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

Numerical 1

For each transistor shown in figure 1, the parameters are $\beta_1 = \beta_2 = 100$ & $V_A = \infty$

a) Determine Q point values

b) Determine the overall small signal voltage gain

c) Determine the input and output resistance R_{is} and R_o

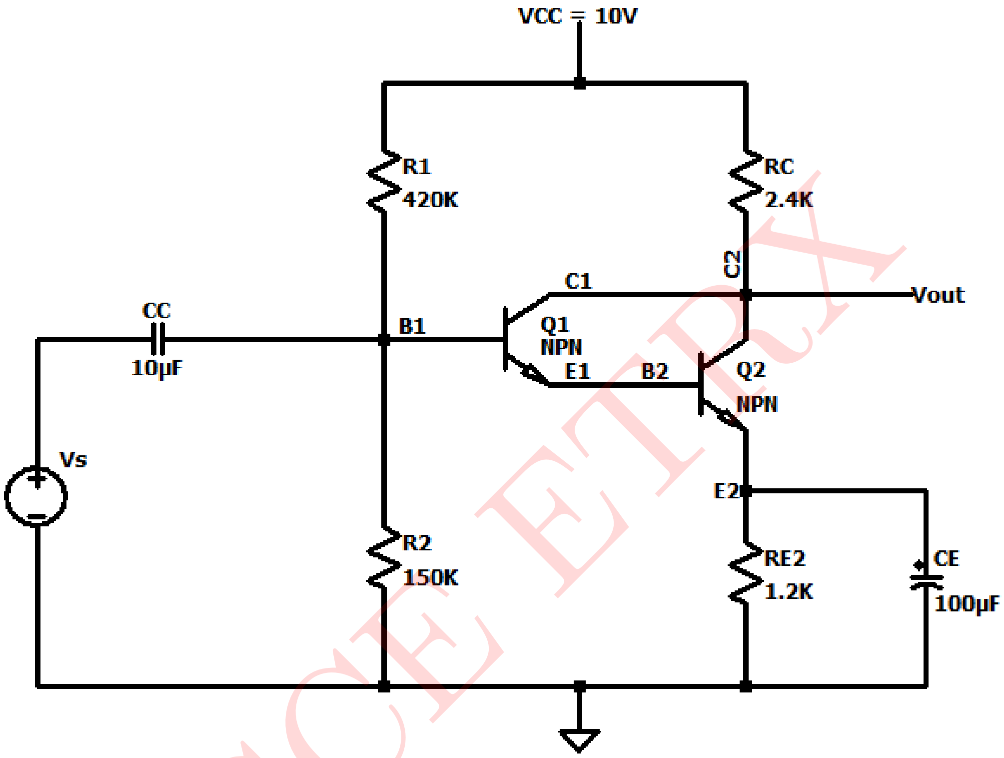

Figure 1: Circuit for Numerical 1

Solution:

DC Anaylsis:

During DC analysis, capacitors become open circuit.

The given circuit is a Darlington pair.

The DC equivalent circuit is shown in figure 2

$R_{th} = R_1 \parallel R_2 = 420k \parallel 150k$

$\mathbf{R_{th} = 110.50k\Omega}$

$$V_{th} = \frac{R_2}{R_1 + R_2} \times V_{CC} = \frac{150k}{150k + 420k} \times 10V$$

$\mathbf{V_{th} = 2.6V}$

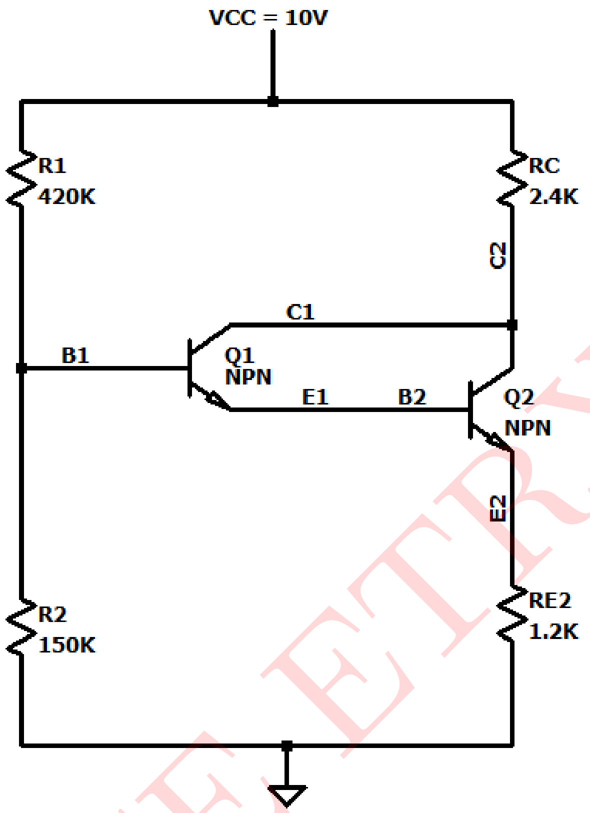

Figure 2: DC Equivalent Circuit

Applying KVL to the base loop for figure 2 we get,

$V_{th} = I_B R_B + V_{BE} + I_E R_E = 0$

$V_{th} - I_{B_1} R_{th} - V_{BE} - (\beta_1 \beta_2) I_{B_1} R_E = 0$

$I_{B_1} = \dfrac{V_{th} - V_{BE}}{R_{th} + (\beta_D) R_E}$

$V_{BE} = V_{BE_1} + V_{BE_2}$

$V_{BE} = 2V_{BE_1} = 2 \times 0.7V$

$\mathbf{V_{BE} = 1.4V}$

$I_{B_1} = \dfrac{2.63 - 1.4}{110.523k + \beta_D \times 1.2k}$

$\mathbf{I_{B_1} = 1.016 \times 10^{-7} A}$

$I_{C_1} = \beta_1 \times I_{B_1} = 100 \times 1.016 \times 10^{-7} A$

$\mathbf{I_{C_1} = 10.16 \mu A}$

Now, $I_{E_1} = (\beta_1 + 1) \times I_{B_1} = 101 \times 1.016 \times 10^{-7} A$

$\mathbf{I_{E_1} = 10.2616 \mu A}$

$I_{E_2} = \beta_D \times I_{B_1} = 100 \times 100 \times 1.016 \times 10^{-7}$

$\mathbf{I_{E_2} = 1.016mA}$

$I_{C_2} = \beta_2 \times I_{B_2} = 100 \times 10.2616 \mu A$

$\mathbf{I_{C_2} = 1.026mA}$

$V_{C_2} = V_{CC} - I_{C_2} R_C = 10 - 1.026mA \times 2.4k$

$\mathbf{V_{C_2} = 7.53V}$

$V_{E_2} = I_{E_2} R_{E_2} = 1.016mA \times 1.2k\Omega$

$\mathbf{V_{E_2} = 1.2V}$

Calculation of small signal parameters:

$$g_{m_1} = \frac{I_{CQ_1}}{V_T} = \frac{10.16\mu A}{0.026V}$$

$\mathbf{g_{m_1} = 390.769 \mu A/V}$

$$r_{\pi_1} = \frac{\beta_1 V_T}{I_{CQ_1}} = \frac{20 \times 26mV}{10.16\mu A}$$

$\mathbf{r_{\pi_1} = 225.905k\Omega}$

$$g_{m_2} = \frac{I_{CQ_2}}{V_T} = \frac{1.026mA}{0.026}$$

$\mathbf{g_{m_2} = 39.461mA/V}$

$$r_{\pi_2} = \frac{\beta_2 V_T}{I_{CQ_2}} = \frac{100 \times 26mV}{1.026mA}$$

$\mathbf{r_{\pi_2} = 2.534k\Omega}$

AC Analysis:

Mid band small signal equivalent circuit is shown in figure 4

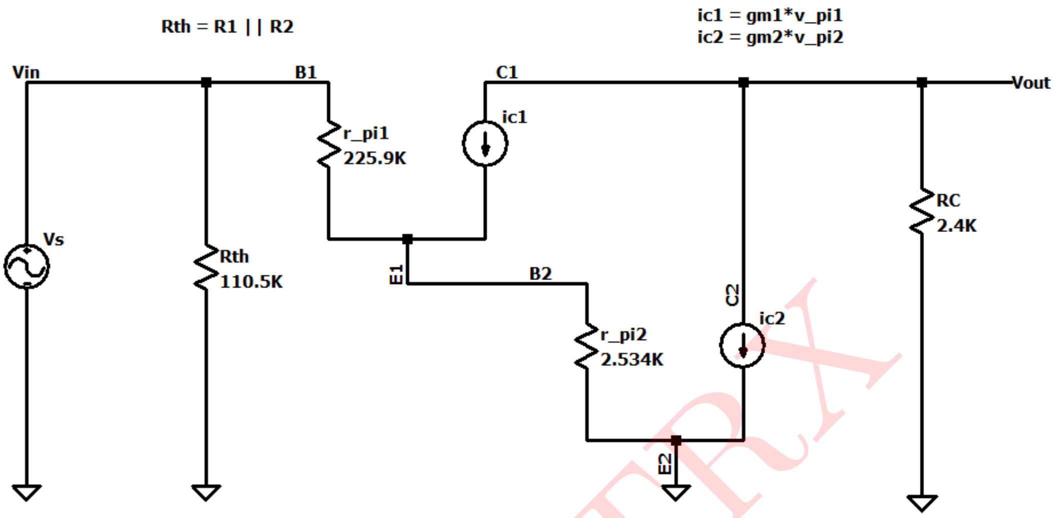

Figure 3: Small Signal Equivalent Circuit

$Z_{i_1} = r_{\pi_1} + (1 + \beta)r_{\pi_2}$

$Z_{i_1} = 225.905k + 101 \times 2.534k$

$\mathbf{Z_{i_1} = 481.839k\Omega}$

Input Impedance of first stage:

$Z_i = R_B \parallel Z_{i_1}$

$Z_i = 110.5k \parallel 481.839k$

$\mathbf{Z_i = 89.89k\Omega}$

$$Z_{o_1} = \frac{R_B + r_{\pi_1}}{1 + \beta_1}$$

$$Z_{o_1} = \frac{110.5k + 225.905k}{101}$$

$\mathbf{Z_{o_1} = 3.33k\Omega}$

$$Z_{o_2} = \frac{Z_{o_1} + r_{\pi_2}}{1 + \beta_2} = \frac{3.33k + 2.534k}{101}$$

$\mathbf{Z_{o_2} = 0.05k\Omega}$

Output Impedance of second stage:

$Z_o = Z_{o_2} \parallel R_C$

$Z_o = 0.05k \parallel 2.4k$

$\mathbf{Z_o = 0.048k\Omega}$

Calculation of current gain of first stage:

$A_{i_1} = \frac{I_{C_1}}{I_{B_1}} = \frac{\beta_1 I_{B_1}}{I_{B_1}}$

$A_{i_1} = \beta_1$

$\mathbf{A_{i_1} = 100}$

Calculation of current gain of second stage:

$A_{i_2} = \frac{I_{C_2}}{I_{B_2}} = \frac{\beta_2 I_{B_2}}{I_{B_2}}$

$A_{i_2} = \beta_2$

$\mathbf{A_{i_2} = 100}$

$A_{it} = A_{i_1} \times A_{i_2} = 100 \times 100$

$\mathbf{A_{it} = 10000}$

Overall current gain:

$A_{i_s} = \frac{I_o}{I_i}$

$A_{i_s} = \frac{I_o}{I_{B_2}} \times \frac{I_{B_2}}{I_{B_1}} \times \frac{I_{B_1}}{I_i}$

$A_{i_s} = A_{i_2} \times A_{i_1} \times \frac{I_B}{I_i} \qquad (I_{B_2} = I_{E_1} \ \& \ I_{E_1} = I_{C_1})$

$A_{i_s} = A_{i_2} \times A_{i_1} \times \frac{R_{th}}{R_{th} + Z_{i_2}} = 100 \times 100 \times \frac{110.5k}{110.5k + 481.839k}$

$\mathbf{A_{i_s} = 1865.485}$

Calculation of voltage gain:

<u>For Stage-1:</u>

$A_{V_1} = \frac{I_{E_1}}{I_{B_1}} \times \frac{r_{\pi 2}}{Z_{i_1}}$

$A_{V_1} = 101 \times \frac{2.534k}{767.672k}$

$\mathbf{A_{V_1} = 0.330}$

<u>For Stage-2:</u>

$A_{V_2} = \frac{I_{C_2}}{I_{B_2}} \times \frac{R_C}{r_{\pi 2}}$

$A_{V_2} = A_{i_2} \times \frac{2.4k}{2.534k}$

$\mathbf{A_{V_2} = 94.713}$

The overall voltage gain $\mathbf{A_{V_T}}$:

$A_{V_T} = A_{V_1} \times A_{V_2} = 0.330 \times 94.713$

$\mathbf{A_{V_T} = 31.255}$

Calculation of output voltage:

$V_o = A_{V_T} \times V_s = 31.255 \times 40mV$

$\mathbf{V_o = 1.250V}$

SIMULATED RESULTS:

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

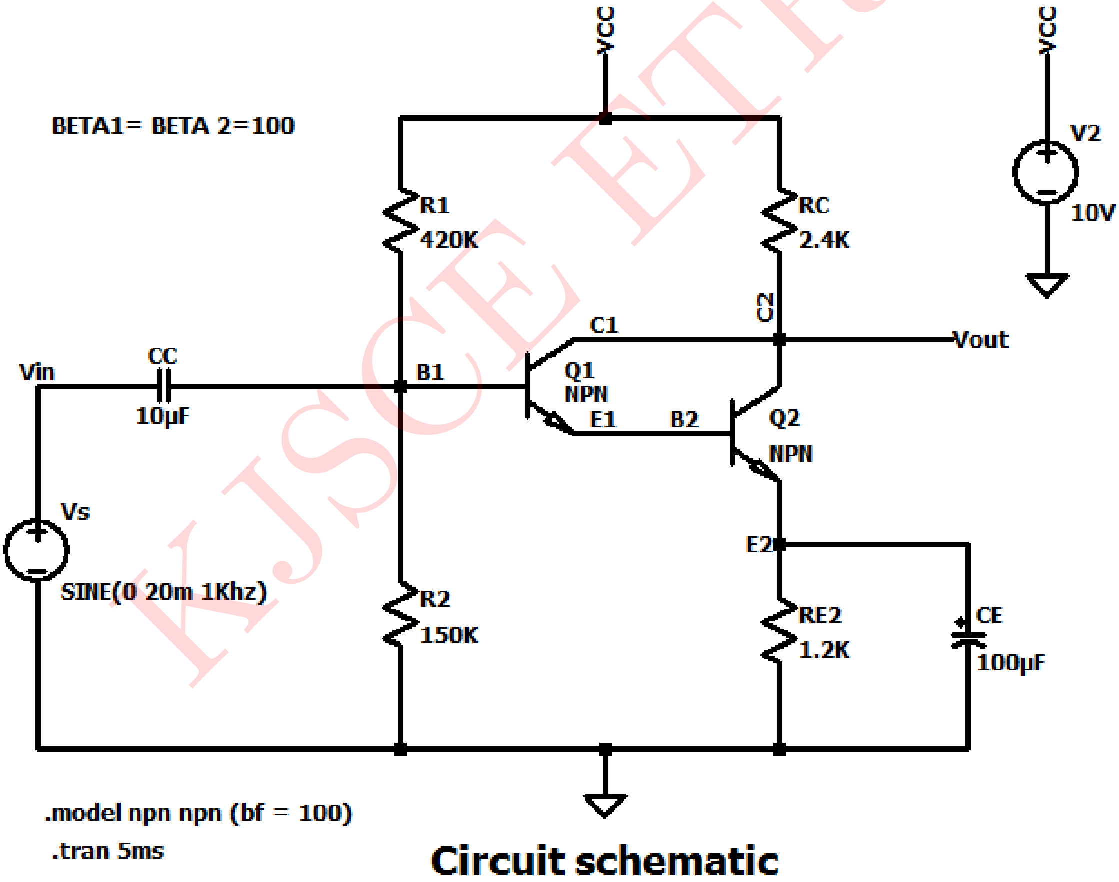

Figure 4: Circuit Schematics: Results

Output Waveforms:

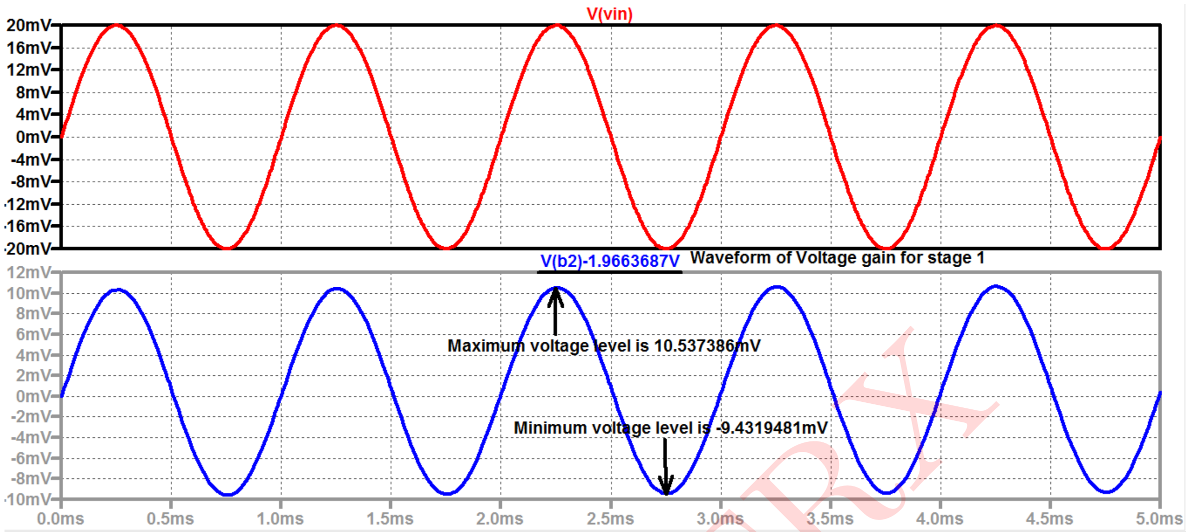

Figure 5: Input and Output Waveforms for 1^{st} Stage

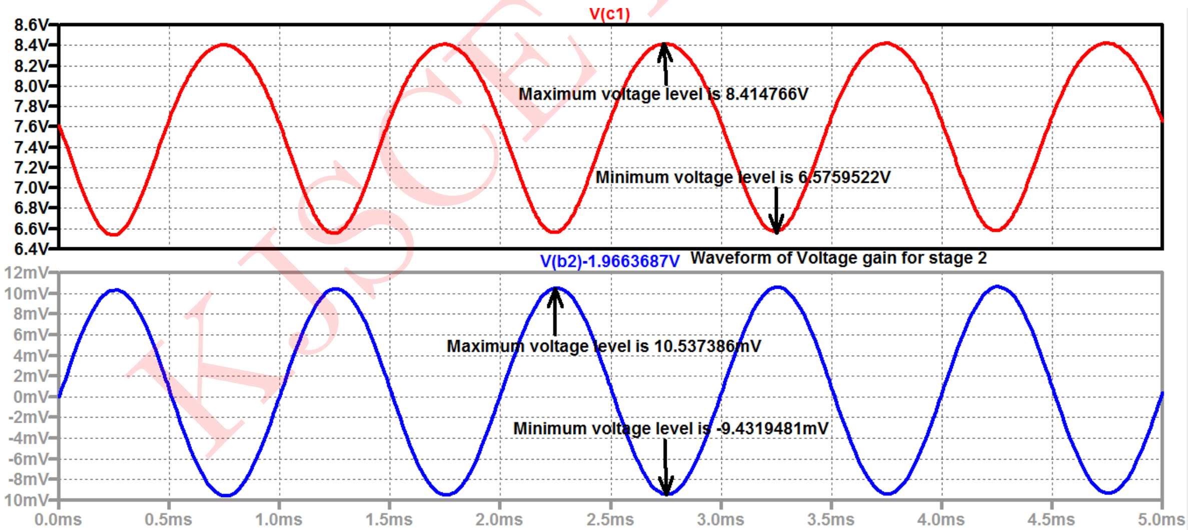

Figure 6: Input and Output Waveforms for 2^{nd} Stage

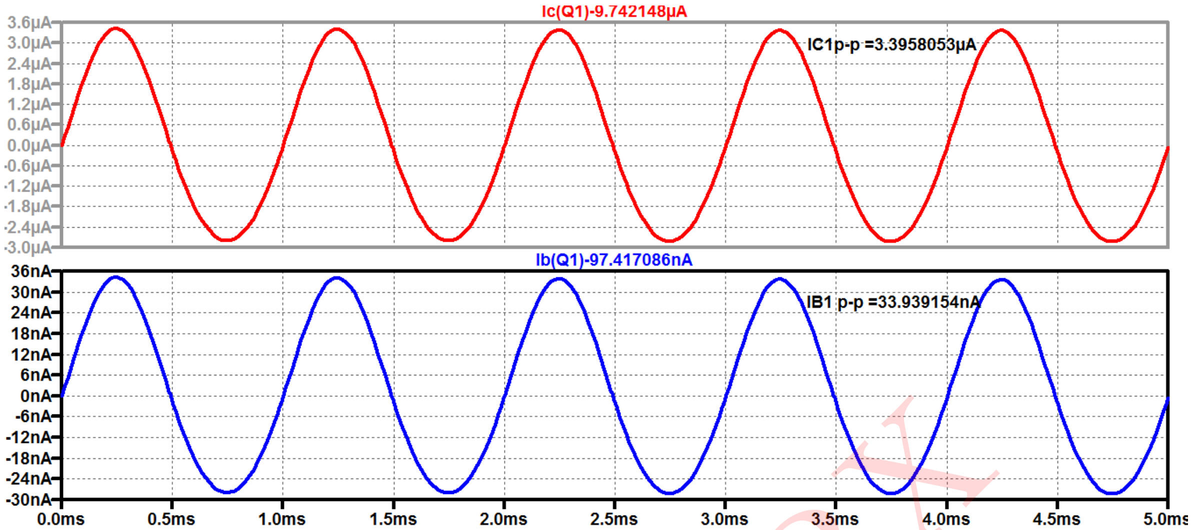

Figure 7: Current Waveforms for the 1^{st} Stage

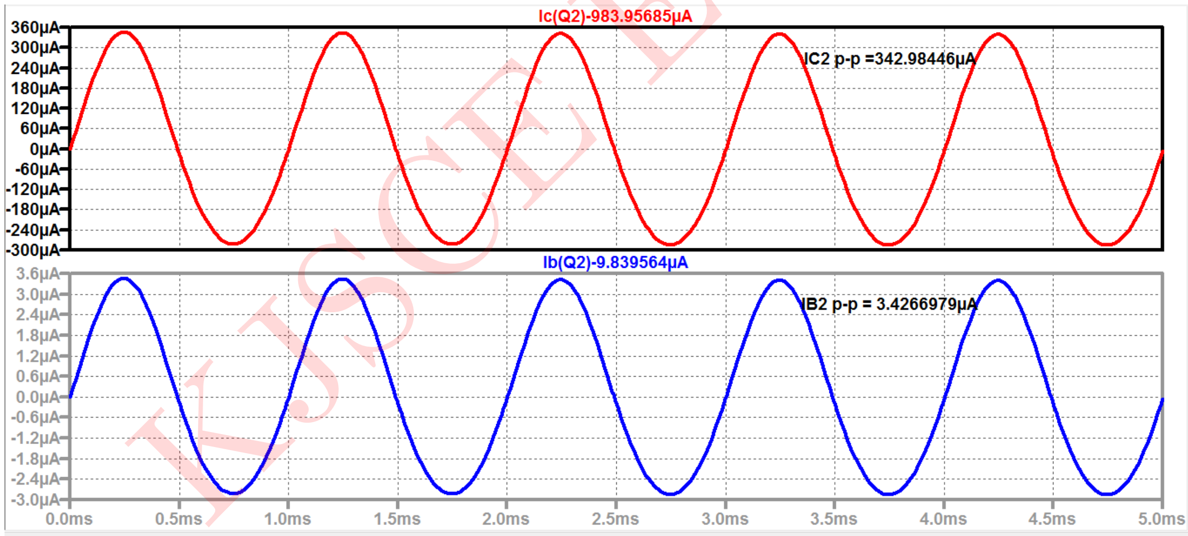

Figure 8: Current Waveforms for the 2^{nd} Stage

Comparison between theoretical and simulated values is given below:

Parameters	**Simulated Values**	**Theoretical Values**
Stage-1: I_{B_1}	$0.97 \times 10^{-7}A$	$1.016 \times 10^{-7}A$
Stage-1: I_{C_1}	$9.742\mu A$	$10.2616\mu A$
Stage-1: I_{E_1}	$9.742\mu A$	$10.2616\mu A$
Stage-2: I_{B_2}	$9.83\mu A$	$10.2616\mu A$
Stage-2: I_{C_2}	$0.98mA$	$1.026mA$
Stage-2: I_{E_2}	$0.98mA$	$1.016mA$
Voltage gain for first stage A_{V_1}	0.41	0.330
Voltage gain for second stage A_{V_2}	92.18	94.712
Overall voltage gain A_{V_T}	37.7	31.255
Current gain for first stage A_{i_1}	99.9	100
Voltage gain for second stage A_{i_2}	99.88	100
Overall current gain A_{i_t}	9978.01	10000
Input Impedance	–	$89.89k\Omega$
Output Impedance	–	$0.048k\Omega$
Output voltage	$1.36V$	$1.250V$

Table 1: Numerical 1

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