The Class A Power Amplifier

(1) For the following CE power amplifier in which the collector resistor serves also as the load resistor. Assume $\beta_{dc} = \beta_{ac} = 100$

(a) Determine the dc Q-point ($I_{EQ}$ and $V_{CEQ}$).

(b) Determine the voltage gain and the power gain.

(2) For the circuit in Problem 1, determine the following:

(a) the power dissipated in the transistor with no load

(b) the total power from the power supply with no load

(c) the signal power in the load with a 500 mV input

(3) Refer to the circuit in Problem 1. What changes would be necessary to convert the circuit to a pnp transistor with a positive supply? What advantage would this have?

(4) Assume a CC amplifier has an input resistance of 2.2 kΩ and drives an output load of 50 Ω. What is the power gain?

(5) Determine the Q-point ($V_{CEq(peak)}$ and $I_{Cq(peak)}$) for each amplifier shown

(6) Find the power gain for each circuit in Problem 5. Neglect $r_e'$
(7) Determine the minimum power rating for the transistor shown.

(8) Find the maximum output signal power to the load and efficiency for the amplifier in problem 7 with a 500 Ω load resistor.

The Class B and Class AB Push-Pull Amplifiers

(9) Refer to the class AB amplifier shown

(a) Determine the dc parameters

\[ V_{BQ1}, V_{BQ2}, V_{EB}, I_{CQ1}, V_{CEO(Q1)}, V_{CEO(Q2)}. \]

(b) For the 5 V rms input, determine the power delivered to the load resistor.

(c) Draw the load line for the npn transistor.

Label the saturation current, \( I_{CQ} \), and show the Q-point.

(10) Refer to the class AB amplifier shown operating with a single power supply.

(a) Determine the dc parameters

\[ V_{BQ1}, V_{BQ2}, V_{EB}, I_{CQ1}, V_{CEO(Q1)}, V_{CEO(Q2)}. \]

(b) Assuming the input voltage is 10 V pp, determine the power delivered to the load resistor.

(11) Refer to the class AB amplifier in problem 10

(a) What is the maximum power that could be delivered to the load resistor?

(b) Assume the power supply voltage is raised to 24 V.

What is the new maximum power that could be delivered to the load resistor?
(12) Refer to the class AB amplifier in Problem 10. What fault or faults could account for each of the following troubles?

(a) a positive half-wave output signal

(b) zero volts on both bases and the emitters

(c) no output: emitter voltage = +15 V

(d) crossover distortion observed on the output waveform

The Class C Amplifier

(13) A certain class C amplifier transistor is on for 10 percent of the input cycle. If $V_{ce}^{sat} = 0.18$ V and $I_c^{sat} = 25$ mA, what is the average power dissipation for maximum output?

(14) What is the resonant frequency of a tank circuit with $L = 10mH$ and $C = 0.001 \mu F$?

(15) What is the maximum peak-to-peak output voltage of a tuned class C amplifier with $V_{cc} = 12$ V?

(16) Determine the efficiency of the class C amplifier described in Problem 15 if $V_{cc} = 12$ V and the equivalent parallel resistance in the collector tank circuit is 50 Ω. Assume that the transistor is on for 10% of the period.
Model Answer

Q1)

(a) \( V_B = \left( \frac{R_2}{R_1 + R_2} \right) V_{CC} = \left( \frac{330 \Omega}{1.0 \text{k}\Omega + 330 \text{k}\Omega} \right) 15 \text{ V} = 3.72 \text{ V} \)

\( V_E = V_B - V_{BE} = 3.72 - 0.7 \text{ V} = 3.02 \text{ V} \)

\( I_{CQ} \equiv I_E = \frac{V_E}{R_{E1} + R_{E2}} = \frac{3.02 \text{ V}}{8.2 \Omega + 36 \Omega} = 68.4 \text{ mA} \)

\( V_{CEQ} = V_{CC} - (I_C)(R_{E1} + R_{E2} + R_L) \)

\( = 15 \text{ V} - (68.4 \text{ mA})(8.2 \Omega + 35 \Omega + 100 \Omega) = 5.14 \text{ V} \)

(b) \( A_v = \frac{R_L}{R_{E1} + r_e'} = \frac{100 \Omega}{8.2 \Omega + 0.37 \Omega} = 11.7 \)

\( R_{in} = \beta_{oc}(R_{E1} + r_e') \parallel R_1 \parallel R_2 \)

\( = 100 \left( \frac{8.2 \Omega + 0.37 \Omega}{330 \Omega \parallel 1.0 \text{k}\Omega} \right) = 192 \Omega \)

\( A_p = A_v^2 \left( \frac{R_{in}}{R_L} \right) = 11.7^2 \left( \frac{192 \Omega}{100 \Omega} \right) = 263 \)

Q2)

a) If \( R_L \) is removed, there is no collector current, hence the power dissipated in the transistor is zero

b) Power is dissipated only in the bias resistors pulse a small amount in \( R_{E1} \) and \( R_{E2} \). Since the load resistor has been removed, the base voltage is altered. The base voltage can be found from the Thevenin equivalent drawn for the bias circuit
So, the total current that passes through the circuit $I_{CC}$ is the current passes through $R_1$

$$I_{CC} = \frac{V_{CC} - V_B}{R_1} = 13.84 \text{ mA}$$

Then, the total power dissipated is $P_T = V_{CC}I_{CC} = 207.65 \text{ mW}$

(c) $A_v = 11.7$ (see problem 1(b)). $V_{in} = 500 \text{ mV}_{pp} = 177 \text{ mV}_{rms}$.

$V_{out} = A_vV_{in} = 11.7(177 \text{ mV}) = 2.07 \text{ V}$

$$P_{out} = \frac{V_{out}^2}{R_L} = \frac{2.07 \text{ V}^2}{100 \Omega} = 42.8 \text{ mW}$$

Q3) The change will be as shown. The advantage of this arrangement is that the load resistor is referenced to ground.
Q4) A CC amplifier has a voltage gain of approximately 1. Therefore,
\[ A_p = \frac{R_{\text{in}}}{R_{\text{out}}} = \frac{2.2 \ \text{k}\Omega}{50 \ \Omega} = 44 \]

Q5) (a) \( R_{\text{IN(base)}} = \beta_{\text{DC}}(R_{E1} + R_{E2}) = (125)(79.7) = 9.96 \ \text{k}\Omega \)
Since \( R_{\text{IN(base)}} > 10R_2 \), it can be neglected.

\[
V_B = \left[ \frac{R_1}{R_1 + R_2} \right] V_{CC} = \left( \frac{510 \ \Omega}{680 \ \Omega + 510 \ \Omega} \right) 12 \ \text{V} = \left( \frac{510 \ \Omega}{1190 \ \Omega} \right) 12 \ \text{V} = 5.14 \ \text{V}
\]

\[
V_E = V_B - 0.7 \ \text{V} = 5.14 \ \text{V} - 0.7 \ \text{V} = 4.44 \ \text{V}
\]

\[
I_{\text{CQ}} \approx I_E = \frac{V_E}{R_E} = \frac{4.44 \ \text{V}}{79.7 \ \Omega} = 55.7 \ \text{mA}
\]

\[
V_{CQ} = V_{CC} - I_{\text{CQ}} R_c = 12 \ \text{V} - (55.7 \ \text{mA})(100 \ \Omega) = 6.43 \ \text{V}
\]

\[
V_{\text{CEQ}} = V_c - V_E = 6.43 \ \text{V} - 4.44 \ \text{V} = 1.99 \ \text{V}
\]

\[
R_c = R_c \parallel R_L = 100 \ \Omega \parallel 100 \ \Omega = 50 \ \Omega
\]

\[
V_{\text{CEQ(\text{sat})}} = V_{\text{CEQ}} + I_{\text{CQ}} R_c = 1.99 \ \text{V} + 55.7 \ \text{mA}(50 \ \Omega) = 4.78 \ \text{V}
\]
Since \( V_{\text{CEQ}} \) is closer to saturation, \( I_c \) is limited to

\[
I_{c(p)} = \frac{V_{\text{CEQ}}}{R_c} = \frac{1.99 \ \text{V}}{50 \ \Omega} = 39.8 \ \text{mA}
\]

\( V_{\text{out}} \) is limited to

\[
V_{\text{out(p)}} = V_{\text{CEQ}} = 1.99 \ \text{V}
\]
(b) \( R_{\text{in(base)}} = \beta_{\text{DC}}(R_{E_1} + R_{E_2}) = (120)(142 \, \Omega) = 17 \, \text{k}\Omega \)

Since \( R_{\text{in(base)}} < 10R_2 \), it is taken into account.

\[
V_B = \left[ \frac{R_2}{R_1 + R_2} \right] \left[ \frac{R_{\text{in(base)}}}{R_{\text{in(base)}}} \right] V_{CC} = \left( \frac{4.7 \, \text{k}\Omega}{12 \, \text{k}\Omega} \right) \left( 17 \, \text{k}\Omega \right) = 2.82 \, \text{V}
\]

\[
V_E = V_B - 0.7 \, \text{V} = 2.82 \, \text{V} - 0.7 \, \text{V} = 2.12 \, \text{V}
\]

\[
I_{CQ} = \frac{V}{R_{E}} = \frac{2.12 \, \text{V}}{142 \, \Omega} = 14.9 \, \text{mA}
\]

\[
V_{CQ} = V_{CC} - I_{CQ}R_C = 12 \, \text{V} - (14.9 \, \text{mA})(470 \, \Omega) = 5.0 \, \text{V}
\]

\[
V_{CEQ} = V_{CQ} - V_E = 5.0 \, \text{V} - 2.12 \, \text{V} = 2.88 \, \text{V}
\]

\[
R_c = R_C \parallel R_L = 470 \, \Omega \parallel 235 \, \Omega = 235 \, \Omega
\]

\[
V_{ce\text{(cutoff)}} = V_{CEQ} + I_{CQ}R_c = 2.88 \, \text{V} + 14.9 \, \text{mA}(235 \, \Omega) = 6.38 \, \text{V}
\]

Since \( V_{CEQ} \) is closer to saturation, \( I_c \) is limited to

\[
I_{cl(p)} = \frac{V_{CEQ}}{R_c} = \frac{2.88 \, \text{V}}{235 \, \Omega} = 12.3 \, \text{mA}
\]

\[
V_{out} \text{ is limited to } V_{out(p)} = V_{CEQ} = 2.88 \, \text{V}
\]

Q6)

(a) \( A_p = A_v^2 \left( \frac{R_{in}}{R_L} \right) \)

\[
A_v \approx \frac{R_c}{R_{E_1}} = \frac{R_C \parallel R_L}{R_{E_1}} = \frac{100 \, \Omega \parallel 100 \, \Omega}{4.7 \, \Omega} = \frac{50 \, \Omega}{4.7 \, \Omega} = 10.6
\]

\[
R_{in} = R_2 \parallel R_{\text{in(base)}} = R_2 \parallel \beta_{ac}R_{E_1}
\]

\[
R_{in} = 680 \, \Omega \parallel 510 \, \Omega \parallel (125)(4.7 \, \Omega) = 680 \, \Omega \parallel 510 \, \Omega \parallel 588 \, \Omega = 195 \, \Omega
\]

\[
A_p = (10.6)^2 \left( \frac{195 \, \Omega}{100 \, \Omega} \right) = 219
\]

(b) \( A_v \approx \frac{R_c}{R_{E_1}} = \frac{R_C \parallel R_L}{R_{E_1}} = \frac{470 \, \Omega \parallel 470 \, \Omega}{22 \, \Omega} = \frac{235 \, \Omega}{22 \, \Omega} = 10.7
\]

\[
R_{in} = 12 \, \text{k}\Omega \parallel 4.7 \, \text{k}\Omega \parallel (120)(22 \, \Omega) = 12 \, \text{k}\Omega \parallel 4.7 \, \text{k}\Omega \parallel 2.64 \, \text{k}\Omega = 1.48 \, \text{k}\Omega
\]

\[
A_p = (10.7)^2 \left( \frac{1.48 \, \text{k}\Omega}{470 \, \Omega} \right) = 361
\]
Q7)

\[ R_{\text{IN(base)}} = \beta_{\text{DC}} R_E = 90(130 \, \Omega) = 11.7 \, \text{k}\Omega \]
\[ R_2 \parallel R_{\text{IN(base)}} = 1.0 \, \text{k}\Omega \parallel 11.7 \, \text{k}\Omega = 921 \, \Omega \]

\[ V_B = \left( \frac{R_2 \parallel R_{\text{IN(base)}}}{R_1 + R_2 \parallel R_{\text{IN(base)}}} \right) V_{\text{CC}} = \left( \frac{921 \, \Omega}{5.62 \, \text{k}\Omega} \right) 24 \, \text{V} = 3.93 \, \text{V} \]
\[ V_E = V_B - 0.7 \, \text{V} = 3.93 \, \text{V} - 0.7 \, \text{V} = 3.23 \, \text{V} \]
\[ I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{3.23 \, \text{V}}{130 \, \Omega} = 24.8 \, \text{mA} \]

\[ V_C = V_{\text{CC}} - I_{CQ} R_c = 24 \, \text{V} - (24.8 \, \text{mA})(560 \, \Omega) = 13.9 \, \text{V} \]
\[ V_{\text{CEQ}} = V_C - V_E = 13.9 \, \text{V} - 3.23 \, \text{V} = 10.7 \, \text{V} \]
\[ P_{\text{D(min)}} = P_{\text{DQ}} = I_{CQ} V_{\text{CEQ}} = (24.8 \, \text{mA})(10.7 \, \text{V}) = 265 \, \text{mW} \]

Q8)

From Problem 7: \( I_{CQ} = 24.8 \, \text{mA} \) and \( V_{\text{CEQ}} = 10.7 \, \text{V} \)
\[ V_{\text{ce(cutoff)}} = V_{\text{CEQ}} + I_{CQ} R_c = 10.7 \, \text{V} + (24.8 \, \text{mA})(264 \, \Omega) = 17.2 \, \text{V} \]

The \( Q \)-point is closer to cutoff than to saturation.

\[ P_{\text{out}} = 0.5 I_{CQ}^2 R_c = 0.5(24.8 \, \text{mA})^2(264 \, \Omega) = 81.2 \, \text{mW} \]

\[ \text{eff} = \frac{P_{\text{out}}}{P_{\text{DC}}} = \frac{P_{\text{out}}}{V_{\text{CC}} I_{\text{CC}}} = \frac{81.2 \, \text{mW}}{(24 \, \text{V})(24.8 \, \text{mA})} = 0.136 \]

Q9)

(a) \( V_{B(Q1)} = 0 \, \text{V} + 0.7 \, \text{V} = 0.7 \, \text{V} \)
\[ V_{B(Q2)} = 0 \, \text{V} - 0.7 \, \text{V} = -0.7 \, \text{V} \]
\[ V_E = 0 \, \text{V} \]
\[ I_{CQ} = \frac{V_{\text{CC}}}{R_1 + R_2} - (-V_{\text{CC}}) - 1.4 \, \text{V} \]
\[ = \frac{9 \, \text{V} - (-9 \, \text{V}) - 1.4 \, \text{V}}{1.0 \, \text{k}\Omega + 1.0 \, \text{k}\Omega} = 8.3 \, \text{mA} \]
\[ V_{\text{CEQ}(Q1)} = 9 \, \text{V} \]
\[ V_{\text{CEQ}(Q2)} = -9 \, \text{V} \]

(b) \( V_{\text{out}} = V_{\text{in}} = 5.0 \, \text{V} \) rms
\[ P_{\text{out}} = \frac{(V_{\text{out}})^2}{R_L} = \frac{5.0 \, \text{V}^2}{50 \, \Omega} = 0.5 \, \text{W} \]
Q9-c)

\[ I_{c(sat)} = \frac{V_{CC}}{R_L} = \frac{9.0 \text{ V}}{50 \Omega} = 180 \text{ mA} \]

\[ V_{ce(off)} = 9 \text{ V} \]

These points define the ac load line as shown in Figure 9-3. The Q-point is at a collector current of 8.3 mA (see problem 9) and the dc load line rises vertically through this point.

Q10)

(a) \[ V_{B(Q1)} = 7.5 \text{ V} + 0.7 \text{ V} = 8.2 \text{ V} \]
\[ V_{B(Q2)} = 7.5 \text{ V} - 0.7 \text{ V} = 6.8 \text{ V} \]
\[ V_E = \frac{15 \text{ V}}{2} = 7.5 \text{ V} \]
\[ I_{Q} = \frac{V_{CC} - 1.4 \text{ V}}{R_1 + R_2} = \frac{15 \text{ V} - 1.4 \text{ V}}{1.0 \text{ k}\Omega + 1.0 \text{ k}\Omega} = 6.8 \text{ mA} \]
\[ V_{CEQ(Q1)} = 15 \text{ V} - 7.5 \text{ V} = 7.5 \text{ V} \]
\[ V_{CEQ(Q2)} = 0 \text{ V} - 7.5 \text{ V} = -7.5 \text{ V} \]

(b) \[ V_{in} = V_{out} = 10 \text{ V}_{pp} = 3.54 \text{ V} \text{ rms} \]
\[ P_L = \frac{(V_L)^2}{R_L} = \frac{(3.54 \text{ V})^2}{75 \text{ \Omega}} = 167 \text{ mW} \]

Q11)

(a) Maximum peak voltage = 7.5 \text{ V}_{p}, \quad 7.5 \text{ V}_{p} = 5.30 \text{ V} \text{ rms}
\[ P_{L(max)} = \frac{(V_L)^2}{R_L} = \frac{(5.30 \text{ V})^2}{75 \text{ \Omega}} = 375 \text{ mW} \]

(b) Maximum peak voltage = 12 \text{ V}_{p}, \quad 12 \text{ V}_{p} = 8.48 \text{ V} \text{ rms}
\[ P_{L(max)} = \frac{(V_L)^2}{R_L} = \frac{(8.48 \text{ V})^2}{75 \text{ \Omega}} = 960 \text{ mW} \]
Q12)  
(a) $C_2$ open or $Q_2$ open  
(b) power supply off, open $R_1$, $Q_1$ base shorted to ground  
(c) $Q_1$ has collector-to-emitter short  
(d) one or both diodes shorted

Q13)  
$$P_{D(\text{avg})} = \left(\frac{t_{\text{on}}}{T}\right) V_{CE(\text{sat})} I_{C(\text{sat})} = (0.1)(0.18 \text{ V})(25 \text{ mA}) = 450 \mu\text{W}$$

Q14)  
$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(10 \text{ mH})(0.001 \mu\text{F})}} = 50.3 \text{ kHz}$$

Q15)  
$$V_{\text{out(pp)}} = 2V_{CC} = 2(12 \text{ V}) = 24 \text{ V}$$

Q16)  
$$P_{\text{out}} = \frac{0.5V_{CC}^2}{R_c} = \frac{0.5(15 \text{ V})^2}{50 \Omega} = 2.25 \text{ W}$$

$$P_{D(\text{avg})} = \left(\frac{t_{\text{on}}}{T}\right) V_{CE(\text{sat})} I_{C(\text{sat})} = (0.1)(0.18 \text{ V})(25 \text{ mA}) = 0.45 \text{ mW}$$

$$\eta = \frac{P_{\text{out}}}{P_{\text{out}} + P_{D(\text{avg})}} = \frac{2.25 \text{ W}}{2.25 \text{ W} + 0.45 \text{ mW}} = 0.9998$$