BENHA UNIVERSITY
FACULTY OF ENGINEERING AT SHOUBRA

**ECE-312**
**Electronic Circuits (A)**

# Lecture # 10
# Power Amplifiers (Class C & D)

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# Agenda

- Amplifier Distortion
- Power Transistor Heat Sinking
- Class C & Class D Amplifiers

# AMPLIFIER DISTORTION

# Amplifier Distortion

- A pure sinusoidal signal has a single frequency at which the voltage varies positive and negative by equal amounts. Any signal varying over less than the full 360° cycle is considered to have distortion.
- Distortion can occur because the device characteristic is not linear, in which case non-linear or ***amplitude distortion*** occurs.
- Distortion can also occur because the circuit elements and devices respond to the input signal differently at various frequencies, this being ***frequency distortion***.
- One technique for describing distorted but period waveforms uses Fourier analysis

- Harmonic Distortion

A signal is considered to have harmonic distortion when there are harmonic frequency components

$$\%\, n\text{th harmonic distortion} = \%\, D_n = \frac{|A_n|}{|A_1|} \times 100\%$$

$A_1$ : amplitude of the fundamental frequency
$A_n$ : amplitude of the *n*th frequency component

- Total Harmonic Distortion

$$\%\, \text{THD} = \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} \times 100\%$$

# Harmonic Distortion

- Second Harmonic Distortion

$$i_C \approx I_{C_Q} + I_0 + I_1 \cos \omega t + I_2 \cos \omega t$$

At point 1 ($\omega t = 0$),

$$i_C = I_{C_{\max}} = I_{C_Q} + I_0 + I_1 \cos 0 + I_2 \cos 0$$
$$I_{C_{\max}} = I_{C_Q} + I_0 + I_1 + I_2$$

At point 2 ($\omega t = \pi/2$),

$$i_C = I_{C_Q} = I_{C_Q} + I_0 + I_1 \cos \frac{\pi}{2} + I_2 \cos \frac{2\pi}{2}$$
$$I_{C_Q} = I_{C_Q} + I_0 - I_2$$

At point 3 ($\omega t = \pi$),

$$i_C = I_{C_{\min}} = I_{C_Q} + I_0 + I_1 \cos \pi + I_2 \cos 2\pi$$
$$I_{C_{\min}} = I_{C_Q} + I_0 - I_1 + I_2$$

Solving the preceding three equations simultaneously gives the following results:

$$I_0 = I_2 = \frac{I_{C_{\max}} + I_{C_{\min}} - 2I_{C_Q}}{4}, \qquad I_1 = \frac{I_{C_{\max}} - I_{C_{\min}}}{2}$$

$$D_2 = \left|\frac{I_2}{I_1}\right| \times 100\%$$

$$D_2 = \left|\frac{\frac{1}{2}(I_{C_{\max}} + I_{C_{\min}}) - I_{C_Q}}{I_{C_{\max}} - I_{C_{\min}}}\right| \times 100\%$$

In a similar manner,

$$D_2 = \left|\frac{\frac{1}{2}(V_{CE_{\max}} + V_{CE_{\min}}) - V_{CE_Q}}{V_{CE_{\max}} - V_{CE_{\min}}}\right| \times 100\%$$

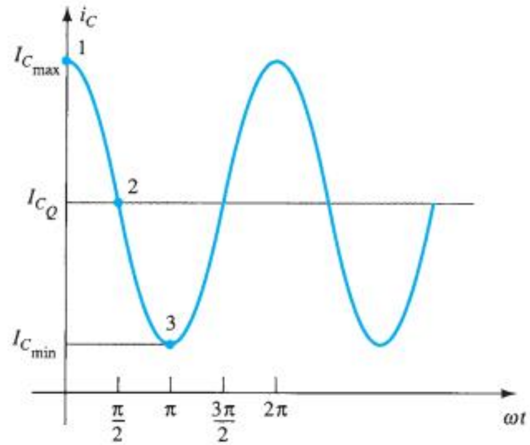


**FIG. 12.20**
*Waveform for obtaining second harmonic distortion.*

- Power of a Signal Having Distortion

$$P_1 = \frac{I_1^2 R_C}{2}$$

$$P = (I_1^2 + I_2^2 + I_3^2 + \cdots)\frac{R_C}{2}$$

$$P = (1 + D_2^2 + D_3^2 + \cdots)I_1^2 \frac{R_C}{2} = (1 + \text{THD}^2)P_1$$

# Graphical Description of Harmonic Components of a Distorted Signal

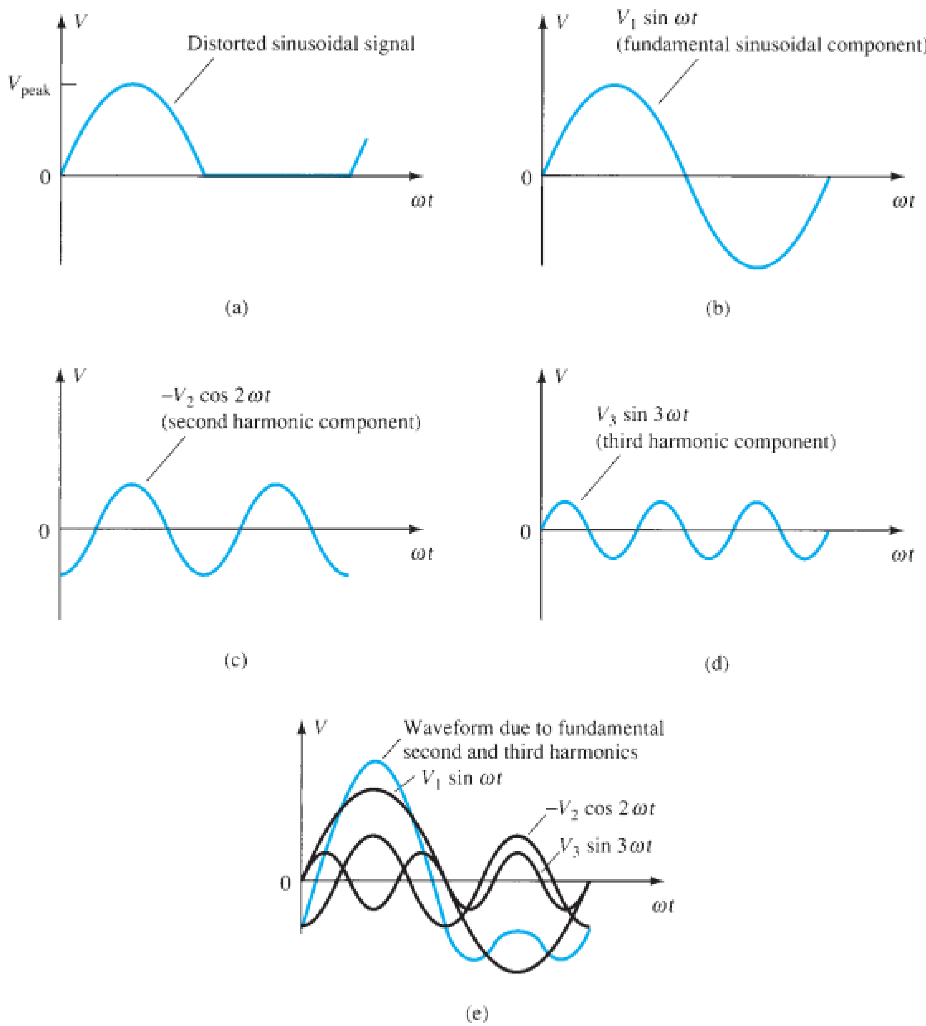


**FIG. 12.21**
*Graphical representation of a distorted signal through the use of harmonic components.*

# POWER TRANSISTOR HEAT SINKING

# Power Transistor Heat Sinking

- The maximum power handled by a particular device and the temperature of the transistor junctions are related since the power dissipated by the device causes an increase in temperature at the junction of the device.

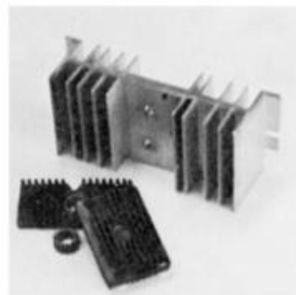

**FIG. 12.22**
*Typical power heat sinks.*

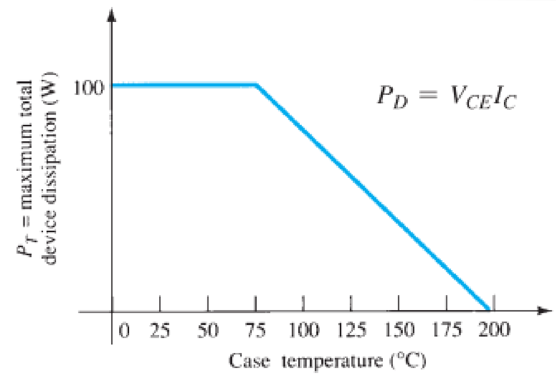


**FIG. 12.23**
*Typical power derating curve for silicon transistors.*

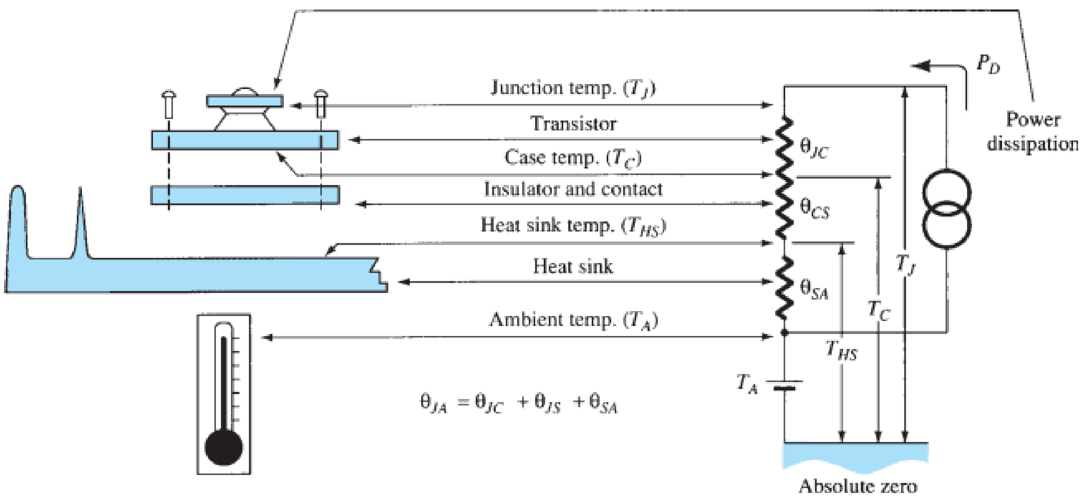


**FIG. 12.24**
*Thermal-to-electrical analogy.*

$\theta_{JA}$ = total thermal resistance (junction to ambient)
$\theta_{JC}$ = transistor thermal resistance (junction to case)
$\theta_{CS}$ = insulator thermal resistance (case to heat sink)
$\theta_{SA}$ = heat-sink thermal resistance (heat sink to ambient)

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

$$T_J = P_D\theta_{JA} + T_A$$

# CLASS C & CLASS D AMPLIFIERS

# Class C Amplifier

- Although class A, class AB, and class B amplifiers are most used as power amplifiers, class D amplifiers are popular because of their very high efficiency.
- Class C amplifiers, although not used as audio amplifiers, do find use in tuned circuits as in communications.

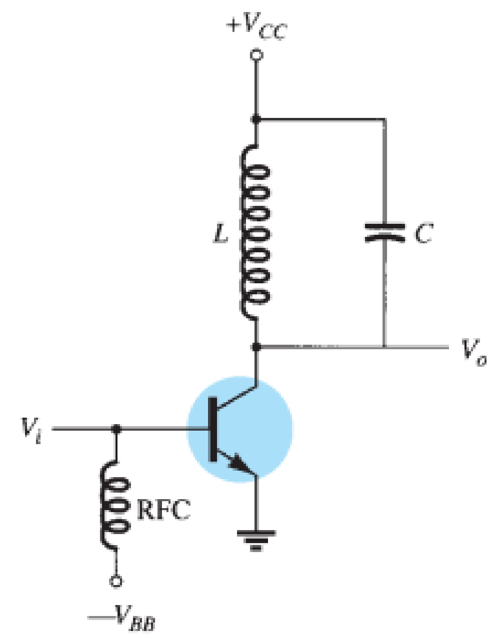


**FIG. 12.25**
*Class C amplifier circuit.*

- The tuned circuit in the output, however, will provide a full cycle of output signal for the fundamental or resonant frequency of the tuned circuit ( L and C tank circuit) of the output.
- This type of operation is therefore limited to use at one fixed frequency, as occurs in a communications circuit, for example.

# Class D Amplifier

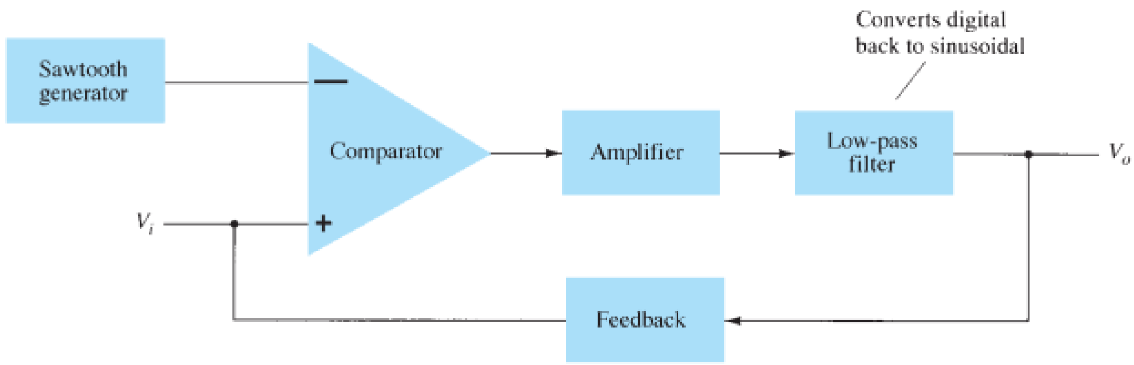


**FIG. 12.27**
*Block diagram of class D amplifier.*

- Class D amplifier is designed to operate with digital or pulse-type signals.
- An efficiency of over 90% is achieved, making it desirable in power amplifiers.
- It is necessary to convert any input signal into a pulse-type waveform before using it to drive a large power load and to convert the signal back into a sinusoidal-type signal to recover the original signal.

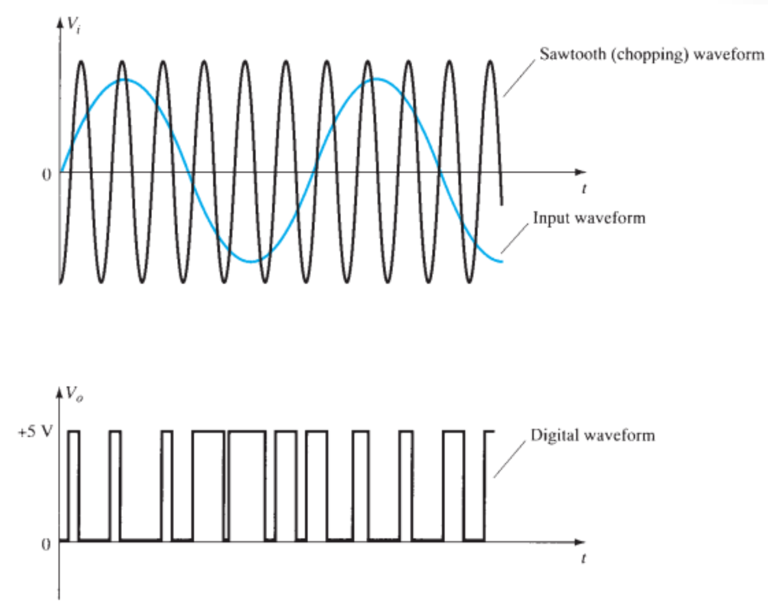


**FIG. 12.26**
*Chopping of a sinusoidal waveform to produce a digital waveform.*

- For more details, refer to:
  - Chapter 12 at R. Boylestad, **Electronic Devices and Circuit Theory**, 11th edition, Prentice Hall.
- The lecture is available online at:
  - http://bu.edu.eg/staff/ahmad.elbanna-courses/11966
- For inquires, send to:
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