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DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Darlington Amplifier

12^{th} **July, 2020** **Numericals**

Numerical 1: For the circuit shown in figure 1 find the voltage gain

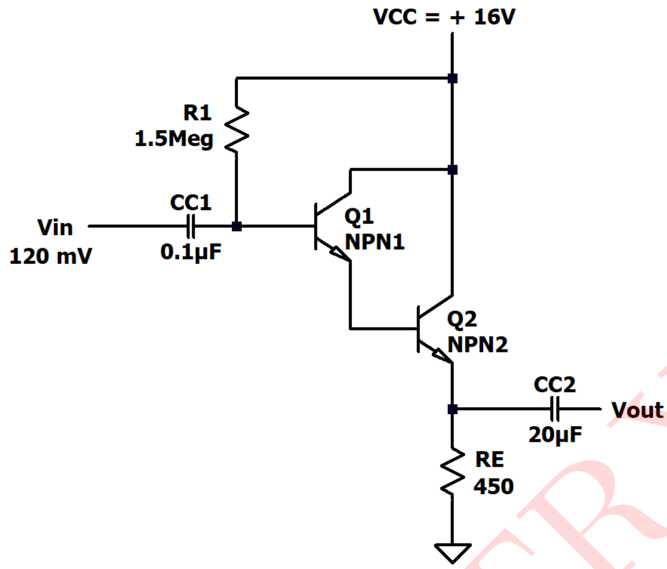

Figure 1: Circuit 1

Solution:
The given circuit is a darlington emitter - follower circuit.

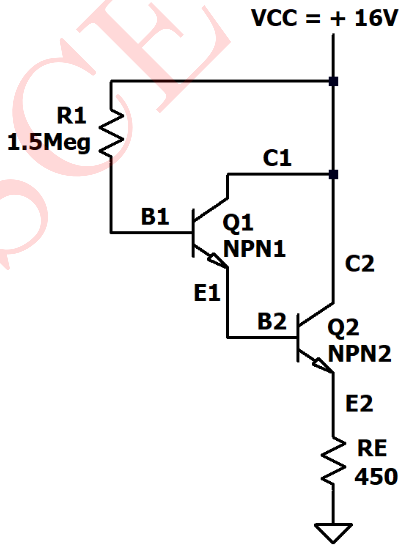

Figure 2: DC Equivalent Circuit

Applying KVl to Base - Emitter loop;

$V_{CC} - I_{B1}R_1 - V_{BE1} - V_{BE2} - I_{E2}R_E = 0$

But, $V_{BE1} + V_{BE2} = V_{BE}$

and $\beta_1 \times \beta_2 = \beta_D$

$V_{CC} - I_{B1}R_1 - V_{BE} - \beta_D I_{B1} R_E = 0$

$I_{B1}(R_1 + \beta_D R_E) = V_{CC} - V_{BE}$

$$I_{B1} = \frac{V_{CC} - V_{BE}}{R_1 + \beta_D R_E} = \frac{16 - 1.6}{(1.5 \times 10^6) + (6000 \times 450)} = \mathbf{3.4285\mu A}$$

Since $\beta_1 \times \beta_2 = \beta_D$, let us consider $\beta_1 = \beta_2 = \sqrt{6000} = \mathbf{77.45}$

$I_{C1} = \beta_1 I_{B1} = 77.45 \times 3.428 \times 10^{-6} = \mathbf{0.265mA}$

$I_{E1} = I_{C1} + I_{B1} = (0.265 \times 10^{-3}) + (3.4285 \times 10^{-6}) = \mathbf{0.268mA}$

$I_{B2} = I_{E1} = \mathbf{0.2648mA}$

$I_{E2} = (\beta_2 + 1)I_{B2} = (77.45 + 1)(0.268 \times 10^{-3}) = \mathbf{21mA}$

$I_{C2} = \beta_2 \times I_{B2} = 77.45 \times 0.268 \times 10^{-3} = \mathbf{20.75mA}$

$V_{E2} = I_{E2}R_E = 21 \times 10^{-3} \times 450 = \mathbf{9.45V}$

$V_{C2} = \mathbf{16V}$

Small Signal Parameters:

$$r_{\pi_1} = \frac{\beta_1 V_T}{I_{C1}} = \frac{77.45 \times 26 \times 10^{-3}}{0.265 \times 10^{-3}} = \mathbf{7.598k\Omega}$$

$$r_{\pi_2} = \frac{\beta_2 V_T}{I_{C2}} = \frac{77.45 \times 26 \times 10^{-3}}{20.75 \times 10^{-3}} = \mathbf{97.045\Omega}$$

Mid frequency AC equivalent circuit:

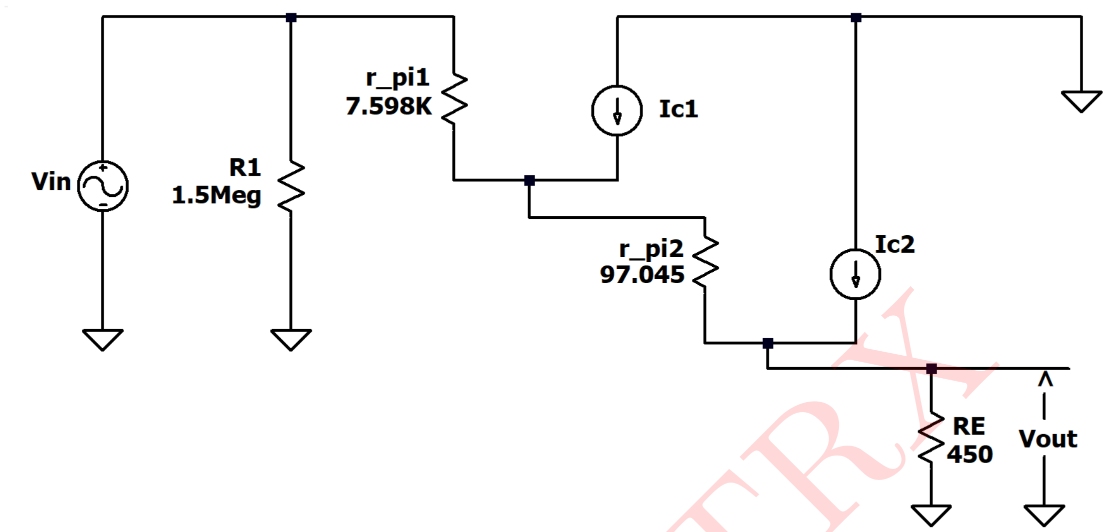

Figure 3: AC mid frequency Equivalent Circuit

Input impedance:

$Z_i = R_1 \; || \; Z_{i1}$

Where, $Z_{i1} = Z_{i2}(\beta_1 + 1) + r_{\pi 1} = (35.399 \times 10^3)(1 + 77.45) + (7.598 \times 10^3) = \mathbf{2.7846M\Omega}$

And $Z_{i2} = r_{\pi 2} + (1 + \beta_2)R_E = 97.045 + (77.45 + 1)(450) = \mathbf{35.399k\Omega}$

$Z_i = 1.5M \; || \; 2.7846M = \mathbf{0.9749M\Omega}$

Output impedance:

$Z_o = Z_{o2} \; || \; R_E$

Where, $Z_{o2} = \dfrac{Z_{o1} + r_{\pi 2}}{1 + \beta_2} = \dfrac{(19.217 \times 10^3) + 97.045}{1 + 77.45} = \mathbf{246.19\Omega}$

And $Z_{o1} = \dfrac{R_1 + r_{\pi 1}}{1 + \beta_1} = \dfrac{1.5 \times 10^6 + 7589}{1 + 77.45} = \mathbf{19.217k\Omega}$

$Z_o = 246.19 \; || \; 450 = \mathbf{159.13\Omega}$

Finding out Current Gain:

$A_i = A_{i1} \times A_{i2}$

Now, $A_{i1} = \dfrac{I_{E1}}{I_{B1}} = \dfrac{I_{B2}}{I_{B1}}$

Also, $A_{i2} = \dfrac{I_{E2}}{I_{B2}}$

Now, $I_{out} = I_{E2}$

Current gain:

$$A_i = \frac{I_{out}}{I_{in}} = \frac{I_{out}}{I_{B2}} \times \frac{I_{B2}}{I_{B1}} = \frac{I_{B1}}{I_{in}} \qquad (\text{here, } A_{i1} = \frac{I_{B2}}{I_{B1}} = \frac{I_{E1}}{I_{B1}} \text{ and } A_{i2} = \frac{I_{E2}}{I_{B2}})$$

Here, $\frac{I_{out}}{I_{B2}} = \frac{I_{E2}}{I_{B2}} = (1+\beta_2) = 1 + 77.45 = \mathbf{78.45} \qquad (\text{since } I_{out} = I_{E2})$

Now, $I_{B2} = I_{E1} = (1+\beta_1)I_{B1}$

$$\frac{I_{B2}}{I_{B1}} = \frac{(1+\beta_1)I_{B1}}{I_{B1}} = 1 + 77.45 = \mathbf{78.45}$$

A_{id} (current gain of darlington pair) $= A_{i1} \times A_{i2} = 78.45 \times 78.45 = \mathbf{6154.4}$

Voltage Gain:

$$A_{VT} = A_{V1} \times A_{V2}$$

Where, $A_{V2} = \frac{V_{out}}{V_1}$ and $A_{V1} = \frac{V_1}{V_{in}}$

$$A_{V2} = \frac{I_{out}}{I_{B2}} \times \frac{R_E}{Z_{i2}} = 78.45 \times \frac{450}{35.399 \times 10^3} = \mathbf{0.997}$$

$$A_{V1} = \frac{V_1}{V_{in}} = \frac{I_{E1}}{I_{B1}} \times \frac{Z_{i2}}{I_{B1}} = 78.45 \times \frac{35.399 \times 10^3}{2.7846 \times 10^6} = \mathbf{0.9997}$$

$$A_{VT} = (0.997)^2 = 0.994$$

Output Voltage:

$$V_{out} = V_{in} \times A_V = 120 \times 10^{-3} \times 0.994 = \mathbf{119.28mV}$$

SIMULATED RESULTS:
Above circuit is simulated in LTspice and the result is as follows:

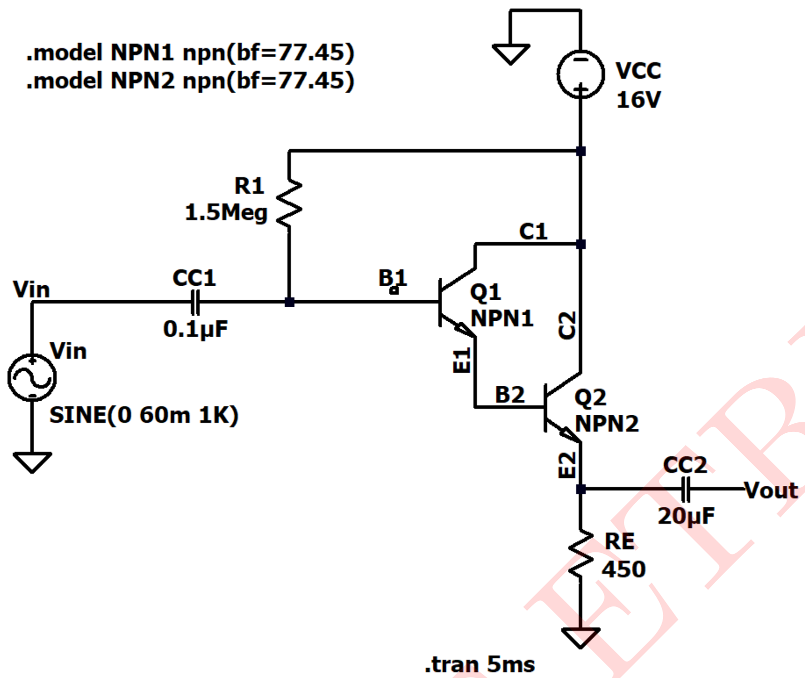

Figure 4: Circuit Schematic

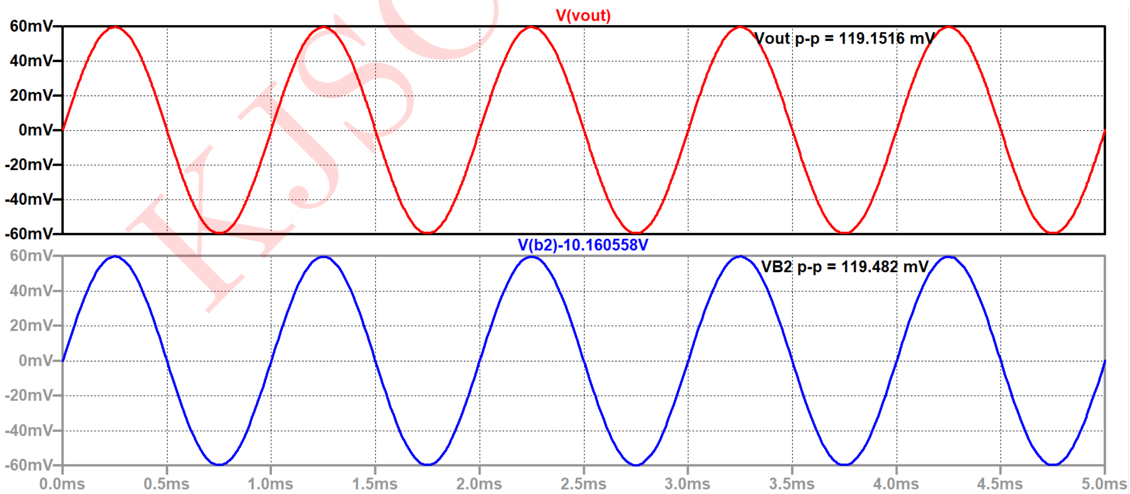

Figure 5: Input output voltage waveform for stage 1

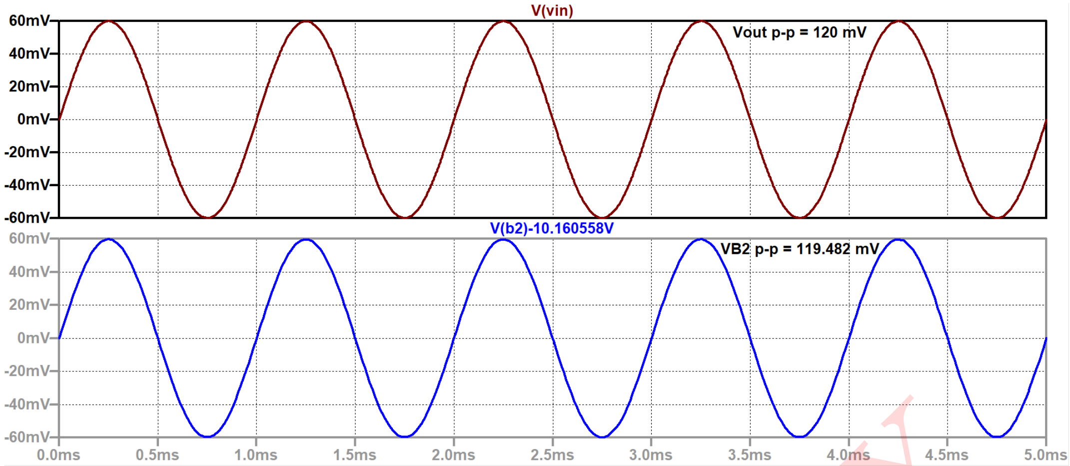

Figure 6: Input output voltage waveform for stage 2

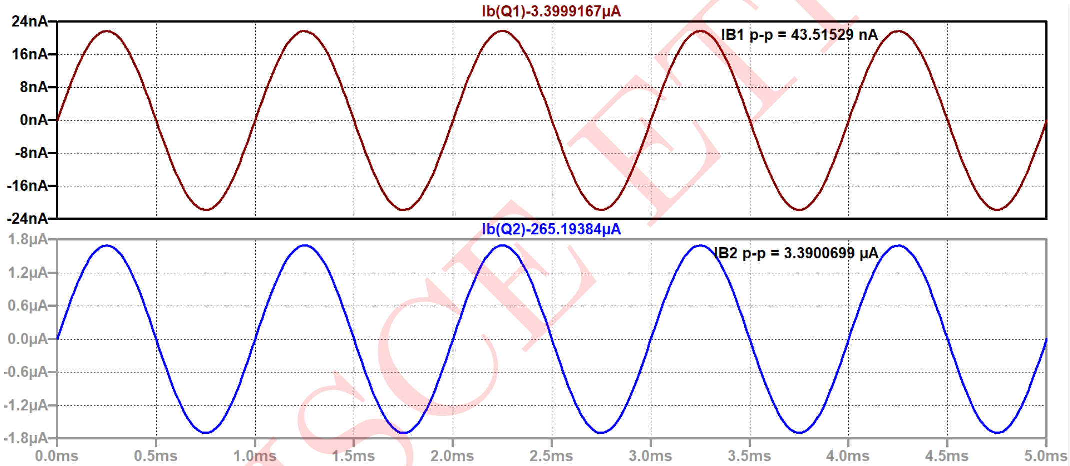

Figure 7: Input output current waveform for stage 1

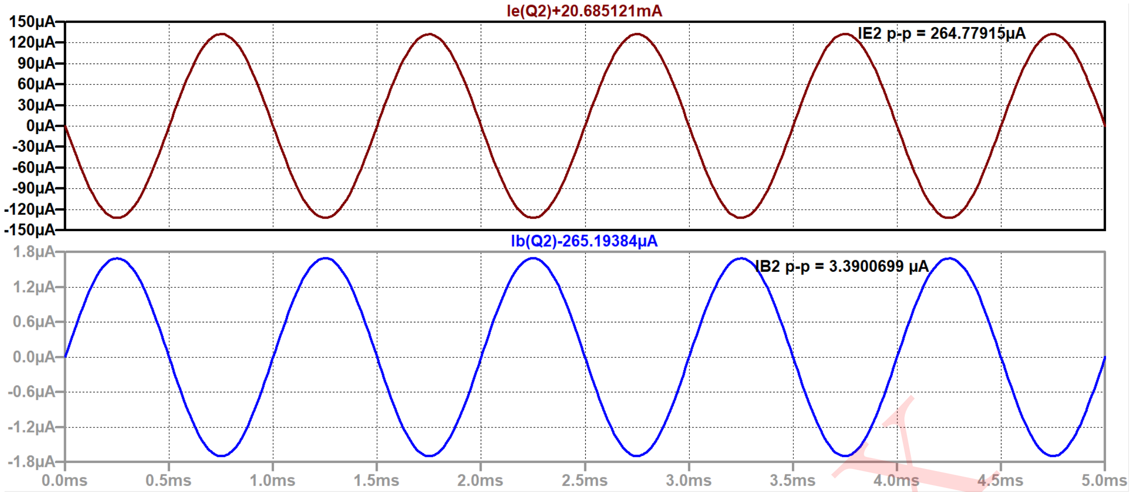

Figure 8: Input output current waveform for stage 2

Comparison between Theoretical and Simulated values :-

Parameters	Theoretical	Simulated
I_{B1}	$3.4285\mu A$	$3.4\mu A$
I_{C1}	0.265 mA	0.261mA
I_{E1}	0.268mA	0.265mA
I_{B2}	0.268mA	0.265mA
I_{C2}	20.75mA	20.42mA
I_{E2}	21mA	2.7mA
V_{C2}	16V	16V
V_{E2}	9.45V	9.3V
Voltage gain of first stage	0.997	0.996
Voltage gain of second stage	0.997	0.997
Current gain of first stage	78.45	78
Current gain of second stage	78.45	78.1
Overall current gain	6154.4	6092.13
Overall voltage gain	0.994	0.993
Input impedance	$0.9749M\Omega$	–
Output impedance	159.13Ω	–
Output voltage	119.28mV	119.1516mV

Table 1: Numerical 1

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