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ELECTRONIC CIRCUITS
Darlington Amplifier

Numerical 1: A two stage circuit is shownin figure 1. It's BJT parameters are $\beta_1 = \beta_2 = 100$, $V_{BE_1} = V_{BE_2} = 0.7$ V. Calculate 1^{st} and 2^{nd} stage DC parameters, current gain, voltage gain, overall current gain and voltage gain, input impedance, output impedance and output voltage. Given: $\beta_1 = \beta_2 = 100$

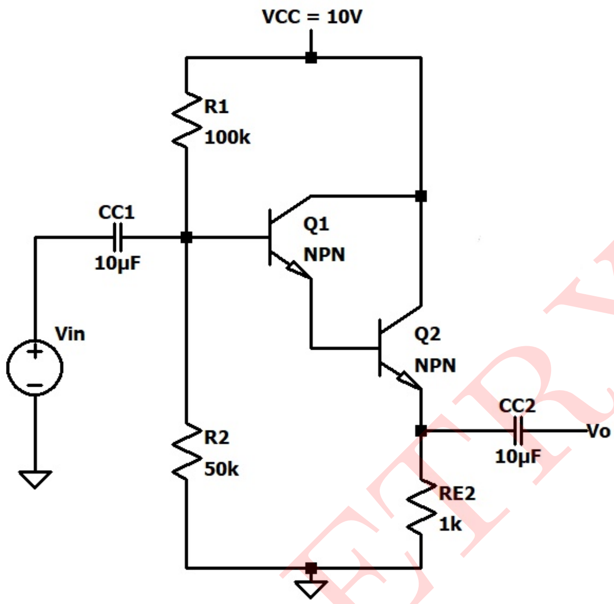

Figure 1: Circuit 1

Solution:

The given circuit 1 is a Darlington pair amplifier employing npn-BJT.

For DC biasing, the capacitors acts as an open source.

DC Analysis:

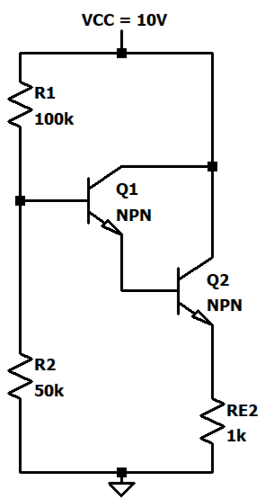

Figure 2: DC Equivalent circuit

$$V_{th} = \frac{V_{CC} \times R_2}{R_1 + R_2}$$

$$V_{th} = \frac{10 \times 50 \times 10^3}{100 \times 10^3 + 50 \times 10^3} = \mathbf{3.33\ V}$$

$$R_{th} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{th} = \frac{100 \times 10^3 \times 50 \times 10^3}{100 \times 10^3 + 50 \times 10^3} = \mathbf{33.33\ k\Omega}$$

Thevenin's Equivalent Circuit:

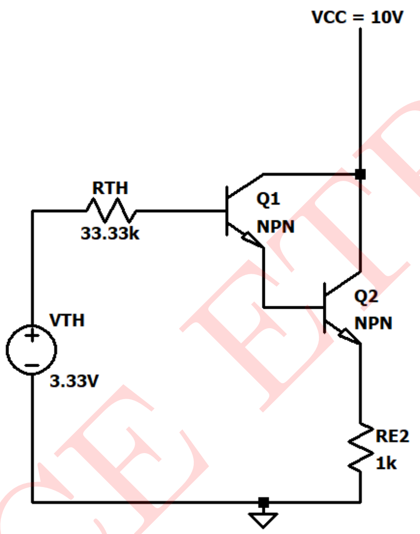

Figure 3: Thevenin's Equivalent circuit

Aplying KVL to the base emitter loop,

$$V_{th} - R_{th}I_{B_1} - V_{BE_1} - V_{BE_2} - I_{E_2}R_{E_2} = 0$$

$$R_{th}I_{B_1} + (1+\beta_1)(1+\beta_2)I_{B_1}R_{E_2} = V_{th} - V_{BE_1} - V_{BE_2}$$

$$...(\because I_{E_2} = (1+\beta_2)I_{B_2},\ I_{B_2} = I_{E_1}\ \&\ I_{E_1} = (1+\beta_1)I_{B_1})$$

$$I_{B_1} = \frac{V_{th} - V_{BE_1} - V_{BE_2}}{R_{th} + (1+\beta_1)(1+\beta_2)R_{E_2}}$$

$$I_{B_1} = \frac{3.33 - 0.7 - 0.7}{33.33 \times 10^3 + (1+00)(1+100) \times 1 \times 10^3} = \mathbf{0.1889\ \mu A}$$

$$I_{C_1} = \beta_1 I_{B_1}$$

$$I_{C_1} = 100 \times 0.1889 \times 10^{-6} = \mathbf{0.01889\ mA}$$

$$I_{E_1} = (1+\beta_1)I_{B_1}$$

$$I_{E_1} = (1+100) \times 0.1889 \times 10^{-6} = \mathbf{0.01907\ mA}$$

Terminal B_2 is connected to terminal E_1,

$$I_{B_2} = I_{E_1} = \mathbf{0.01907\ mA}$$

$I_{C_2} = \beta_2 I_{B_2}$

$I_{C_2} = 100 \times 0.01907 \times 10^{-3} = \mathbf{1.9079\ mA}$

$I_{E_2} = (1+\beta_2) I_{B_2}$

$I_{E_2} = (1+100) \times 0.01907 \times 10^{-3} = \mathbf{1.9269\ mA}$

Voltage across terminal C_2 is given as,

$V_{C_2} = V_{CC} = \mathbf{10\ V}$

Voltage across terminal E_2 can be given as,

$V_{E_2} = I_{E_2} R_{E_2}$

$V_{E_2} = 1.9269 \times 10^{-3} \times 1 \times 10^{3} = \mathbf{1.9269\ V}$

AC Analysis:

Small signal parameters:

$$r_{\pi_1} = \frac{\beta_1 V_T}{I_{E_1}}$$

$$r_{\pi_1} = \frac{100 \times 26 \times 10^{-3}}{0.01907 \times 10^{-3}} = \mathbf{136.339\ k\Omega}$$

$$r_{\pi_2} = \frac{\beta_2 V_T}{I_{E_2}}$$

$$r_{\pi_2} = \frac{100 \times 26 \times 10^{-3}}{1.9269 \times 10^{-3}} = \mathbf{1.349\ k\Omega}$$

$$g_{m_1} = \frac{I_{C_1}}{V_T}$$

$$g_{m_1} = \frac{0.01889 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{0.726\ mA/V}$$

$$g_{m_2} = \frac{I_{C_2}}{V_T}$$

$$g_{m_2} = \frac{1.9079 \times 10^{-3}}{26 \times 10^{-3}} = \mathbf{73.38\ mA/V}$$

Small Signal Equivalent Circuit is shown in figure 4:

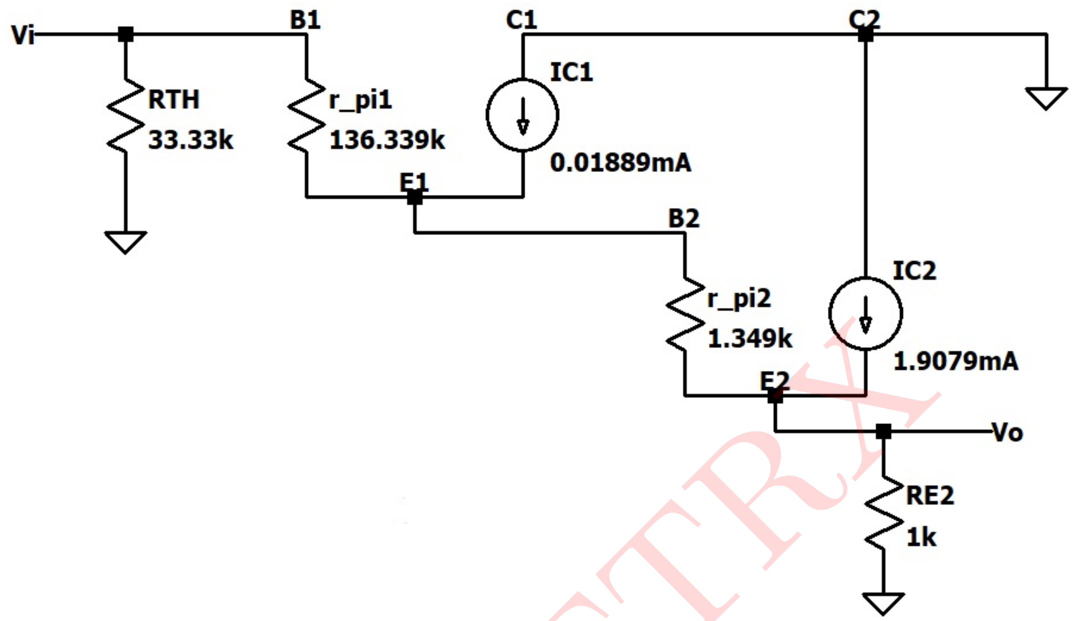

Figure 4: Small Signal Equivalent Circuit

Input impedance of stage 1:

$Z_{i_2} = r_{\pi_2} + (1+\beta_2)R_{E_2}$

$Z_{i_2} = 1.349 \times 10^3 + (1+100) \times 1 \times 10^3 = \mathbf{102.349\ k\Omega}$

$Z_{i_1} = (1+\beta_1)Z_{i_2} + r_{\pi_1}$

$Z_{i_1} = (1+100) \times 102.349 \times 10^3 + 136.339 \times 10^3 = \mathbf{10.4735\ M\Omega}$

$Z_i = (R_{th}\ ||\ Z_{i_1})$

$Z_i = (33.33 \times 10^3\ ||\ 10.4735 \times 10^6) = \mathbf{33.224\ k\Omega}$

Output impedance of stage 2:

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

$$Z_{o_1} = \frac{33.33 \times 10^3 + 136.339 \times 10^3}{1+100} = \mathbf{1.679\ k\Omega}$$

$$Z_{o_2} = \frac{Z_{o_1} + r_{\pi_2}}{1+\beta_2}$$

$$Z_{o_2} = \frac{1.679 \times 10^3 + 1.349 \times 10^3}{1+100} = \mathbf{29.98\ \Omega}$$

$Z_o = Z_{o_2}\ ||\ R_{E_2}$

$Z_o = 29.98\ ||\ 1 \times 10^3 = \mathbf{29.1073\ \Omega}$

Current gain of stage 1:

$$A_{i_1} = \frac{I_{E_1}}{I_{B_1}}$$

$$A_{i_1} = \frac{(1+\beta_1)I_{B_1}}{I_{B_1}}$$

$$A_{i_1} = (1+\beta_1) = \mathbf{101}$$

Current gain of stage 2:

$$A_{i_2} = \frac{I_{E_2}}{I_{B_2}}$$

$$A_{i_2} = \frac{(1+\beta_2)I_{B_2}}{I_{B_2}}$$

$$A_{i_2} = (1+\beta_2) = \mathbf{101}$$

Overall voltage gain:

$$A_{i_T} = A_{i_1} \times A_{i_2}$$

$$A_{i_T} = 101 \times 101 = \mathbf{10201}$$

Stage 1 Voltage gain:

$$A_{V_1} = \frac{V_{o_1}}{V_i}$$

$$A_{V_1} = \frac{I_{E_1} \times Z_{i_2}}{I_{B_1} \times Z_{i_1}}$$

$$A_{V_1} = A_{i_1} \times \frac{Z_{i_2}}{Z_{i_1}}$$

$$A_{V_1} = 101 \times \frac{102.349 \times 10^3}{10.4735 \times 10^6} = \mathbf{0.9869}$$

Stage 2 Voltage gain:

$$A_{V_2} = \frac{V_o}{V_{o_1}}$$

$$A_{V_2} = \frac{I_o \times R_E}{I_{B_2} \times Z_{i_2}}$$

$$A_{V_2} = A_{i_2} \times \frac{R_E}{Z_{i_2}}$$

$$A_{V_2} = 101 \times \frac{1 \times 10^3}{102.349 \times 10^3} = \mathbf{0.9868}$$

Overall voltage gain:

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

$$A_{V_T} = 0.9869 \times 0.9868 = \mathbf{0.9738}$$

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

$$A_{V_T} \text{ in dB} = 20\log_{10}(0.9738) = -\mathbf{0.2306\ dB}$$

Output Voltage:

$V_o = A_{V_T} V_i$

$V_o = 0.9738 \times 100 \times 10^{-3} = \mathbf{97.38\ mV}$

SIMULATED RESULTS:

Above circuit is simulated in LTspice. The results are presented below:

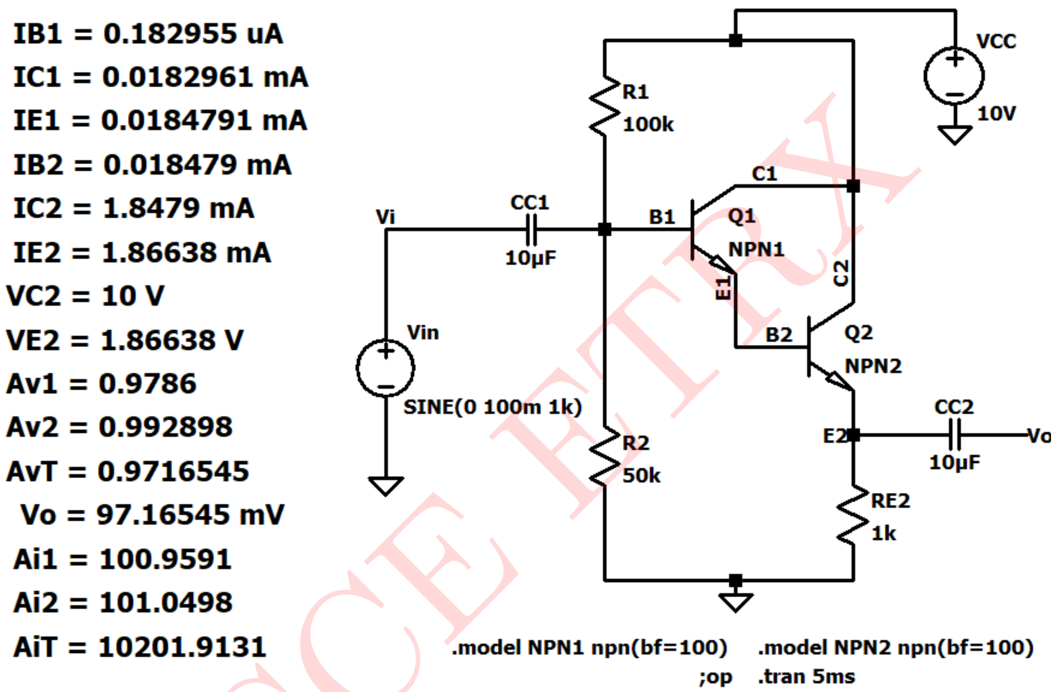

Figure 5: Circuit Schematic 1: Results

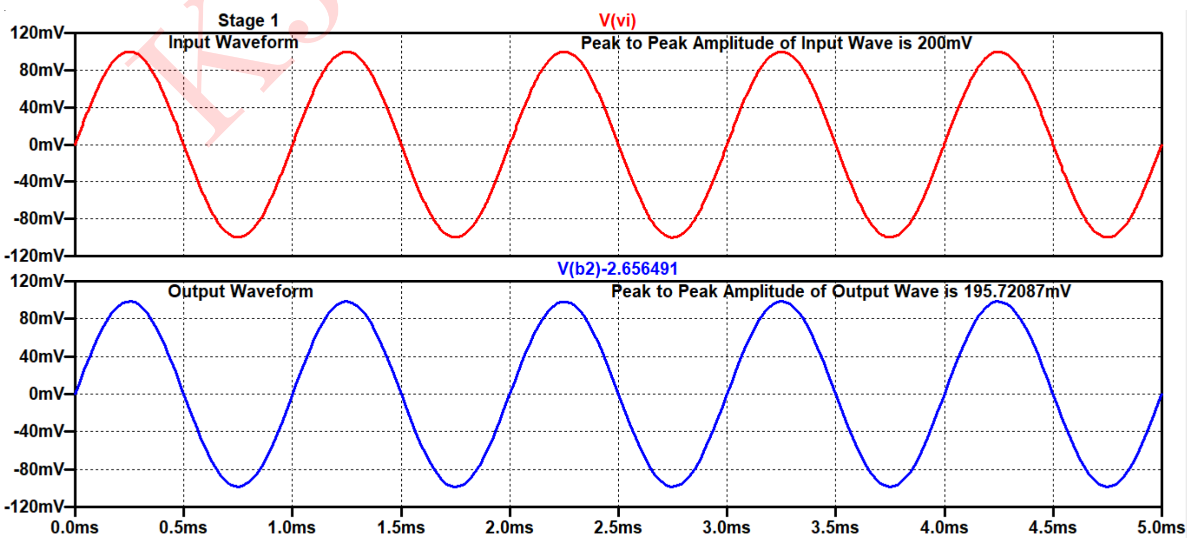

Figure 6: Input & Output waveforms for stage 1 voltage gain

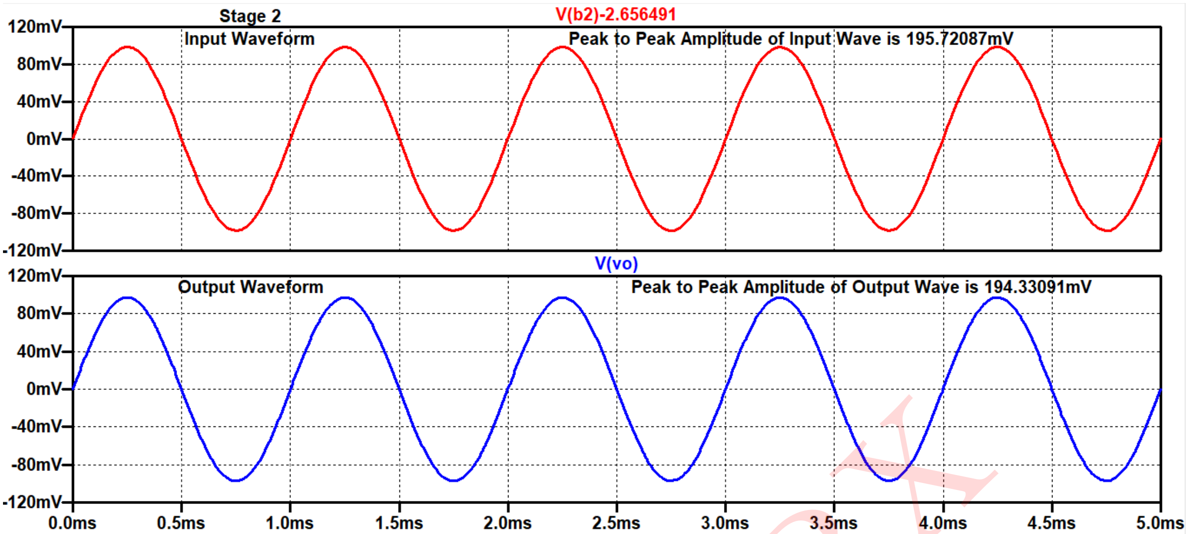

Figure 7: Input & Output waveforms for stage 2 voltage gain

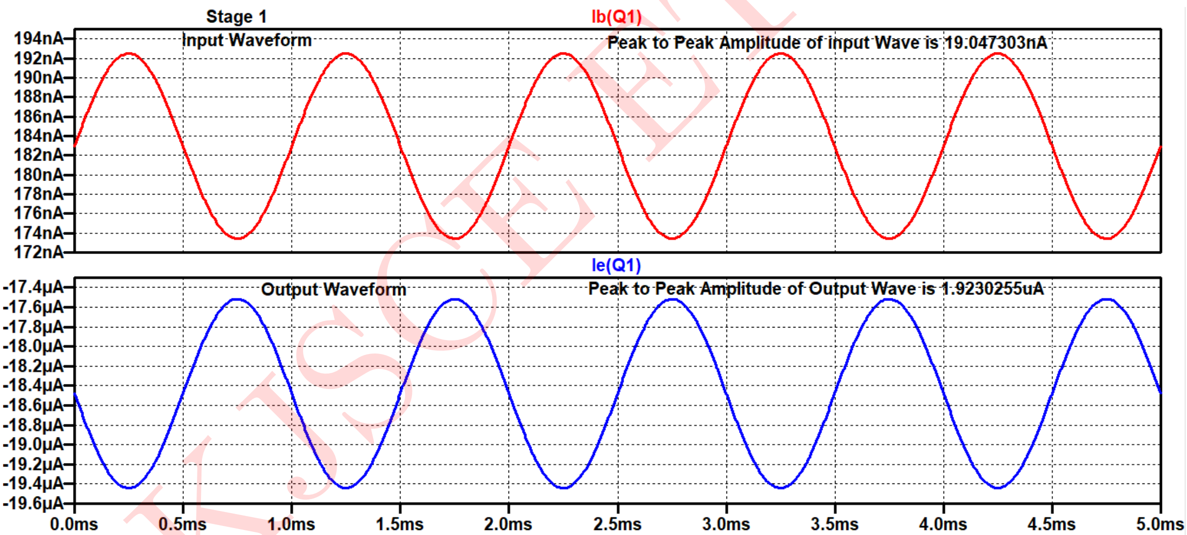

Figure 8: Input & Output waveforms for stage 1 current gain

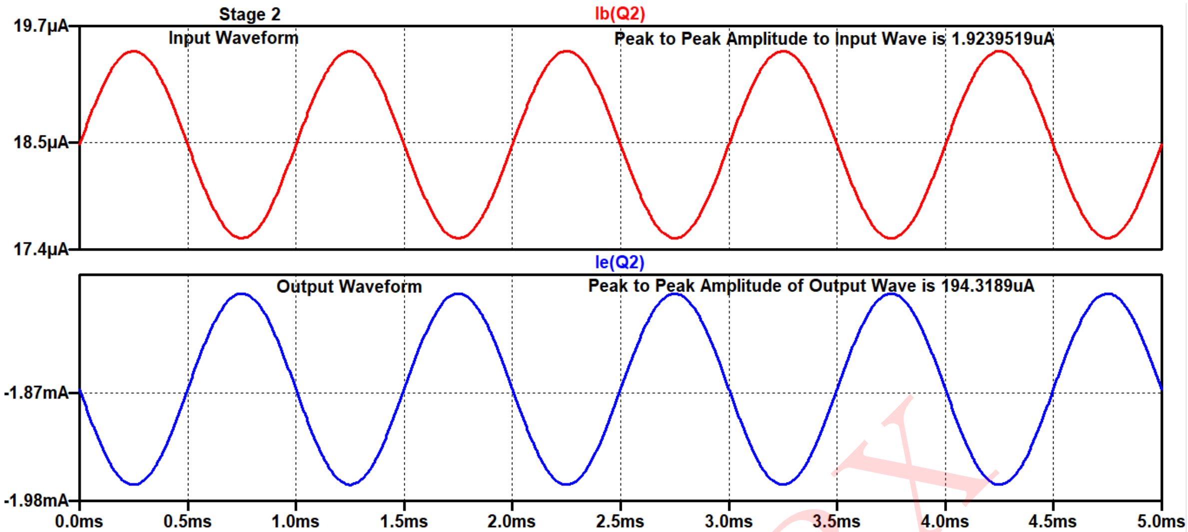

Figure 9: Input & Output waveforms for stage 2 current gain

Comparison of theoretical and simulated values:

Parameters	Theoretical Values	Simulated Values
I_{B_1}	0.1889 μA	0.1829 μA
I_{C_1}	0.01889 mA	0.01829 mA
I_{E_1}	0.01907 mA	0.01847 mA
I_{B_2}	0.01907 mA	0.01847 mA
I_{C_2}	1.9079 mA	1.8479 mA
I_{E_2}	1.9269 mA	1.8663 mA
V_{C_2}	10 V	10 V
V_{E_2}	1.9269 V	1.8663 V
Voltage gain of stage 1: A_{V_1}	0.9869	0.9786
Voltage gain of stage 2: A_{V_2}	0.9868	0.9928
Overall voltage gain: A_{VT} in dB	0.9738 dB	0.9716 dB
Current gain of stage 1: A_{i_1}	101	100.9591
Current gain of stage 2: A_{i_2}	101	101.0498
Overall Current gain: A_{i_T}	10201	10201.9131
Input impedance of stage 1	33.224 kΩ	–
Output impedance of stage 2	29.1073 Ω	–
Output Voltage	97.38 mV	97.1654 mV

Table 1: Numerical 1

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