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ELECTRONIC CIRCUITS
CASCODE AMPLIFIER

16^{th} **July, 2020** **Numericals**

1. A two-stage circuit is shown in Figure 1. The BJT parameters are $\beta_1 = \beta_2 = 150, V_{BE_1} = V_{BE_2} = 0.7$ V
a) Calculate the DC parameters , i.e. V_{B_1}, V_{B_2}, V_{E_1}, V_{E_2}, I_{E_1}, I_{E_2}, I_{C_1}, I_{C_2}, V_{C_1}, V_{C_2}, V_{E_1}, V_{E_2}, V_{CE_1} and V_{CE_2} of the circuit
b) Determine the input and output impedance
c) Calculate the voltage gain for the circuit

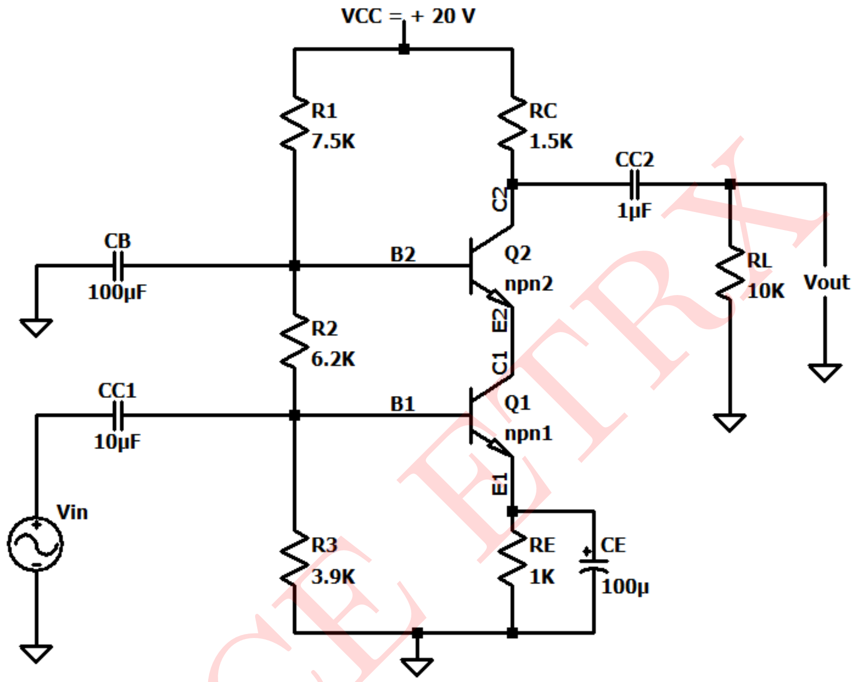

Figure 1: Circuit 1

Solution:
DC Analysis:
The capacitors act as open circuit.

$$f = 0, \therefore X_C = \frac{1}{2\pi f C} = \infty$$

The DC equivalent circuit is shown in Figure 2

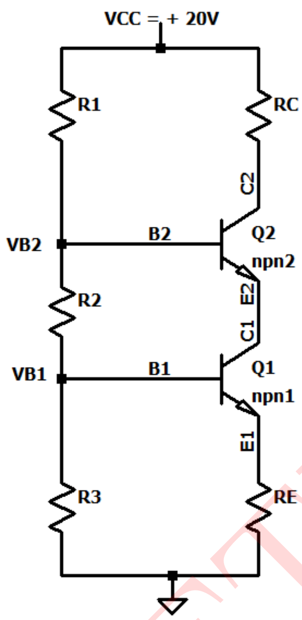

Figure 2: DC equivalent circuit

$\beta_1 = \beta_2 = 150$, $I_{C_1} = I_{C_2} = I_{E_1} = I_{E_2}$

$$V_{B_1} = \frac{R_3}{R_1 + R_2 + R_3} \times V_{CC} = \frac{3.9k}{3.9k + 6.2k + 7.5k} \times 20$$

$\therefore V_{B_1} = \mathbf{4.4318\ V}$

$$V_{B_2} = \frac{R_3 + R_2}{R_1 + R_2 + R_3} \times V_{CC} = \frac{3.9k + 6.2k}{3.9k + 6.2k + 7.5k} \times 20$$

$\therefore V_{B_2} = \mathbf{11.477\ V}$

$V_{E_1} = V_{B_1} - V_{BE_1} = 4.4318 - 0.7$

$\therefore V_{E_1} = \mathbf{3.7318\ V}$

$$I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7318}{1k}$$

$\therefore I_{E_1} = \mathbf{3.7318\ mA}$

$I_{C_1} = I_{C_2} = I_{E_2} = I_{E_1} = \mathbf{3.7318\ mA}$

$$I_{B_1} = I_{B_2} = \frac{I_{C_1}}{\beta} = \mathbf{24.87\ \mu A}$$

$V_{C_2} = V_{CC} - I_{C_2} R_C = 20 - (3.7318 \times 10^{-3} \times 1.5k)$

$\therefore V_{C_2} = \mathbf{14.4023\ V}$

$V_{E_2} = V_{B_2} - V_{BE_2} = 11.477 - 0.7$

$\therefore V_{E_2} = \mathbf{10.777\ V}$

$V_{CE_1} = V_{C_1} - V_{E_1} = 10.777 - 3.7318 = \mathbf{7.045\ V}$

$V_{CE_2} = V_{C_2} - V_{E_2} = 14.4023 - 10.777 = \mathbf{3.625\ V}$

Small-signal parameters:

$$r_{\pi_1} = r_{\pi_2} = \frac{\beta V_T}{I_{CQ}} = \frac{150 \times 26 \times 10^{-3}}{3.7318 \times 10^{-3}} = 1.045\ \mathrm{k\Omega}$$

$$g_{m_1} = g_{m_2} = \frac{I_{CQ}}{V_T} = \frac{3.7318 \times 10^{-3}}{26 \times 10^{-3}} = 143.53\frac{mA}{V}$$

The mid-band AC equivalent circuit is shown in Figure 3

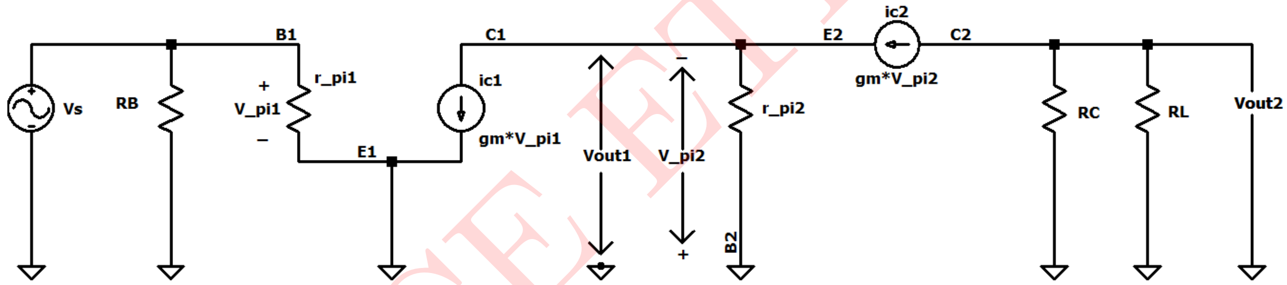

Figure 3: Mid frequency equivalent circuit

Input impedence $Z_i = R_B||r_{\pi_1} = R_2||R_3||r_{\pi_1} = (3.9k||6.2k)||1.045k$

$\therefore Z_i = \mathbf{727.458\Omega}$

Output impedence $Z_o = R_C||R_L = 1.5k||10k$

$\therefore Z_o = \mathbf{1.3\ k\Omega}$

$A_{V_2} = g_m(R_C||R_L) = 143.53 \times 10^{-3} \times 1.3k = 186.59$

$$A_{V_1} = -g_m\left(\frac{r_\pi}{1+\beta}\right) = \frac{-143.53 \times 10^{-3} \times 1.045k}{151} = -0.9933$$

$A_{V_T} = A_{V_1} \times A_{V_2} = 186.59 \times -0.9933$

$\therefore A_{V_T} = -185.34$

$|A_{V_T}|$ (in dB) $= 20log_{10}A_{V_T} = 20log_{10}(185.34)$

$\therefore |A_{V_T}|$ (in dB) $= \mathbf{45.359\ dB}$

$V_o = V_{in} \times A_{V_T} = 20 \times 10^{-3} \times 185.34 = \mathbf{3.7068\ V}$

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

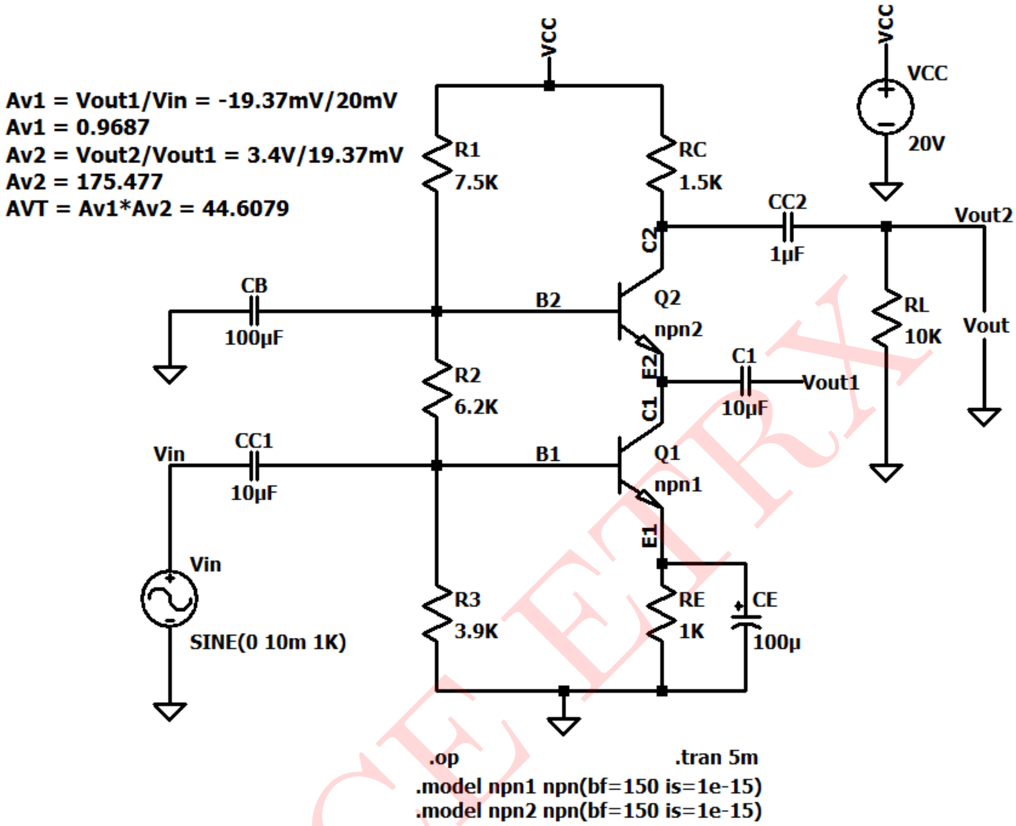

Figure 4: Circuit schematic

The input and output waveforms for voltage gain A_{V_1} are shown in Figure 5

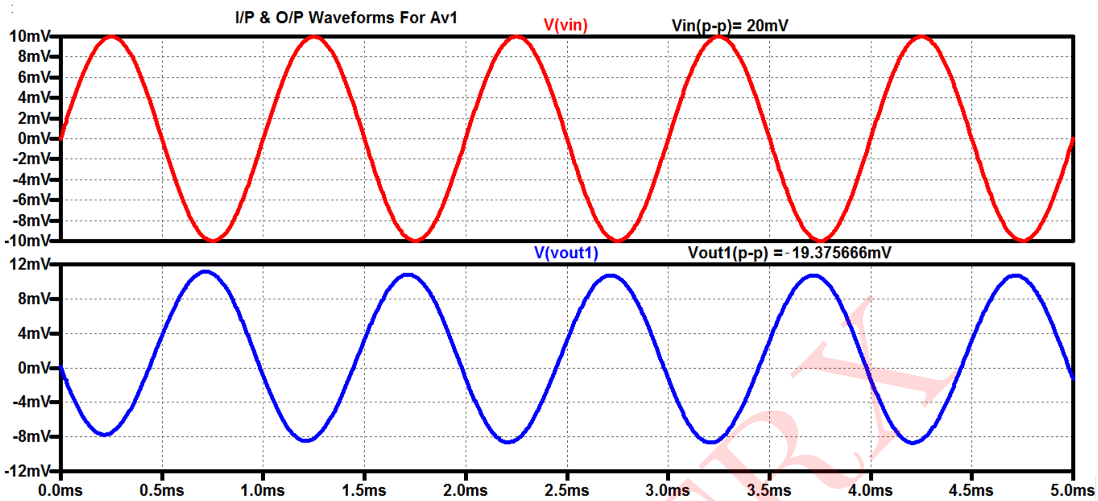

Figure 5: Input and output waveforms for voltage gain A_{V_1}

The input and output waveforms for voltage gain A_{V_2} are shown in Figure 6

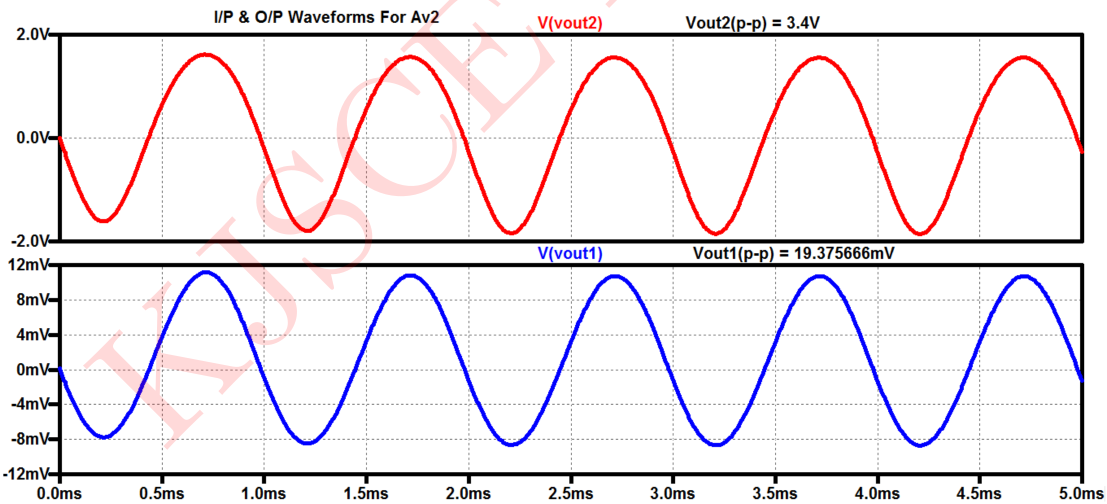

Figure 6: Input and output waveforms for voltage gain A_{V_2}

Comparison of theoretical and simulated values:

Parameters	Theoretical	Simulated
I_{B_1}	24.87866 μA	23.5086 μA
I_{C_1}	3.7318 mA	3.5498 mA
I_{E_1}	3.7318 mA	3.57346 mA
I_{B_2}	24.87866 μA	23.5086 μA
I_{C_2}	3.7318 mA	3.52629 mA
I_{E_2}	3.7318 mA	3.5498 mA
V_{E_2}	10.777 V	10.5895 V
V_{C_2}	14.4023 V	14.7106 V
Voltage gain of 1^{st} stage (A_{V_1})	-0.9933	-0.9687
Voltage gain of 2^{nd} stage (A_{V_2})	186.59	175.477
Overall voltage gain A_{V_T}	45.359 dB	44.6079 dB
Input impedance of 1^{st} stage	727.458 Ω	–
Output impedance of 2^{nd} stage	1.3 kΩ	–
Output voltage	3.7068 V	3.4 V

Table 1: Numerical 1

2. A two-stage circuit is shown in Figure 7. The BJT parameters are
$k_{n_1} = k_{n_2} = 0.8$ mA/V^2 and $V_{TN_1} = V_{TN_2} = 0.8$ V
a) Calculate the DC parameters , i.e. V_{G_1}, V_{G_2}, V_{GS_1}, V_{GS_2}, I_{D_1}, I_{D_2}, V_{D_1}, V_{D_2}, V_{S_1}, V_{S_2}, V_{DS_1}, V_{DS_2} of the circuit
b) Determine the input and output impedance of the circuit
c) Calculate the voltage gain for the circuit

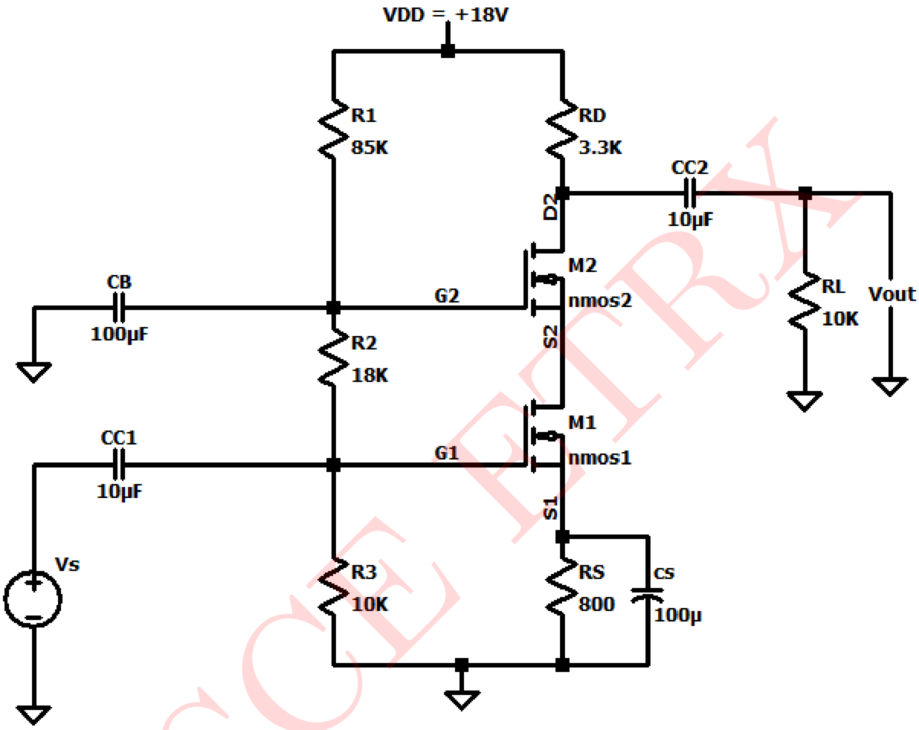

Figure 7: Circuit 2

Solution:
DC Analysis:
The capacitors act as open circuit.

$$f = 0, \therefore X_C = \frac{1}{2\pi f C} = \infty$$

$$R_T = R_1 + R_2 + R_3 = 113 \text{ k}\Omega$$

The DC equivalent circuit is shown in Figure 8

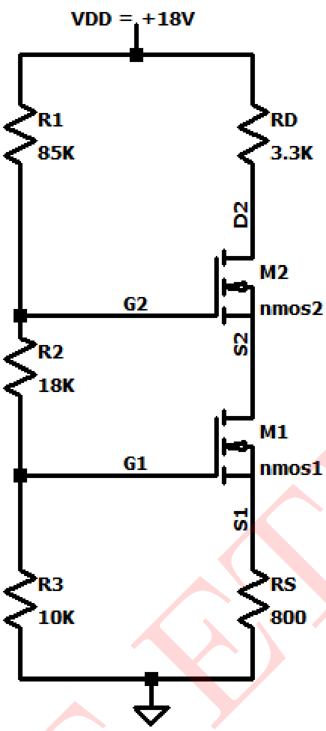

Figure 8: DC equivalent circuit

$$V_{G_1} = \frac{R_3}{R_T} \times V_{DD} = \frac{10k}{113k} \times 18$$

$\therefore V_{G_1} = \mathbf{1.59292\ V}$

$$V_{G_2} = \frac{R_2 + R_3}{R_T} \times V_{DD} = \frac{18k + 10k}{113k} \times 18$$

$\therefore V_{G_2} = \mathbf{4.4601769\ V}$

$$V_{GS_1} = V_{G_1} - V_{S_1}$$

$$V_{GS_1} = 1.59292 - I_{D_1} R_S$$

$$\therefore V_{GS_1} = 1.59292 - (800 \times I_{D_1}) \qquad ....(1)$$

$$I_{D_1} = k_n (V_{GS_1} - V_{TN_1})^2$$

$$\therefore I_{D_1} = 0.8 \times 10^{-3} \times (V_{GS_1} - 0.8)^2 \qquad ....(2)$$

Putting (2) in (1), we get

$$V_{GS_1} = 1.59292 - [800 \times 0.8 \times 10^{-3} \times (V_{GS_1} - 0.8)^2]$$

$$V_{GS_1} = 1.59292 - 0.64 V_{GS_1}^2 + 1.024 V_{GS_1} - 0.4096$$

$\therefore 0.64V_{GS_1}^2 - 0.024V_{GS_1} - 1.18332 = 0$

$V_{GS_1} = 1.3786$ V or $V_{GS_1} = -1.3411$ V

Since $V_{GS_1} > V_{TN_1}$, $\therefore V_{GS_1} = \mathbf{1.3786\ V}$

From equation (2), $I_{D_1} = 0.8 \times 10^{-3} \times (1.3786 - 0.8)^2$

$\therefore I_{D_1} = 0.2678$ mA

$I_{D_1} = I_{D_2} = \mathbf{0.2678\ mA}$

$V_{D_2} = V_{DD} - I_{D_2}R_D = 18 - 0.2678 \times 10^{-3} \times 3.3k$

$\therefore V_{D_2} = \mathbf{17.116\ V}$

$V_{GS_2} = V_{GS_1} = V_{G_2} - V_{S_2} = 1.3786$ V

$\therefore V_{S_2} = 4.4601769 - 1.3786 = \mathbf{3.08157\ V}$

$V_{DS_2} = V_{D_2} - V_{S_2} = 17.116 - 3.08157 = \mathbf{14.03443\ V}$

$V_{D_1} = V_{S_2} = \mathbf{3.08157\ V}$

$V_{DS_1} = V_{D_1} - V_{S_1} = \mathbf{2.86733\ V}$

Small-signal parameters:

$g_{m_1} = g_{m_2} = 2k_n(V_{GS} - V_{TN}) = 2 \times 0.8 \times 10^{-3} \times (1.3786 - 0.8)$

$\therefore g_{m_1} = g_{m_2} = 0.92576mA/V$

The mid-band AC equivalent circuit is shown in Figure 9

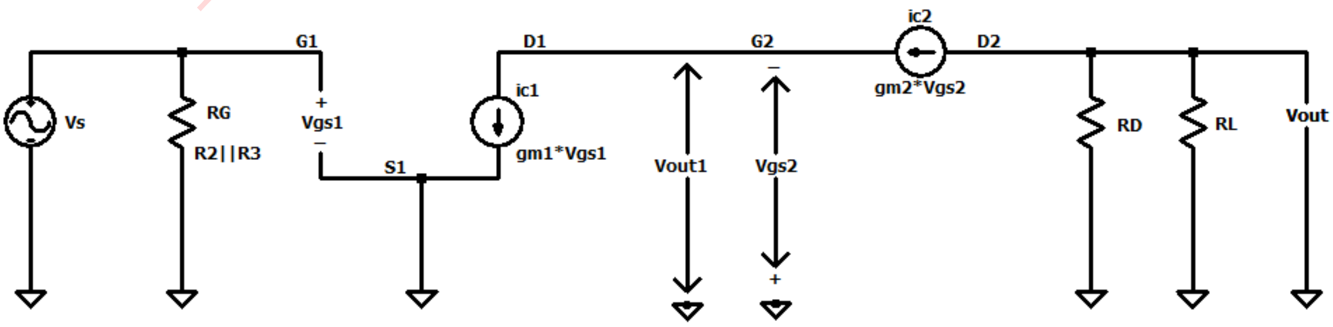

Figure 9: Mid frequency equivalent circuit

$g_{m_2} V_{gs_2} = g_{m_1} V_{gs_1}$

$R_G = R_2 || R_3$

Input impedence $Z_i = R_G = R_2 || R_3 = 18k || 10k$

$\therefore Z_i = \mathbf{6.42857\ k\Omega}$

Output impedence $Z_o = R_D || R_L = 3.3k || 10k$

$\therefore Z_o = \mathbf{2.4812\ k\Omega}$

$$A_{V_2} = \frac{V_o}{V_1} = \frac{-g_{m_2} V_{gs_2} (R_D || R_L)}{-V_{gs_2}} = g_{m_2} (R_D || R_L)$$

$\therefore A_{V_2} = 0.92576 \times 10^{-3} \times 2.4812k = 2.29699$

$$A_{V_1} = \frac{V_1}{V_S} = \frac{-V_{gs_2}}{V_{gs_1}} = \frac{-V_{gs_1}}{V_{gs_1}} = -1$$

$A_{V_T} = A_{V_1} \times A_{V_2} = 2.29699 \times -0.1$

$\therefore A_{V_T} = -2.29699$

$|A_{V_T}|$ (in dB) $= 20 log_{10} A_{V_T} = 20 log_{10}(2.29699)$

$\therefore |A_{V_T}|$ (in dB) $=$ **7.223180209 dB**

$V_o = V_{in} \times A_{V_T} = 20 \times 10^{-3} \times 2.29699 =$ **45.9399 mV**

SIMULATED RESULTS:

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

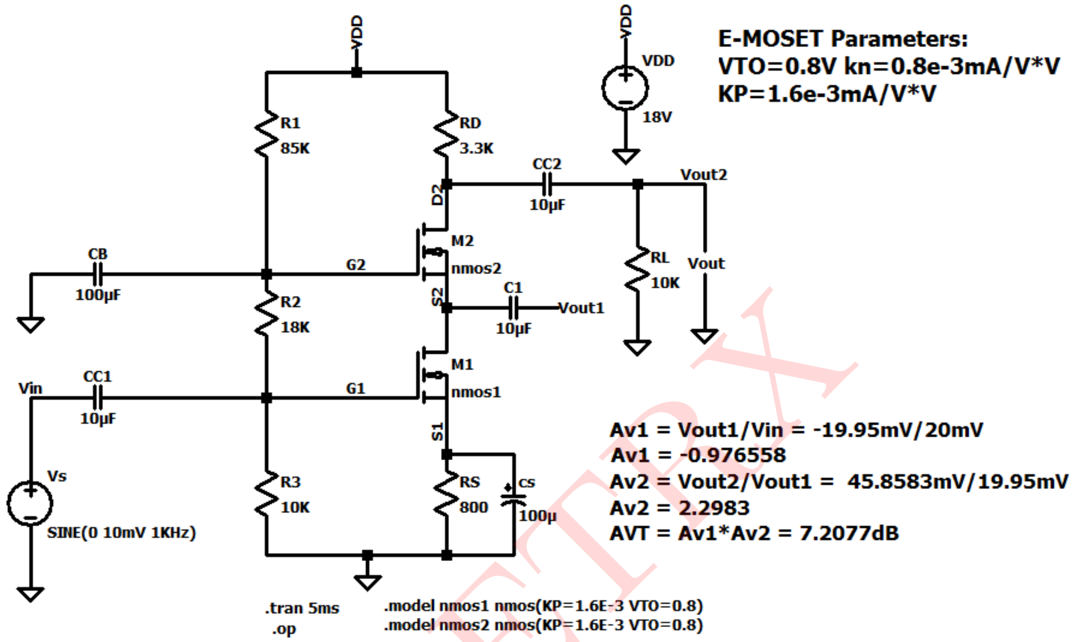

Figure 10: Circuit schematic

The input and output waveforms for voltage gain A_{V_1} are shown in Figure 11

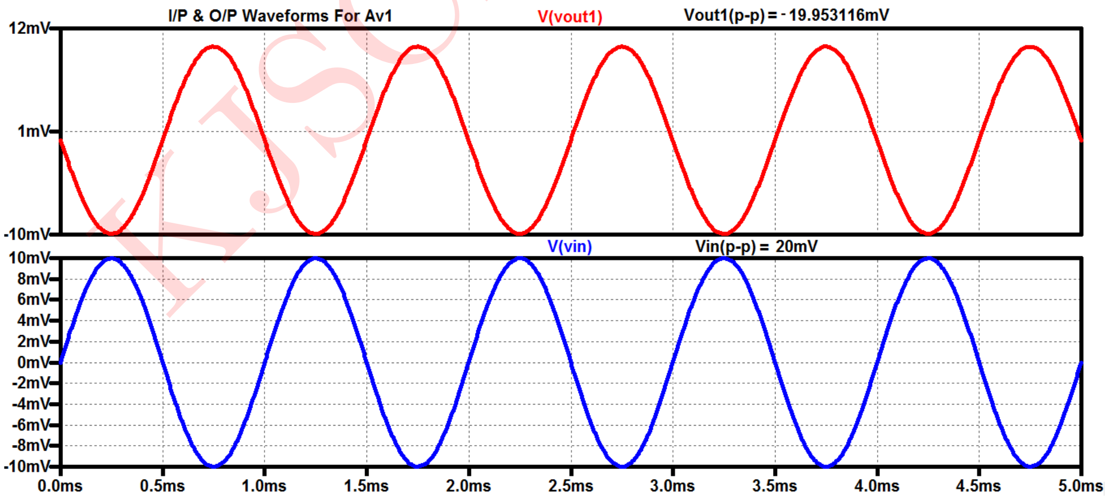

Figure 11: Input and output waveforms for voltage gain A_{V_1}

The input and output waveforms for voltage gain A_{V_2} are shown in Figure 12

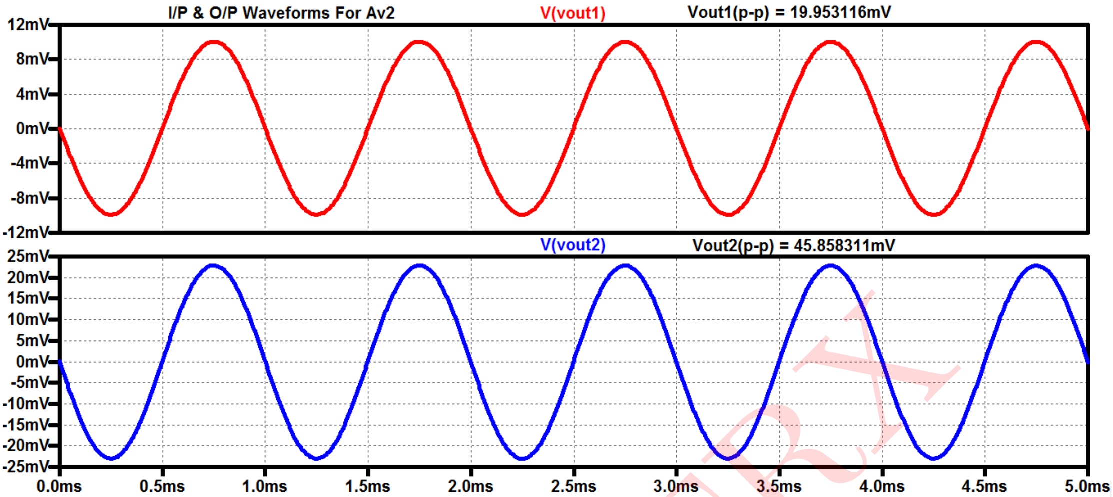

Figure 12: Input and output waveforms for voltage gain A_{V_2}

Comparison of theoretical and simulated values:

Parameters	Theoretical	Simulated
V_{G_1}	1.59292 V	1.59292 V
V_{D_1}	3.08157 V	3.08154 V
V_{S_1}	0.2143 V	0.214284 V
I_{D_1}	0.2678 mA	0.267856 mA
V_{G_2}	4.460179 V	4.46018
V_{D_2}	17.116 V	17.1161
V_{S_2}	3.08157 V	3.08154 V
I_{D_2}	0.2678 mA	0.267856 mA
Voltage gain of 1^{st} stage (A_{V_1})	-1	-0.997
Voltage gain of 2^{nd} stage (A_{V_2})	2.29699	2.2983
Overall voltage gain A_{V_T}	7.22318 dB	7.077 dB
Input impedance of 1^{st} stage	6.42867 kΩ	–
Output impedance of 2^{nd} stage	2.4812 kΩ	–
Output voltage	45.9399 mV	45.858311 mV

Table 2: Numerical 2