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

Numerical 1:

For the differential shown in figure 1 Find, a) Name of the circuit b) Q-point c) Differential voltage gain d) Common mode gain e) CMRR

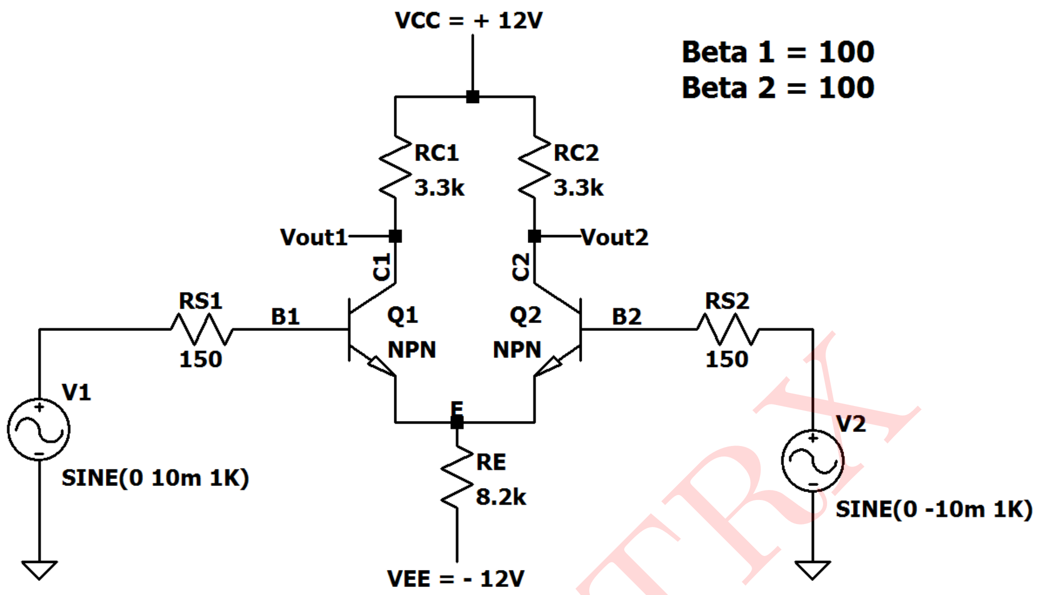

Figure 1: Circuit 1

Solution:

Above circuit 1 is a Dual Input Balanced Output(DIBO) differential amplifier

DC Analysis:-

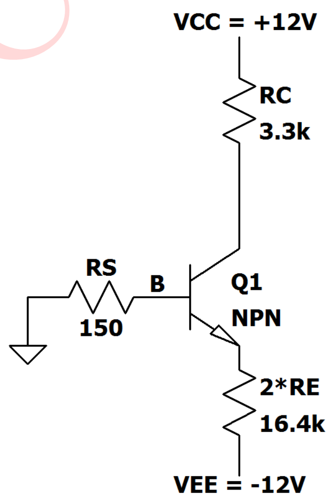

Figure 2: DC Equivalent Circuit

$$I_B = \frac{V_{EE} - V_{BE}}{R_S + 2(1+\beta)R_E} = \frac{12 - 0.7}{150 + (2 \times 101 \times 8.2k)} = 6.82\mu A$$

$\boldsymbol{I_B = 6.82\mu A}$

$I_C = \beta I_B = 100 \times 6.82\mu A = 0.68mA$

$\boldsymbol{I_C = 0.68mA}$

$\boldsymbol{I_{C_1} = I_{C_2} = I_C = 0.68mA}$

$V_{CE} = V_{CC} + V_{EE} - I_C(R_C + 2R_E) = 12 + 12 - 0.68mA(3.3k + 2 \times 8.2k) = 10.6V$

$\boldsymbol{V_{CE} = 10.6V}$

$V_{C_1} = V_{C_2} = V_{CC} - I_C R_C = 12 - (0.68 \times 3.3) = 9.756V$

$\boldsymbol{V_{C_1} = V_{C_2} = 9.756V}$

$V_{CE} = V_C - V_E$

$V_E = V_C - V_{CE} = 9.756 - 10.6 = -0.844V$

$\boldsymbol{V_{E_1} = V_{E_2} = -0.844V}$

$$r_\pi = \frac{\beta V_T}{I_C} = \frac{100 \times 26mV}{0.68mA} = 3.82k\Omega$$

$\boldsymbol{r_\pi = 3.82k\Omega}$

$$|A_d| = \frac{\beta R_C}{R_S + r_\pi} = \frac{100 \times 3.3k}{150 + 3.82k} = 83.12$$

$\boldsymbol{|A_d| = 83.12}$

$$A_{cm} = \left|\frac{R_C}{2R_E}\right| = \left|\frac{3.3k}{2 \times 8.2k}\right| = 0.201$$

$\boldsymbol{A_{cm} = 0.201}$

$$CMRR = \left|\frac{A_d}{A_{cm}}\right| = \frac{83.12}{0.201} = 413.53$$

$CMRR = 413.53$

$CMRR_{dB} = 20log_{10}(413.53) = 52.33dB$

$\boldsymbol{CMRR_{dB} = 52.33dB}$

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

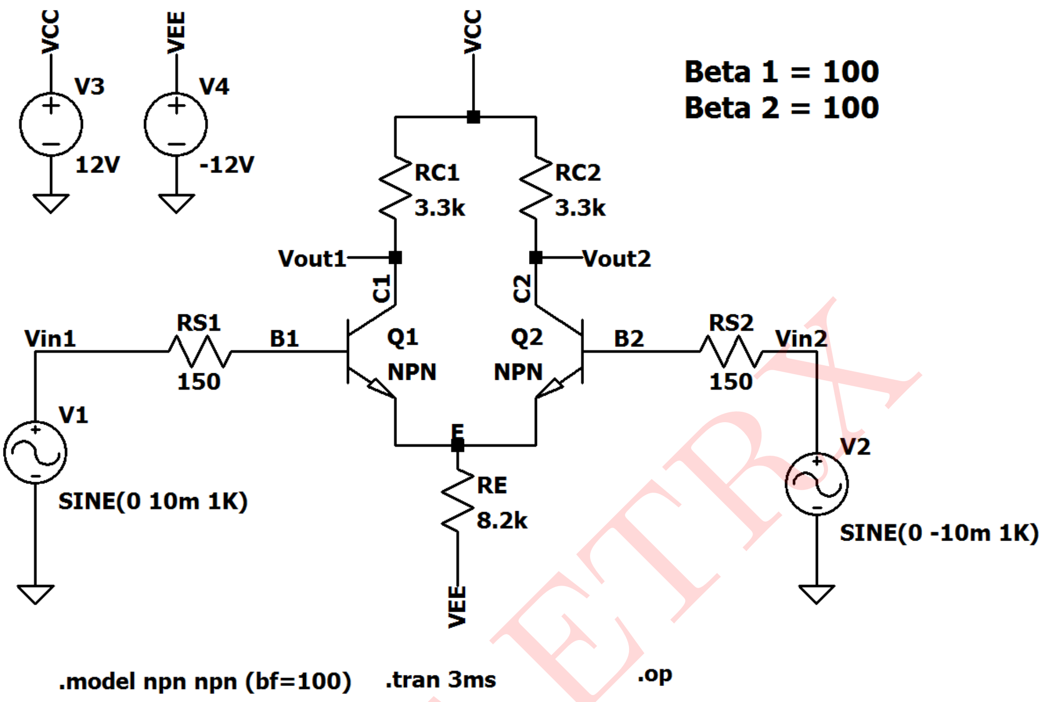

Figure 3: Circuit Schematic 1

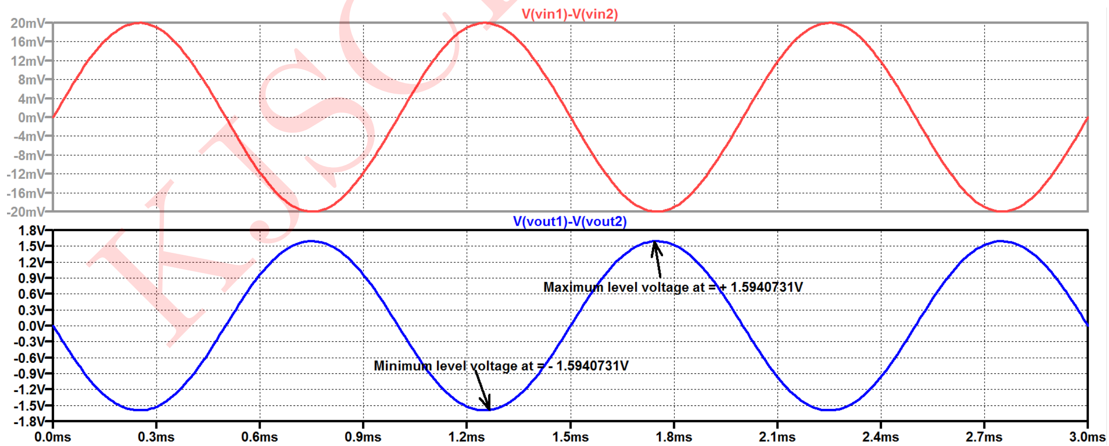

Figure 4: Input and Output Waveforms

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{C_1}, I_{C_2}	$0.68mA$, $0.68mA$	$0.68mA$, $0.68mA$
V_{C_1}, V_{C_2}	$9.76V$, $9.76V$	$9.76V$, $9.76V$
V_{CE_1}, V_{CE_2}	$10.6V$, $10.6V$	$10.6V$, $10.6V$
$\|A_d\|$	83.12	79.71
A_{cm}	0.201	–
$CMRR_{dB}$	52.33	–

Table 1: Numerical 1

Numerical 2:
For the differential shown in figure 5 Find, a) Name of the circuit b) Current through R_{D_1}, R_{D_2}, R_{S_1}, R_{S_2} c) V_{D_1}, V_{D_2}, V_{GS_1}, V_{GS_2} d) Differential voltage gain e) Common mode gain f) CMRR in dB
Assume: $V_{TN_1} = V_{TN_2} = 1V$, $k_{n_1} = k_{n_2} = 50mA/V^2$

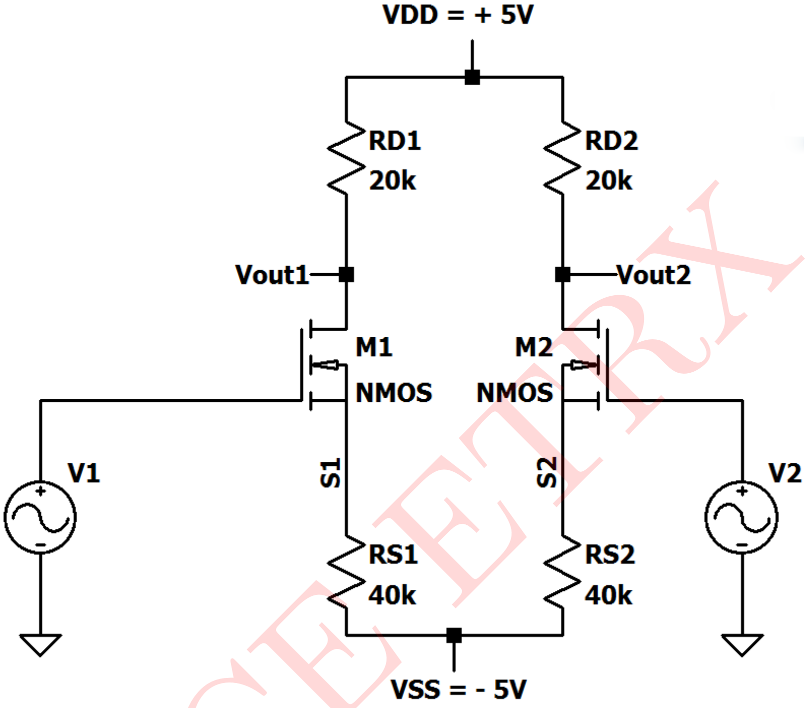

Figure 5: Circuit 2

Solution:

Above circuit 2 is a Dual Input Balanced Output(DIBO) differential amplifier

DC Analysis:-

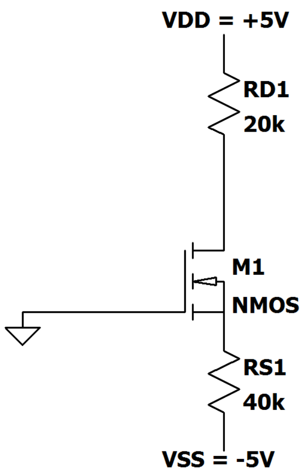

Figure 6: DC Equivalent Circuit

Apply KVL to the Gate-Source loop:-

$V_{GS} = V_{SS} - I_D R_S$

$V_{GS} = 5 - I_D(40k)$ ....(1)

$I_D = k_n(V_{GS} - V_{TN})^2$

$I_D = 50 \times 10^{-6}(V_{GS} - 1)^2$ ....(2)

Putting 2 in 1, we get

$V_{GS} = 5 - (40k \times 50 \times 10^{-6}(V_{GS} - 1)^2)$

$V_{GS} = 5 - 2({V_{GS}}^2 + 1 - 2V_{GS})$

$V_{GS} = 5 - 2{V_{GS}}^2 - 2 + 4V_{GS}$

$2{V_{GS}}^2 - 3V_{GS} - 3 = 0$

$V_{GS} = 2.18V$

or

$V_{GS} = -0.686V$[We reject this values as, $(V_{GS} > V_{TN})$]

$\therefore \boldsymbol{V_{GS} = 2.18V}$

From 1,

$$I_D = \frac{5 - V_{GS}}{40k} = \frac{5 - 2.18}{40k} = 70.5\mu A$$

$\boldsymbol{I_D = 70.5\mu A}$

Applying KVL to the Drain-Source loop:-

$V_{DD} - I_D R_{D_1} - V_{DS} - I_D R_{S_1} - V_{GS} = 0$

$V_{DS_1} = V_{DS_2} - V_{DD} - I_D(R_{D_1} + R_{S_1}) - V_{GS}$

$$V_{DS_1} = 5 - (-5) - \frac{70.5}{10^6}(20k + 40k) = 5.77V$$

$\boldsymbol{V_{DS_1} = 5.77V}$

$V_{D_1} = V_{DD} - I_D R_{D_1} = 5 - (70.5\mu A \times 20k) = 3.59V$

$\boldsymbol{V_{D_1} = V_{D_2} = 3.59V}$

$g_{m_1} = g_{m_2} = g_m = 2k_n(V_{GS} - V_{TN}) = 2 \times 50 \times 10^{-6}(2.18 - 1) = 1.18 \times 10^{-4}A/V$

$\boldsymbol{g_{m_1} = g_{m_2} = g_m = 1.18 \times 10^{-4}A/V}$

$|A_d| = g_m R_D = 1.18 \times 10^{-4} \times 20 \times 10^3 = 2.36$

$\boldsymbol{|A_d| = 2.36}$

$$A_{cm} = \left| \frac{g_m R_D}{1 + g_m R_S} \right| = \left| \frac{1.18 \times 10^{-4} \times 20k}{1 + (1.18 \times 10^{-4} \times 40k)} \right| = 0.413$$

$\boldsymbol{A_{cm} = 0.413}$

$$CMRR = \left| \frac{A_d}{A_{cm}} \right| = \frac{2.36}{0.413} = 5.714$$

$CMRR = 5.714$

$CMRR_{dB} = 20log_{10}(5.714) = 15.14dB$

$\boldsymbol{CMRR_{dB} = 15.14dB}$

SIMULATED RESULTS:

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

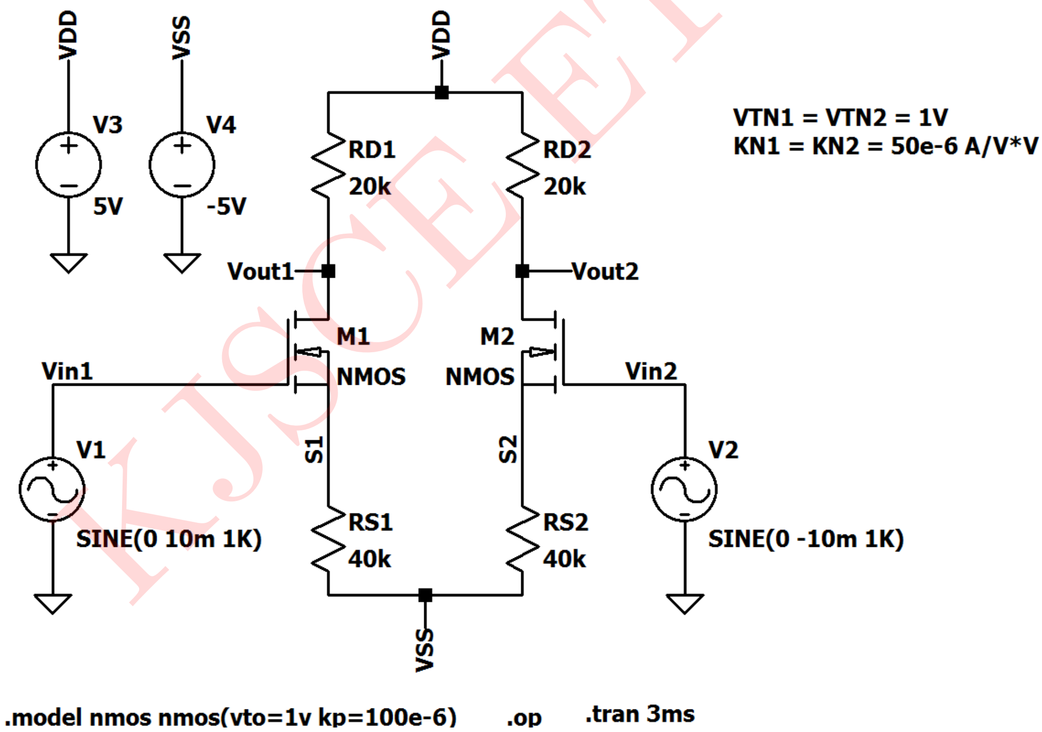

Figure 7: Circuit Schematic 2

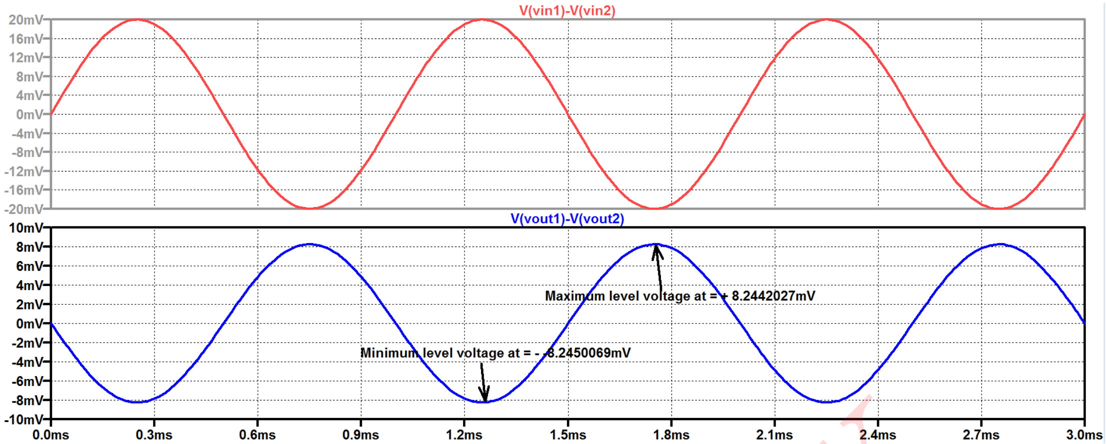

Figure 8: Input and Output Waveforms

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{D_1}, I_{D_2}	$70.5\mu A$, $70.5\mu A$	$70.4\mu A$, $70.4\mu A$
V_{D_1}, V_{D_2}	$3.59V$, $3.59V$	$3.59V$, $3.59V$
V_{DS_1}, V_{DS_2}	$5.77V$, $5.77V$	$5.77V$, $5.77V$
$\|A_d\|$	2.36	2.41
A_{cm}	0.413	–
$CMRR_{dB}$	15.14	–

Table 2: Numerical 2

Numerical 3:

For the differential amplifier shown in figure 9, Find:- a) DC values of V_{out_1}, V_{out_2} b) Double ended output gain(A_d).

Given: $\beta_1 = \beta_2 = 100$

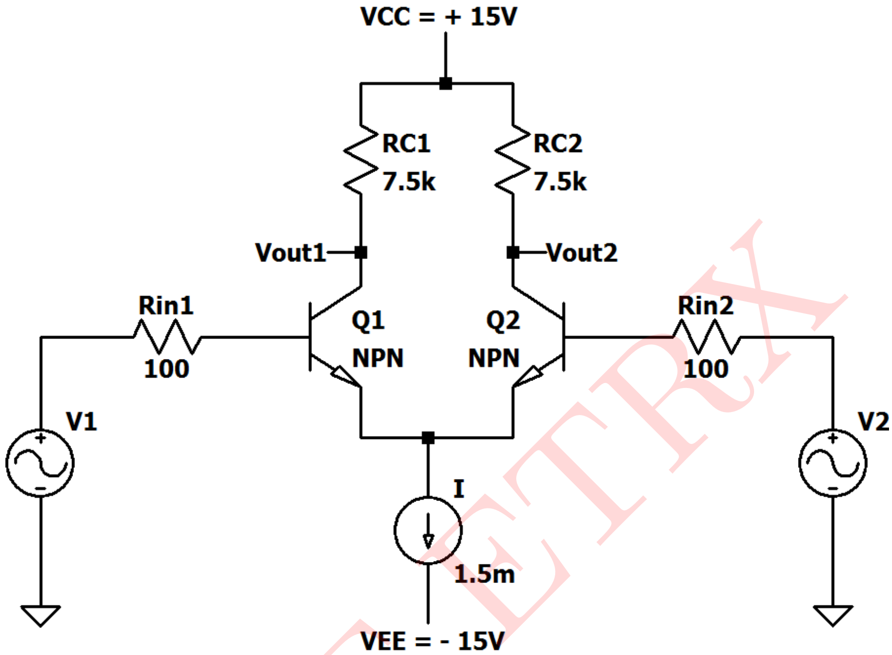

Figure 9: Circuit 3

Solution:

$I_{E_1} = I_{E_2} = \dfrac{I}{2} = \dfrac{1.5mA}{2} = 0.75mA$

Let, $I_{C_1} \approx I_{E_1}$ & $I_{C_2} \approx I_{E_2}$

$\therefore \boldsymbol{I_{C_1} = I_{C_2} = 0.75mA}$

DC value of $V_{out_1} = V_{CC} - I_{C_1}R_{C_1} = 15 - (0.75mA \times 7.5k) = 9.375V$

$\therefore \boldsymbol{V_{out_1} = V_{C_1} = 9.375V}$ $\quad [\because V_{C_1} = V_{out_1}]$

DC value of $V_{out_2} = V_{CC} - I_{C_2}R_{C_2} = 15 - (0.75mA \times 7.5k) = 9.375V$

$\therefore \boldsymbol{V_{out_2} = V_{C_2} = 9.375V}$ $\quad [\because V_{C_2} = V_{out_2}]$

$r_\pi = \dfrac{\beta V_T}{I_C} = \dfrac{100 \times 26mV}{0.75mA} = 3.467k\Omega$

$\boldsymbol{r_\pi = 3.467k\Omega}$

$$A_d = \frac{V_{out_1} - V_{out_2}}{V_1 - V_2} = \frac{-\beta R_C}{r_\pi + R_{in}}$$
$$A_d = \frac{-100 \times 7.5k}{3.467k + 100} = -210.26$$
$$\boldsymbol{A_d = -120.26}$$

SIMULATED RESULTS:

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

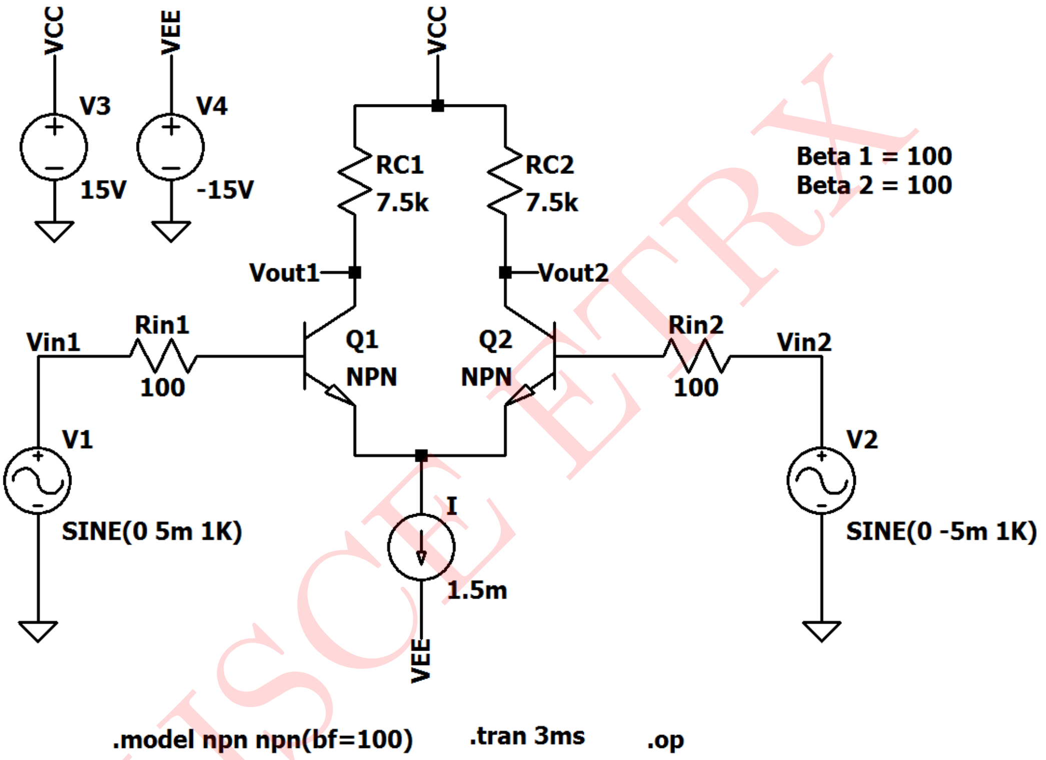

Figure 10: Circuit Schematic 3

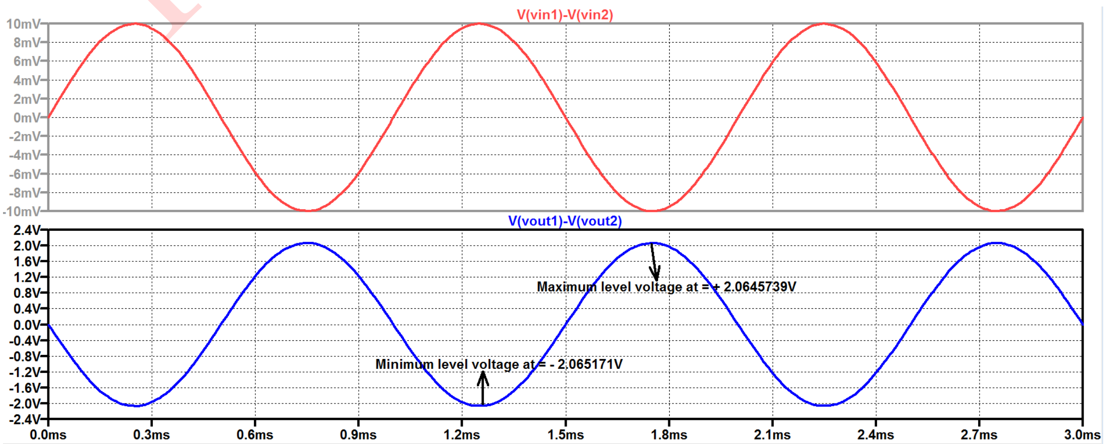

Figure 11: Input and Output waveforms

Comparison of Theoretical and Simulated Values:

Parameters	Theoretical	Simulated
I_{C_1}, I_{C_2}	$0.75mA$, $0.75mA$	$0.74mA$, $0.74mA$
V_{C_1}, V_{C_2}	$9.375V$, $9.375V$	$9.43V$, $9.43V$
$\|A_d\|$	210.26	206.49

Table 3: Numerical 3

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