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

Numerical 1:
For the circuit shown in figure 1, the BJT parameters are $\beta_1 = \beta_2 = 120$, $V_{BE_1} = V_{BE_2} = 0.7V$
a) Calculate DC parameters of the circuit.
b) Calculate input and output impedance of the circuit.
c) Calculate overall voltage gain for the circuit.
Given:- $V_S = 20mV$

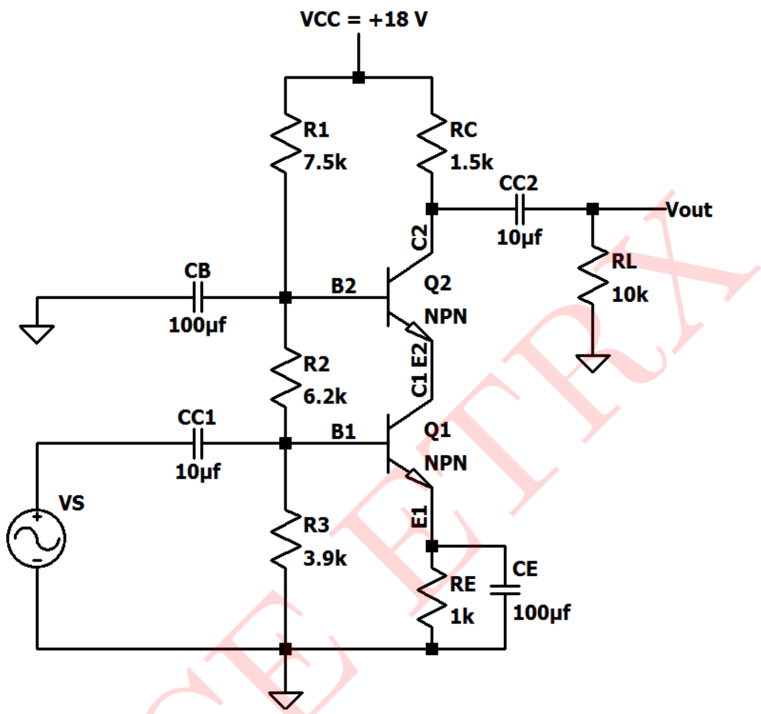

Figure 1: Circuit 1

Solution:

DC Analysis:-

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

$$V_{B_1} = \frac{R_3}{R_1 + R_2 + R_3} \times V_{CC} = \frac{3.9k\Omega}{3.9k\Omega + 6.2k\Omega + 7.5k\Omega} \times 18 = 3.988V$$

$\boldsymbol{V_{B_1} = 3.988V}$

$$V_{B_2} = \frac{R_3 + R_2}{R_1 + R_2 + R_3} \times V_{CC} = \frac{3.9k\Omega + 6.2k\Omega}{3.9k\Omega + 6.2k\Omega + 7.5k\Omega} \times 18 = 10.33V$$

$\boldsymbol{V_{B_1} = 10.33V}$

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

$V_{E_1} = V_{B_1} - V_{BE_1} = 3.99V - 0.7V = 3.29V$

$\boldsymbol{V_{E_1} = 3.29V}$

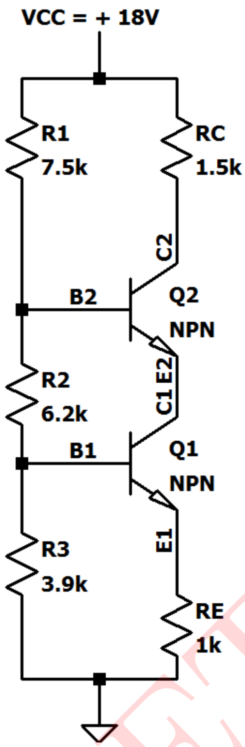

Figure 2: DC Equivalent circuit

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

$I_{E_1} = \frac{V_{E_1}}{R_E} = \frac{3.29}{1k\Omega} = 3.29mA$

$\boldsymbol{I_{E_1} = 3.29mA}$

$\boldsymbol{I_{C_1} = I_{C_2} = I_{E_1} = I_{E_2} = 3.29mA}$

$V_{C_2} = V_{CC} - I_{C_2} R_C = 18 - (3.29 \times 1.5) = 13.07V$

$\boldsymbol{V_{C_2} = 13.07V}$

$V_{E_2} = V_{B_2} - V_{BE_2} = 10.33 - 0.7V = 9.63V$

$\boldsymbol{V_{E_2} = V_{C_1} = 9.63V}$

$I_{B_1} = \frac{I_{C_1}}{\beta_1} = \frac{3.29mA}{120} = 27.42\mu A$

$I_{B_2} = \frac{I_{C_2}}{\beta_2} = \frac{3.29mA}{120} = 27.42\mu A$

$\boldsymbol{I_{B_1} = I_{B_2} = 27.42\mu A}$

Small-Signal parameters:-

$$g_m = \frac{I_C}{V_T} = \frac{3.29mA}{26mV} = 126.54\ mA/V$$

$$\boldsymbol{g_{m_1} = g_{m_2} = 126.54\ mA/V}$$

$$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{27.42\mu A} = 948.33\Omega$$

$$\boldsymbol{r_{\pi_1} = r_{\pi_2} = 948.33\Omega}$$

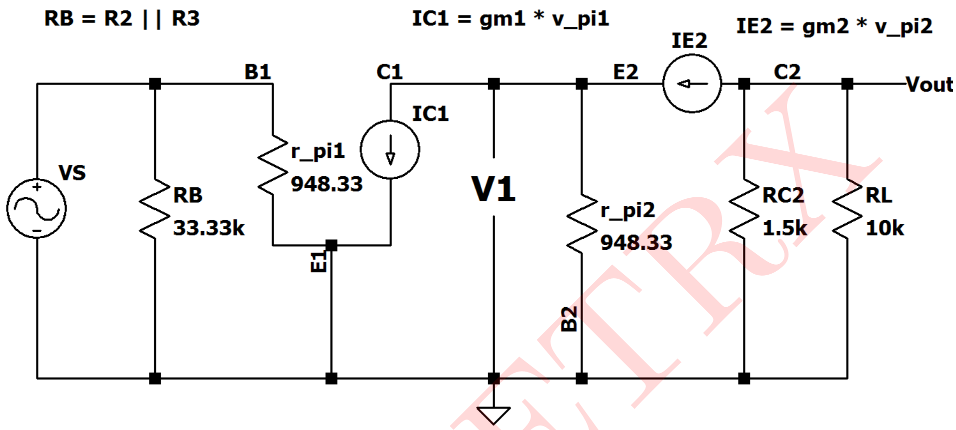

Figure 3: Small Signal Equivalent Circuit

Input Impedance

$$Z_i = R_2 \mid\mid R_3 \mid\mid r_{\pi_1} = 3.9k \mid\mid 6.2k \mid\mid 948.33 = 910.915\Omega$$

$$\boldsymbol{Z_i = 910.915\Omega}$$

$$Z_i = R_C \mid\mid R_L = 1.5k \mid\mid 10k = 1.3k\Omega$$

$$\boldsymbol{Z_o = 1.3k\Omega}$$

Voltage Gain of Stage 1(A_{V_1}):-

$$A_{V_1} = \frac{V_1}{V_{in}}$$

$$V_1 = -g_{m_1} V_{\pi_1} \left(\frac{r_{\pi_2}}{1 + \beta_2} \right)$$

$$V_{in} = V_{\pi_1}$$

$$A_{V_1} = \frac{V_1}{V_{in}} = -g_{m_1} \left(\frac{r_{\pi_2}}{1 + \beta_2} \right) = -126.54 \left(\frac{948.33}{121} \right) = -0.99175$$

$$\boldsymbol{A_{V_1} = -0.99175}$$

Voltage Gain of Stage 2(A_{V_2}):-

$$A_{V_2} = \frac{V_{out}}{V_1} = \frac{-g_{m_2} V_{\pi_2}(R_C \mid\mid R_L)}{-V_{\pi_2}} = g_{\pi_2}(R_C \mid\mid R_L)$$

$$A_{V_2} = 126.54(1.5k\Omega \mid\mid 10k\Omega) = 126.54mA/V \times 1300 = 164.5$$

$$\boldsymbol{A_{V_2} = 164.5}$$

Overall mid-band voltage gain $= A_{V_1} \times A_{V_2} = 164.5 \times -0.99175 = -163.14$

$$\boldsymbol{A_{V_T} = -163.14}$$

$$\boldsymbol{A_{V_T} \text{ in dB} = 20log_{10}(163.14) = 44.25dB}$$

Output voltage:-

$$V_{out} = A_{V_T} \times V_S = -163.14 \times 40mV = -6.52V$$

$$\boldsymbol{V_{out} = -6.52V}$$

SIMULATED RESULTS:

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

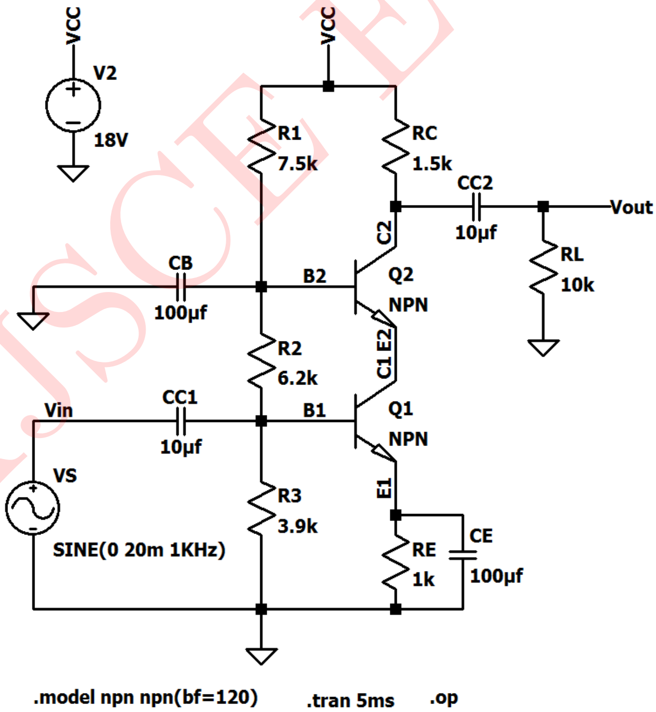

Figure 4: Circuit Schematic 1

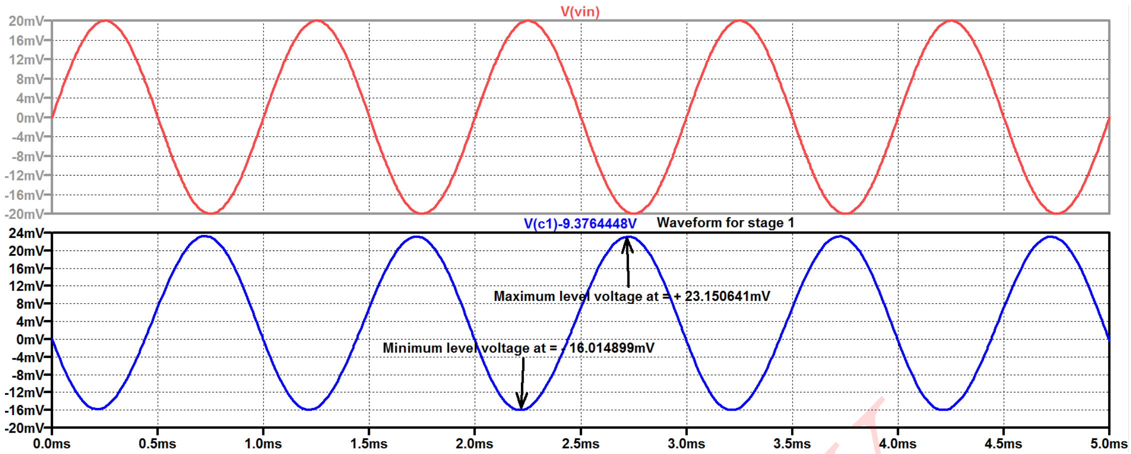

Figure 5: Input and Output waveform for stage 1

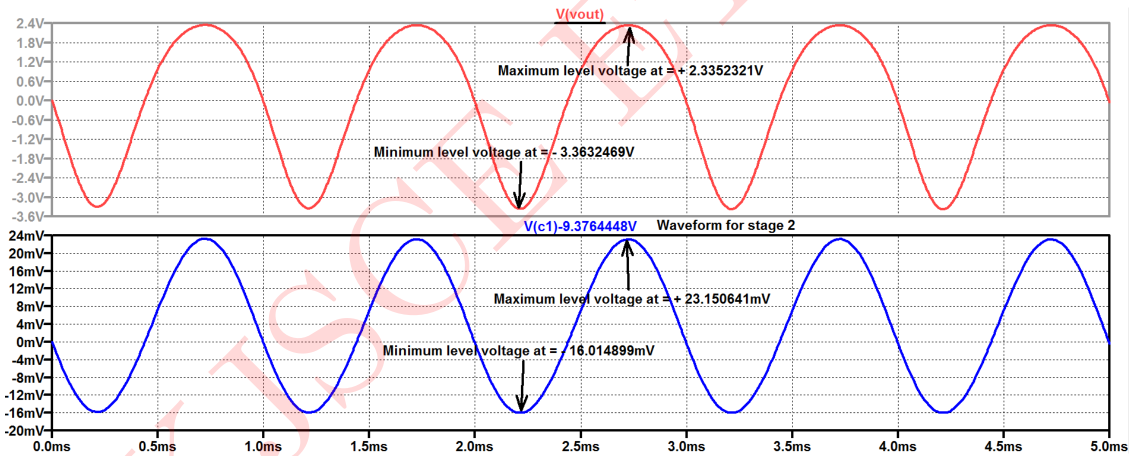

Figure 6: Input and Output waveform for stage 2

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{B_1}, I_{B_2}	$27.42\mu A$, $27.42\mu A$	$27.34\mu A$, $27.14\mu A$
I_{C_1}, I_{C_2}	$3.29mA$, $3.29mA$	$3.04mA$, $3.02mA$
I_{E_1}, I_{E_2}	$3.29mA$, $7.406V$	$3.07mA$, $3.04mA$
V_{C_1}, V_{C_2}	$9.63V$, $13.07V$	$9.38V$, $13.47V$
V_{B_1}, V_{B_2}	$3.99V$, $10.33V$	$3.87V$, $10.18V$
V_{E_1}, V_{E_2}	$3.29V$, $9.63V$	$3.07V$, $9.38V$
A_{V_1}	-0.99175	-0.979
A_{V_2}	164.5	148.63
$A_{V_T}(dB)$	$44.25dB$	$43.26dB$
V_{out}	$-6.52V$	$-5.72V$
Z_i, Z_o	$910\Omega, 1.3k\Omega$	$-$

Table 1: Numerical 1

Numerical 2:
For the circuit shown in figure 7, the E-MOSFET parameters are $k_{n_1} = k_{n_2} = 0.8mA/V^2$, $V_{TN_1} = V_{TN_2} = 0.8V$
a) Calculate DC parameters of the circuit.
b) Calculate input and output impedance of the circuit.
c) Calculate overall voltage gain for the circuit.
Given:- $V_S = 20mV$

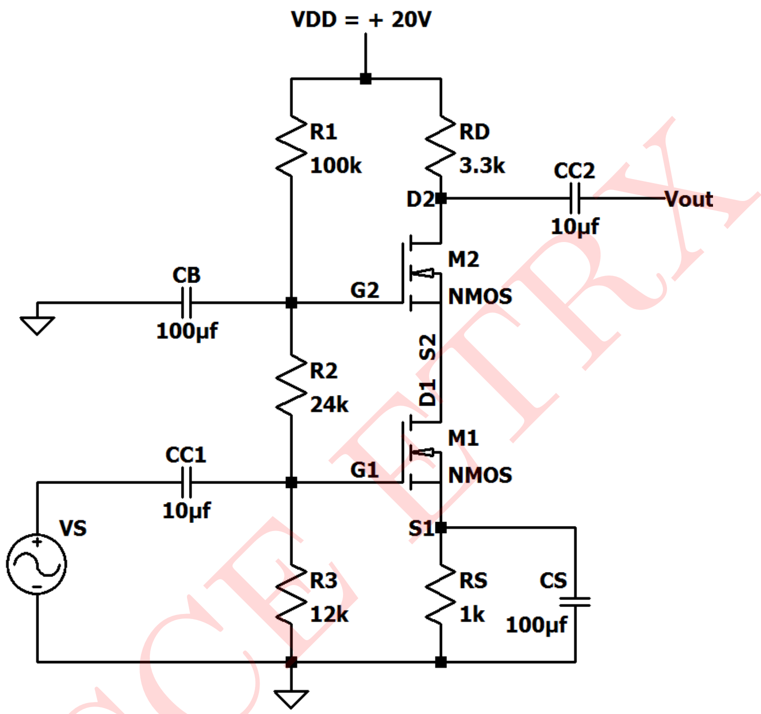

Figure 7: Circuit 2

Solution:

DC Analysis:-

$R_T = R_1 + R_2 + R_3 = 136K\Omega$

$$V_{G_1} = \left(\frac{R_3}{R_1 + R_2 + R_3}\right) \times V_{DD} = \left(\frac{12k}{136k}\right) 20 = 1.765V$$

$\boldsymbol{V_{G_1} = 1.765V}$

$$V_{G_2} = \left(\frac{R_3 + R_2}{R_1 + R_2 + R_3}\right) \times V_{DD} = \left(\frac{12k + 24k}{136k}\right) 20 = 5.294V$$

$\boldsymbol{V_{G_2} = 5.294V}$

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

$V_{GS_1} = 1.765 - I_{D_1} R_S = 1.765 - 1000 I_{D_1}$ ....(1)

For E-MOSFET, drain current is given by:-

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

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

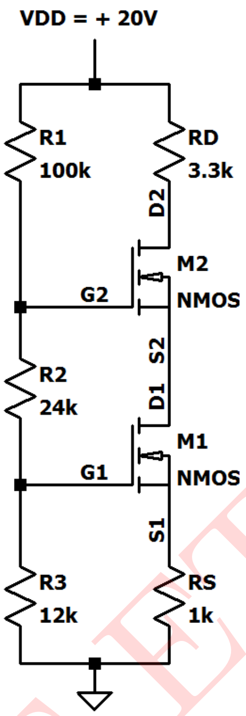

Figure 8: DC Equivalent circuit

Put (2) in (1), we get

$V_{GS_1} = 1.765 - 0.8 \times 10^{-3} \times 10^{3}(V_{GS_1} - 0.8)^2$

$V_{GS_1} = 1.765 - 0.8({V_{GS_1}}^2 + 0.64 - 1.6V_{GS_1})$

$V_{GS_1} = 1.765 - 0.8{V_{GS_1}}^2 - 0.512 + 1.28V_{GS_1}$

$0.8{V_{GS_1}}^2 - 0.28V_{GS} - 1.2527 = 0$

Solving above quadratic equation we get

$V_{GS_1} = 1.4385V$

or

$V_{GS_1} = -1.0885V$, We reject this value, as $(V_{GS_1} > V_{TN_1})$

$\therefore \boldsymbol{V_{GS_1} = 1.4385V}$

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

$I_{D_1} = 0.8 \times 10^{-3}(1.4385 - 0.8)^2 = 0.326mA$

$\boldsymbol{I_{D_1} = I_{D_2} = 0.326mA}$

$V_{D_2} = V_{DD} - I_{D_2}R_D = 20 - (0.326 \times 3.3) = 18.923V$

$\boldsymbol{V_{D_2} = 18.923V}$

$V_{S_1} = I_{D_1}R_S = 0.326 \times 1 = 0.326V$

$\boldsymbol{V_{S_1} = 0.326V}$

$V_{GS_1} = V_{GS_2} = V_{G_2} - V_{S_2} = 1.4385V$

$\boldsymbol{V_{GS_1} = V_{GS_2} = 1.4385V}$

$V_{S_2} = V_{G_2} - 1.4385 = 5.294 - 1.4385 = 3.855V$

$\boldsymbol{V_{S_2} = V_{D_1} = 3.855V}$

$V_{DS_2} = V_{D_2} - V_{S_2} = 18.923 - 3.855 = 15.068V$

$\boldsymbol{V_{DS_2} = 15.068V}$

$V_{DS_1} = V_{D_1} - V_{S_1} = 3.855 - 0.326 = 3.529V$

$\boldsymbol{V_{DS_1} = 3.529V}$

Small-Signal parameters:-

$g_{m_1} = g_{m_2} = 2k_n(V_{GS} - V_{TN})$

$g_{m_1} = gm_2 = 2 \times 0.8 \times 10^{-3}(1.4385 - 0.8) = 1.022mA/V$

$\boldsymbol{g_{m_1} = g_{m_2} = 1.022\ mA/V}$

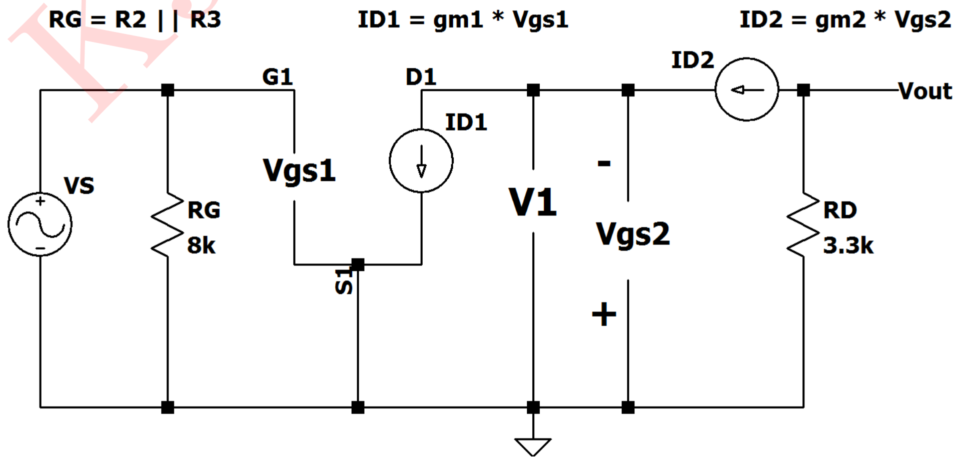

Figure 9: Small Signal Equivalent Circuit

Input and Output Impedance

$Z_i = R_G = R_3 \mid\mid R_2 = 8k\Omega$

$\boldsymbol{Z_i = 8k\Omega}$

$Z_o = R_D = 3.3k\Omega$

$\boldsymbol{Z_o = 3.3k\Omega}$

Voltage Gain of Stage 1(A_{V_1}):-

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

$\boldsymbol{A_{V_1} = -1}$

Voltage Gain of Stage 2(A_{V_2}):-

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

$A_{V_2} = 1.022 \times 10^{-3} \times 3.3 \times 10^3 = 3.373$

$\boldsymbol{A_{V_2} = 3.373}$

Overall mid-band voltage gain $= A_{V_1} \times A_{V_2} = -1 \times 3.373 = -3.373$

$\boldsymbol{A_{V_T} = -3.373}$

$\boldsymbol{A_{V_T}}$ **in dB** $\boldsymbol{= 20 log_{10}(3.373) = 10.56 dB}$

Output voltage:-

$V_{out} = A_{V_T} \times V_S = -3.373 \times 40mV = -134.92mV$

$\boldsymbol{V_{out} = -134.92mV}$

SIMULATED RESULTS:

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

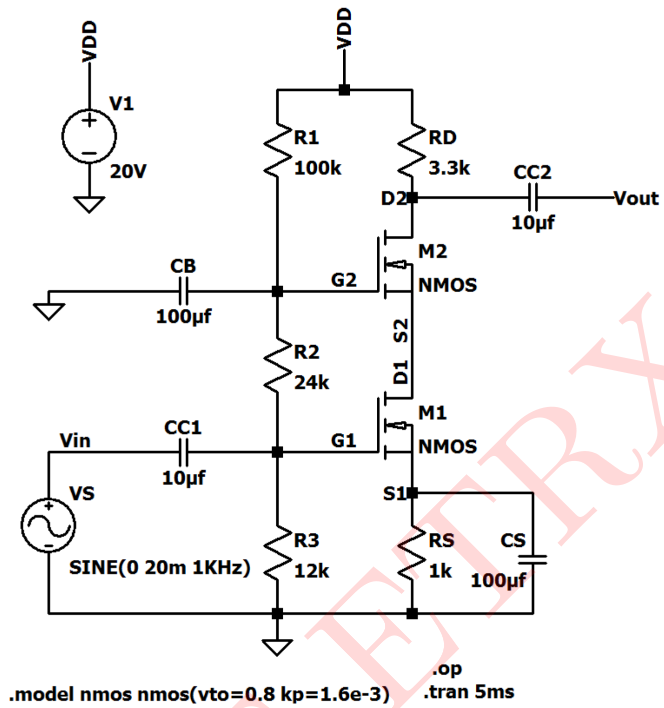

Figure 10: Circuit Schematic 2

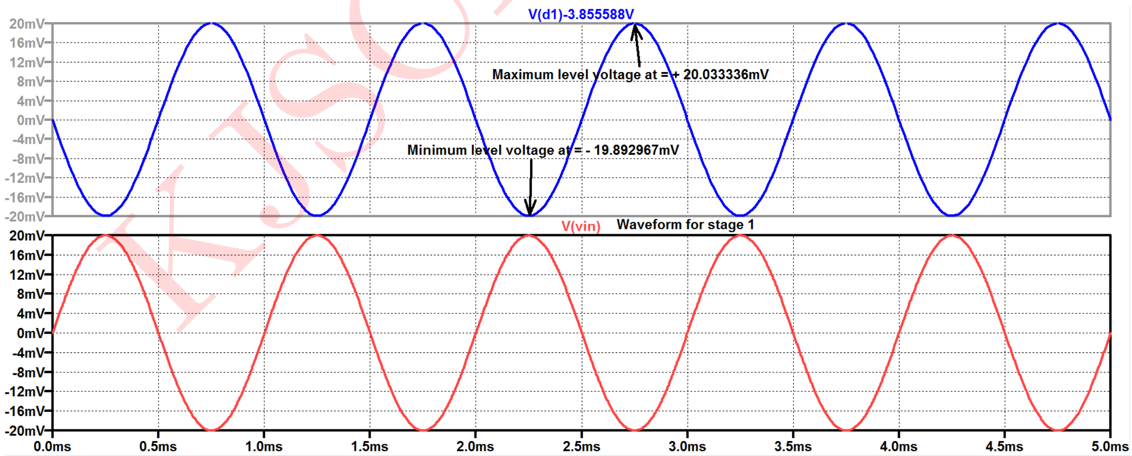

Figure 11: Input and Output waveform for stage 1

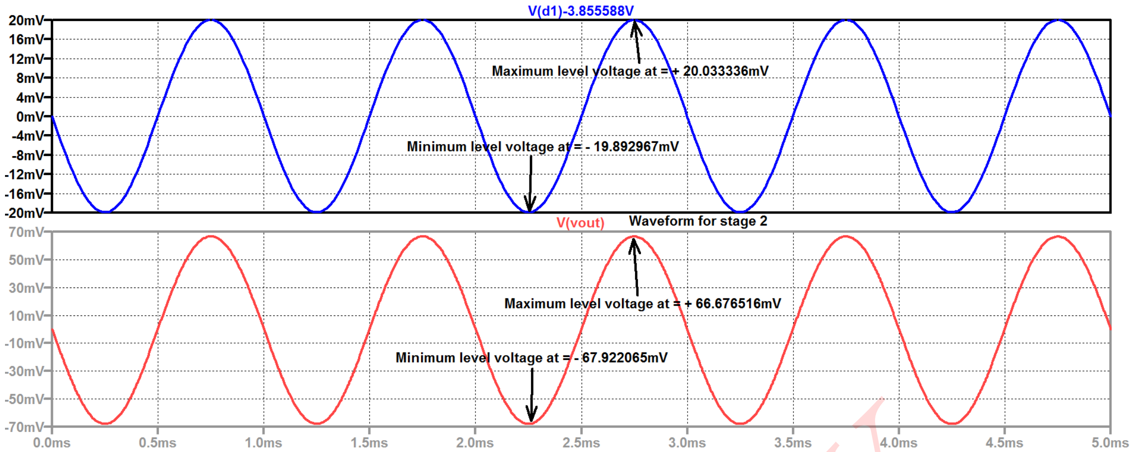

Figure 12: Input and Output waveform for stage 2

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{D_1}, I_{D_2}	$0.326mA$, $0.326mA$	$0.326mA$, $0.326mA$
V_{G_1}, V_{G_2}	$1.765V$, $5.294V$	$1.765V$, $5.294V$
V_{S_1}, V_{S_2}	$0.326V$, $3.855V$	$0.326V$, $3.855V$
V_{D_1}, V_{D_2}	$3.855V$, $18.923V$	$3.855V$, $18.923V$
A_{V_1}	-1	-0.998
A_{V_2}	3.373	3.371
$A_{V_T}(dB)$	10.56	10.54
V_{out}	$-134.92mV$	$-134.59mV$
Z_i, Z_o	$8k\Omega, 3.3k\Omega$	$-$

Table 2: Numerical 2

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