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DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
DARLINGTON AMPLIFIER

16^{th} **July, 2020** **Numerical**

1. For the circuit shown in Figure 1, calculate the amplifier voltage gain, DC bias values, current gain, input and output impedance and output voltage
Given, $\beta_D = 600$ and $V_{BE} = 1.6$ V

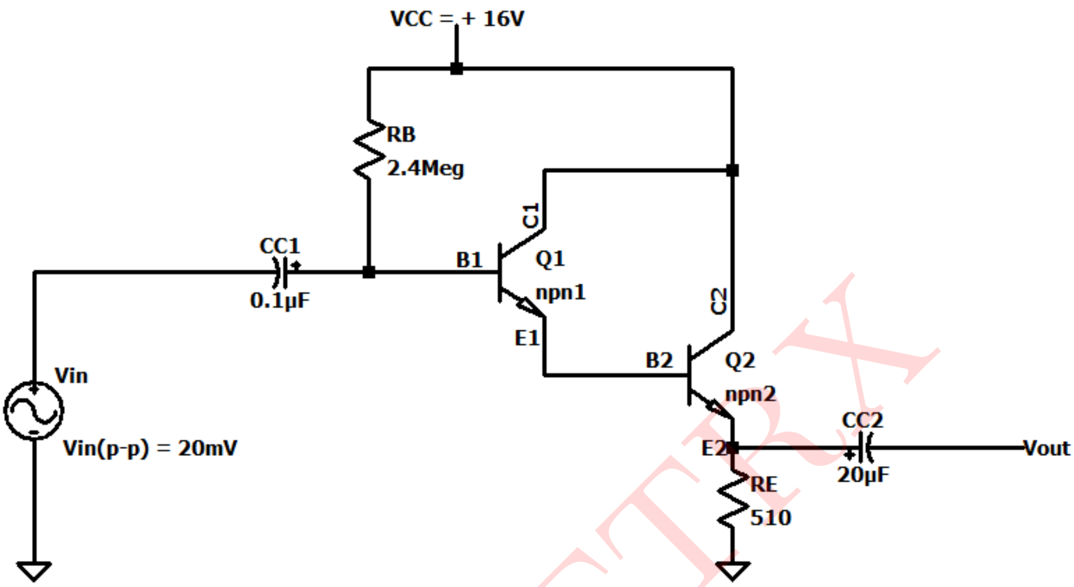

Figure 1: Circuit 1

Solution:
The above circuit is a common-collector Darlington amplifier

$\beta_D = 6000$

$\beta_D = \beta_1 \times \beta_2$

Considering $\beta_1 = \beta_2$, $\beta_D = \beta^2$ (where $\beta_1 = \beta_2 = \beta$)

$\therefore \beta = \beta_1 = \beta_2 = 77.459$

DC Analysis:
The capacitors act as open circuit.

$f = 0, \therefore X_C = \dfrac{1}{2\pi f C} = \infty$

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The DC equivalent circuit is shown in Figure 2

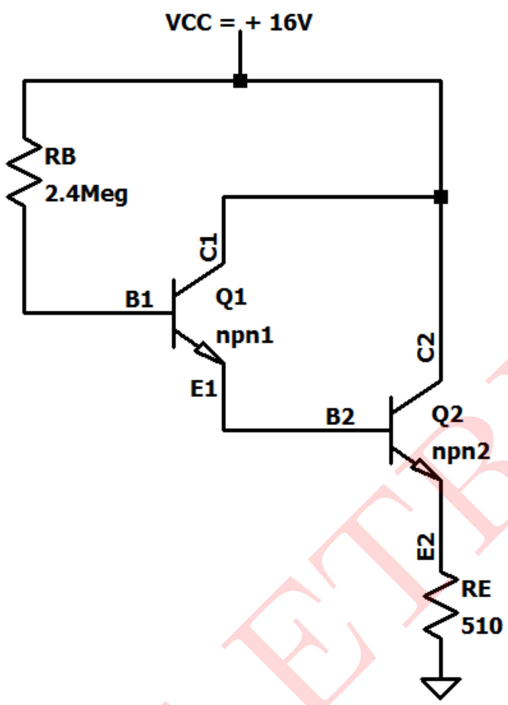

Figure 2: DC equivalent circuit

Applying KVL to the base-emitter loop

$V_{CC} - I_{B_1Q}R_B - V_{BE} - I_{E_2Q}R_E = 0$

For Darlington, $I_{E_2} = \beta_D \times I_{B_1}$

$V_{CC} - I_{B_1Q}R_B - V_{BE} - \beta_D I_{B_1} R_E = 0$

$\therefore I_{B_1Q} = \dfrac{V_{CC} - V_{BE}}{R_B + \beta_D R_E} = \dfrac{16 - 1.6}{2.4M + (6000 \times 510)}$

$\therefore I_{B_1Q} = \mathbf{2.63736\mu A}$

$I_{C_1} = \beta_1 I_{B_1Q} = 77.459 \times 2.63736 \times 10^{-6}$

$\therefore I_{C_1Q} = \mathbf{0.204287\ mA}$

$I_{E_1} = I_{C_1} + I_{B_1} = 0.204287\text{ mA} + 2.63736\ \mu\text{A}$

$\therefore I_{E_1} = \mathbf{0.206924\ mA}$

$I_{E_1} = I_{B_2} = \mathbf{0.206924\ mA}$

$I_{C_2} = \beta_2 I_{B_2} = 77.459 \times 0.206924 \times 10^{-3}$

$\therefore I_{C_2} = \mathbf{16.028\ mA}$

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$I_{E_2} = I_{C_2} + I_{B_2} = 16.028 \text{ mA} + 0.206924 \text{ mA}$

$\therefore I_{E_2} = \mathbf{16.235\ mA}$

$V_{E_2} = I_{E_2} R_E = 16.235 \times 10^{-3} \times 510$

$\therefore V_{E_2} = \mathbf{8.27987\ V}$

$V_{C_2} = V_{C_1} = \mathbf{16\ V}$

Small-signal parameters:

$$r_{\pi_1} = \frac{\beta_1 V_T}{I_{C_1}} = 9.858 \text{ k}\Omega$$
$$r_{\pi_2} = \frac{\beta_2 V_T}{I_{C_2}} = 125.6509\Omega$$

The mid-band AC equivalent circuit is shown in Figure 3

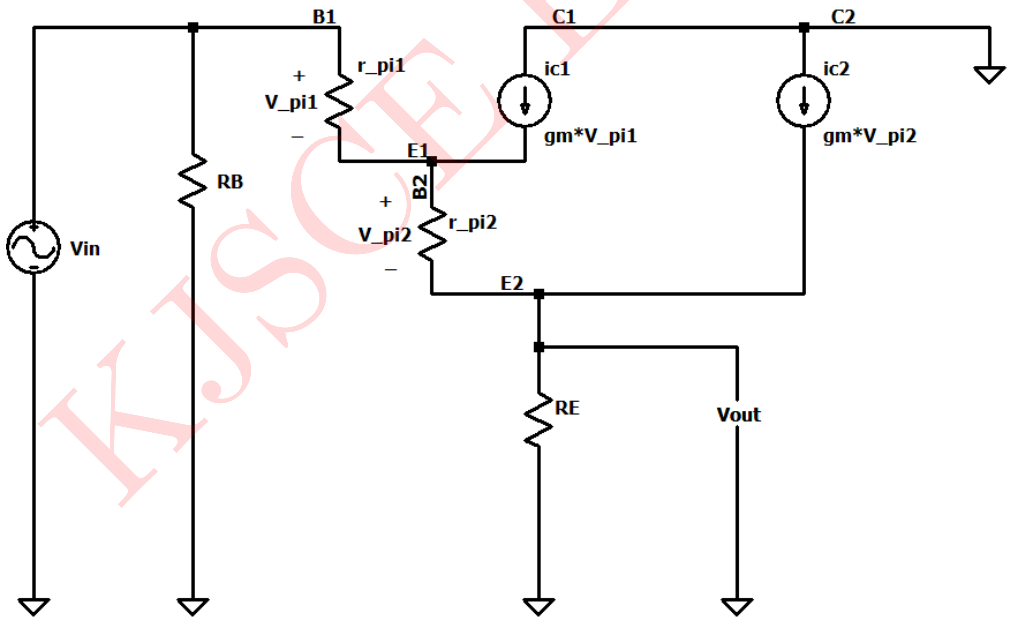

Figure 3: Mid frequency equivalent circuit

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Input impedance:

$Z_{i_2} = r_{\pi_2} + (1+\beta_2)R_E = 125.65098 + (78.459 \times 510)$

$\therefore Z_{i_2} = 40.1397 \text{ k}\Omega$

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

$Z_{i_1} = (40.1397k \times 78.459) + 9.858k$

$\therefore Z_{i_1} = 3.159 \text{ M}\Omega$

$Z_i = R_B || Z_{i_1} = 2.4M || 3.159M$

$\therefore Z_i = \mathbf{1.66299\ M\Omega}$

Output impedance:

$Z_{o_1} = \dfrac{R_B + r_{\pi_1}}{1+\beta_1} = \dfrac{2.4M + 9.858k}{1 + 77.459}$

$\therefore Z_{o_1} = 30.714 \text{ k}\Omega$

$Z_{o_2} = \dfrac{30.714k + 125.65098}{1 + 77.459} = 393.067\Omega$

$Z_o = Z_{o_2} || R_E = 393.067 || 510$

$\therefore Z_o = \mathbf{221.9815\Omega}$

Current gain:

$A_{i_1} = \dfrac{I_{E_1}}{I_{B_1}} = \dfrac{(1+\beta_1) \times I_{B_1}}{I_{B_1}} \therefore A_{i_1} = 78.459$

$A_{i_2} = \dfrac{I_{E_2}}{I_{B_2}} = 1 + \beta_2 = 78.459$

$A_{i_T} = A_{i_2} \times A_{i_1} = 78.459 \times 78.459$

$\therefore A_{i_T} = 6155.814$

$|A_{i_T}|$ in dB$= 20log_{10}(6155.8) = \mathbf{75.7856\ dB}$

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Voltage gain:

$$A_{V_2} = \frac{V_{out}}{V_1} = \frac{I_o}{I_{B_2}} \times \frac{R_E}{Z_{i_2}} = A_{i_2} \times \frac{R_E}{Z_{i_2}}$$

$$\therefore A_{V_2} = 78.459 \times \frac{510}{40.1397k} = 0.99687$$

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

$$\therefore A_{V_1} = 78.459 \times \frac{40.1397k}{3.159M} = 0.9969$$

$$A_{V_T} = A_{V_1} \times A_{V_2} = 0.9969 \times 0.99687$$

$$\therefore A_{V_T} = 0.993799$$

$|A_{V_T}|$ (in dB) $=$ **75.7856 dB**

Output voltage $V_o = A_{V_T} \times V_i = 0.993779 \times 20 \times 10^{-3} =$ **19.87558 mV**

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SIMULATED RESULTS:

Above circuit is simulated using LTspice and the results are presented below:

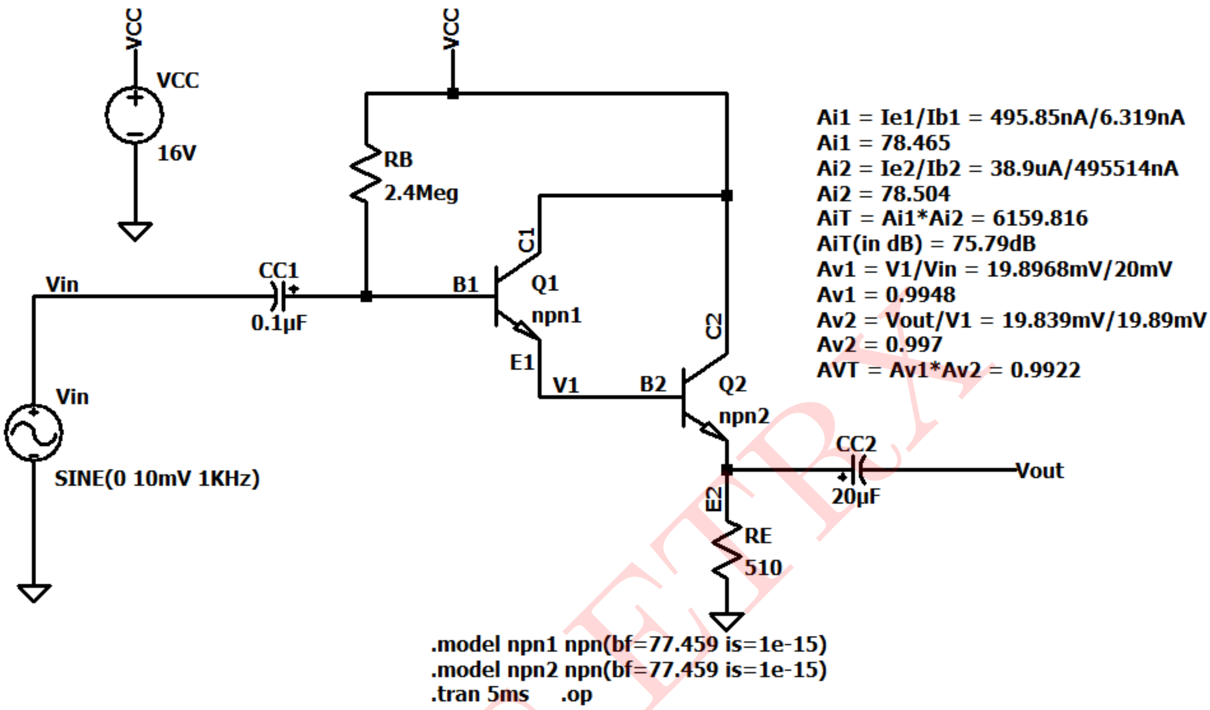

Figure 4: Circuit schematic

The input and output waveforms for current gain A_{i_1} are shown in Figure 5

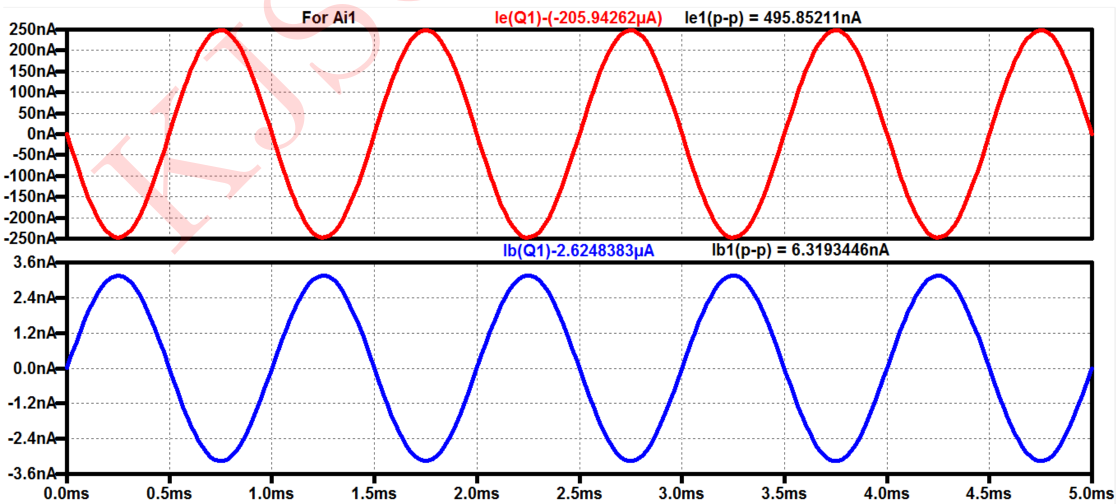

Figure 5: Input and output waveforms for current gain A_{i_1}

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The input and output waveforms for current gain A_{i_2} are shown in Figure 6

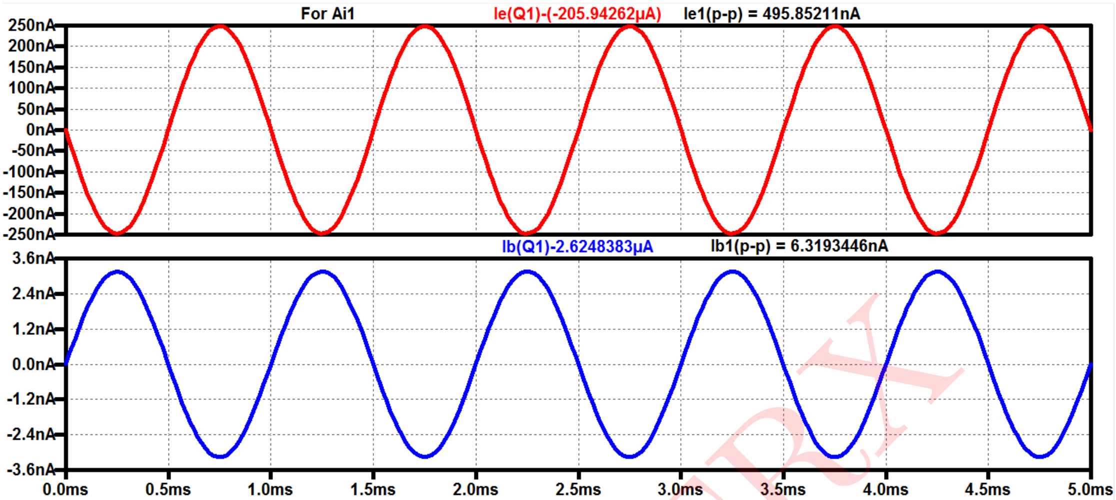

Figure 6: Input and output waveforms for voltage gain A_{i_2}

The input and output waveforms for voltage gain A_{V_1} are shown in Figure 7

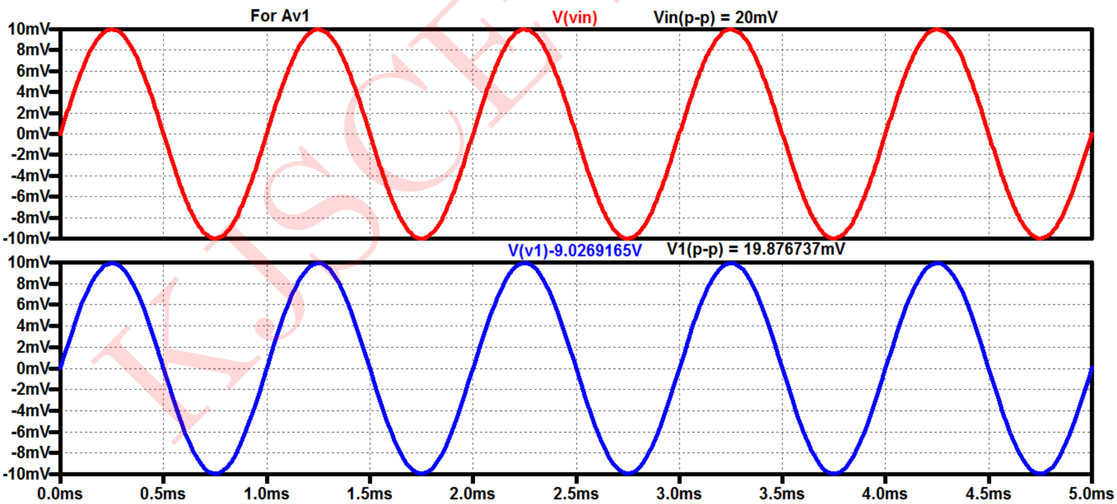

Figure 7: Input and output waveforms for voltage gain A_{V_1}

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The input and output waveforms for voltage gain A_{V_2} are shown in Figure 8

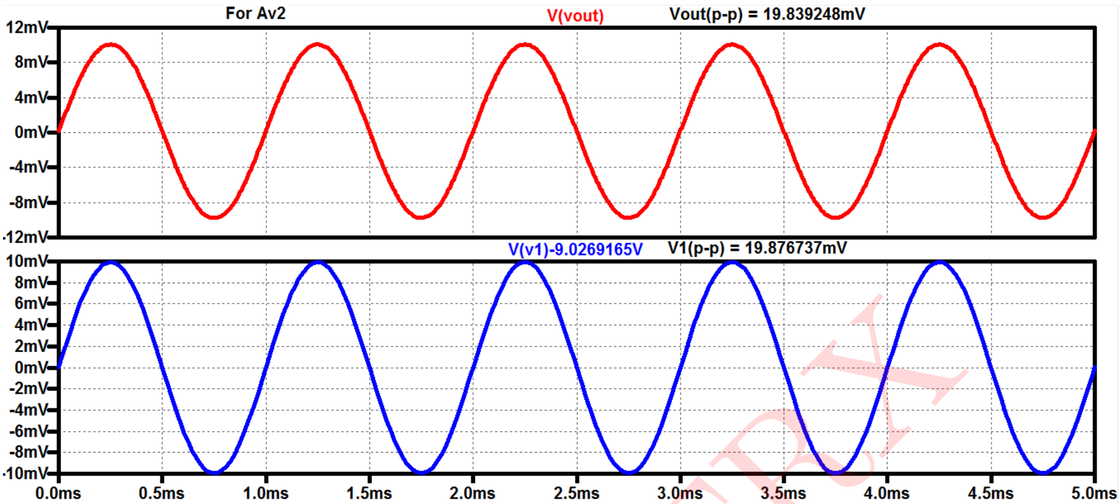

Figure 8: Input and output waveforms for voltage gain A_{V_2}

Comparison of theoretical and simulated values:

Parameters	Theoretical	Simulated
I_{B_1}	2.63736 μA	2.62484 μA
I_{C_1}	0.204287 mA	0.203318 mA
I_{E_1}	0.206924 mA	0.205943 mA
I_{B_2}	0.206924 mA	0.205943 mA
I_{C_2}	16.028 mA	15.9521 mA
I_{E_2}	16.235 mA	16.1581 mA
V_{E_2}	8.27987 V	8.24061 V
V_{C_2}	16 V	16 V
Voltage gain of 1^{st} stage (A_{V_1})	0.9969	0.9948 μA
Voltage gain of 2^{nd} stage (A_{V_2})	0.99687	0.997 μA
Overall voltage gain A_{V_T}	0.99377	0.9922
Current gain of 1^{st} stage (A_{i_1}) I_{B_1}	78.459	78.465 μA
Current gain of 2^{nd} stage (A_{i_2})	78.459	78.504 μA
Overall current gain A_{i_T}	75.7856 dB	75.79 dB
Input impedance of 1^{st} stage	1.66299 MΩ	–
Output impedance of 2^{nd} stage	221.9815 Ω	–
Output voltage	19.87558 mV	19.839 mV

Table 1: Numerical 1

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