ASSIGNMENT 04 – Amplifier Design

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Note: The thermal voltage V_T is approximated to be 20 mV in the Assignment and the given set of specifications are given below.

Supply voltage V_{CC}	24V DC
Load R_L	16 Ω
Overall voltage gain $A_v = \frac{v_O}{v_{in}}$	120
Stage 1 output	Maximum voltage swing
Stage 2 output	Class A operation
Transistor 1 current gain β_1	100
Transistor 1 BE voltage V_{BE_1}	0.6V
Transistor 2 current gain β_2	400
Transistor 2 BE voltage V_{BE_2}	0.5V

Q1

Let the quiescent emitter current of the output leg be I_{E_2}. Since we assume the ***Class A operation*** of the transistor Q_2, the bias point $V_{CE_2} = V_{CC}/2$.

$$\therefore I_{E_2} = \frac{V_{CC}/2}{R_L} = \frac{V_{CC}}{2.R_L} = \frac{24\ V}{2.16\ \Omega} = 750\ mA$$

Q2

- Collector-emitter current ratio (α_2)

$$\alpha_2 = \frac{\beta_2}{\beta_2 + 1} = \frac{400}{400 + 1} = 0.9975$$

- Collector current (I_{C_2})

$$I_{C_2} = \alpha_2.I_{E_2} = 0.9975 \times 750\ mA = 748.1297\ mA$$

- Transconductance (g_{m_2})

$$g_{m_2} = \frac{I_{C_2}}{V_T} = \frac{748.1297\ mA}{20\ mV} = 37.4065\ S$$

- Intrinsic emitter resistance (r_{e_2})

$$r_{e_2} = \frac{\alpha_2}{g_{m_2}} = \frac{0.9975}{37.4065\ S} = 0.0267\ \Omega$$

Q3

Consider the voltage gain of stage 2 of the amplifier, $\frac{v_O}{v_{in_2}}$. Then,

$$A_{v_2} = \frac{v_O}{v_{in_2}} = \frac{R_L}{r_{e_2} + R_L} = \frac{16\ \Omega}{16 + 0.0267\Omega} = 0.9983$$

Q4

Let the base current of Q_2 be I_{B_2},

$$I_{B_2} = \frac{1}{\beta_2}.I_{C_2} = \frac{1}{400} \times 748.1297\ mA = 1.8703\ mA$$

Q5

Since $V_{BB_2} = V_{BE_2} + V_{R_L} = 0.5 + 12 = 12.5\ V$ and $I_{R_{B_4}} = I_{B_2}/9 = 1.8703\ mA/9 = 0.2078\ mA$,

$$\therefore R_{B_4} = \frac{V_{BB_2}}{I_{R_{B_4}}} = \frac{12.5\ V}{0.2078\ mA} = 60.15\ k\Omega$$

Therefore voltage drop across $R_{B_3}, V_{R_{B_3}} = 24 - 12.5 = 11.5\ V$ and $I_{R_{B_3}} = I_{B_2} + I_{R_{B_4}} = I_{B_2} + I_{B_2}/9 = \frac{10}{9}.I_{B_2} = \frac{10}{9} \times 1.8703\ mA = 2.078\ mA$.

$$\therefore R_{B_3} = \frac{V_{R_{B_3}}}{I_{R_{B_3}}} = \frac{11.5\ V}{2.078\ mA} = 5.5338\ k\Omega$$

Q6

From the Question 03 of the Assignment 02, input resistance of stage 2 (R_{in_2}) can be written as follows.

$$\begin{aligned} R_{in_2} &= (R_{B_3} /\!/ R_{B_4}) /\!/ [(\beta_2 + 1)(r_{e_2} + R_L)] \\ &= (5.5338\ k\Omega /\!/ 60.15\ k\Omega) /\!/ ((400 + 1) \times (16 + 0.0267)) \\ &= 5.0676\ k\Omega /\!/ ((400 + 1) \times (16 + 0.0267)) \\ &= 2833.3954\ \Omega \end{aligned}$$

Q7

- Collector current (I_{C_1}),

$$I_{C_1} = \frac{1}{500} \times I_{C_2} = \frac{1}{500} \times 748.1297\ mA = 1.4963\ mA$$

- Transconductance (g_{m_1})

$$g_{m_1} = \frac{I_{C_1}}{V_T} = \frac{1.4963\ mA}{20\ mV} = 0.0748\ S$$

Q8

Since the Overall voltage gain $A_v = \frac{v_O}{v_{in}} = 120$ and the voltage gain of stage 2 of the amplifier is $A_{v_2} = 0.9983$, the required gain of stage 1 is,

$$A_{v_1} = \frac{A_v}{A_{v_2}} = 120/0.9983 = 120.2043$$

From the Question 05 of the Assignment 02, voltage gain of stage 1 of the amplifier cam be written as follows. And therefore R_{C_1} can be directly calculated from it.

$$\begin{aligned} -A_{v_1} &= -g_{m_1}.(R_{C_1} /\!/ R_{in_2}) \\ 120.2043 &= 0.0748\,(R_{C_1} /\!/ 2833.3954\ \Omega) \\ \therefore R_{C_1} &= 3712.7730\ \Omega \end{aligned}$$

Since Stage 1 output is specified to have a maximum voltage swing, then $V_{CE_2} = V_{CC}/2 = 12\ V$. By using the result of Question 02 of the Assignment 01 and using the fact that $I_{E_1} = \frac{\beta_1+1}{\beta_1}.I_{C_1}$

$$\begin{aligned} V_{CC} &= I_{C_1}.R_{C_1} + V_{CE_1} + I_{E_1}.R_{E_1} \\ I_{E_1}.R_{E_1} &= V_{CC} - V_{CE_1} - I_{C_1}.R_{C_1} \\ \frac{\beta_1+1}{\beta_1}.I_{C_1}.R_{E_1} &= V_{CC} - V_{CE_1} - I_{C_1}.R_{C_1} \\ R_{E_1} &= \frac{\beta_1}{\beta_1+1} \times \left[\frac{V_{CC} - V_{CE_1} - I_{C_1}.R_{C_1}}{I_{C_1}}\right] \\ &= \frac{100}{100+1} \times \left[\frac{24\ V - 12\ V - 1.4963\ mA \times 3712.7730\ \Omega}{1.4963\ mA}\right] \\ &= 4264.3655\ \Omega \end{aligned}$$

Q9

Let the base current of Q_1 be I_{B_1},

$$I_{B_1} = \frac{1}{\beta_1}.I_{C_1} = \frac{1}{100} \times 1.4963\ mA = 14.963\ \mu A$$

Since the design decision has made to make $I_{R_{B_2}} = I_{B_1}/9 = 14.963\ \mu A/9 = 1.6626\ \mu A$ and $V_{BB_1} = V_{BE_1} + V_{R_{E_1}} = V_{BE_1} + I_{E_1}.R_{E_1} = 0.6 + 6.4446\ V = 7.0446\ V$.

$$\therefore R_{B_2} = \frac{V_{BB_1}}{I_{R_{B_2}}} = \frac{7.0446\ V}{1.6626\ \mu A} = 4.2374\ M\Omega$$

Therefore voltage drop across R_{B_1}, $V_{R_{B_1}} = 24 - 7.0446 = 16.9554\ V$ and $I_{R_{B_1}} = I_{B_1} + I_{R_{B_2}} = I_{B_1} + I_{B_1}/9 = \frac{10}{9}.I_{B_1} = \frac{10}{9} \times 14.963\ \mu A = 16.6256\ \mu A$.

$$\therefore R_{B_1} = \frac{V_{R_{B_1}}}{I_{R_{B_1}}} = \frac{16.9554\ V}{16.6256\ \mu A} = 1.0198\ M\Omega$$

Q10

From Question 04 of the Assignment 03, where V_p is the peak value of the AC signal at the load.

$$P_{L,AC} = \frac{V_p^2}{2.R_L}$$
$$4W = \frac{V_p^2}{2 \times 16}$$
$$\therefore V_p = 8\sqrt{2} = 11.3137\ V$$

Since the total gain of the amplifier is 120, peak value of the AC signal at the input is $V_p/120 = \frac{8\sqrt{2}}{120} = \frac{\sqrt{2}}{15} = 94.28\ mV$. Assume v_{in} is a pure sinusoidal signal with an angular velocity of ω then it can be written as,

$$\therefore v_{in} = 94.28 \sin(\omega.t)\ \ mV$$

Q11

Let corresponding peak voltage at the R_L to a small signal input having a peak voltage of 85 mV be V_p. Then,

$$V_p = 85\ mV \times 120 = 10.2\ V$$

Form the Question 06 of the Assignment 03, efficiency of the output leg ($\eta_{output\ leg}$),

$$\eta_{output\ leg} = \frac{V_p^2}{V_{CC}^2}$$
$$= \frac{10.2^2}{24^2}$$
$$= 0.180625$$

$$\therefore \eta_{output\ leg} = 18.0625\ \%$$