 \times R_C}{4.5k}$$

$R_C = 1.636k\Omega$

Select $R_C = 1.636k\Omega$, 1/4 W (H.S.V)

4) Selection of Q point:

$V_{CC} = 20V$

$V_{CEQ} = V_{CC}/2 = 10V$

$V_{RE} = 0.1V_{CC} = 0.1 \times 20 = 2$

KVL to C-E loop of BJT

$V_{CC} - V_{RC} - V_{CEQ} = V_{RE} = 0$

$V_{RC} = V_{CC} - V_{CEQ} - V_{RE} = 20 - 12 = 8$

$V_{RC} = I_{CQ}R_C = 8$

$$I_{CQ} = \frac{V_{RC}}{R_C} = \frac{8}{1.8k} = 4.44\text{mA}$$

5) Selection of R_E:

$V_{RE} = 2V$

$I_{EQ}R_E = 2$

$$R_E = \frac{2}{I_{CQ}} = \frac{2}{4.44m} = 450.45\Omega$$

Select $R_E = 420\Omega$, 1/4 W (H.S.V)

6) Selection of R_1 and R_2:

S≤8, let S = 7

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

$$7 = \frac{1+290}{1+290\left(\dfrac{420}{R_B+420}\right)}$$

$R_B = 2.582k\Omega$

$R_B = R_1||R_2 = 2.582k$ ——— (1)

$$V_B = \frac{R_2}{R_1+R_2}V_{CC} \text{——- (2)}$$

KVL at B-E loop

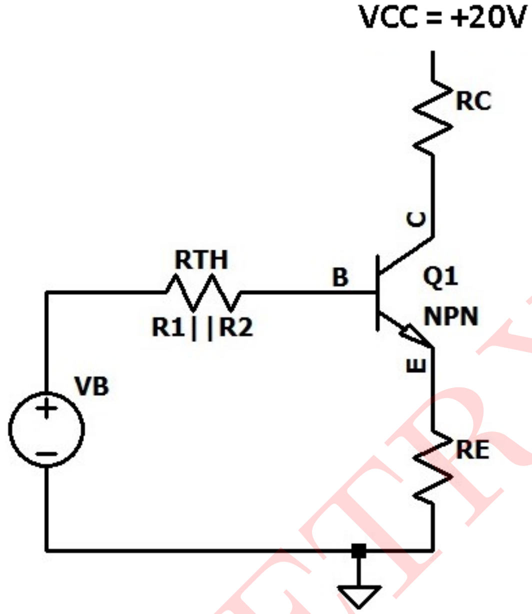

Figure 11: DC equivalent circuit

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

$V_B = I_{CQ}R_B/\beta + V_{BE} + I_{CQ}R_E$

$V_B = 4.44 \times 2.582/290 + 0.7 + 4.44m \times 420 = 2.6V$

Now from (2)

$2.6 = \dfrac{R_2}{R_1 + R_2} V_{CC}$

$\dfrac{R_2}{R_1 + R_2} = 0.13$ ——— (3)

Solving equations (3) and (1)

$R_1(0.13) = 2.582k$

$R_1 = 19.86k\Omega$

Select $R_1 = 22k\Omega$, 1/4 W (H.S.V)

From (3)

$\dfrac{R_2}{22k + R_2} = 0.13$

$R_2 = 3.287k\Omega$

Select $R_2 = 3.3k\Omega$, 1/4 W (H.S.V)

Design of 1^{st} Stage:

7) Selection of Q point:

a) For mid point baising: $I_D = \dfrac{I_{DSS}}{2} = \dfrac{7}{2} = 3.5\text{mA}$

b) $I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_p}\right)^2$

$\dfrac{3.5}{7} = \left(1 - \dfrac{V_{GS}}{V_p}\right)^2$

$0.5 = \left(1 - \dfrac{V_{GS}}{V_p}\right)^2$

$V_{GS} = V_p\left(1 - \sqrt{\dfrac{I_D}{I_{DSS}}}\right)$

$V_{GS} = -2.5\left(1 - \sqrt{\dfrac{1}{2}}\right)$

$V_{GS} = -0.732\text{V}$

c) Calculation g_m:

$g_m = g_{mo}\left(1 - \dfrac{V_{GS}}{V_p}\right)$

$g_m = 5600 \times 10^{-6}\left(1 - \dfrac{-0.732}{-2.5}\right)$

$g_m = 3.96\text{m℧}$

8) Selection of R_S:

$V_{GS} = -I_D R_S$

$R_S = -V_{GS}/I_D = -(-0.732)/3.5mA = 209.142\Omega$, 1/4 W (H.S.V)

Select $R_S = 180\Omega$, 1/4 W (H.S.V)

9) Selection of R_D:

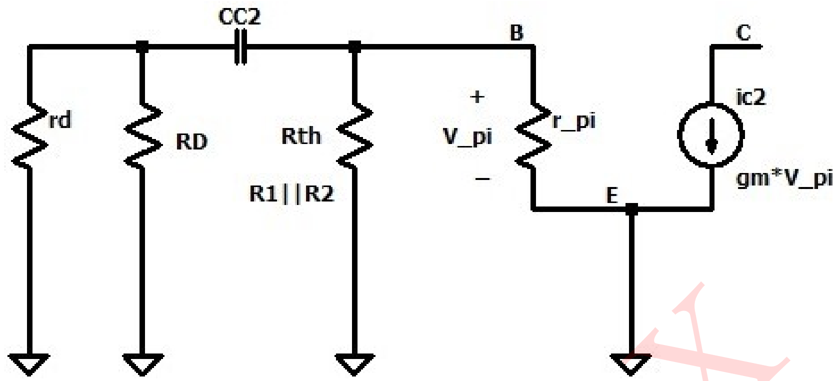

Figure 12: Small signal equivalent circuit for RD

$A_{V_2} = \dfrac{h_{fe(typ)R_C}}{h_{ie}} = \dfrac{330 \times 1.8k}{4.5k} = 132$

$A_{V_1} = \dfrac{A_V}{A_{V_2}} = 450/132 \approx 3.41$

$A_{V_1} = 3.5$

$A_{V_1} = -g_m(r_d||R_D||R_1||R_2||h_{ie})$

$3.5 = 3.96 \times 10^{-3}(R_D||1.69k)$

$R_{D2} = 1.853k\Omega$

Select $R_{D2} = 2.2k\Omega$, 1/4 W (H.S.V)

10) Selection of R_G:

Select $R_G = 1\text{M}\Omega$, 1/4 W (H.S.V)

11) Selection of C_{C1}, C_{C2}, C_{C3}:

a) Selection of C_{C1}:

$C_{C1} = \dfrac{1}{2\pi \times f_{LCC1} R_G} \qquad (f_{LCC1} = f_L \leq 20Hz)$

$R_{eq} = R_G = 1.2M\Omega$

$C_{C1} = \dfrac{1}{2\pi \times 20 \times 1.2 \times 10^6}$

$C_{C1} = 6.631$ nF

Select $C_{C1} = 6.8$ nF, 50V (H.S.V)

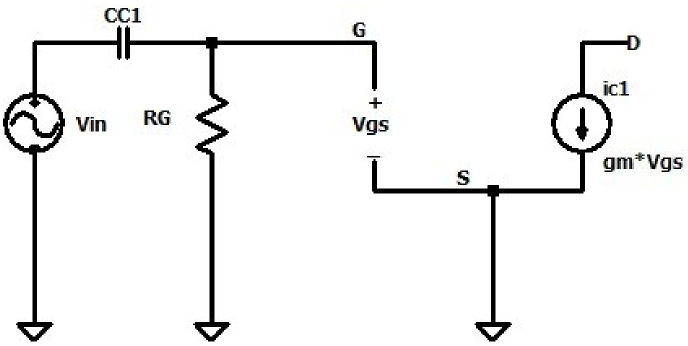

Figure 13: Small signal equivalent circuit for CC1

b) Selection of C_{C2}:

$$C_{C2} = \frac{1}{2\pi \times f_{LCC2} R_{eq}} \qquad (f_{LCC2} = f_L \leq 20Hz)$$

$$R_{eq} = (r_d||R_D) + R_1||R_2||h_{ie} = (50k||2.2k)22k||3.3k||4.5k = 3.856k\Omega$$

$$C_{C2} = \frac{1}{2\pi \times 3.856 \times 10^3 \times 20}$$

$$C_{C2} = 2.06\mu\text{F}$$

Select $C_{C2} = 2.2\mu$F, 50V (H.S.V)

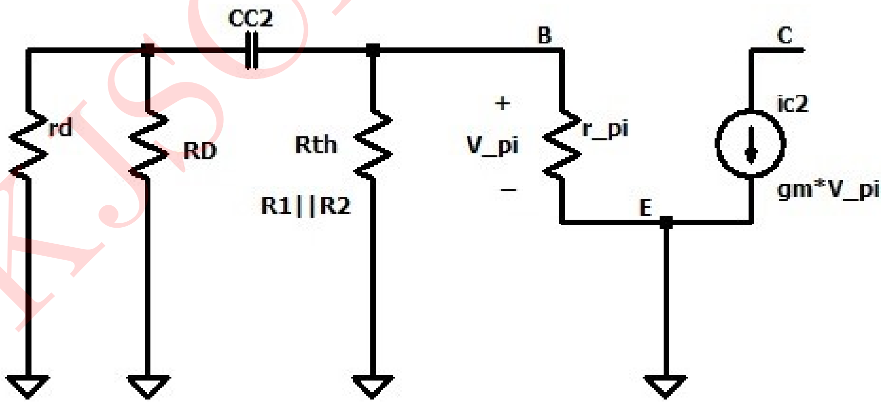

Figure 14: Small signal equivalent circuit for CC2

c) Selection of C_{C3}:

$$C_{C3} = \frac{1}{2\pi \times f_{LCC2} R_{eq}} \qquad (f_{LCC3} = f_L \leq 20Hz)$$

$$R_{eq} = 1.8k\Omega$$

$$C_{C3} = \frac{1}{2\pi \times 1.8 \times 10^3 \times 20}$$

$$C_{C3} = 4.42\text{nF}$$

Select $C_{C3} = 4.7\mu$F, 50V (H.S.V)

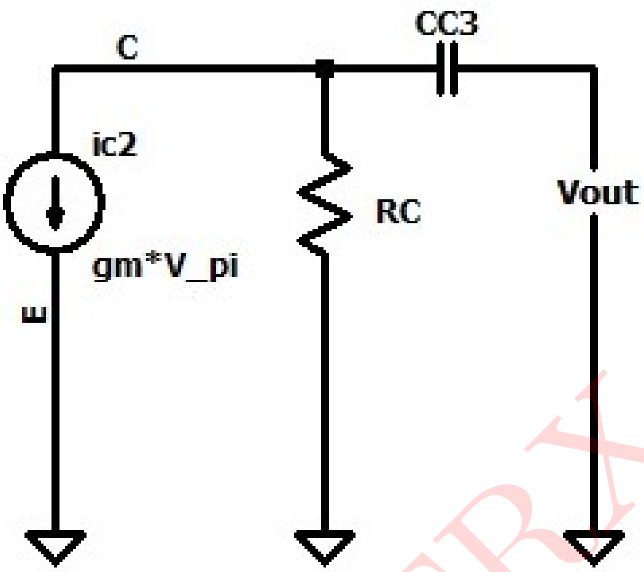

Figure 15: Small signal equivalent circuit for CC3

12) Selection of C_S, C_E:

a)Selection of C_S:

$$C_S = \frac{1}{2\pi \times f_{LCS} R_{eq}}$$

$$R_{eq} = \frac{1}{g_m} || R_S = \frac{1}{3.9603 \times 10^{-3}} || 180 = 105.0887$$

$$C_{S1} = C_{S2} = \frac{1}{2\pi \times 105.0877 \times 20} = 75.724\mu F$$

$C_S \geq 361.715\mu F$

Select $C_S = 82\mu$F, 50V (H.S.V)

b)Selection of C_E:

$X_{CE} = 0.1 R_E$

$$C_E = \frac{1}{2\pi \times f_{LCS} 0.1 R_E}$$

$$C_{S1} = C_{S2} = \frac{1}{2\pi \times 0.1 \times 420 \times 20} = 189.47\mu F$$

Select $C_S = 220\mu$F, 50V (H.S.V)

13) Designed Circuit is:

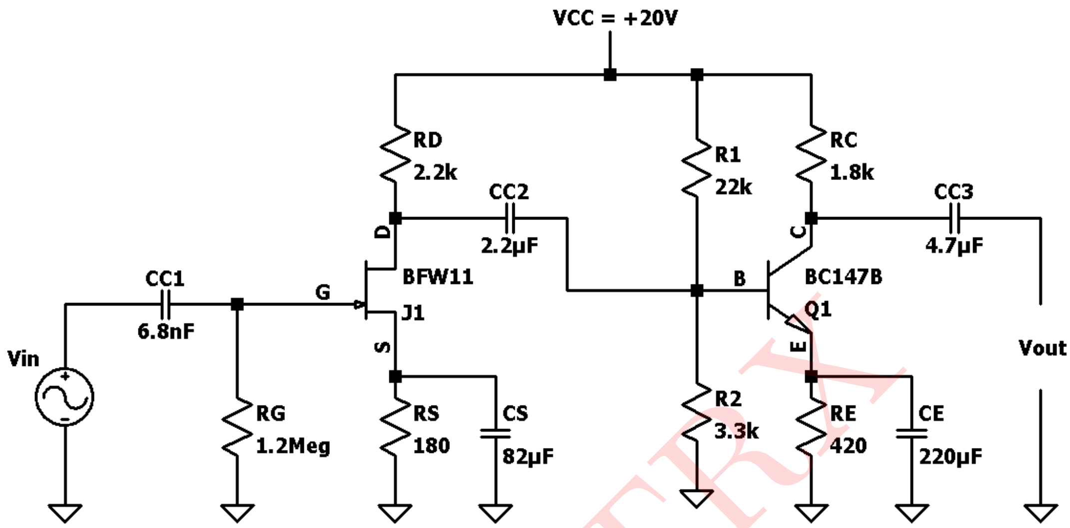

Figure 16: Designed circuit 1

Verification of overall gain:

$Z_i = R_G = 1.2M\Omega$

$Z_o = R_C = 1.8k\Omega$

$A_{V_2} = -g_{m2}R_C = 3.96m(50k||6.2k)$

$g_{m2} = I_{CQ}/V_T = 170.76mA$

$A_{V_2} = -307.368$

$A_{V_1} = g_m(r_d \;||\; R_D \;||\; R_1 \;||\; R_2 \;||\; r_\pi) =$ 3.96m(50k || 2.2k || 22k || 3.3k || 111.698k)

$A_{V_1} = -2.799$

$A_{V_T} = A_{V_2} \times A_{V_1} =$ -307.368 $\times$ -2.799

$A_{V_T} =$ **860.544** ($\because A_V \geq 220$)

$A_{V_T} = 20\log_{10}(860.544)$

$A_{V_T} =$ **58.6954 dB**

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

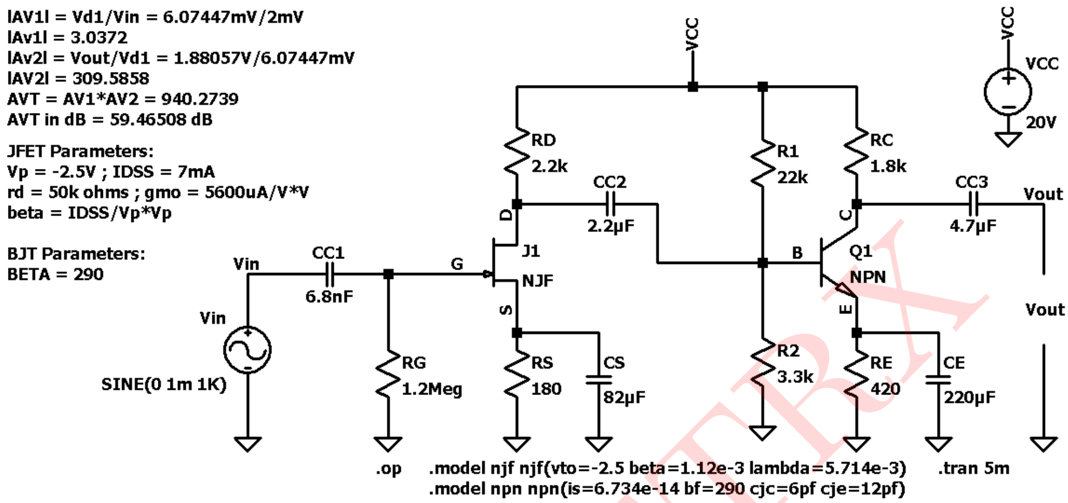

Figure 17: Circuit schematic 1

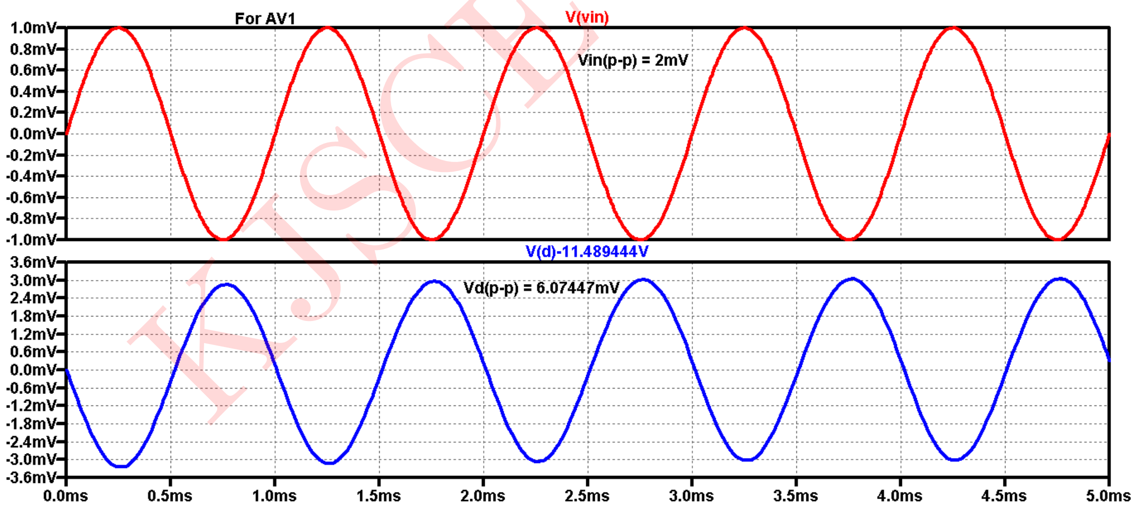

Figure 18: Circuit Schematic: Input Output Waveform A_{V_1}

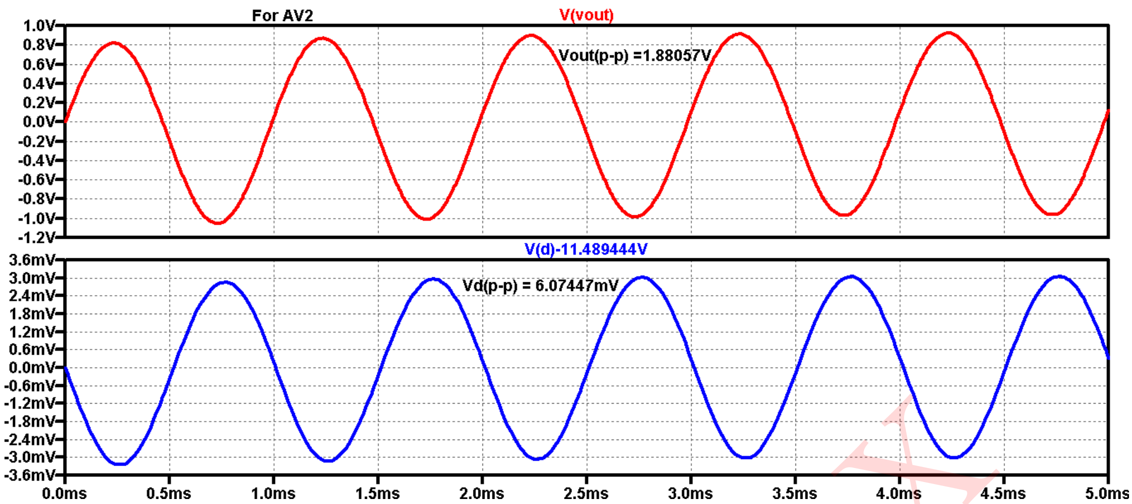

Figure 19: Circuit Schematic: Input Output Waveform A_{V_2}

Comparsion between observed and theoretical values :

Parameters	Observed	Theoretical
I_{DQ}, V_{GSQ}	3.86mA, -0.6963V	3.5mA, -0.732V
I_B, V_C	15.598μA, 4.552mA	15.3103μA, 4.44mA
V_B, V_E	2.563V, 1.9186V	2.6V, 1.871V
A_{V_1}	-3.0372	-2.799
A_{V_2}	-309.5858	$-$ 307.368
A_{V_T} in dB	59.465	58.6954
Z_i	$-$	1.2MΩ
Z_o	$-$	1.8kΩ

Table 2: Numerical 2