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

Numerical 1:
For the ciruit shown below in figure 1,
a) Determine DC parameters of both the stages
b) Determine overall voltage gain A_{V_T} in dB
b) Determine input and output impedance
b) Determine output voltage
Given: $V_{BE_1} = V_{BE_2} = 0.6V$, $\beta_1 = \beta_2 = 100$

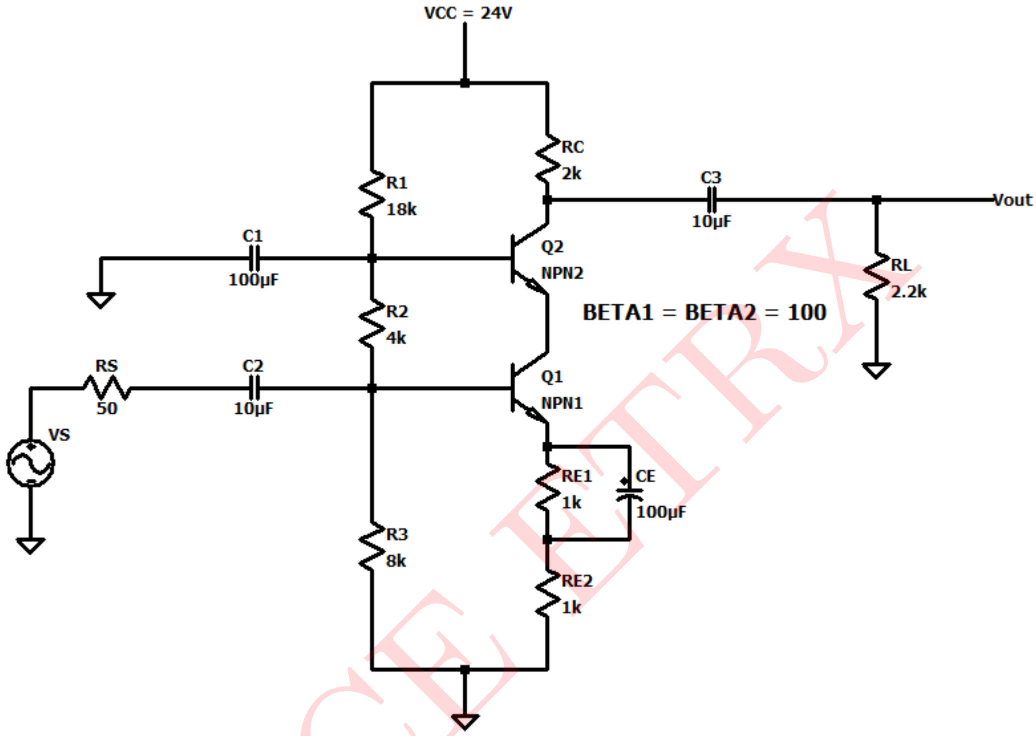

Figure 1: Circuit 1

Solution:
DC analysis of cascode(CE-CB):

$$V_{B_1} = \frac{R_3}{R_1 + R_2 + R_3} \times V_{CC} = \frac{8k\Omega}{18k\Omega + 4k\Omega + 8k\Omega} \times 24V = \mathbf{6.4V}$$

$$V_{B_2} = \frac{R_3 + R_2}{R_1 + R_2 + R_2} \times V_{CC} = \frac{8k\Omega + 4k\Omega}{8k\Omega + 4k\Omega + 8k\Omega} \times 24V = \mathbf{9.6V}$$

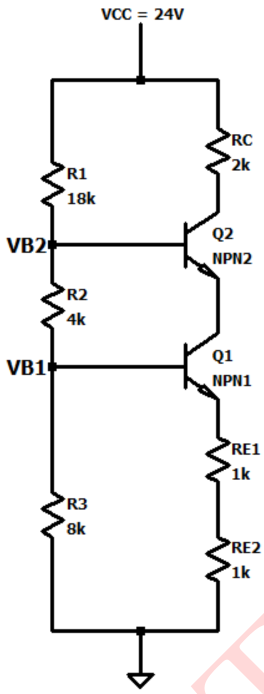

Figure 2: DC equivalent circuit

$\because V_{E_1} = V_{B_1} - V_{BE_1} = 6.4V - 0.6V = \mathbf{5.8V}$

Also, $V_{E_1} = \dfrac{I_{E_1}}{R_E}$

$$\therefore I_{E_1} = \frac{V_{E_1}}{R_E} \qquad (\because R_E = R_{E_1} + R_{E_2} = 1k\Omega + 1k\Omega = 2k\Omega)$$

$$= \frac{5.8V}{2k\Omega} = \mathbf{2.9mA}$$

$\because I_{C_1} = I_{C_2} = I_{E_1} = I_{E_2}$

$\because I_{C_1} = I_{C_2} = I_{E_1} = I_{E_2} = \mathbf{2.9mA}$

$$\therefore I_{B_1} = I_{B_2} = \frac{I_{E_1}}{(1+\beta)}$$

$$= \frac{2.9mA}{100} = \mathbf{29\mu A}$$

$$\because V_{C_2} = V_{CC} - I_{C_2} - R_C$$
$$= 24V - (2.9mA)(2k\Omega)$$
$$= 24V - 5.8V = \mathbf{18.2V}$$

$$\because V_{E_2} = V_{B_2} - V_{BE_2}$$
$$= 9.6V - 0.6V = \mathbf{9V}$$

$\because V_{E_2} = V_{C_1} = \mathbf{9V}$

Small signal parameters:

$$r_\pi = r_{\pi_1} = r_{\pi_2} = \frac{\beta V_T}{I_{CQ}}$$
$$= \frac{100 \times 26mV}{2.9mA} = \mathbf{0.8965k\Omega}$$

$$g_m = g_{m_1} = g_{m_2} = \frac{I_{CQ}}{V_T}$$
$$= \frac{2.9mA}{26mV} = \mathbf{111.538mA/V}$$

Mid-frequency AC equivalent circuit:

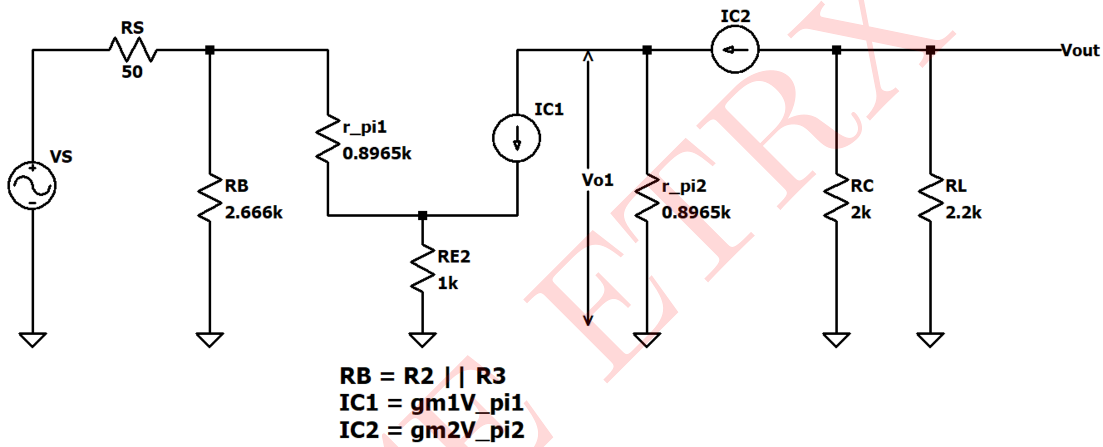

Figure 3: Mid-frequency AC equivalent circuit

Input impedance,

$$Z_i = R_B \parallel (r_{\pi_1} + (1+\beta_1)R_{E_2})$$
$$= R_2 \parallel R_3 \parallel (r_{pi_1} + (1+\beta_1)R_{E_2}) \qquad (\because R_B = R_2 \parallel R_3)$$
$$= 4k\Omega \parallel 8k\Omega \parallel (0.8965k\Omega + (101)1k\Omega)$$
$$= \frac{4k\Omega \times 8k\Omega}{4k\Omega + 8k\Omega} \parallel 101.8965k\Omega$$
$$= 2.666k\Omega \parallel 101.8965k\Omega$$
$$= \frac{2.666k\Omega \times 101.8965k\Omega}{2.666k\Omega + 101.8965k\Omega} = \mathbf{2.598k\Omega}$$

Input impedance with R_S,

$$Z_{in} = Z_i + R_S$$
$$= 2.598k\Omega + 50\Omega = \mathbf{2.648k\Omega}$$

Output impedance,

$$Z_o = R_C \parallel R_L$$
$$= \frac{2k\Omega \times 2.2k\Omega}{2k\Omega + 2.2k\Omega} = \mathbf{1.047k\Omega}$$

$$
\begin{aligned}
A_{V_1} &= \frac{V_{o_1}}{V_i} \\
&= \frac{-1}{1 + g_m R_{E_2}} \\
&= \frac{-1}{1 + (111.538 mA/V)(1k\Omega)} \\
&= \frac{-1}{1 + 111.538} = -\mathbf{0.00885}
\end{aligned}
$$

$$
\begin{aligned}
A_{V_2} &= \frac{V_{out}}{V_{o_1}} \\
&= g_m (R_C \parallel R_L) \\
&= 111.538 mA/V (2k\Omega \parallel 2.2k\Omega) \\
&= 111.538 mA/V \left(\frac{2k\Omega \times 2.2k\Omega}{2k\Omega + 2.2k\Omega} \right) \\
&= 111.538 mA/V \times 1.047k\Omega = \mathbf{116.78}
\end{aligned}
$$

$$
\begin{aligned}
A_{V_T} &= A_{V_1} \times A_{V_2} \\
&= -0.00885 \times 116.78 = -\mathbf{1.037}
\end{aligned}
$$

$$
\begin{aligned}
A_{V_{T_S}} &= A_{V_T} \times \frac{Z_i}{Z_i + R_S} \\
&= -1.037 \times \frac{2.598k\Omega}{2.598k\Omega + 50\Omega} \\
&= -1.307 \times 0.98 = -\mathbf{1.017}
\end{aligned}
$$

$$
\begin{aligned}
\because A_{V_{T_S}} &= \frac{V_{out}}{V_S} \\
\therefore V_{out} &= A_{V_{T_S}} \times V_S \\
&= -1.017 \times 20mV = -\mathbf{20.34mV}
\end{aligned}
$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows:

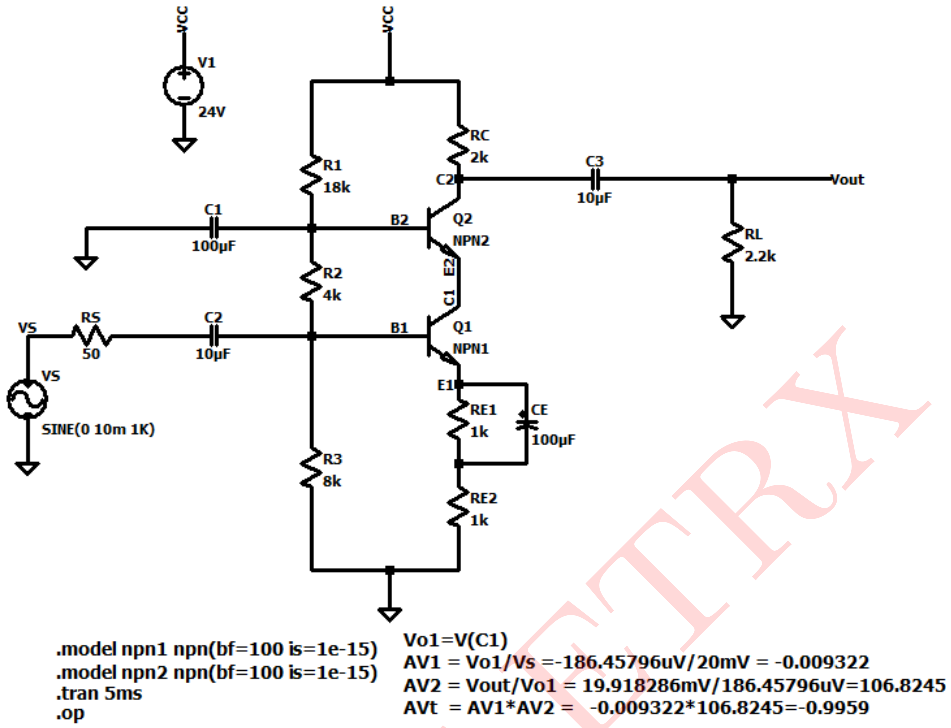

Figure 4: Circuit Schematic

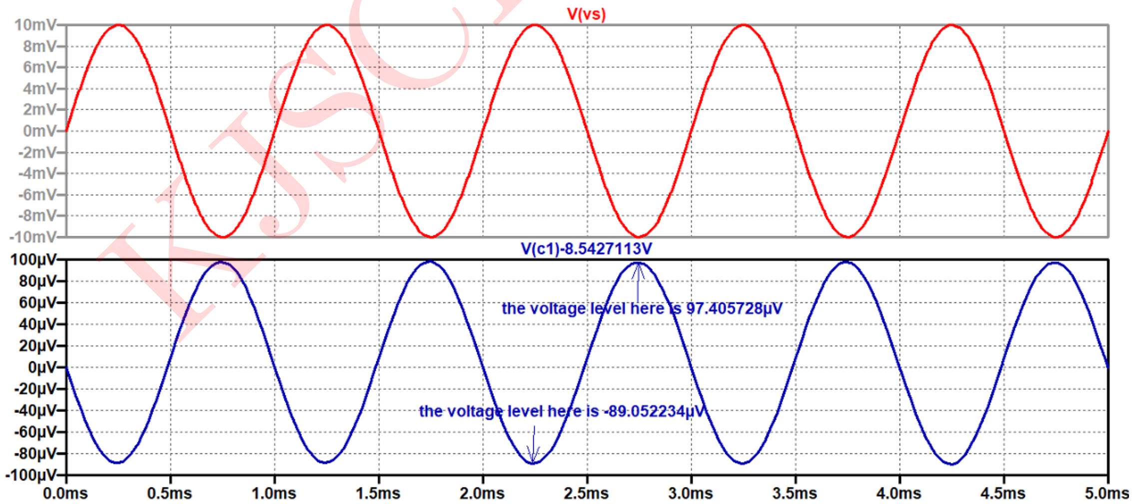

Figure 5: Input and ouput waveforms for Stage 1 voltage gain

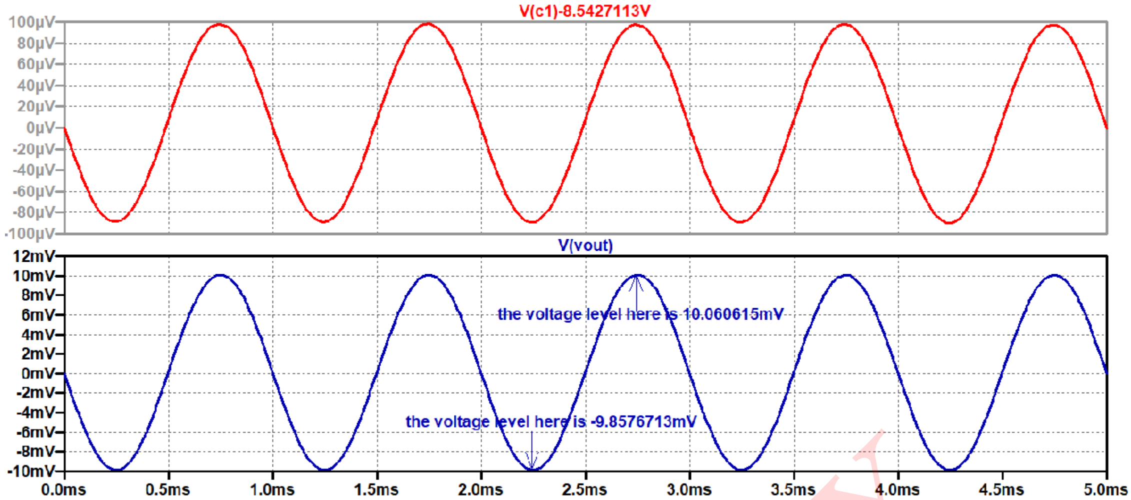

Figure 6: Input and ouput waveforms for Stage 2 voltage gain

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
1st stage DC parameters: V_{B_1}, V_{C_1}, V_{E_1}, I_{C_1}, I_{B_1}, I_{E_1}	6.4V, 9V, 5.8V, 2.9mA, 29μA, 2.9mA	6.1173V, 8.5427V, 8.3773V, 2.6620mA, 26.6205μA, 2.6688mA
2nd stage DC parameters: V_{B_2}, V_{C_2}, V_{E_2}, I_{C_2}, I_{B_2}, I_{E_2}	9.6V, 18.2V, 9V, 2.9mA, 29μA, 2.9mA	9.2824V, 18.7286V, 8.5427V, 2.6356mA, 26.356μA, 2.6620mA
Voltage gain of 1st stage A_{V_1}	-0.00885	-0.009322
Voltage gain of 2nd stage A_{V_2}	116.78	106.8245
Overall voltage gain $A_{V_{T_S}}$	-1.017	-0.9959
Input impedance of 1st stage Z_{in}	2.648kΩ	–
Output impedance of 2nd stage Z_o	1.047kΩ	–
Output voltage V_{out}	-20.34mV	-19.9182mV

Table 1: Numerical 1

Numerical 2:

A two stage circuit is shown below in figure 7. It's E-MOSFET parameters are $k_{n_1} = k_{n_2} = 1.2mA/V^2$, $V_{TN_1} = V_{TN_2} = 1.5V$

a) Calculate the DC parameters of the circuits i.e V_{G_1}, V_{G_2}, V_{GS_1}, I_{D_1}, I_{D_2}, V_{D_2}, V_{S_1}, V_{S_2}, V_{DS_2}, V_{D_1}, V_{DS_1} and V_{GS_2}

b) Calculate input impedance of the circuit

c) Calculate output impedance of the circuit

d) Calculate voltage gain of the circuit

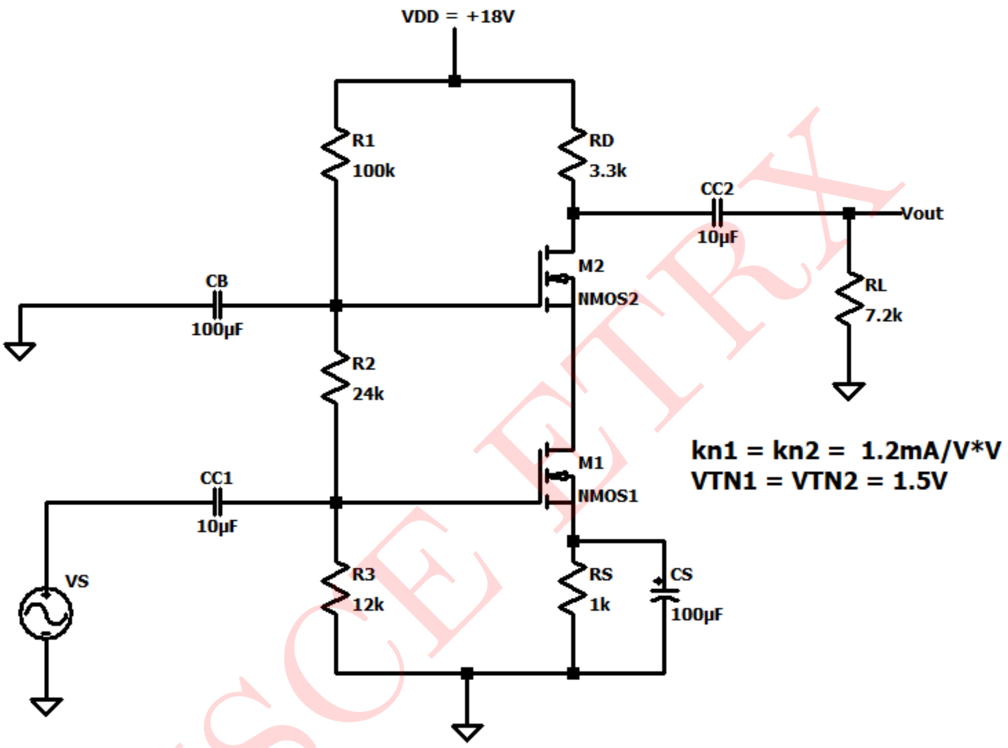

Figure 7: Circuit 2

Solution:

DC analysis:

$$R_T = R_1 + R_2 + R_3$$
$$= 100k\Omega + 24k\Omega + 12k\Omega = \mathbf{136k\Omega}$$

$$V_{G_1} = \frac{R_3}{R_T} \times V_{DD} = \frac{12k\Omega}{136k\Omega} \times 18V = \mathbf{1.588V}$$

$$V_{G_2} = \frac{R_2 + R_3}{R_T} \times V_{DD} = \frac{24k\Omega + 12k\Omega}{136k\Omega} \times 18V = \mathbf{4.764V}$$

$$V_{GS_1} = V_{G_1} - V_{S_1}$$
$$= 1.588V - I_{D_1} R_S$$
$$= 1.588V - I_{D_1}(1k\Omega) \qquad ....(1)$$

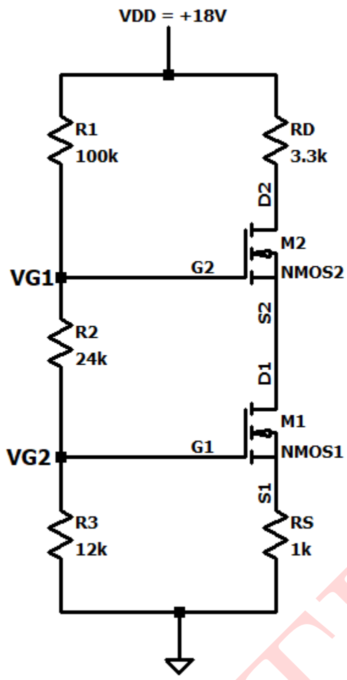

Figure 8: DC equivalent circuit

In MOSFET,

$I_{D_1} = k_{n_1}(V_{GS_1} - V_{TN_1})^2$

$I_{D_1} = 1.2mA/V^2(V_{GS_1} - 1.5V)^2 \qquad ....(2)$

Put (2) in (1), we get

$V_{GS_1} = 1.588 - \left[1.2mA/V^2(V_{GS} - 1.5V)^2\right](1k\Omega)$

$V_{GS_1} = 1.588 - 1.2({V_{GS}}^2 - 3V_{GS} + 2.25)$

$V_{GS_1} = -1.2{V_{GS}}^2 + 3.6V_{GS} - 1.112$

$0 = -1.2{V_{GS}}^2 + 2.6V_{GS} - 1.112$

$V_{GS_1} = 1.580V$ or $V_{GS_1} = 0.586V$

We reject the value $V_{GS} = 0.586V \qquad (\because V_{GS_1} > V_{TN_1})$

$V_{GS_1} = \mathbf{1.580V}$

Also, $V_{GS_1} = V_{GS_2} = \mathbf{1.580V}$

$I_{D_1} = k_{n_1}(V_{GS_1} - V_{TN_1})^2$

$\quad = 1.2mA/V^2(1.580V - 1.5V)^2$

$\quad = 1.2mA/V^2(0.08)^2 = \mathbf{7.68\mu A}$

$\therefore I_{D_1} = I_{D_2} = \mathbf{7.68\mu A}$

$V_{D_2} = V_{DD} - I_{D_2}R_D$

$\quad = 18V - (7.68\mu A)(3.3k\Omega)$

$\quad = 18V - 0.025V = \mathbf{17.97V}$

$V_{S_1} = I_{D_1} R_S$
$= (7.68\mu A)(1k\Omega) = \mathbf{0.0076V}$

$\because V_{GS_1} = V_{GS_2} = V_{G_2} - V_{S_2}$
$1.580V = 4.764V - V_{S_2}$
$V_{S_2} = 4.764V - 1.580V = \mathbf{3.184V}$

$\because V_{DS_2} = V_{D_2} - V_{S_2}$
$V_{DS_2} = 17.97V - 3.184V = \mathbf{14.786V}$

$\because V_{D_1} = V_{S_2} = \mathbf{3.184V}$

$V_{DS_1} = V_{D_1} - V_{S_1}$
$V_{DS_2} = 3.184V - 0.0076V = \mathbf{3.1764V}$

Small signal parameters:
$g_{m_1} = g_{m_2} = 2k_n(V_{GS} - V_{TN})$
$= 2 \times 1.2mA/V^2(1.580V - 1.5V) = \mathbf{0.192mA/V}$

Mid-frequency AC equivalent circuit:

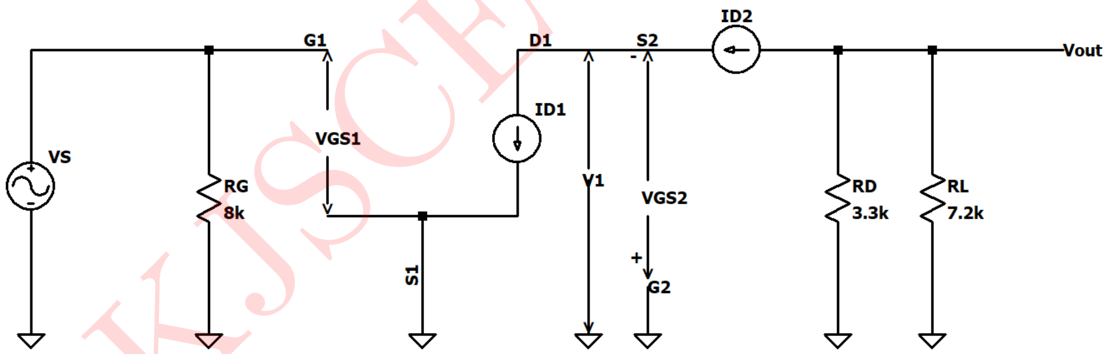

Figure 9: Mid-frequency AC equivalent circuit

Input impedance,
$Z_i = R_G$
$= R_2 \parallel R_3$
$= 24k\Omega \parallel 2k\Omega$
$$= \frac{24k\Omega \times 2k\Omega}{24k\Omega + 2k\Omega} = \mathbf{8k\Omega}$$

Output impedance,

$$Z_o = R_D \parallel R_L$$
$$= \frac{3.3k\Omega \times 7.2k\Omega}{3.3k\Omega + 7.2k\Omega} = \mathbf{2.26k\Omega}$$

$$A_{V_1} = \frac{V_1}{V_s}$$
$$= \frac{-V_{gs_2}}{V_{gs_1}}$$
$$= \frac{-V_{gs_1}}{V_{gs_1}} \qquad (\because V_{gs_2} = V_{gs_1})$$
$$= \mathbf{-1}$$

$$A_{V_2} = \frac{V_o}{V_1}$$
$$= \frac{-g_{m_2} V_{gs_2}(R_D \parallel R_L)}{-V_{gs_2}}$$
$$= g_{m_2}(R_D \parallel R_L)$$
$$= 0.192mA/V(3.3k\Omega \parallel 7.2k\Omega)$$
$$= 0.192mA/V \left(\frac{3.3k\Omega \times 7.2k\Omega}{3.3k\Omega + 7.2k\Omega}\right)$$
$$= 0.192mA/V \times 2.26k\Omega = \mathbf{0.433}$$

$$A_{V_T} = A_{V_1} \times A_{V_2}$$
$$= -1 \times 0.433 = -\mathbf{0.433}$$

Also, $A_{V_T} = \dfrac{V_{out}}{V_S}$

$$\therefore V_{out} = A_{V_T} \times V_S$$
$$= -0.433 \times 20mV = -\mathbf{8.66mV}$$

SIMULATED RESULTS:
Above circuit is simulated in LTspice and results are as follows:

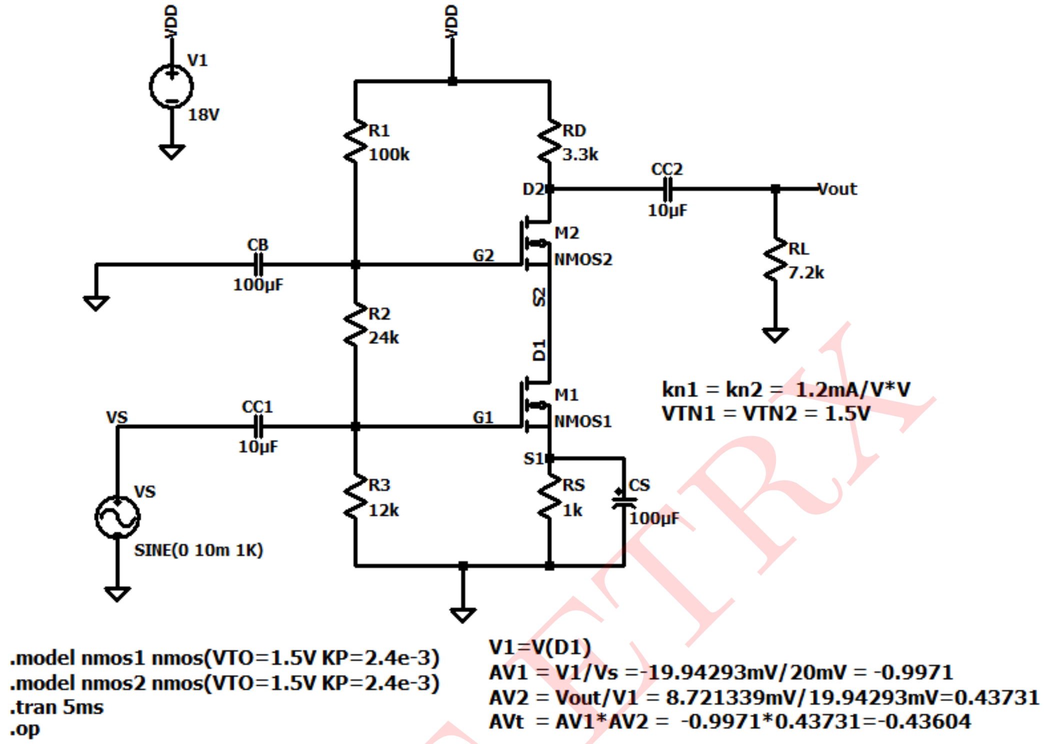

Figure 10: Circuit Schematic

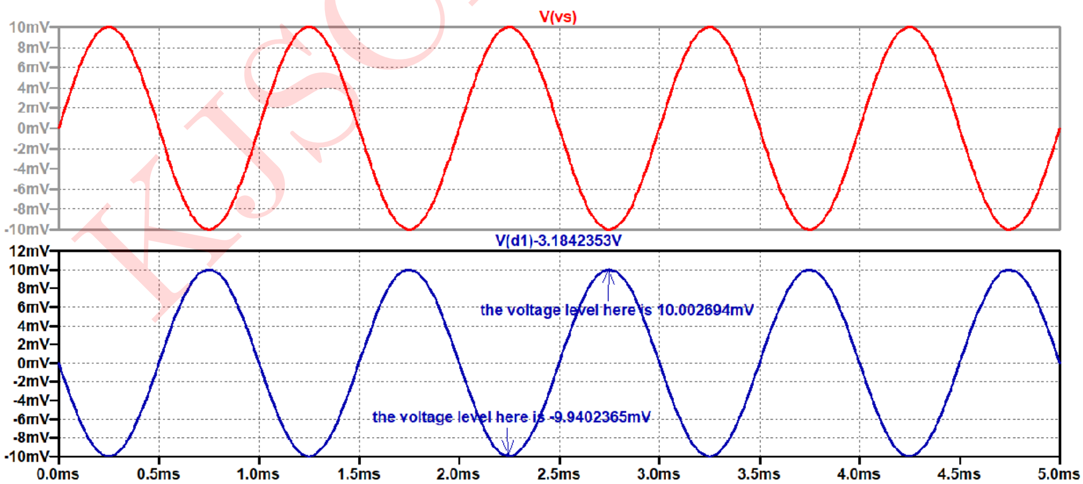

Figure 11: Input and ouput waveforms for Stage 1 voltage gain

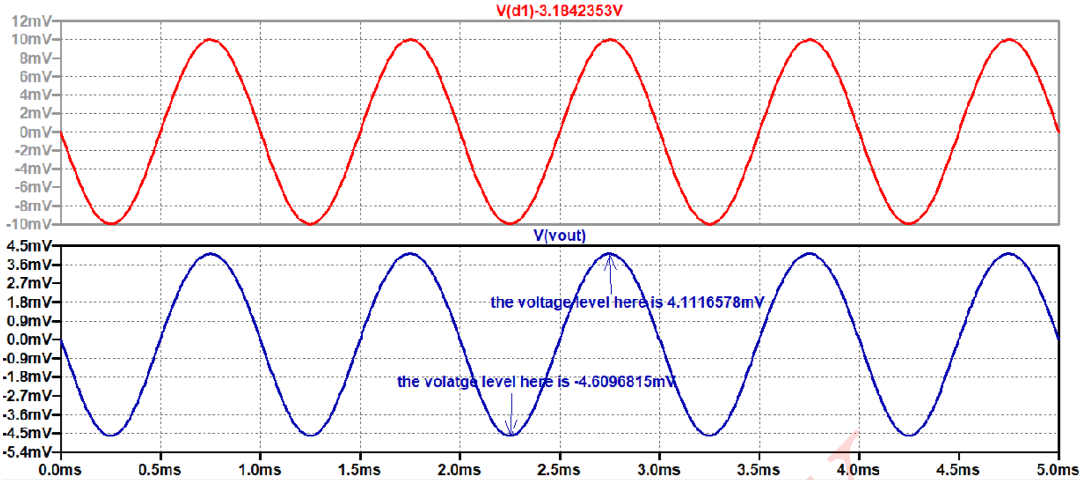

Figure 12: Input and ouput waveforms for Stage 2 voltage gain

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
1st stage DC parameters: V_{G_1}, V_{D_1}, V_{S_1}, I_{D_1}	1.588V, 3.184V, 0.0076V, 7.68μA	1.58824V, 3.1824V, 0.00776V, 7.7696μA
2nd stage DC parameters: V_{G_2}, V_{D_2}, V_{S_2}, I_{D_2}	4.764V, 17.97V, 3.184V, 7.68μA	4.7647V, 17.9744V, 3.1842V, 7.7706μA
Voltage gain of 1st stage A_{V_1}	-1	-0.009322
Voltage gain of 2nd stage A_{V_2}	0.433	0.43731
Overall voltage gain A_{V_T}	-0.433	-0.43604
Input impedance of 1st stage Z_i	8kΩ	–
Output impedance of 2nd stage Z_o	2.26kΩ	–
Output voltage	-8.66mV	-8.7213mV

Table 2: Numerical 2

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