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

Numerical 1:

For the cascade amplifier circuit shown in figure 1, calculate the voltage gain A_V and output voltage V_o. Given $\beta_1 = 200$ & $\beta_2 = 200$

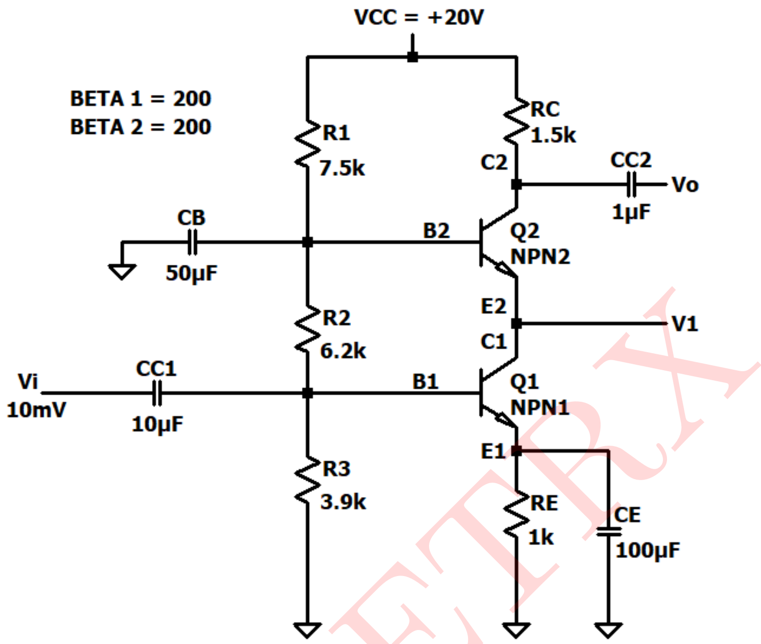

Figure 1: Circuit 1

Solution:

DC Analysis:

We open circuit all the capacitors as the frequency is $0Hz$,

$$\therefore X_C = \frac{1}{2\pi f_C} = \infty$$

Thus the circuit becomes as shown in figure 2,

$$\beta_1 = \beta_2 = 200;\ I_{C_1} = I_{C_2} = I_{E_1} = I_{E_2}$$

Assuming $I_{B_1} = I_{B_2}$ are very small,

$$V_{B_1} = \frac{R_3}{R_1 + R_2 + R_3} \times V_{CC} \qquad \text{[Considering } I_{B_2} \cong 0]$$

$$= \frac{3.9k\Omega}{7.5k\Omega + 6.2k\Omega + 3.9k\Omega} \times 20V$$

$$= \mathbf{4.4318V}$$

$$V_{B_2} = \frac{R_3 + R_2}{R_1 + R_2 + R_3} \times V_{CC} \qquad \text{[Considering } I_{B_1} \cong 0]$$

$$= \frac{3.9k\Omega + 6.2k\Omega}{7.5k\Omega + 6.2k\Omega + 3.9k\Omega} \times 20V = \mathbf{11.477V}$$

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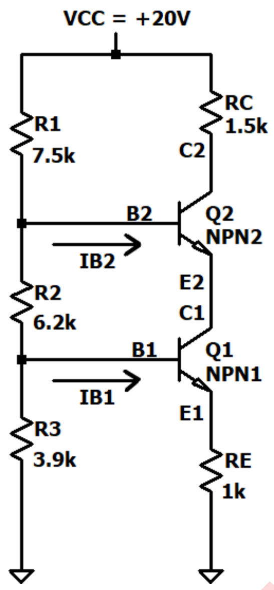

Figure 2: DC Equivalent Circuit

$$\begin{aligned} V_{E_1} &= V_{B_1} - V_{BE_1} & [V_{BE_1} = V_{B_1} - V_{E_1}] \\ &= 4.4318 - 0.7 \\ &= \mathbf{3.7318V} \end{aligned}$$

$$V_{E_1} = I_{E_1} R_E$$

$$I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.7318V}{1k\Omega} = \mathbf{3.7318mA}$$

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

$$\begin{aligned} V_{C_2} &= V_{CC} - I_{C_2} R_C \\ &= 20 - (3.7138mA \times 1.5k\Omega) \\ &= \mathbf{14.4023V} \end{aligned}$$

$$\begin{aligned} V_{E_2} &= V_{B_2} - V_{BE_2} \\ &= 11.477V - 0.7V \\ &= \mathbf{10.777V} \end{aligned}$$

$$\begin{aligned} V_{CE_1} &= V_{C_1} - V_{E_1} \\ &= 10.477 - 3.7318 \\ &= \mathbf{7.045V} \end{aligned}$$

$$\begin{aligned} V_{CE_2} &= V_{C_2} - V_{E_2} \\ &= 14.4023 - 10.777 \\ &= \mathbf{3.625V} \end{aligned}$$

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Small Signal Parameters:

$\beta_1 = \beta_2 = \beta = 200,\ I_{CQ_1} = I_{CQ_2} = 3.7318mA$

$$r_{\pi_1} = r_{\pi_2} = \frac{\beta V_T}{I_{CQ}} = \frac{200 \times 0.026V}{3.7318mA} = \mathbf{1.393k\Omega}$$

$$g_{m_1} = g_{m_2} = \frac{I_{CQ}}{V_T} = \frac{3.7318mA}{0.026V} = \mathbf{143.53mA/V}$$

Mid Frequency AC Equivalent Circuit:

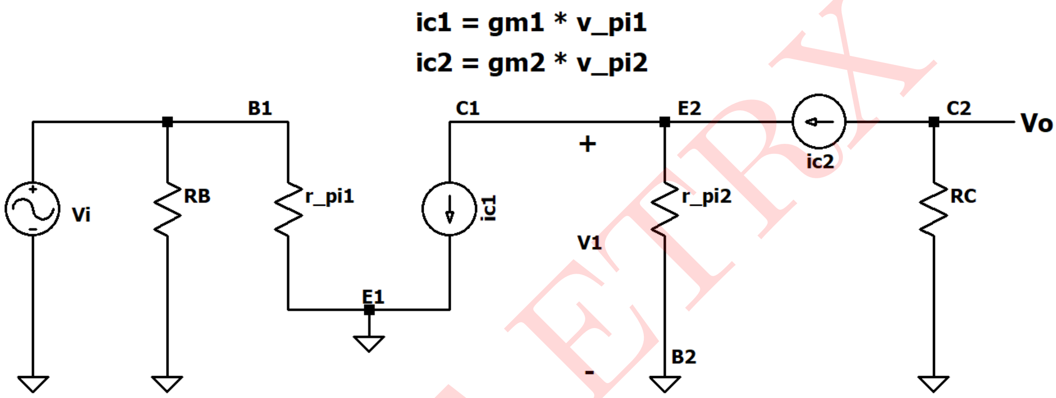

Figure 3: Small Signal Equivalent Circuit

$$\begin{aligned} R_B &= R_2 \parallel R_3 \\ &= 3.9k\Omega \parallel 6.2k\Omega \\ &= \mathbf{2.394k\Omega} \end{aligned}$$

Input Impedance of 1st stage ($\mathbf{Z_i}$):

$$\begin{aligned} Z_i &= R_B \parallel r_{\pi_1} \\ &= 2.394k\Omega \parallel 1.393k\Omega \\ &= \mathbf{880.6\Omega} \end{aligned}$$

Output Impedance of 2nd stage ($\mathbf{Z_o}$):

$Z_o = R_C = 1.5k\Omega$

$Z_o = \mathbf{1.5k\Omega}$

Gain of CB stage : $Av_2 = \dfrac{V_o}{V_1}$

$$\begin{aligned} Av_2 &= g_m(R_C) \\ &= (143.53mA/V)(1.5k\Omega) \\ &= \mathbf{215.295} \end{aligned}$$

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Gain of CE stage : $Av_1 = \dfrac{V_1}{V_i}$

$$Av_i = -g_m\left(\frac{r_\pi}{1+\beta}\right)$$
$$= -(143.53mA/V)\left(\frac{1.393k\Omega}{1+200}\right)$$
$$= \mathbf{-0.9947}$$

Overall Voltage Gain ($\mathbf{A_{V_T}}$):

$$A_{V_T} = \frac{V_o}{V_i} = \frac{V_1}{V_i} \times \frac{V_o}{V_1}$$

$$A_{V_T} = Av_1 \times Av_2$$
$$= (-0.9947) \times (215.295)$$
$$= \mathbf{-214.1539}$$

$$A_{V_T} \text{ in dB} = 20\log_{10}(|A_{V_T}|)$$
$$= 20\log_{10}(214.1539)$$
$$= \mathbf{46.614}\text{dB}$$

Output Voltage ($\mathbf{V_o}$):

Input Voltage: $V_i = 10mV$ [peak to peak]

$$A_{V_T} = \frac{V_o}{V_i} \implies V_o = A_{V_T} \times V_i$$

$$\therefore V_o = A_{V_T} \times V_i$$
$$= -214.1539 \times 10mV$$
$$= \mathbf{-2.14V} \quad \text{[peak to peak]}$$

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SIMULATED RESULTS

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

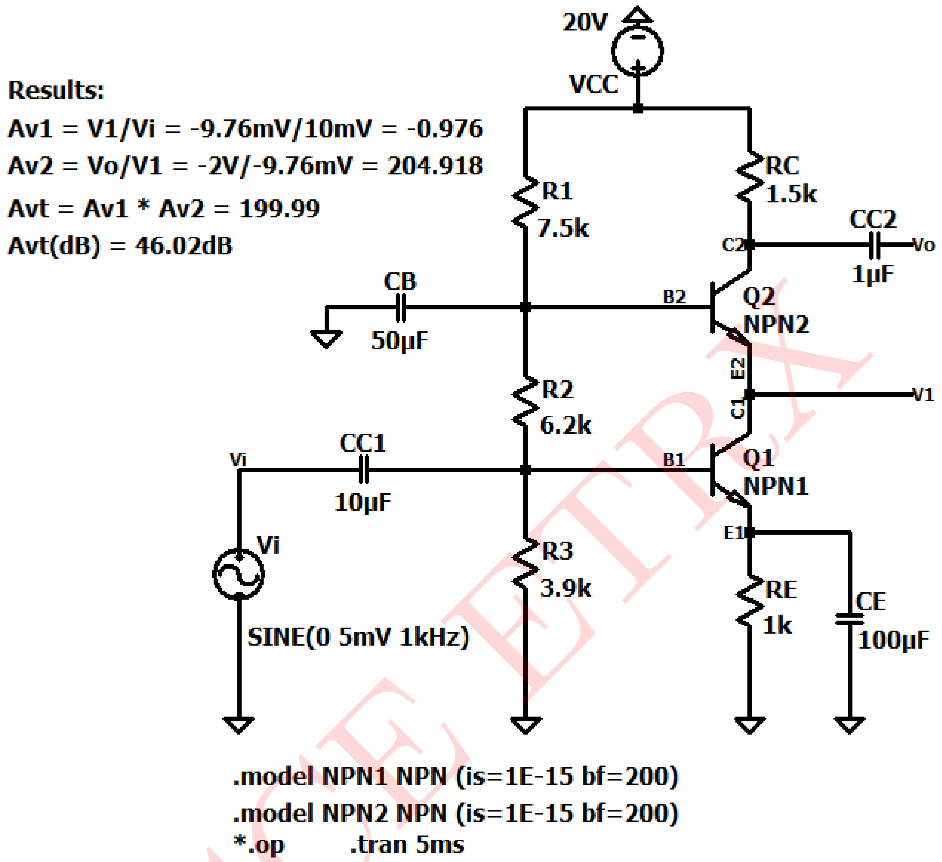

Figure 4: Circuit Schematic

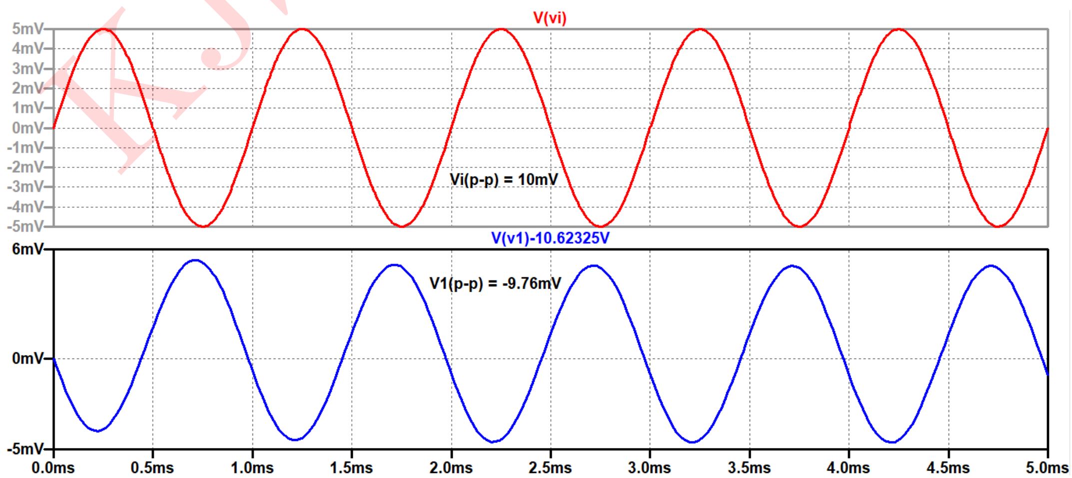

Figure 5: Input Output waveforms of 1st stage

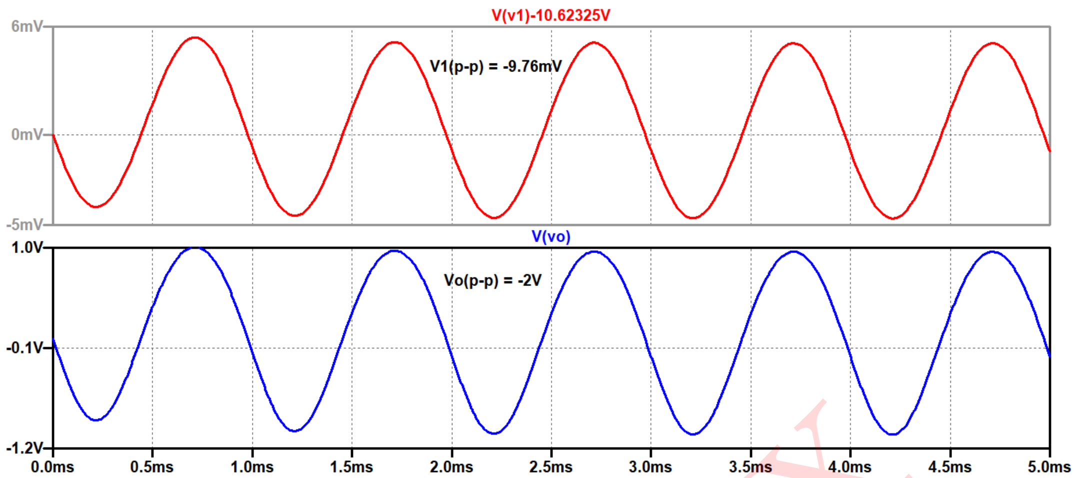

Figure 6: Input Output waveforms of 2nd stage

Comparison of Theoretical and Simulated results:

Parameters	Theoretical	Simulated
V_{B_1}	$4.4318V$	$4.34782V$
V_{C_1}	$10.777V$	$10.6233V$
V_{E_1}	$3.7318V$	$3.60015V$
I_{C_1}	$3.7318mA$	$3.582mA$
I_{B_1}	$18.659\mu A$	$17.9112\mu A$
I_{E_1}	$3.7318mA$	$3.60015mA$
V_{B_2}	$11.4777V$	$11.3708V$
V_{C_2}	$14.4023V$	$14.6534V$
V_{E_2}	$10.777V$	$10.6233V$
I_{C_2}	$3.7318mA$	$3.56441mA$
I_{B_2}	$18.659\mu A$	$17.822\mu A$
I_{E_2}	$3.7318mA$	$3.58224mA$
Voltage gain of 1^{st} stage: Av_1	-0.9947	-0.976
Voltage gain of 2^{nd} stage: Av_2	215.295	204.918
Overall Voltage gain: A_{V_T} in dB	$46.614dB$	$46.02dB$
Input Impedance of 1^{st} stage: Z_i	880.6Ω	$-$
Output Impedance of 2^{nd} stage: Z_o	$1.5k\Omega$	$-$
Output Voltage: V_o	$-2.14V$	$-2V$

Table 1: Numerical 1

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Numerical 2:

Determine the small signal volatge gain of the cascode circuit shown in figure 7. The transistors parameters are: $k_{n_1} = k_{n_2} = 0.8mA/V^2$, $V_{TN_1} = V_{TN_2} = 1.2V$ and $\lambda_1 = \lambda_2 = 0$

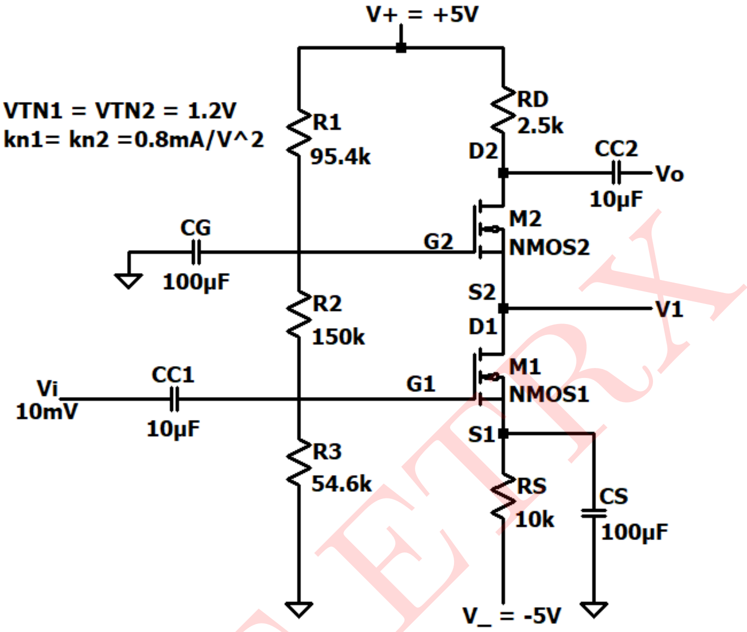

Figure 7: Circuit 2

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Solution:

DC Analysis:

We open circuit all the capacitors as the frequency is $0Hz$,

$$\therefore X_C = \frac{1}{2\pi f_C} = \infty$$

Thus the circuit becomes as shown in figure 8,

Since $I_{G_1} = I_{G_2} = 0A$

$\therefore R_1$, R_2 & R_3 are in series

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 95.4k\Omega + 150k\Omega + 54.6k\Omega \\ &= \mathbf{300k\Omega} \end{aligned}$$

$$\begin{aligned} V_{G_1} &= \frac{R_3}{R_T} \times V_+ \\ &= \frac{54.6k\Omega}{300k\Omega} \times 5 \\ &= \mathbf{0.91V} \end{aligned}$$

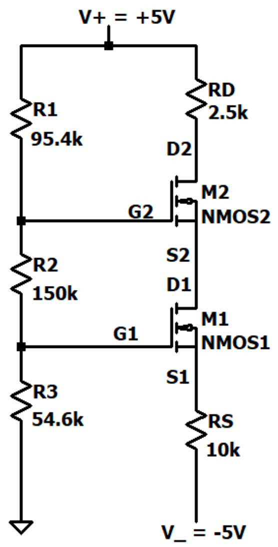

Figure 8: DC Equivalent Circuit

$$V_{G_2} = \frac{R_2 + R_3}{R_T} \times V_+$$
$$= \frac{54.6k\Omega + 150k\Omega}{300k\Omega} \times 5$$
$$= \mathbf{3.41V}$$

We know,

$$V_{GS_1} = V_{G_1} - V_{S_1}$$
$$= 0.91 - V_{S_1}$$

Applying KVL at the Source treminal of M_1,

$$V_{S_1} - I_{D_1}R_S = V_-$$
$$V_{S_1} = I_{D_1}R_S + V_- = (10k)I_{D_1} - 5$$

$$V_{GS_1} = 0.91 - (10k)I_{D_1} + 5$$
$$= 5.91 - (10k)I_{D_1} \qquad .....(1)$$

Also,

$$I_{D_1} = k_{n_1}(V_{GS_1} - V_{TN_1})^2$$
$$= (0.8mA/V^2)(V_{GS_1} - 1.2)^2 \qquad .....(2)$$

Substitute equation (2) in equation (1),

$$V_{GS_1} = 5.91 - 8(V_{GS_1}^2 - 2.4V_{GS_1} + 1.44)$$
$$= 5.91 - 8V_{GS_1}^2 + 19.2V_{GS_1} - 11.52$$

$$8V_{GS_1}^2 - 18.2V_{GS_1} + 5.61 = 0$$
$$\therefore V_{GS_1} = 1.9V, 0.36V$$
$$\because V_{GS} > V_{TP}\ , \therefore V_{GS_1} = \mathbf{1.9V}$$

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

$I_{D_1} = (0.8mA/V^2)(1.9V - 1.2V)^2 = 0.4mA$

$I_{D_1} = I_{D_2} = \mathbf{0.4mA}$

$$\begin{aligned} V_{D_2} &= V_+ - I_{D_2}R_D \\ &= 5 - (0.4mA)(2.5k\Omega) \\ &= \mathbf{4V} \end{aligned}$$

$$\begin{aligned} V_{S_1} &= I_{D_1}R_S + V_- \\ &= (0.4mA)(10k\Omega) - 5 \\ &= \mathbf{-1V} \end{aligned}$$

$V_{GS_1} = V_{GS_2} = \mathbf{1.9V}$

$V_{GS_2} = V_{G_2} - V_{S_2}$

$1.9V = 3.14V - V_{S_2}$

$V_{S_2} = \mathbf{1.51V}$

$$\begin{aligned} V_{DS_2} &= V_{D_2} - V_{S_2} \\ &= 4V - 1.51V \\ &= \mathbf{2.49V} \end{aligned}$$

$V_{D_1} = V_{S_2} = \mathbf{1.51V}$

$$\begin{aligned} V_{DS_1} &= V_{D_1} - V_{S_1} \\ &= 1.51V - (-1) \\ &= \mathbf{2.51V} \end{aligned}$$

Small Signal Parameters:

$k_n = k_{n_1} = k_{n_2} = 0.8mA/V^2$, $V_{GS} = V_{GS_1} = V_{GS_2} = 1.9V$, $V_{TN} = V_{TN_1} = V_{TN_2} = 1.2V$

$g_{m_1} = g_{m_2} = 2k_n(V_{GS} - V_{TN}) = 2(0.8mA/V^2)(1.9 - 1.2) = \mathbf{1.12mA/V}$

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AC (Mid Frequency) Equivalent Circuit:

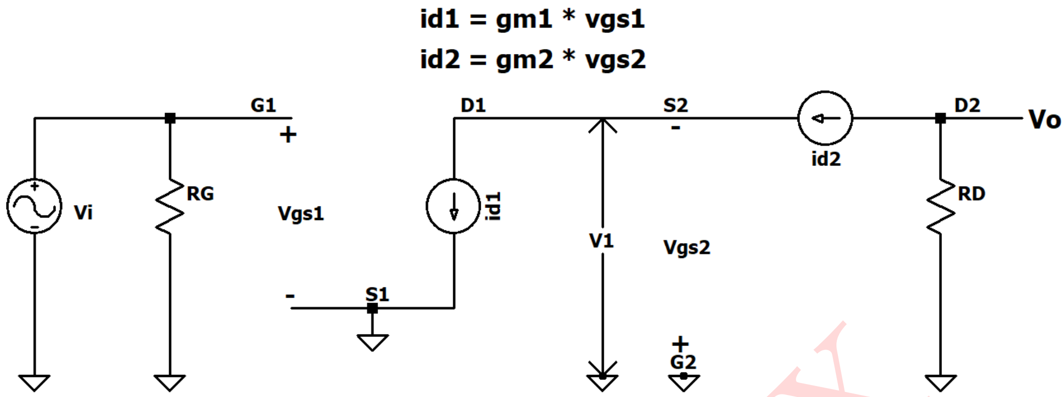

Figure 9: Small Signal Equivalent Circuit

$\because V_{gs_1} = V_{gs_2} \quad \& \quad g_{m_1} = g_{m_2}$

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

$R_G = R_2 \parallel R_3$

$Z_i = R_G = R_2 \parallel R_3 = 150k\Omega \parallel 54.6k\Omega = \mathbf{40k\Omega}$

$Z_o = R_D = \mathbf{2.5k\Omega}$

Voltage Gain of second stage : $Av_2 = \dfrac{V_o}{V_1}$

$$\begin{aligned} Av_2 &= \frac{-g_{m_2} V_{gs_2} R_D}{-V_{gs_2}} \\ &= g_{m_2} R_D \\ &= (1.12mA/V)(2.5k\Omega) \\ &= \mathbf{2.8} \end{aligned}$$

Voltage Gain of first stage : $Av_1 = \dfrac{V_1}{V_i}$

$$Av_1 = \frac{V_1}{V_i} = \frac{-V_{gs_2}}{V_{gs_1}} = \frac{-V_{gs_1}}{V_{gs_1}} = -1$$

$Av_1 = \mathbf{-1}$

Overall Voltage Gain ($\mathbf{A_{V_T}}$):

$$A_{V_T} = \frac{V_o}{V_s}$$

$$A_{V_T} = Av_1 \times Av_2 = \mathbf{-2.8}$$

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$$
\begin{aligned}
A_{V_T} \text{ in dB} &= 20\log_{10}(|A_{V_T}|) \\
&= 20\log_{10}(2.8) \\
&= \mathbf{8.943}\text{dB}
\end{aligned}
$$

Output Voltage ($\mathbf{V_o}$):

$$A_{V_T} = \frac{V_o}{V_i} \quad \Longrightarrow \quad V_o = A_{V_T} \times V_i$$

Input Voltage: $V_i = 10mV$ [peak to peak]

$$
\begin{aligned}
\therefore V_o &= A_{V_T} \times V_i \\
&= -2.8 \times 10mV \\
&= \mathbf{-28mV} \quad \text{[peak to peak]}
\end{aligned}
$$

SIMULATED RESULTS

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

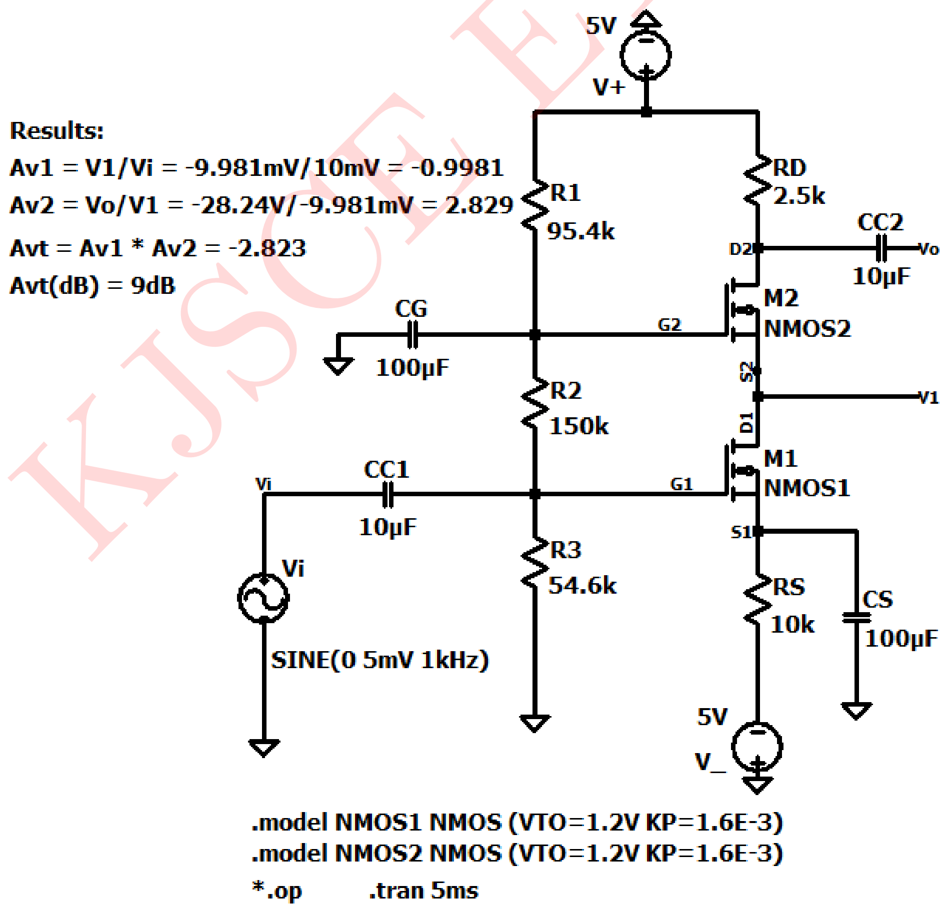

Figure 10: Circuit Schematic

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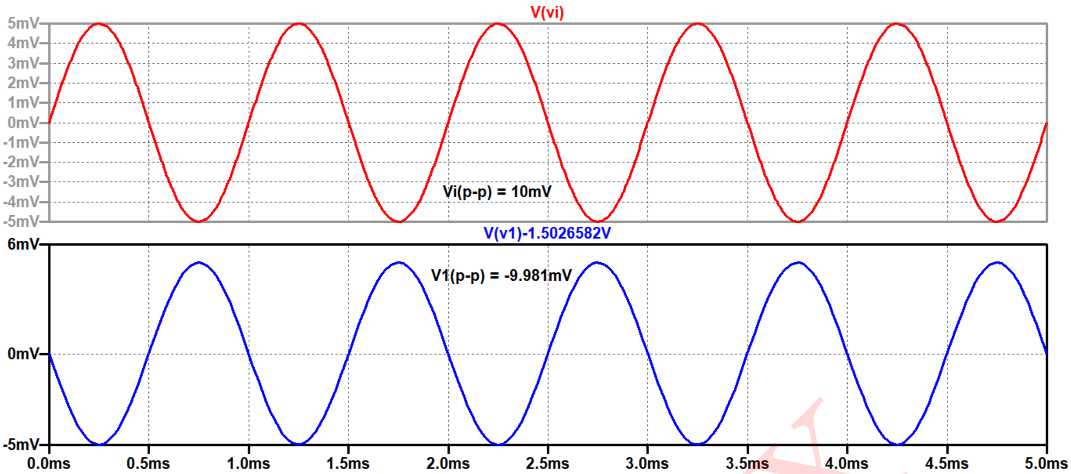

Figure 11: Input Output waveforms of 1st stage

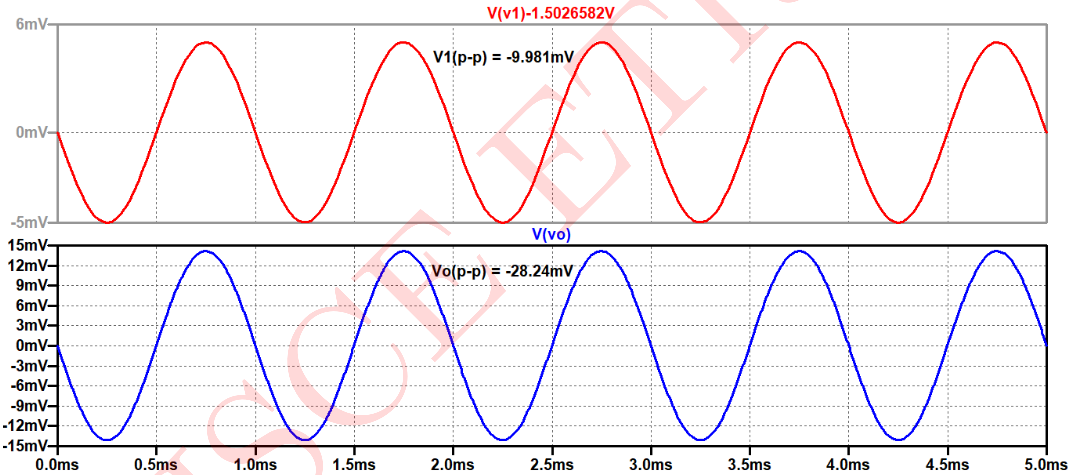

Figure 12: Input Output waveforms of 2nd stage

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Comparison of Theoretical and Simulated results:

Parameters	Theoretical	Simulated
V_{G_1}, V_{G_2}	$0.91V$, $3.41V$	$0.91V$, $3.41V$
V_{D_1}, V_{D_2}	$1.51V$, $4V$	$1.502V$, $3.999V$
V_{S_1}, V_{S_2}	$-1V$, $1.51V$	$-0.997V$, $1.502V$
I_{D_1}, I_{D_2}	$0.4mA$, $0.4mA$	$0.4mA$, $0.4mA$
Voltage gain of 1^{st} stage: Av_1	-1	-0.9981
Voltage gain of 2^{nd} stage: Av_2	2.8	2.829
Overall Voltage gain: A_{V_T} in dB	$8.934dB$	$9dB$
Input Impedance of 1^{st} stage: Z_i	$40k\Omega$	–
Output Impedance of 2^{nd} stage: Z_o	$2.5k\Omega$	–
Output Voltage: V_o	$-28mV$[peak to peak]	$-28.24mV$[peak to peak]

Table 2: Numerical 2

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