CHAPTER 7
POWER AMPLIFIERS

7-1 THE CLASS A POWER AMPLIFIER
- Any amplifier biased in the linear region (active region) is called a class A amplifier.
- The amplifiers discussed in Chapter 6 are an example of class A amplifiers.
- The main purpose of a power amplifier is to deliver power to the load rather than voltage.
- Any amplifier that has a power rating of more than 1Watt is considered a power amplifier.
- With such power, heat dissipation in the components need to be considered.
- Figure 1 shows a typical input/output relation of a class A power amplifier.

7.1.1 Centered Q-Point
- When the Q-point is at the center of the load line, maximum class A output signal can be obtained.
- This is shown in Figure 2. The Q-point provides the maximum AC output in terms of the AC collector current and AC collector voltage.
- If the Q-point is closer to cutoff then the output is clipped from the negative cycle shown in Figure 3(a).
- If the Q-point is closer to saturation then the output is clipped from the positive cycle shown in Figure 3(b).

7.1.2 Power Gain
- Power gain of an amplifier is defined as ratio of power delivered to load to input power.
\[ A_P = \frac{P_L}{P_{in}} \]
For the class A amplifier discussed in Chapter 6, we can find the power gain as

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

### 7.1.3 DC Quiescent Power (Power at Q-point)
- The power dissipation of a transistor with no AC signal input is the product of its Q-point collector current and voltage.

\[ P_{DQ} = I_{CQ} V_{CEQ} \]

- The above represents the maximum power that a class A amplifier can handle. So the transistor used should have higher rating than the maximum deliverable power.

### 7.1.4 Output Power
- The output power in general is the product of the \textit{rms load current} and \textit{rms load voltage}.
- For a CE amplifier maximum peak output voltage is

\[ V_{c(max)} = I_{CQ} R_c \]

Where \( R_c = R_c \parallel R_L \). The rms value will be \( 0.707V_{c(max)} \).

- The maximum peak output current is

\[ I_{c(max)} = \frac{V_{CEQ}}{R_c} \]

The rms value is \( 0.707I_{c(max)} \).
- So the maximum signal power output will be

\[ P_{out(max)} = (0.707I_c)(0.707V_c) = 0.5I_{CQ}V_{CEQ} \]

**NOTE: REFER EXAMPLE 7-1 PAGE 344**

### 7.1.5 Efficiency
- The efficiency of any amplifier is the \textit{ratio of the output signal power supplied to the load to the total power from the DC supply}.
- The DC power from the supply is given by

\[ P_{DC} = 2I_{CQ}V_{CEQ} \]

- The maximum efficiency, \( \eta_{max} \), of a class A amplifier is

\[ \eta_{max} = \frac{P_{out}}{P_{DC}} = \frac{0.5I_{CQ}V_{CEQ}}{2I_{CQ}V_{CEQ}} = 0.25 \]

- So the maximum efficiency of a class A amplifier cannot be higher than 25%.
- Practically it is even less (about 10%). This makes class A amplifier not very efficient power amplifiers.

**NOTE: REFER EXAMPLE 7-2 PAGE 345**

### 7.2 The Class B and Class AB Push-Pull Amplifiers
- When an amplifier is biased at cutoff then it a class B amplifier.
- Class B amplifier conduct in the linear region for 180° of the input cycle while it is at cutoff for the rest of the 180°.
- Class AB amplifiers conduct for slightly more than 180°.
- The main advantage of class B and AB amplifier over the class A amplifier is its higher efficiency.
- This means it can deliver more output power for a given amount of input power.
- The term push-pull refers to fact that class B and AB amplifiers 2 transistors for each cycle of input signal.

### 7.2.1 Class B Operation
- Class B operation in shown in Figure 4.
- Class B amplifier is biased at cutoff.
- So $I_{CQ}=0$ and $V_{CEQ}=V_{CE(cutoff)}$.

### 7.2.2 Class B Push-Pull Operation
- Figure 5 shows that the circuit conducts only in the positive cycle.
- It is necessary to add a second class B amplifier to conduct in the negative cycle.
- This combination is **Push-Pull** operation.
- There are two ways to achieve a push pull operation.
  - Transformer Coupling
  - Complementary Symmetry Transistors

#### Transformer Coupling
- Class B amplifier with transformer coupling is shown in Figure 6.
- The center-tapped input transformer produces the out-of-phase input signal for the 2 transistors.
- Both transistors are $npn$.
- Q1 will conduct in the positive while Q2 will conduct in the negative cycle.
- The output transformer will combine the 2 outputs of Q1 and Q2.

#### Complementary Symmetry Transistors
- Class B amplifier with complementary symmetry transistors is shown in Figure 7.
- It consists of 2 emitter-followers and both positive and negative supplies.
- This is a complimentary amplifier because Q1 is npn while Q2 is pnp transistor.
- Q1 conducts in the positive cycle while Q2 conducts in the negative cycle.

Crossover Distortion
- When the base voltage is zero as in the case of the circuit in Figure 7, both transistors are off and the input signal voltage must exceed $V_{BE}$ before a transistor conducts.
- So in between the positive and negative cycle, there is a time when no transistor is conducting as shown in Figure 8.
- The resulting distortion in the output waveform is called **crossover distortion**.

![Crossover distortion diagram](image)

### 7.2.3 Biasing the Push-Pull Amplifier for Class AB Operation
- To overcome the distortion, biasing is adjusted to overcome the $V_{BE}$.
- This results in class AB amplifier.
- In class AB amplifier the transistor are biased into conduction even when there is no input signal.
- This is achieved by voltage-divider and diode arrangement as shown in Figure 9.
- When D1 and D2 are same, R1 and R2 are same and Q1 and Q2 are of same type, then the currents in the transistor are same.
- The collector current can be given as
  \[
  I_{CQ} = \frac{V_{CC} - 0.7V}{R_1}
  \]

AC Operation
- The AC collector saturation current with a push-pull amplifier is given as
  \[
  I_{C(sat)} = \frac{V_{CC}}{R_L}
  \]
- The AC load line for the class AB amplifier is shown in Figure 9.
- Under maximum condition, Q1 and Q2 are alternatively driven from near cutoff to near saturation that is for Q1 from 0V to $+V_{CC}$ and for Q2 from 0V to $-V_{CC}$.
- The main advantage of class B/AB amplifier over the class A amplifier is that there is very little current in the transistor when there is no input signal. This results in low power dissipation when there is no signal.
In class A amplifier, they are biased at almost the center of the load line. This results in flow of current from the supply even when there is no input signal resulting in power dissipation.

Therefore class B/AB amplifier has more efficiency as compared to class A amplifier.

\[
I_{\text{out(rms)}} = 0.707I_{\text{out(peak)}} = I_{\text{c(sat)}}
\]

\[
V_{\text{out(rms)}} = 0.707V_{\text{out(peak)}} = 0.707V_{\text{CEQ}} = 0.707V_{\text{CC}}/2
\]

DC Input Power
- The DC input power from \( V_{\text{CC}} \) is given by

\[
P_{\text{DC}} = I_{\text{CC}}V_{\text{CC}} = \frac{I_{\text{c(sat)}}V_{\text{CC}}}{\pi}
\]

Efficiency
- Efficiency is defined as the ratio of AC output power to DC input power. So

\[
\eta = \frac{P_{\text{out}}}{P_{\text{DC}}} = \frac{0.25I_{\text{c(sat)}}V_{\text{CC}}}{I_{\text{c(sat)}}V_{\text{CC}}/\pi} = 0.25\pi = 0.79 = 79\%
\]

NOTE: REFER EXAMPLE 7-4 and 7-5 PAGE 353 and 354

7.2.5 Input Resistance
- The 2 amplifiers configuration in class B/AB are emitter-follower so its input resistance is given as

\[
R_{\text{in}} = \beta_{ae}(r_e + R_L)\left|R_1\right|\left|R_2\right|
\]
7-3 THE CLASS C AMPLIFIER

- Class C amplifiers are biased such that the conduction occurs for very much less than 180°.
- Class C amplifiers are more efficient than class A, B and AB amplifiers.
- They are generally used in radio frequency applications.

7.3.1 Basic Class C Operation

- Class C amplifier operation is shown in Figure 10 with a resistive common emitter configuration.

- It is biased below cutoff with negative voltage (-V_{BB}) supply.
- The AC input signal has a peak value slightly greater than \(|V_{BB}| + V_{BE}\) so the base voltage exceeds the barrier potential for a very short time near the positive peak as shown in Figure 10(b).
- At this time, the transistor is turned on. The ideal maximum collector current is \(I_{C\text{(sat)}}\) and the ideal minimum collector voltage is \(V_{CE\text{(sat)}}\).

7.3.2 Power Dissipation

- Power dissipation of class C amplifier is low because it is on for a very small percentage of the input signal.
- Figure 11(a) shows collector current pulse with time between successive pulses is $T$.
- Figure 11(b) shows the collector current and voltage during on time of the transistor.
- Under ideal conditions, $I_c = I_{c\text{(sat)}}$ and $V_c = V_{ce\text{(sat)}}$ when the transistor is on.
- The power dissipation during on time is 
  \[ P_{D\text{(on)}} = I_{c\text{(sat)}}V_{ce\text{(sat)}} \]
- As the transistor is on for very short time and off for a long time, the average power dissipation is given as
  \[ P_{D\text{(avg)}} = \left( \frac{t_{\text{on}}}{T} \right) P_{D\text{(on)}} = \left( \frac{t_{\text{on}}}{T} \right) I_{c\text{(sat)}}V_{ce\text{(sat)}} \]

### NOTE: REFER EXAMPLE 7-7 PAGE 359

#### 7.3.3 Tuned Operation
- As the output of class C amplifier is not an amplified replica of the input signal, it is necessary to use a parallel resonant circuit (tank) as shown in Figure 12.

The tank consists of a capacitor and inductor in parallel. It produces voltage oscillation across it with a resonant frequency given by

\[ f_r = \frac{1}{2\pi\sqrt{LC}} \]

- The short pulse of current on each cycle maintains the sinusoidal oscillation output voltage across the tank as shown in Figure 12.
7.3.4 Maximum Output Power

- The peak-to-peak voltage across the tank circuit is approximately $2V_{CC}$, the maximum output power can be given as

$$P_{out} = \frac{V_{rms}^2}{R_c} = \frac{0.5V_{CC}^2}{R_c}$$

- The total power that must be supplied to the amplifier is

$$P_T = P_{out} + P_{D(avg)}$$

- Therefore the efficiency is given as

$$\eta = \frac{P_{out}}{P_{out} + P_{D(avg)}}$$

- When $P_{out} \gg P_{D(avg)}$, then efficiency of class C amplifier is close to 1 (100%).

NOTE: REFER EXAMPLE 7-8 PAGE 363