K. J. SOMAIYA COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Low and High frequency respone of single stage amplifier

Q1. For the network of figure determine C_C such that lower -3 dB frequency is 15Hz, find $A_{V_{mid}}$

Given: $\beta = 200$, $R_B = 430\text{k}\Omega$, $R_E = 2.5\text{k}\Omega$, $V_{CC} = 10\text{V}$, $R_S = 500\Omega$, $V_A = \infty$

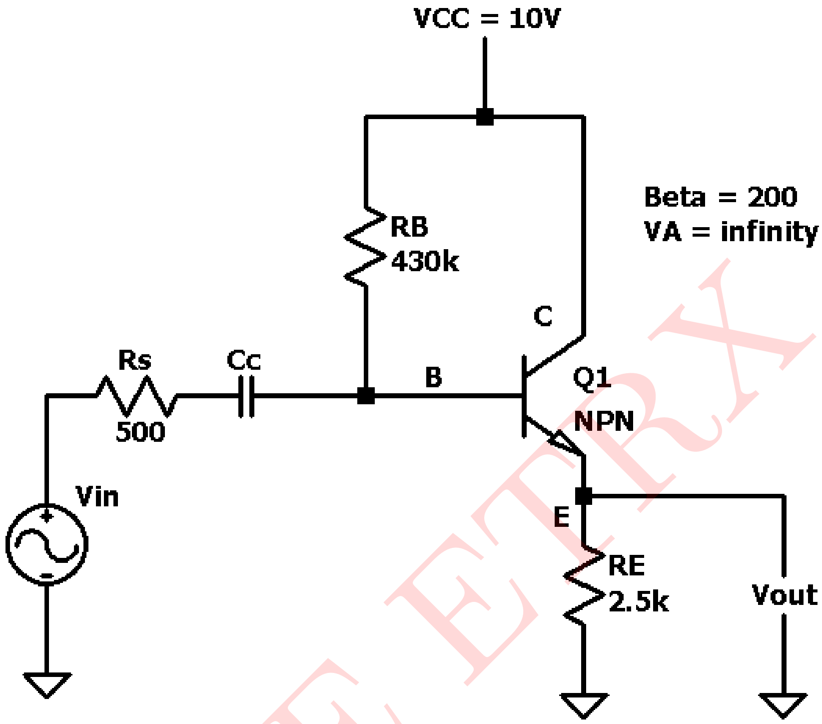

Figure 1: Circuit 1

Solution:

Above circuit is common emitter voltage divider BJT Amplifier

DC Analysis:

Applying KVL to input loop of circuit 1:

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

$I_C = \beta I_B$

$I_E = I_C + I_B$

$I_E = (1 + \beta) I_B$

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1 + \beta) R_E}$$

$$I_B = \frac{10 - 0.7}{430 \times 10^3 + 201 \times 2.5 \times 10^3}$$

$I_B = \mathbf{9.9731\mu A}$

$I_C = \beta I_B$

$I_C = \mathbf{1.9946mA}$

Small signal equivalent for C_C

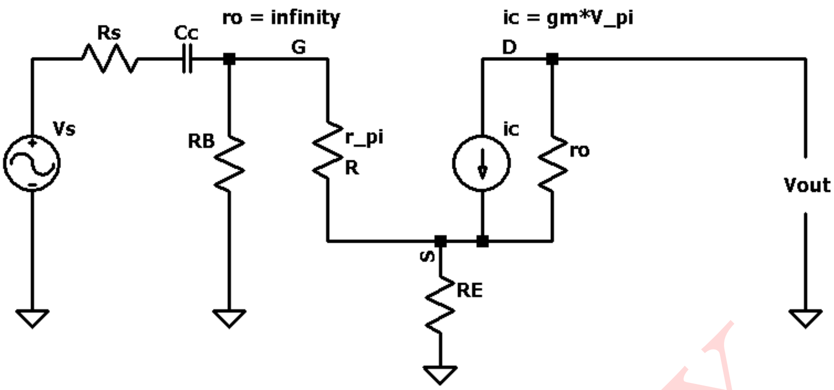

Figure 2: Small signal equivalent circuit fo C_C

We know that $f_{LCC} = \dfrac{1}{2\pi R_{eq} C_C}$

$R_{eq} = R_i + R_o$

$R_o = R_B || (r_\pi + (\beta+1)R_E)$ $\quad$ ($\because$ current through R_π is I_B, current through R_E is I_E also $I_E = (1+\beta)I_B$)

$R_i = R_s$

Small signal parameters:

$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{26 \times 10^{-3}}{9.9731 \times 10^{-6}} = \mathbf{506.1950}\ \Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.9946 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{76.7165\ mA/V}$$

$R_o = R_B || (R_\pi + (\beta+1)R_E)$

$R_o = 430k || (2.607k + (201)2.5k)$

$R_o = 430 \times 10^3 || (505.107 \times 10^3)$

$R_o = \mathbf{232.268\ k}\Omega$

$R_{eq} = R_i + R_o$

$R_{eq} = 500 + 232.268k\Omega$

$R_{eq} = \mathbf{232.768k}\Omega$

$$f_{LCC} = \frac{1}{2\pi R_{eq} C_C}$$

$$C_C = \frac{1}{2\pi \times 232.768 \times 10^3 \times 15}$$

$C_C = \mathbf{45.583}$

Small signal equivalent circuit for A_{vmid}:

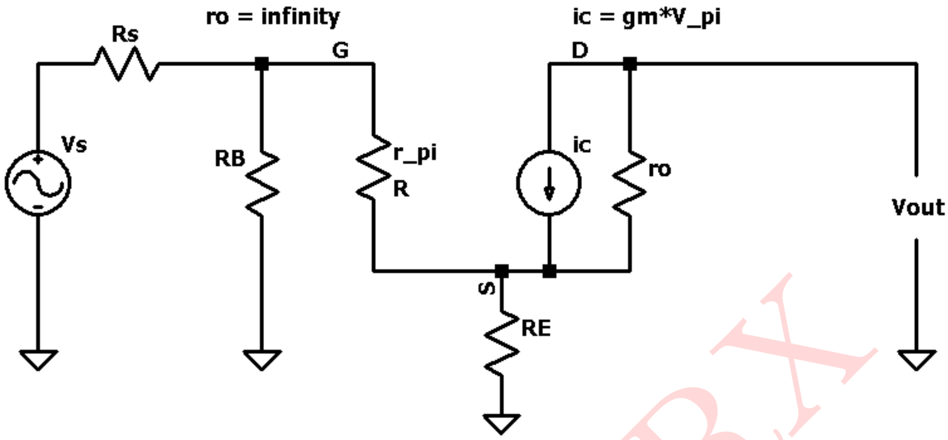

Figure 3: Small signal equivalent circuit for $A_{V_{mid}}$

$$A_{V_{mid}} = \frac{V_o}{V_S}$$

$$A_{V_{mid}} = \frac{V_o}{V_i} \times \frac{V_i}{V_S}$$

$$\frac{V_o}{V_i} = \frac{-R_E}{\frac{1}{g_m} + R_E} = \frac{-2.5k}{\frac{1}{76.715mA/V} + 2.5k}$$

$$\frac{V_o}{V_i} = \mathbf{-0.9948}$$

$$\frac{V_i}{V_S} = \frac{Z_i}{Z_i + R_S}$$

$$Z_i = R_o = 232.268k\Omega$$

$$\frac{V_i}{V_S} = \frac{232.268 \times 10^3}{232.268 \times 10^3 + 500}$$

$$\frac{V_i}{V_S} = \mathbf{0.9978}$$

$$A_{V_{mid}} = (0.9978) \times (-0.9948) = \text{-0.9926}$$

$$A_{V_{mid}} \text{ in dB} = 20 \log_{10}(|0.9926|)$$

$$A_{V_{mid}} \text{ in dB} = \mathbf{-64.301\ mdB \approx 0}$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows

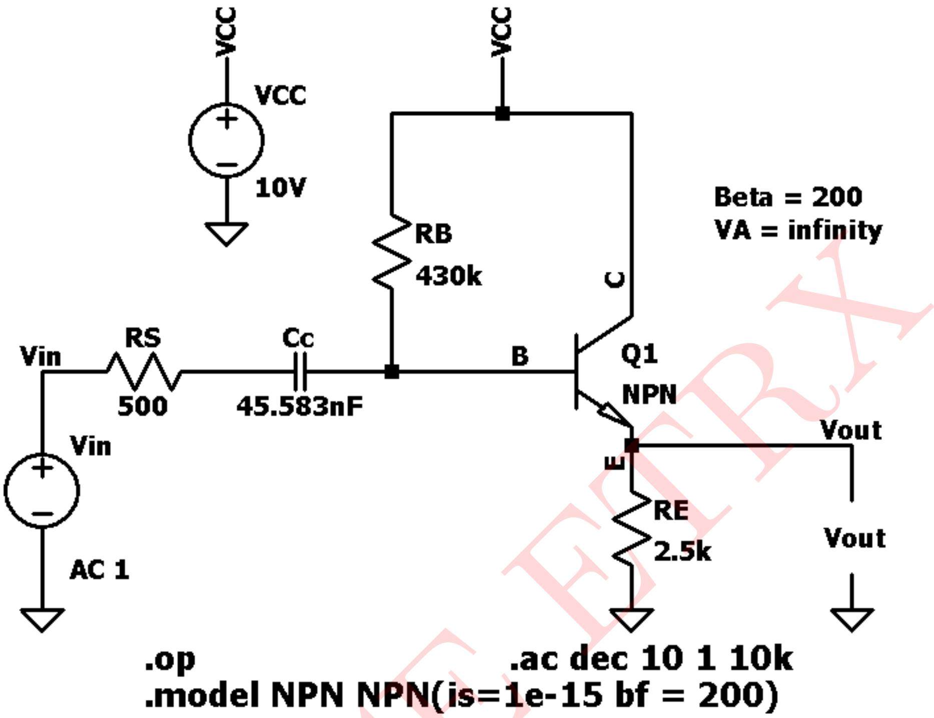

Figure 4: Circuit Schematic

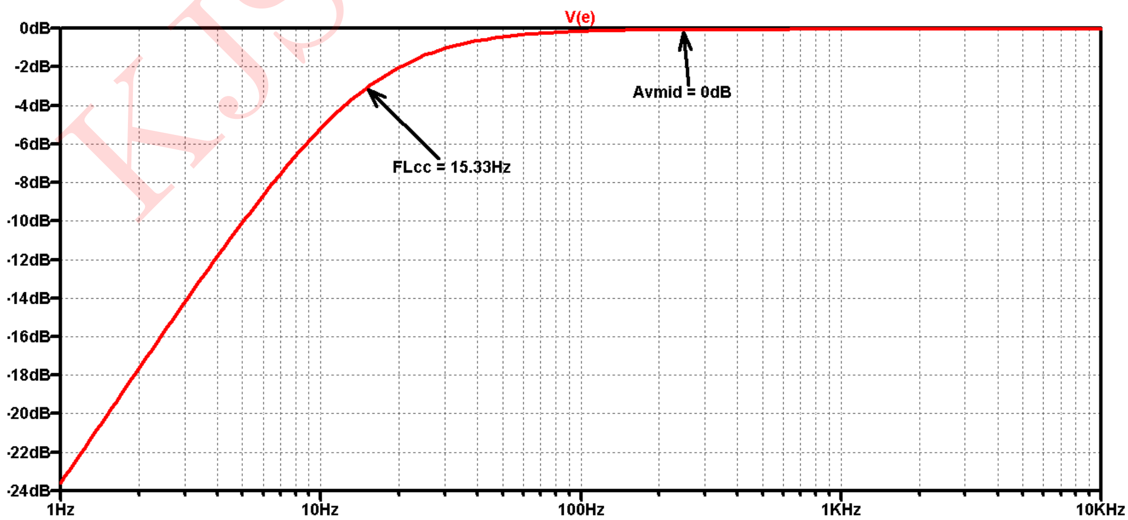

Figure 5: Circuit Schematic: Input Output Waveform

Comparsion between simulated and theoretical values :

Parameters	Theoretical	Simulated
I_{CQ}	1.974mA	1.994mA
$A_{V_{mid}}$	0dB	$\approx$ 0dB
Lower cutoff frequency due to C_C	15.33Hz	15Hz

Table 1: Numerical 1

Q2. For the circuit shown, determine lower cutoff frequency and $A_{V_{mid}}$
Given: $V_P = -7V$, $r_d = \infty\Omega$, $R_S = 1k\Omega$, $R_G = 1M\Omega$, $R_D = 4.7k\Omega$, $R_L = 2.2k\Omega$, $R_{sig} = 10k\Omega$, $C_S = 2\mu F$, $C_C = 0.5\mu F$, $C_G = 0.01\mu F$, $V_{DD} = 20V$, $I_{DSS} = 8mA$

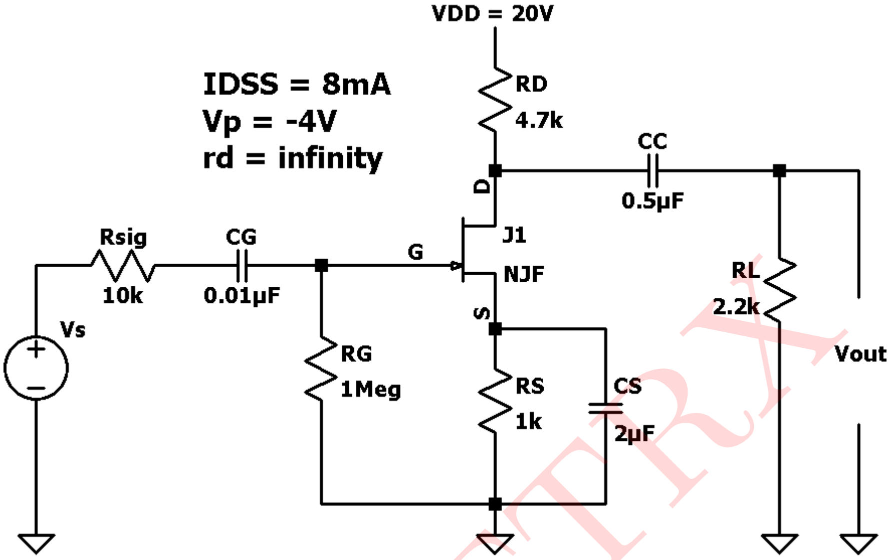

Figure 6: Circuit 2

Solution:

DC Analysis:-

Applying KVL to the input loop:-

$V_{GS} = -I_D R_S$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_D = 8mA\left(1 - \frac{V_{GS}}{(-4)}\right)^2$$

$$V_{GS} = -8mA\left(1 + \frac{V_{GS}}{(-4)} + \frac{V_{GS}^2}{16}\right)^2 \times 1k\Omega$$

$V_{GS} = -8 - 0.5{V_{GS}}^2 - 4V_{GS}$

$0.5{V_{GS}}^2 + 5V_{GS} + 8 = 0$

Solving above quadratic equation, we get

$V_{GS} = -2V$

or

$V_{GS} = -8V$, We reject this value, as $(V_{GS} > V_P)$

$\therefore \boldsymbol{V_{GS} = -2.479V}$

$$I_D = -\frac{V_{GS}}{R_S} = \frac{-2V}{1k\Omega} = 2.mA$$

$\boldsymbol{I_D = 2.065mA}$

Small-Signal parameters:-

$$g_{m_o} = \left|\frac{2I_{DSS}}{V_P}\right| = \frac{2 \times 8}{-4} = 2mA/V$$

$$g_m = g_{m_o}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 2 \times \left(1 - \frac{-2}{-4}\right) = 2\ mA/V$$

$$\boldsymbol{g_m = 2\ mA/V}$$

Low frequceny equivalent circuit for C_G:-

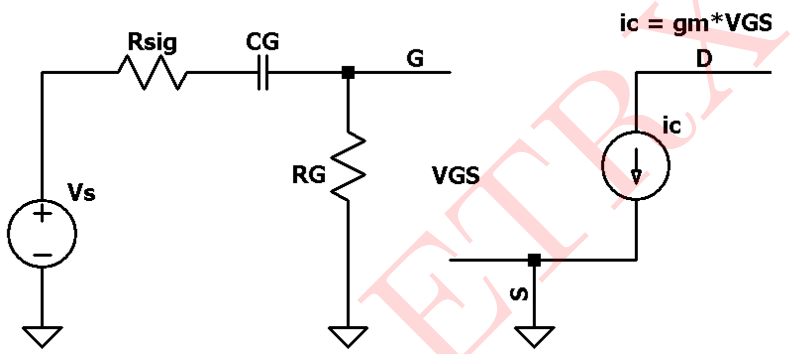

Figure 7: Small Signal low frequency equivalent circuit for C_G

$$R_{eq} = R_{sig} + R_G = 10k\Omega + 1M\Omega$$

$$f_{LCG} = \frac{1}{2\pi \times C_G \times R_{eq}} = \frac{1}{2\pi \times (10k + 1M) \times 0.1\mu F} = 15.76Hz$$

$$\boldsymbol{f_{LCC1} = 15.76Hz}$$

Low frequency equivalent circuit for C_S:-

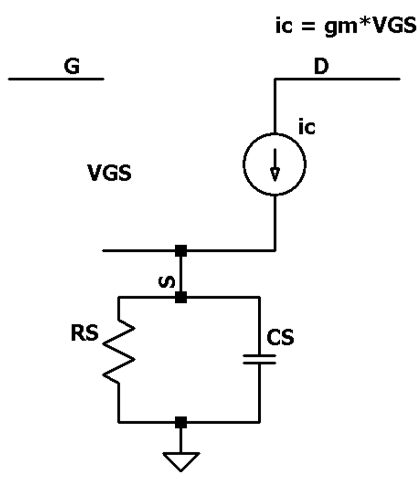

Figure 8: Small Signal low frequency equivalent circuit for C_S

$$R_{eq} = R_S + \frac{1}{g_m} = (1k + \frac{1}{2mA/V}) = 333.33k\Omega$$

$$f_{LCS} = \frac{1}{2\pi \times C_S \times R_{eq}} = \frac{1}{2\pi \times 333.33 \times 2\mu F} = 238.734Hz$$

$$\boldsymbol{f_{LCC2} = 238.734Hz}$$

Low frequceny equivalent circuit for C_C:-

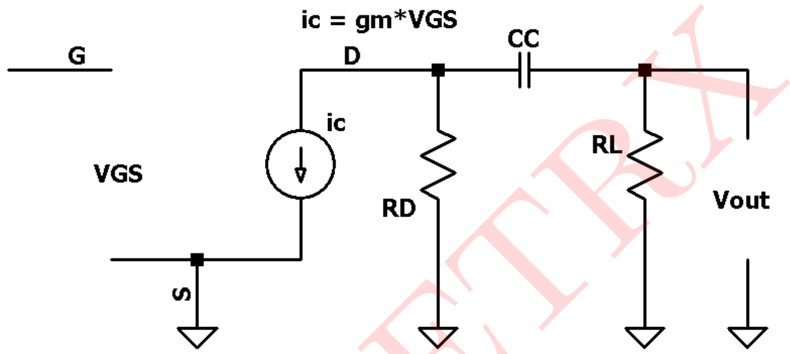

Figure 9: Small Signal low frequency equivalent circuit for C_C

Since $V_S = 0$; and also gate and source are open circuit $\rightarrow \therefore R_{sig}$ & R_G are ignored

$R_{eq} = R_D + R_L = 4.7\text{k} + 2.2\text{k} = 6.9\text{k}$

$$f_{LCC} = \frac{1}{2\pi \times C_C \times R_{eq}} = \frac{1}{2\pi \times 6.9k \times 0.5\mu F} = 46.13Hz$$

$$\boldsymbol{f_{LCC2} = 46.13Hz}$$

Complete low frequency AC equivalent circuit:-

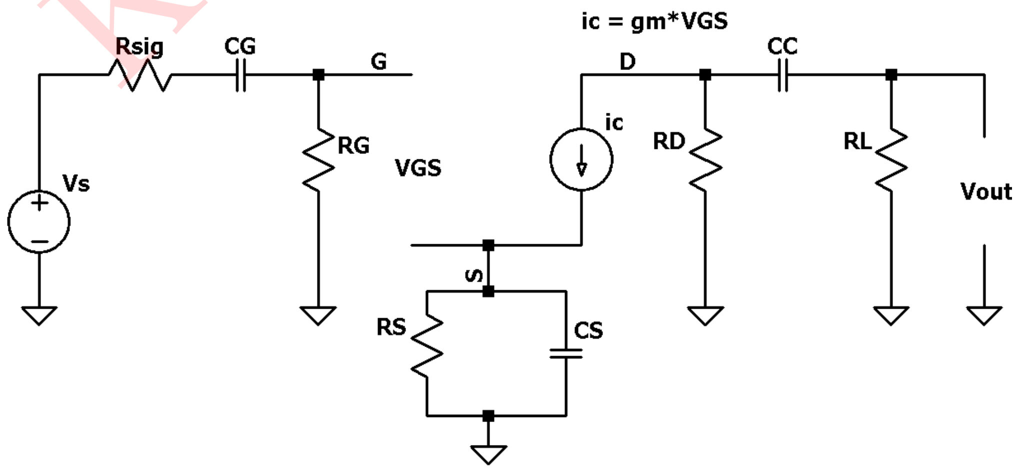

Figure 10: Complete low frequency AC equivalent circuit

Since, $f_{LCS} > f_{LCC2} > f_{LCC1}$

$\therefore$ **Lower cut-off frequency** $= \boldsymbol{f_{LCS}} = \mathbf{238.73}\boldsymbol{Hz}$

AC mid frequency equivalent circuit:-

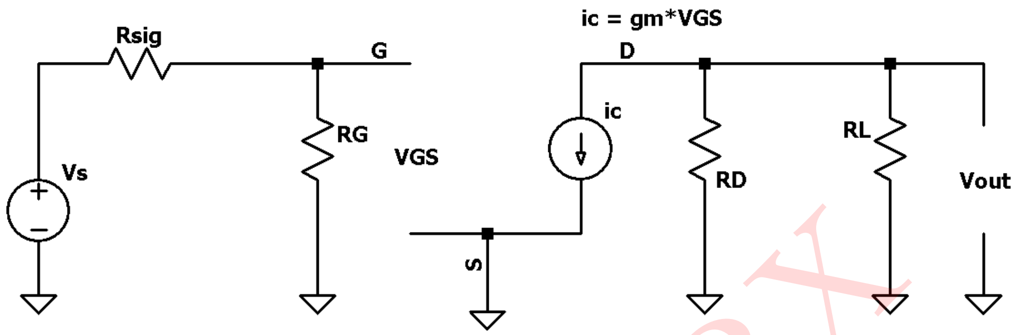

Figure 11: AC mid frequency equivalent circuit

$A_{V_{mid}} = \dfrac{V_{out}}{V_{in}} = -g_m(r_d \;||\; R_D \;||\; R_L\;)$

$A_{V_{mid}} = 26mA/V(\infty \;||\; 4.7k \;||\; 2.2k\;) = -2.99$

$\boldsymbol{A_{V_{mid}}} = \mathbf{-2.99}$

Input Impedance:-

$A_{V_{mid}}$ with $R_{sig} = \dfrac{V_{out}}{V_S} = \dfrac{V_{out}}{V_{in}} \times \dfrac{V_{in}}{V_S}$

$\dfrac{V_{in}}{V_S} = \dfrac{R_G}{R_G + R_{sig}} = \dfrac{1M\Omega}{10k\Omega + 1M\Omega} = 0.999$

$A_{V_{mid}}$ with $R_{sig} = 0.99 \times 2.99 = -2.96$

$\boldsymbol{A_{V_{mid}}}$ **with** $\boldsymbol{R_{sig}} = \mathbf{-2.96}$

$A_{V_{mid}}$ in $dB = 20log_{10}(2.96) = 9.42dB$

$\boldsymbol{A_{V_{mid}}}$ **in** $\boldsymbol{dB} = \mathbf{5.818}\boldsymbol{dB}$

SIMULATED RESULTS:
Above circuit was simulated in LTSpice and results are presented below:

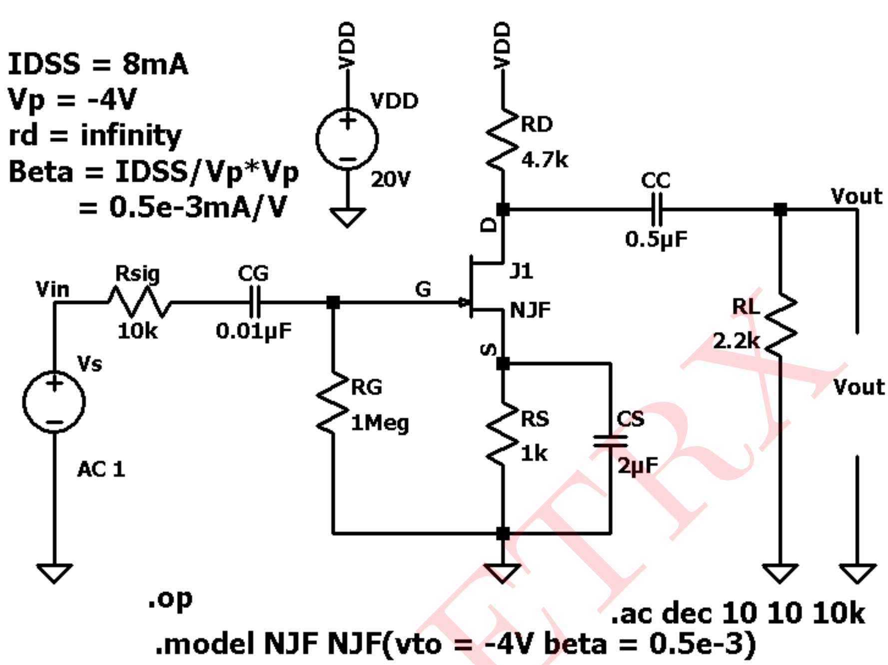

Figure 12: Circuit Schematic 1

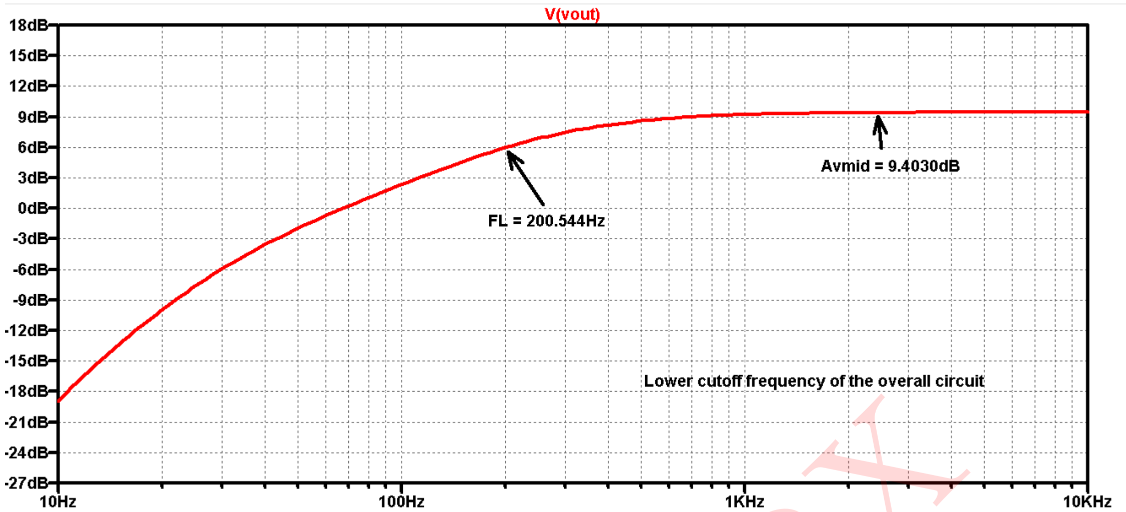

Figure 13: Low frequency response of the circuit

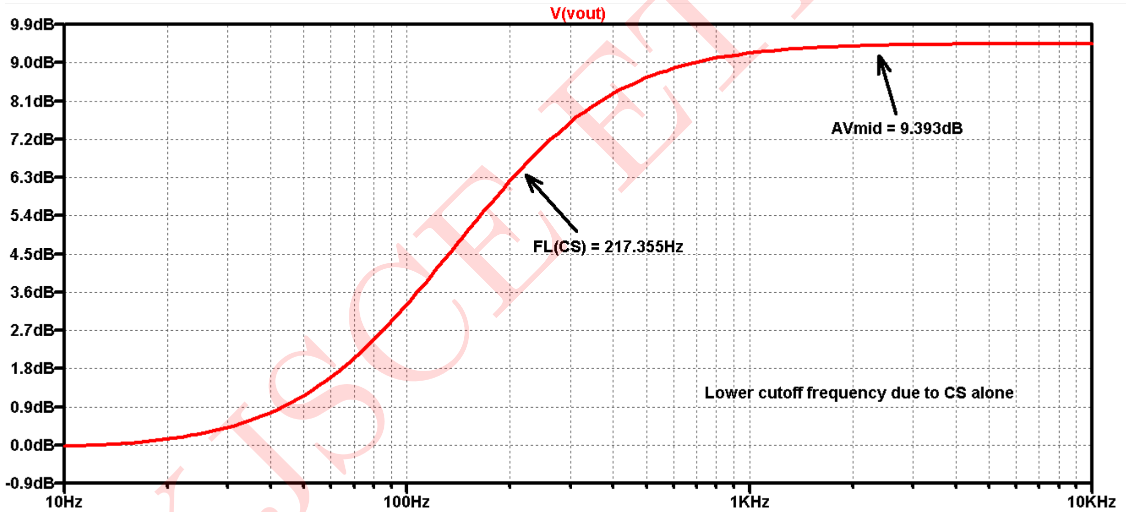

Figure 14: Low frequency response for C_S

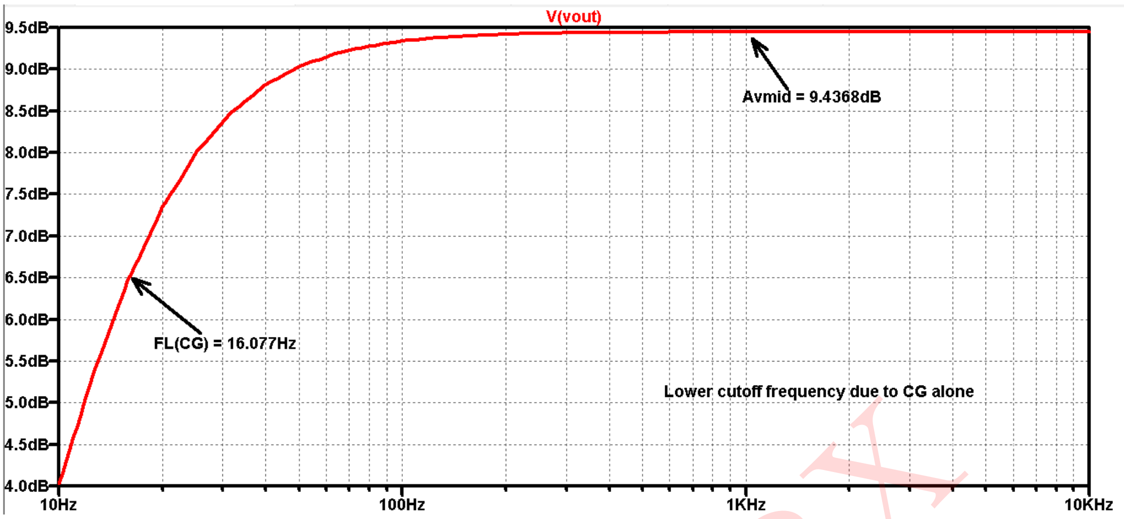

Figure 15: Low frequency response for C_G

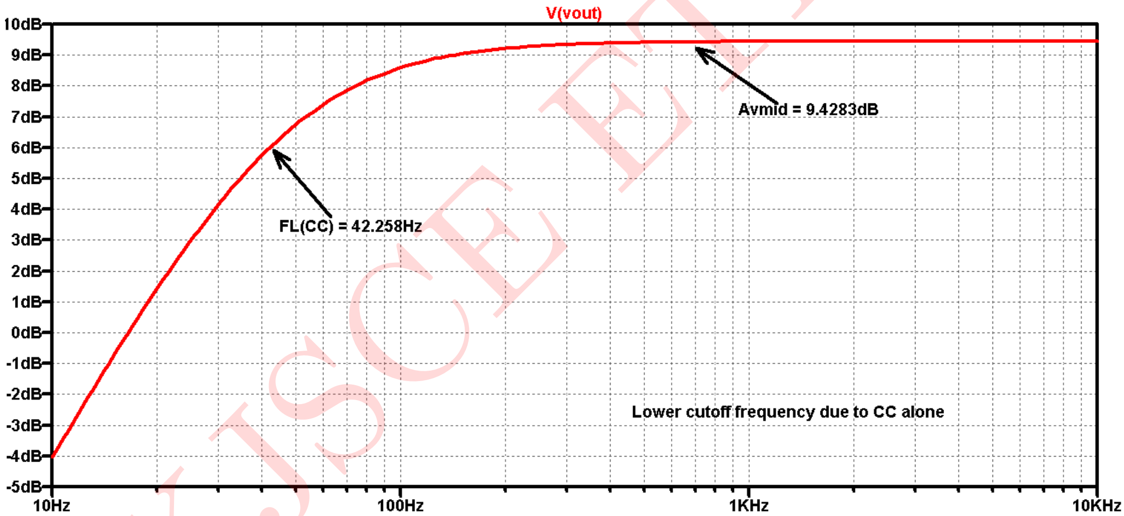

Figure 16: Low frequency response for C_C

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{DQ}	$2mA$	$2mA$
Lower cut-off frequency due to C_G	$16.077Hz$	$15.76Hz$
Lower cut-off frequency due to C_C	$42.258Hz$	$46.13Hz$
Lower cut-off frequency due to C_S	$271.35Hz$	$238.73Hz$
Overall cut-off frequency f_L	$200.54Hz$	$238.73Hz$
Mid-band Voltage gain A_V in dB	$9.403dB$	$9.42dB$

Table 2: Numerical 2

Q3. Find the complete frequency respones of the circuit shown

Given: $V_P = -7V$, $r_d = \infty\Omega$, $R_S = 1k\Omega$, $R_G = 1M\Omega$, $R_D = 4.7k\Omega$, $R_L = 2.2k\Omega$, $R_{sig} = 10k\Omega$, $C_S = 2\mu F$, $C_C = 0.5\mu F$, $C_G = 0.01\mu F$, $V_{DD} = 20V$, $I_{DSS} = 8mA$,$C_{wi} = 5pF$, $C_{wo} = 6pF$, $C_{gd} = 2pF$, $C_{gs} = 4pF$, $C_{ds} = 0.5pF$

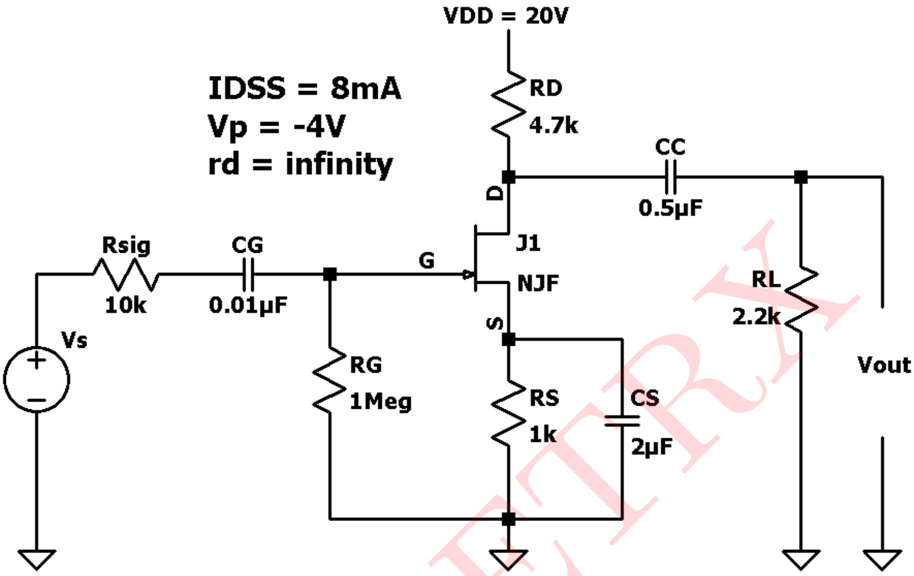

Figure 17: Circuit 3

Solution:

DC Analysis:-

Applying KVL to the input loop:-

$V_{GS} = -I_D R_S$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_D = 8mA\left(1 - \frac{V_{GS}}{(-4)}\right)^2$$

$$V_{GS} = -8mA\left(1 + \frac{V_{GS}}{(-4)} + \frac{V_{GS}^2}{16}\right)^2 \times 1k\Omega$$

$V_{GS} = -8 - 0.5{V_{GS}}^2 - 4V_{GS}$

$0.5{V_{GS}}^2 + 5V_{GS} + 8 = 0$

Solving above quadratic equation, we get

$V_{GS} = -2V$ or $V_{GS} = -8V$, We reject this value, as $(V_{GS} > V_P)$

$\therefore \boldsymbol{V_{GS} = -2.479V}$

$$I_D = -\frac{V_{GS}}{R_S} = \frac{-2V}{1k\Omega} = 2.mA$$

$\boldsymbol{I_D = 2.065mA}$

Small-Signal parameters:-

$$g_{m_o} = \left|\frac{2I_{DSS}}{V_P}\right| = \frac{2\times 8}{-4} = 2mA/V$$

$$g_m = g_{m_o}\left(1-\frac{V_{GS}}{V_P}\right)^2 = 2\times\left(1-\frac{-2}{-4}\right) = 2\ mA/V$$

$$\boldsymbol{g_m = 2\ mA/V}$$

Low frequency equivalent circuit for C_G:-

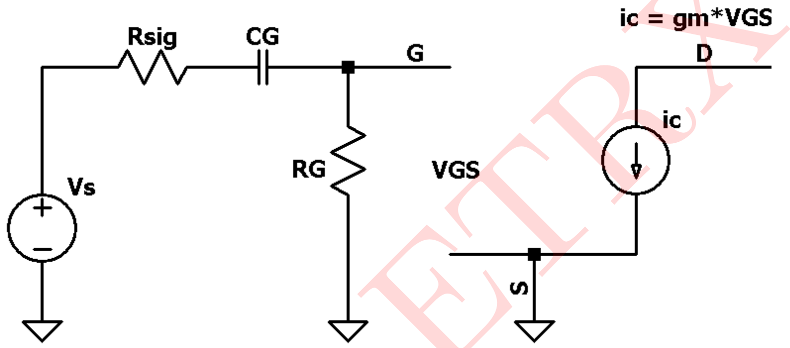

Figure 18: Small Signal low frequency equivalent circuit for C_G

$$R_{eq} = R_{sig} + R_G = 10k\Omega + 1M\Omega$$

$$f_{LCG} = \frac{1}{2\pi\times C_G\times R_{eq}} = \frac{1}{2\pi\times(10k+1M)\times 0.1\mu F} = 15.76Hz$$

$$\boldsymbol{f_{LCC1} = 15.76Hz}$$

Low frequency equivalent circuit for C_S:-

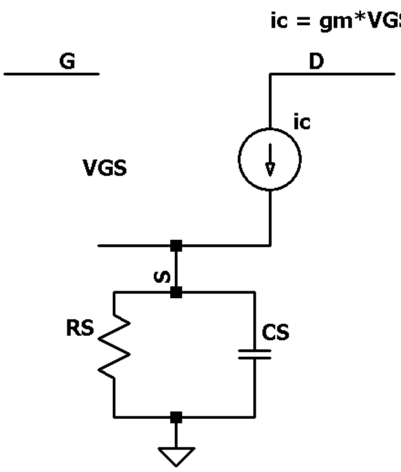

Figure 19: Small Signal low frequency equivalent circuit for C_S

$$R_{eq} = R_S + \frac{1}{g_m} = (1k + \frac{1}{2mA/V}) = 333.33k\Omega$$

$$f_{LCS} = \frac{1}{2\pi \times C_S \times R_{eq}} = \frac{1}{2\pi \times 333.33 \times 2\mu F} = 238.734Hz$$

$$\boldsymbol{f_{LCC_2} = 238.734Hz}$$

Low frequency equivalent circuit for C_C:-

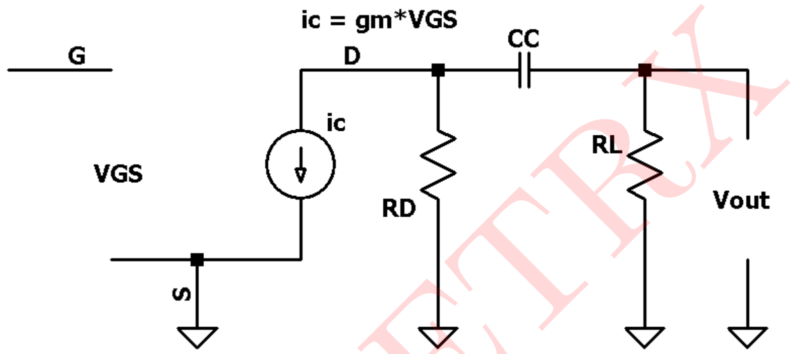

Figure 20: Small Signal low frequency equivalent circuit for C_C

Since $V_S = 0$; and also gate and source are open circuit $\rightarrow \therefore R_{sig}$ & R_G are ignored

$R_{eq} = R_D + R_L = 4.7\text{k} + 2.2\text{k} = 6.9\text{k}$

$$f_{LCC} = \frac{1}{2\pi \times C_C \times R_{eq}} = \frac{1}{2\pi \times 6.9k \times 0.5\mu F} = 46.13Hz$$

$$\boldsymbol{f_{LCC_2} = 46.13Hz}$$

Complete low frequency AC equivalent circuit:-

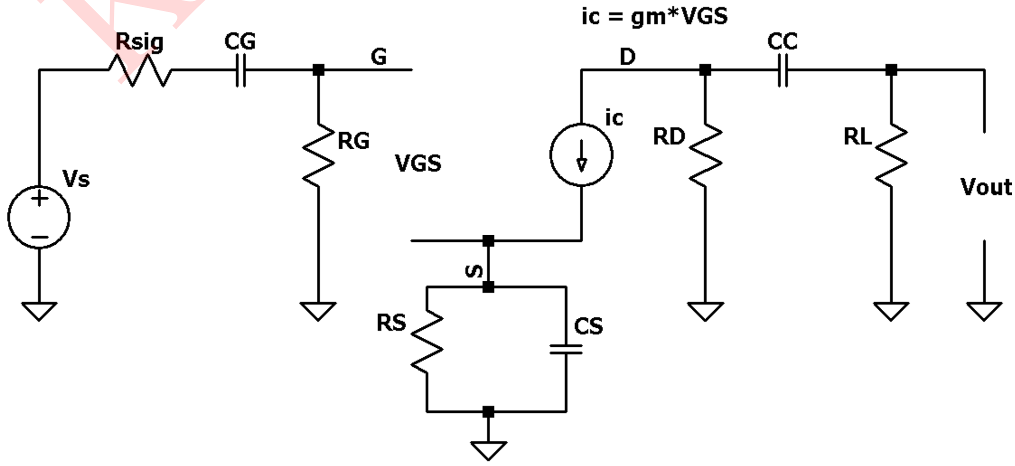

Figure 21: Complete low frequency AC equivalent circuit

Since, $f_{LCS} > f_{LCC2} > f_{LCC1}$

$\therefore$ **Lower cut-off frequency** $= \boldsymbol{f_{LCS} = 238.73Hz}$

AC mid frequency equivalent circuit:-

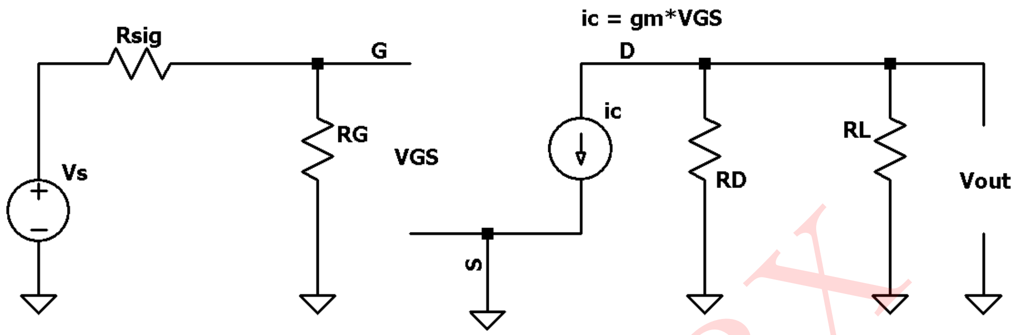

Figure 22: AC mid frequency equivalent circuit

$A_{V_{mid}} = \frac{V_{out}}{V_{in}} = -g_m(r_d \mid\mid R_D \mid\mid R_L\ )$

$A_{V_{mid}} = 26mA/V(\infty \mid\mid 4.7k \mid\mid 2.2k\ ) = -2.99$

$\boldsymbol{A_{V_{mid}} = -2.99}$

$A_{V_{mid}}$ with $R_{sig} = \frac{V_{out}}{V_S} = \frac{V_{out}}{V_{in}} \times \frac{V_{in}}{V_S}$

$\frac{V_{in}}{V_S} = \frac{R_G}{R_G + R_{sig}} = \frac{1M\Omega}{10k\Omega + 1M\Omega} = 0.999$

$A_{V_{mid}}$ with $R_{sig} = 0.99 \times 2.99 = -2.96$

$\boldsymbol{A_{V_{mid}}}$ **with** $\boldsymbol{R_{sig} = -2.96}$

$A_{V_{mid}}$ in $dB = 20log_{10}(2.96) = 9.42dB$

$\boldsymbol{A_{V_{mid}}}$ **in** $\boldsymbol{dB = 5.818dB}$

High frequency equivalent circuit for entire circuit:-

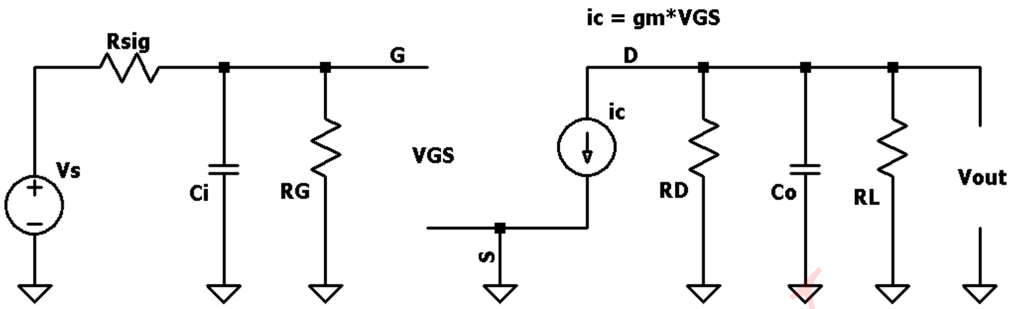

Figure 23: High frequency equivalent circuit for entire circuit

$C_i = C_{gs} + C_{mi} + C_{wi}$

$C_{mi} = C_{gd}(1 - A_{V_{mid}})$ (By Millers Theorem)

$C_{mi} = 2pF(1 - (-2.697))$

$C_{mi} = 7.93pF$

$C_i = 4pF + 7.93pF + 5pF = 16.93pF$

$C_{mo} = C_{gd}(1 - \frac{1}{A_{V_{mid}}})$ (By Millers Theorem)

$C_{mo} = 2pF(1 + \frac{1}{2.967})$

$C_{mo} = 2.674pF$

$C_o = 0.5pF + 2.674pF + 6pF$

$C_o = 9.174pF$

High frequceny equivalent circuit for C_i:-

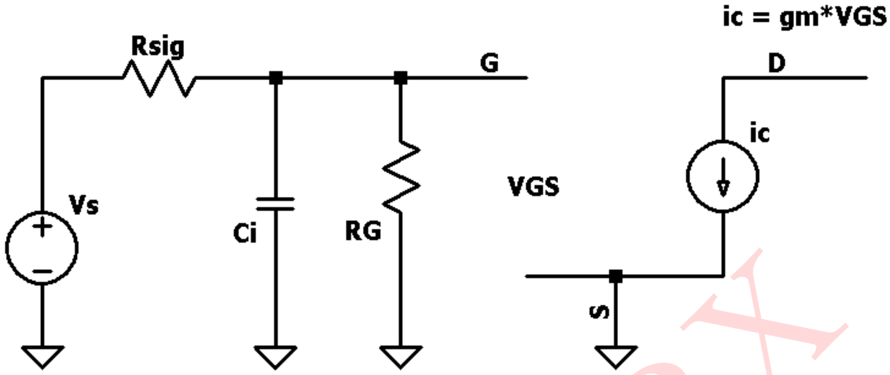

Figure 24: High frequceny equivalent circuit for C_i

$R_{eq} = R_{sig} \mid\mid R_G = 10\text{k} \mid\mid 1\text{M} = 9.9\text{k}\Omega$

$f_{Hi} = \dfrac{1}{2\pi \times C_i \times R_{eq}} = \dfrac{1}{2\pi \times 9.9k \times 16.93} = 949.57KHz$

$\boldsymbol{f_{Hi} = 949.57KHz}$

$\therefore$ **Higher cut-off frequency** $= \boldsymbol{f_{Hi} = 949.57KHz}$

High frequceny equivalent circuit for C_o:-

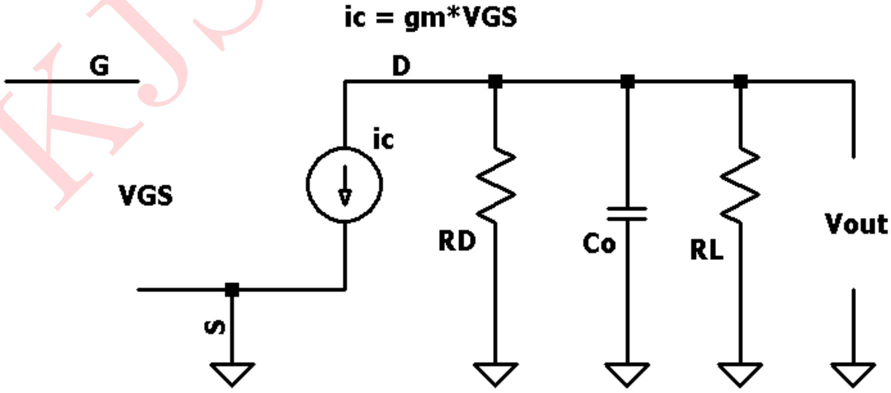

Figure 25: High frequceny equivalent circuit for C_o

$R_{eq} = R_D \parallel R_L = 4.7\text{k} \parallel 2.2\text{K} = 1.498\text{k}\Omega$

$$f_{Ho} = \frac{1}{2\pi \times C_o \times R_{eq}} = \frac{1}{2\pi \times 1.498k \times 9.174pF} = 11.58MHz$$

$\boldsymbol{f_{Ho} = 11.58MHz}$

$\therefore$ **Higher cut-off frequency** $= \boldsymbol{f_{Ho} = 11.58MHz}$

We select $f_H = 949.57KHz$ as the higher frequency of the circuit $\because f_{Ho} < f_{Hi}$

SIMULATED RESULTS:
Above circuit was simulated in LTSpice and results are presented below:

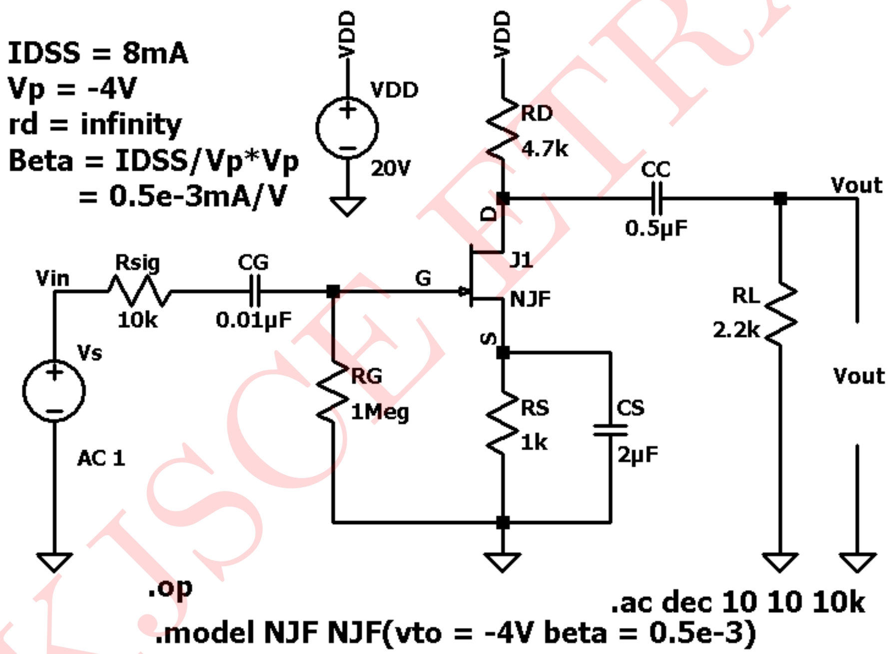

Figure 26: Circuit Schematic 1

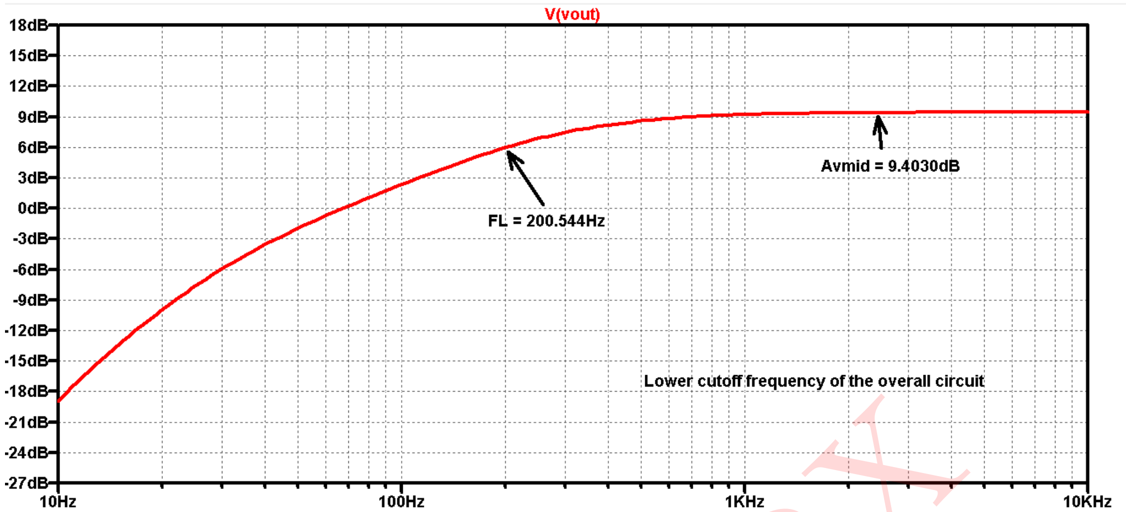

Figure 27: Low frequency response of the circuit

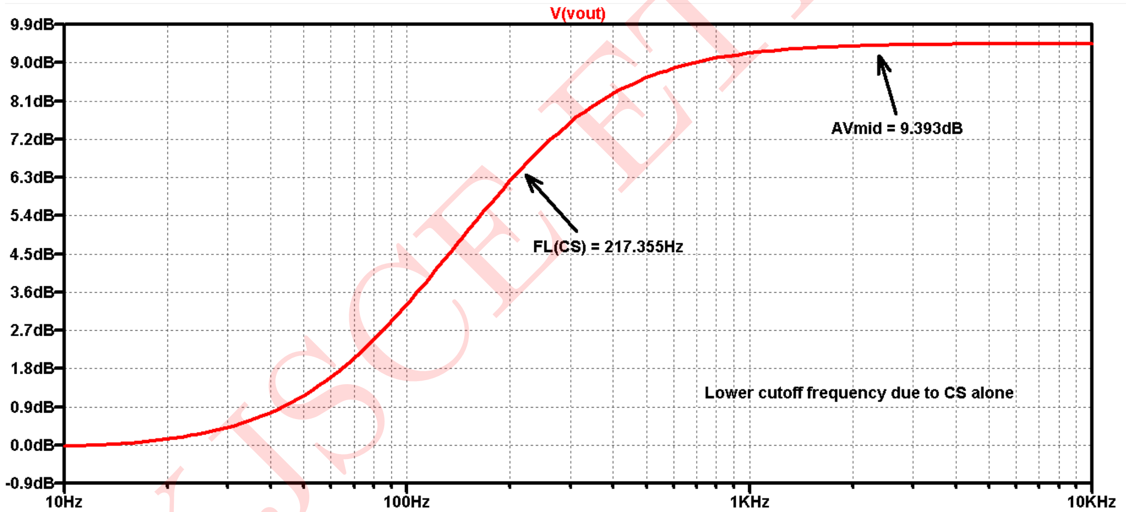

Figure 28: Low frequency response for C_S

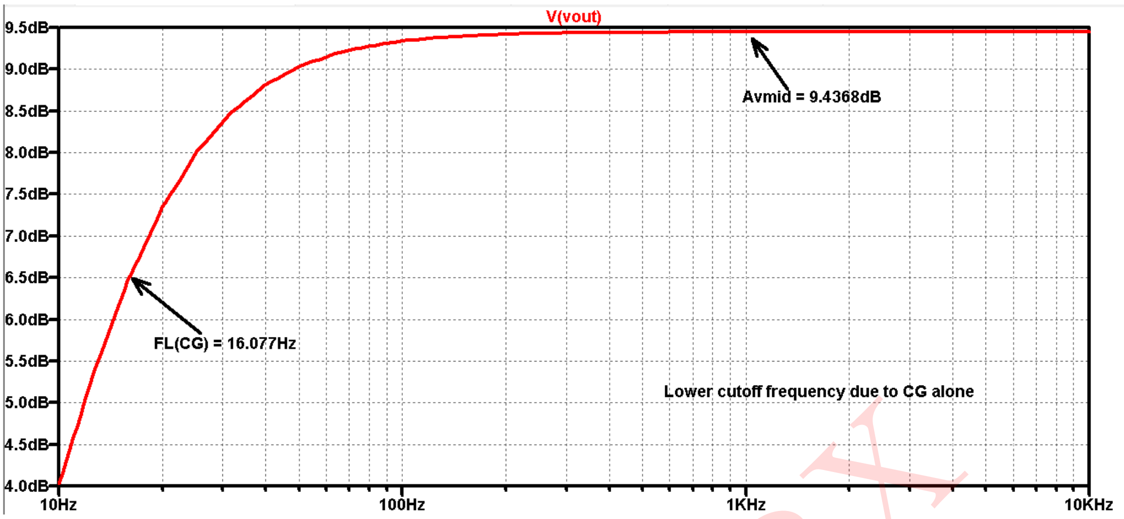

Figure 29: Low frequency response for C_G

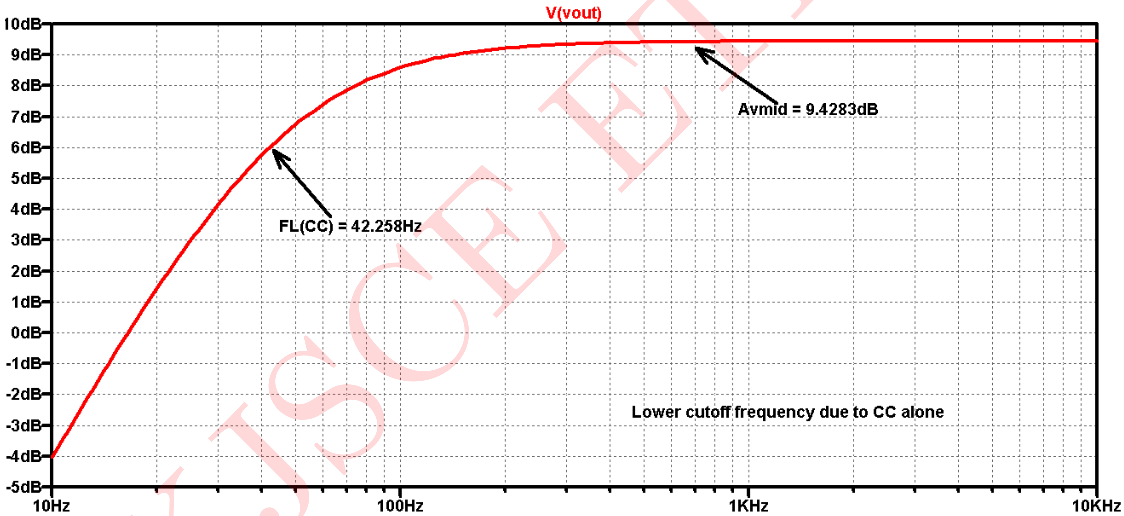

Figure 30: Low frequency response for C_C

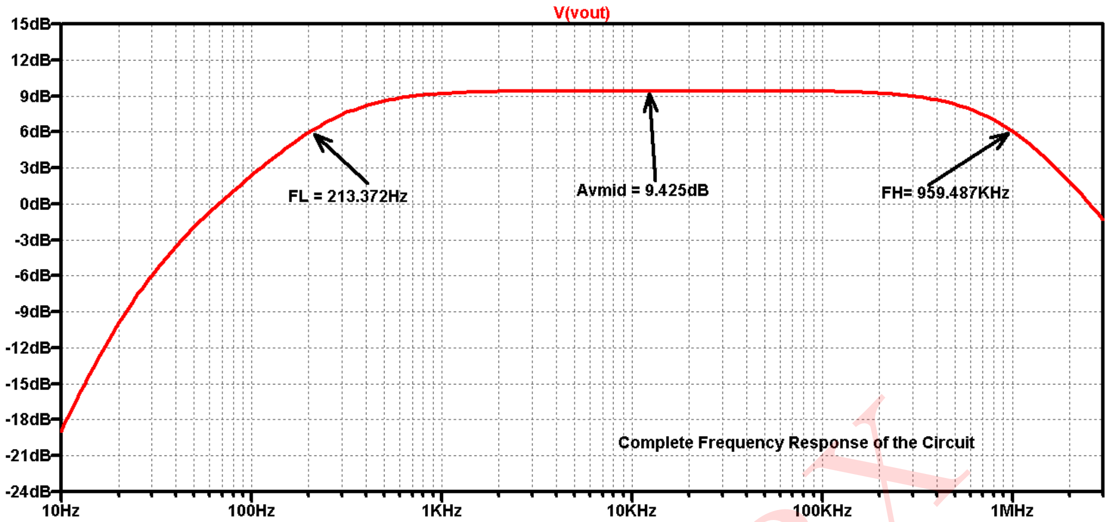

Figure 31: Complete frequency response of the circuit

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{DQ}	$2mA$	$2mA$
Lower cut-off frequency due to C_G	$16.077Hz$	$15.76Hz$
Lower cut-off frequency due to C_C	$42.258Hz$	$46.13Hz$
Lower cut-off frequency due to C_S	$271.35Hz$	$238.73Hz$
Overall cut-off frequency f_L	$200.54Hz$	$238.73Hz$
Overall cut-off frequency f_H	$959.487KHz$	$949.57KHz$
Mid-band Voltage gain A_V in dB	$9.403dB$	$9.42dB$

Table 3: Numerical 3

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