Chapter 11

Output Stages
Learning Objectives

1) The classification of **amplifier output stages**

2) Analysis and design of a **variety of output-stage types**

3) Overview of **power amplifiers**
Introduction

- One important aspect of an multistage amplifier is output resistance

- How to deliver signal to a load with low resistance

- Output stages:
  1) amplify current while maintaining voltage level
  2) provide low output resistance

- Most important aspect of output stage design is efficiency

- Because of the large signal level at the output and small-signal models cannot be applied

- Total harmonic distortion (THD): linearity of output stage
Commonly Used Output Stages
- Class A
- Class B
- Class AB
11.1 Classification of Output Stages

- Output stages are classified according to collector (or drain) current waveform that results when input signal is applied.

**Figure 11.1**: Collector current waveforms for transistors operating in (a) class A, (b) class B, (c) class AB, and (d) class C amplifier stages.
Class A Output Stage: Biasing Scheme

DC level at 0 V $v_I$ $v_{BE1}$ $i_{E1}$ $i_L$ $v_O$

Figure 11.2 An emitter follower ($Q1$) biased with a constant current $I$ supplied by transistor $Q2$. 
11.2 Class A Output Stage

Figure 11.3 Transfer characteristic of the emitter follower in Fig. 11.2. This linear characteristic is obtained by neglecting the change in $v_{BE1}$ with $i_L$. The maximum positive output is determined by the saturation of $Q_1$. In the negative direction, the limit of the linear region is determined either by $Q_1$ turning off or by $Q_2$ saturating, depending on the values of $I$ and $R_L$. 
11.3 Class B Output Stage

Figure 11.5: A class B output stage.
11.3 Class B Output Stage

Figure 11.6: Transfer characteristic for the class B output stage in Fig. 11.5.
Cross-over Distortion
11.4 Class AB Output Stage

- **Crossover distortion** can be virtually eliminated by biasing the complementary output transistor with small nonzero current.

- **A bias voltage** $V_{BB}$ is applied between $Q_N$ and $Q_P$. DC level at 0 V.

![Diagram of Class AB Output Stage]

*Diagram showing a Class AB output stage with transistors $Q_N$ and $Q_P$, bias voltage $V_{BB}$, and load resistor $R_L$. The diagram includes current arrows and voltage levels.*
Figure 11.12: Transfer characteristic of the class AB stage in Fig. 11.11.
Class AB: Biasing using Diodes

Biasing Diodes
Class AB: Biasing using Resistors and Diodes

Biasing scheme in Lab5

DC level at 0 V →

\[ \text{VCC} \]
\[ 15V \]
\[ RB1 \]
\[ 1k\Omega \]
\[ Q1 \]
\[ 2N2222A \]
\[ D1 \]
\[ 1N4148 \]
\[ IN \]
\[ RB2 \]
\[ 1k\Omega \]
\[ Q3 \]
\[ PN2907A \]
\[ O U T \]
\[ \text{VEE} \]
\[ -15V \]
Class AB: Biasing using $V_{BE}$ multiplier

$V_{BE}$ Multiplier

Diagram of the Class AB biasing circuit using $V_{BE}$ multiplier.
Class AB: Biasing using Transistors

Biasing Transistors

Class AB Stage

\[ v_I \]
\[ i_I \]
\[ v_O \]
\[ v_{CC} \]
\[ R_L = 100 \, \Omega \]
CMOS Class AB

Diode-Connected MOSFETs

Class AB Stage

$Q_1$, $Q_2$, $Q_P$, $Q_N$

$I_{BIAS}$

$V_{DD}$

$V_{GS}$

$V_{SS}$

$u_I$, $u_O$
Power Amplifiers
Figure 11.25 The popular TO3 package for power transistors: The case is metal with a diameter of about 2.2 cm; the outside dimension of the “seating plane” is about 4 cm. The seating plane has two holes for screws to bolt it to a heat sink. The collector is electrically connected to the case. Therefore an electrically insulating but thermally conducting spacer is used between the transistor case and the “heat sink.”
11.8.2 Use of Compound Devices

Darlington Pair

Compound pnp
11.8.2 Use of Compound Devices

Class AB output stage with Darlington *nnp* and compound *pnp* and $V_{BE}$ multiplier for biasing.
Figure 11.36 The simplified internal circuit of the LM380 IC power amplifier. (Courtesy: National Semiconductor Corporation.)
Summary

- Output stages are classified according to the transistor conduction angle: class A (360°), class AB (slightly more than 180°), class B (180°), and class C (less than 180°).

- The most common class A output stage is the emitter-follower. It is biased at a current greater than the peak load current.

- The class A output stage dissipates its maximum power under quiescent conditions (\(v_O = 0\)). It achieves a maximum power conversion efficiency of 25%.
Summary

- The class B stage is biased at zero current, and thus dissipates no power in quiescence.
- The class B stage can achieve a power conversion efficiency as high as 78.5%.
- The class B stage suffers from crossover distortion.
- The class AB output stage is biased at a small current; thus both transistors conduct for small input signals, and crossover distortion is virtually eliminated.
- Power BJTs can be created with Darling pair and Compound pnp to provide very high current gain.