Power Amplifiers

- Introduction
- Definitions and amplifier types
- Series fed class A amplifiers
- Transformer coupled class A amplifier
- Transformer coupled amplifier continuation
- Numerical
- Class B amplifier operation
- Class B amplifier circuits
- Numerical
- Amplifier distortion
- Numerical
- Second harmonic distortion
- Power transistor heat sinking
- Thermal analogy of power transistor
- Class C and class D amplifiers
- Numerical
Introduction

- Amplifier receives a signal from some pickup transducer or other input source and provides larger version of the signal.
- In small signal amplifiers the main factors are usually amplification, linearity and magnitude of gain.

Classes of PAs

- Amplifier classes represent the amount the output signal varies over one cycle of operation for a full cycle of input signal
- So the following classes of PA are defined
  - Class A
  - Class B
  - Class AB
  - Class C
  - Class D

Class A amplifier

- Class A amplifying devices operate over the whole of the input cycle such that the output signal is an exact scaled-up replica of the input with no clipping. Class A amplifiers are the usual means of implementing small-signal amplifiers. They are not very efficient. a theoretical maximum of 50% is obtainable with inductive output coupling and only 25% with capacitive coupling.
- In a Class A circuit, the amplifying element is biased so the device is always conducting to some extent, and is operated over the most linear portion of its characteristic curve Because the device is always conducting, even if there is no input at all, power is drawn from the power supply. This is the chief reason for its inefficiency.
Class B

- Class B amplifiers only amplify half of the input wave cycle. As such they create a large amount of distortion, but their efficiency is greatly improved and is much better than Class A. Class B has a maximum theoretical efficiency of 78.5% (i.e., $\pi/4$). This is because the amplifying element is switched off altogether half of the time, and so cannot dissipate power.

- A single Class B element is rarely found in practice, though it can be used in RF power amplifier where the distortion levels are less important. However, Class C is more commonly used for this.
Class AB

- A practical circuit using Class B elements is the complementary pair or "push–pull" arrangement. Here, complementary or quasi-complementary devices are used to each amplify the opposite halves of the input signal, which is then recombined at the output. This arrangement gives excellent efficiency, but can suffer from the drawback that there is a small mismatch at the "joins" between the two halves of the signal.
- Class AB sacrifices some efficiency over class B in favor of linearity, so will always be less efficient (below 78.5%). It is typically much more efficient than class A.
Class C

- Class C amplifiers conduct less than 50% of the input signal and the distortion at the output is high, but high efficiencies (up to 90%) are possible. Some applications (for example, megaphones) can tolerate the distortion. A much more common application for Class C amplifiers is in RF transmitters, where the distortion can be vastly reduced by using tuned loads on the amplifier stage.
- The input signal is used to roughly switch the amplifying device on and off, which causes pulses of current to flow through a tuned circuit.
Class D

- Class D amplifiers are much more efficient than Class AB power amplifiers. As such, Class D amplifiers do not need large transformers and heavy heatsinks, which means that they are smaller and lighter in weight than an equivalent Class AB amplifier. All power devices in a Class D amplifier are operated in on/off mode.
- These amplifiers use pulse width modulation,
Comparison of Amplifier classes

<table>
<thead>
<tr>
<th>parameters</th>
<th>A</th>
<th>AB</th>
<th>B</th>
<th>C*</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating cycle</td>
<td>360°</td>
<td>180-360°</td>
<td>180°</td>
<td>Less than 180°</td>
<td>Pulse operation</td>
</tr>
<tr>
<td>Power efficiency</td>
<td>25-50%</td>
<td>Between 25% (50%) and 78.5%</td>
<td>78.5%</td>
<td>Typically over 90%</td>
<td></td>
</tr>
</tbody>
</table>

* class C is usually not used for delivering large amounts of power, thus the efficiency is not given here.

Series fed class A amplifiers

- It is a fixed bias circuit.
DC bias operation

The DC bias set by Vcc and Rb

\[ I_B = \frac{V_{CC} - 0.7V}{R_B} \]

Collector current \( I_C = \beta I_B \)

Collector –emitter voltage

\[ V_{CE} = V_{CC} - I_C R_C \]

Load line

Power considerations

- The power into an amplifier is provided by the power supply
- With no input supply, current drawn is collector bias current \( I_{Cq} \)

\[ p_i(dc) = V_{CC} I_{Cq} \]

Output power

- The output voltage and current varying around the bias point provide ac power to the load.
Using rms signals

- \( P_0(\text{ac}) = V_{CE(\text{rms})} I_{C(\text{rms})} \)
  - \( = I_{C(\text{rms})}^2 R_c \)
  - \( = V_{CE(\text{rms})}^2 / R_c \)

- **Using peak signals**

  The ac power delivered to the load is
  \[ p_0 = \frac{V_{CE(p)} I_{C(p)}}{2} \]
  or
  \[ = \frac{I_{C(p)}^2}{2} R_c \]
  \[ = \frac{V_{CE(p)}^2}{2R_c} \]

- **Using peak-peak signals**

  \( P_0(\text{ac}) = \frac{V_{CE(p-p)} I_{C(p-p)}}{8} \)
  - \( = \frac{I_{C(p-p)}^2}{8} R_c \)
  - \( = \frac{V_{CE(p)}^2}{8R_c} \)

**Efficiency**

- **Efficiency of an amplifier** represents the amount of ac power delivered from dc source. It can be calculated using

\[
\% \eta = \frac{P_{o(\text{ac})}}{P_{i(\text{dc})}} \times 100
\]

**Maximum Efficiency**

- **Maximum voltage swing** \( V_{CE(p-p)} = V_{CC} \)
- **Maximum current swing** \( I_{C(p-p)} = V_{CC} / R_c \)
- **Maximum power**

\[
P_{o(\text{ac})} = \frac{V_{cc}(V_{cc} / R_c)}{8}
\]

- The maximum power input evaluated using dc bias current set to half of the maximum value....
- Maximum $P_i(dc) = V_{cc}(\text{maximum } I_c)$
  
  $$= V_{cc} \frac{V_{cc}/R_c}{2}$$

- Maximum efficiency = \(\text{maximum } P_o(ac)/\text{maximum } P_i(dc)\) x 100
  
  $$= \frac{V_{cc}^2/8R_c}{V_{cc}^2/2R_c} \times 100$$

  $$= 25\%$$

**Maximum efficiency**

- The maximum efficiency of a class A series fed amplifier is thus seen to be 25%.
- The maximum efficiency occurs only for ideal conditions of both voltage and current swing, thus practical circuits will have less than this percentage.

**Numerical**

Calculate input power, output power and efficiency of the amplifier circuit for the circuit shown below for an input voltage that increases the base current by 10mA peak.

Data given

- $V_{CC}=20V$
- $R_c=20\text{ ohms}$
- $R_b=1k\text{ ohms}$
- $\beta=25$
Solution

Hint: use the above derived formulae

- \( P_{o(ac)} = 0.625 \text{W} \)
- \( P_{i(dc)} = 9.6 \text{W} \)
- Efficiency = 6.5\%
The transformer can step up or step down a voltage applied to primary coil.

\[ \frac{I_2}{I_1} = \frac{N_1}{N_2} \quad \frac{V_2}{V_1} = \frac{N_2}{N_1} \]

Transformer coupled class A PA
• A form of class A amplifier having maximum efficiency of 50% uses transformer to couple the output signal to the load.

Impedance transformation

\[ \frac{R_{L_1}}{R_L} = \frac{R_2}{R_1} = \frac{V_2/I_2}{V_1/I_1} = \frac{V_2}{V_1} \frac{I_1}{I_2} = \frac{N_2}{N_1} \frac{N_2}{N_1} = \left( \frac{N_2}{N_1} \right)^2 \]

If \( \alpha = N_1/N_2 \) Then Above equation reduces to

\[ \frac{R_{L_1}}{R_L} = \frac{R_1}{R_2} = \left( \frac{N_1}{N_2} \right)^2 = \alpha^2 \]
Load resistance reflected to the primary side as,

\[ R_1 = \alpha^2 R_2 \]

\[ OR \]

\[ R_L^1 = \alpha^2 R_L \]

Transformer coupled amplifier
- Drawing DC and AC load line
- Signal swing and output AC power

\[ V_{CE(p-p)} = V_{CE\max} - V_{CE\min} \]

\[ I_{C(p-p)} = I_{C\max} - I_{C\min} \]

\[ P_{o(ac)} = \frac{(V_{CE\max} - V_{CE\min})(I_{C\max} - I_{C\min})}{8} \]

\[ V_L = V_2 = \frac{N_2}{N_1} V_1 \]

Power across the load can be expressed as

\[ P_L = \frac{V_{L(rms)}}{R_L} \]

- \[ I_1 = I_2 = N_1/N_2 I_C \]
- with the output ac power then calculated using

\[ P_L = I_L^2(rms) R_L \]
Numerical
Calculate the ac power delivered to 8 ohm speaker for the circuit shown below.
The circuit component values result in a dc base current of 6mA, and the input signal Vi results in a peak base current swing of 4mA.

Solution:
Step 1: dc load line is drawn vertically from voltage point
\[ V_{CEQ} = V_{CC} = 10V \]
Step 2: for IB=6mA the operating point
\[ V_{CEQ} = 10V \text{ and } I_{CQ} = 140mA \]
Step 3: the effective resistance seen at the primary is \( R_L' = (N1/N2)^2 \cdot R_L \), 72 ohms.
Step 4: the ac load line can be drawn of slope 1/72.
\[ I_C = V_{CE}/R_L' = 10/72 = 139mA \]
Mark point A on graph.
\[ I_{CEQ} + I_C = 140mA + 139mA \]
Connect point A through the point Q to obtain the ac load line.
For a given base current of 4mA peak, the maximum and minimum collector current and collector–emitter voltage obtained from graph:

\[ P_o(ac) = \frac{(V_{CE_{max}} - V_{CE_{min}})(I_{C_{max}} - I_{C_{min}})}{8} \]

\[ P_o(ac) = \frac{(18.3 - 1.7)(255m - 25m)}{8} = 0.477W \]

**Efficiency**

The input dc power obtained from the supply is calculated from the supply dc voltage and thus average power drawn from the supply \( P_i(dc) = V_{CC} I_{CQ} \)

For the transformer coupled amplifier power dissipated by the transformer is small (due to small resistance)

The only power loss considered here is that dissipated by the power transistor and calculated by:

\[ P_Q = P_i(dc) - P_o(ac) \]

\[ \eta = \frac{P_o(ac)}{P_i(dc)} \times 100 \]

**Maximum theoretical efficiency**

\[ \%\eta = 50 \left( \frac{(V_{CE_{max}} - V_{CE_{min}})}{(V_{CE_{max}} + V_{CE_{min}})} \right)^2 \% \]
Larger the value of VCEmax and smaller the value of VCEmin, the closer the efficiency approaches the theoretical limit of 50%.

**Numerical**

Calculate the efficiency of a transformer coupled class A amplifier for a supply of 12V and outputs of:

a. V(p)=12V  
b. V(p)=6V  
c. V(p)=2V

**Solution:**

Here V_{CE}=V_{CC}=12V, the maximum and minimum of the voltage swing are

- V_{CEmax}=V_{CEQ}+V(p)=12V+12V=24V
- V_{CEmin}=V_{CEQ}-V(p)=12V-12V=0V
- This results in efficiency of ,

\[
\eta = 50 \left( \frac{24 - 0}{24 + 0} \right)^2 = 50\%
\]

**Case ii.**

- V_{CEmax}=V_{CEQ}+V(p)=12V+6V=18V  
- V_{CEmin}=V_{CEQ}-V(p)=12V-6V=6V  
- This results in efficiency of 12.5%

**Case iii.**

- V_{CEmax}=V_{CEQ}+V(p)=12V+2V=14V  
- V_{CEmin}=V_{CEQ}-V(p)=12V-2V=10V  
- This results in efficiency of 1.39%
Class B Amplifier operation

- Class B operation is provided when the dc bias leaves the transistor biased just off, the transistor turning on when the ac signal is applied.
- This is essentially no bias and conducts for only one half cycle.
- To obtain output for full cycle, it is required to use two transistors and have each conduct on opposite half-cycles, the combined operation providing a full cycle of output on opposite half cycles of output signal.
- Since one part of the circuit pushes the signal high during one half cycle and other part pulls the signal low during the other half cycle, the circuit is referred to as push-pull circuit.
- Class B operation provides greater efficiency than was possible using single transistor in class A operation.

Class B push-pull
Power equations

• Input DC power

\[ P_{i(dc)} = V_{cc} I_{dc} \]

➤ Here \( I_{dc} \) is the average current drawn

➤ Hence \( I_{dc} \) can be written as

\[ I_{dc} = \frac{2}{\Pi} I(p) \]

➤ Hence input power is equal to

\[ P_{i(dc)} = V_{cc} \left( \frac{2}{\Pi} I(p) \right) \]

➤ Output ac power can be evaluated as,

\[ P_{o(ac)} = \frac{V_{L}^2(rms)}{R_L} \]

Efficiency:

\[ \% \eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100 \]

\[ \% \eta = \frac{V_{L}^2(p)/2R_L}{V_{cc}[(2/\Pi)I(p)]} \times 100\% \]

\[ = \frac{\Pi}{4} \cdot \frac{V_{L}(p)}{V_{cc}} \times 100 = 78.5\% \]
Power dissipated by output transistors

- \( P_{2Q} = P_i^{(dc)} - P_o^{(ac)} \)
- Power handled by each transistor = \( P_{2Q}/2 \)

Numerical:

For a class B amplifier providing a 20V peak signal to a load of 16 ohms (speaker) and power supply of VCC=30V, determine the input power, output power, and circuit efficiency.

Solution:

Hint: use the above derived formulae
- \( P_i^{(dc)} = 23.9W \)
- \( P_o^{(ac)} = 12.5W \)
- Efficiency = 52.3%

For a class B amplifier using supply of VCC=30V and driving a load of 16 ohms determine the maximum input power, output power and transistor dissipation.

Solution:

Hint: use the above derived formulae
- \( P_o^{(ac)} = 28.125W \)
- \( P_i^{(dc)} = 35.81W \)
- Efficiency = 78.54%
- \( P_q = 5.7W \)
Efficiency in another form

\[ P_{o(ac)} = \frac{V_L^2(p)}{2R_L} \]

\[ P_i(dc) = V_{cc}I_{dc} = V_{cc}\left[\frac{2V_L(p)}{\pi R_L}\right] \]

\[ \%\eta = \frac{VL2(p)/2RL}{V_{cc}\left[\frac{2V_L(p)}{\pi R_L}\right]} \times 100 \]

\[ \%\eta = \frac{78.54}{V_{cc}} \]

Numerical

1. Calculate the efficiency of a class B amplifier for a supply voltage of VCC=24V with peak output voltages of

   a. VL(p)=22V
   b. VL(p)=6V
Class B amplifier circuits

- To obtain phase inverted signals.
  - To use transformers using op-amps
  - Using transistors

Phase splitter circuits

Using BJT
Using op-amp

Transformer coupled push-pull amplifier
Complementary symmetry circuits

![Complementary symmetry circuit diagram]

**Working of the circuit**

- Every transistor will conduct for half cycle
- Single input signal is applied to the base of both transistors
- npn transistor will be biased in conduction for positive half cycle of the input.
- During negative half cycle pnp transistor is biased into conduction when input goes to negative.

**Disadvantages**

- One disadvantage is that the need of two separate voltage supplies.
- Cross over distortion in the output signal
- This cross over distortion is referred to as the nonlinearity in the output signal during cross over from positive to negative or vice-versa. This is due to the fact that, none of the transistors are on near zero input and thus output does not follow input.
Complementary symmetry push-pull circuit using Darlington transistors

- This circuit provides higher output current and lower output resistance.
- Here the load resistance is matched by low output resistance of the driving source.

Quasi complementary push-pull transformer less power amplifier

- In practical circuit it is preferred to use npn for both high-current-output devices.
- Practical means of obtaining complementary operation while using same, matched transistors for the output is provided by a quasi complementary circuit.
• Here push-pull operation is achieved by using complementary transistors (Q1 and Q2) before the matched npn output transistors (Q3 and Q4)
• Q1 and Q3 forms a Darlington connection
• Q2 and Q4 forms a feedback connection, which similarly provides low-impedance to drive the load.
• Resistor R2 can be adjusted to minimize cross over distortion by adjusting the dc bias condition.
• This is the most popular form of power amplifier used today.
Numerical

For the circuit shown calculate input power, output power and power handled by each transistor and circuit efficiency.

- Given Vcc=+25V and VEE=-25V
- Input vi=12V
- Load resistance=4 ohms

Solution:

Hint: use the above derived formulae.

- Po(ac)=36.125W
- Pi(dc)=67.75W
- PQ=15.8W
- Efficiency=53.3%
**Numerical**

For the circuit calculate maximum input power, maximum output power, input voltage for maximum power operation and power dissipated by the output transistor at this voltage.

Solution:

Hint: use the above derived formulae

- $P_{\text{dc}}=99.47\,\text{W}$
- $P_{\text{ac}}=78.125\,\text{W}$
- Efficiency=78.54%
- To achieve maximum power operation the output voltage must be $V_{\text{L(p)}}=V_{\text{CC}}$
- $P_Q=21.3\,\text{W}$

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**Numerical**

For the circuit shown, determine the maximum power dissipated by the output transistors and the input voltage at which this occurs.

Solution:

- $P_Q=31.66\,\text{W}$
- $V_L=15.9\,\text{V}$
Amplifier distortion

- Any signal varying over less than the full $360^\circ$ cycle is considered to have distortion.
- An ideal amplifier is capable of amplifying a pure sinusoidal signal to provide a larger version, the resulting waveform being a pure sinusoidal frequency sinusoidal signal.
- When distortion occurs, output will not be an exact duplicate of input signal (except for magnitude)
- Distortion can occur because the device characteristic is not linear. In this 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, a method that describes any periodic waveform in terms of its fundamental frequency component and frequency components at integer multiples- these components are called harmonic components or harmonics.

Example

A fundamental frequency of 1KHz could result in harmonics of 2KHz, 3KHz, 4KHz so on.,

- 1KHz is termed as fundamental frequency
- 2KHz is termed as second harmonic
- 3KHz is termed as third harmonic and so on.,
Harmonic Distortion

- A signal is considered to have harmonic distortion when there are harmonic frequency components.
- If fundamental frequency has amplitude $A_1$, and $n^{th}$ frequency component has an amplitude of $A_n$.
- Harmonic distortion can be defined as

\[
\% \text{ nth harmonic distortion} = \frac{|A_n|}{|A_1|} \times 100\%
\]

Numerical

Calculate the harmonic distortion components for an output signal having fundamental amplitude of 2.5V, second harmonic amplitude of 0.1V, and fourth harmonic amplitude of 0.05V.

Solution:

\[
\% D = \frac{|A_2|}{|A_1|} \times 100\% = \frac{0.25}{2.5} \times 100\% = 10\%
\]

\[
\% D = \frac{|A_3|}{|A_1|} \times 100\% = \frac{0.1}{2.5} \times 100\% = 4\%
\]

\[
\% D = \frac{|A_4|}{|A_1|} \times 100\% = \frac{0.05}{2.5} \times 100\% = 2\%
\]
Total harmonic distortion

When an output signal has a number of individual harmonic distortion components, the signal can be seen to have a total harmonic distortion based on the individual elements as combined by relation,

\[
\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots} \times 100\%
\]

Numerical

Calculate the total harmonic distortion for the amplitude components given in previous example

Solution:

\[
\%THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots} \times 100\%
\]

\[
\%THD = \sqrt{0.1^2 + 0.04^2 + 0.02^2 + \ldots} \times 100\%
\]

\[
\%THD = 10.95\%
\]

Second harmonic distortion

\[I_c = I_{cQ} + I_o + I_1 \cos \omega t + I_2 \cos \omega t\]

- \(I_{cQ}\) → quiescent current
- \(I_o\) → additional dc current due to non zero average of the distorted signal
- \(I_1\) → fundamental component of current
- \(2\) → second harmonic current due to twice the fundamental frequency

Solving for \(I_1\) and \(I_2\),

\[I_o = I_2 = \frac{I_c \text{ max} + I_c \text{ min} - 2I_{cQ}}{4}\]

\[I_1 = \frac{I_c \text{ max} - I_c \text{ min}}{2}\]
Definition of second harmonic can be

\[ D_2 = \left| \frac{1}{2} \left( V_{CE_{\text{max}}} + V_{CE_{\text{min}}} \right) - V_{CEQ} \right| \times 100\% \]

In voltage terms

\[ D_2 = \left| \frac{1}{2} \left( V_{CE_{\text{MAX}}} + V_{CE_{\text{MIN}}} \right) - V_{CEQ} \right| \times 100\% \]

**Numerical**

An output waveform displayed on oscilloscope provides the following measurements,

i. \( V_{CE_{\text{min}}} = 1V; \ V_{CE_{\text{max}}} = 22V; \ V_{CEQ} = 12V \)

ii. \( V_{CE_{\text{min}}} = 4V; \ V_{CE_{\text{max}}} = 20V; \ V_{CEQ} = 12V \)

solution:

\[ i. \ D_2 = \left| \frac{1}{2} (22 + 1) - 12 \right| \times 100\% = 2.38\% \]

\[ i. \ D_2 = \left| \frac{1}{2} (20 + 4) - 12 \right| \times 100\% = 0\% (\text{no distortion}) \]
Power of signal having distortion

- Power delivered to the load resistor \( R_c \) due to the fundamental component of the distorted signal is
  \[
  P_1 = \frac{I_1^2 R_c}{2}
  \]
- Total power due to all the harmonic components of the distorted signal is,
  \[
  P = (I_1^2 + I_2^2 + I_3^2 + \ldots) \frac{R_c}{2}
  \]

In terms of Total harmonic distortion

\[
P = (1 + D_2^2 + D_3^2 + \ldots)I_1^2 \frac{R_c}{2}
\]
\[
P = (1 + THD^2)P_1
\]

Numerical

For harmonic distortion reading of \( D_2=0.1, D_3=0.02 \) and \( D_4=0.01 \), with \( I_1=4A \) and \( R_c=8 \text{ ohms} \), calculate THD, fundamental power component and total power.

Solution: THD=0.1

\[
P_1 = 64W
\]
\[
P = 64.64W
\]

Graphical description of harmonic components of distorted signal

- All the components are obtained by Fourier analysis
- Conclusion: any periodic signal can be represented by adding a fundamental component and all harmonic components varying in amplitude and at various phase angles.
Power transistor heat sinking

Heat is produced in transistors due to the current flowing through them. If you find that a transistor is becoming too hot to touch it certainly needs a heat sink! The heat sink helps to dissipate (remove) the heat by transferring it to the surrounding air.

- Maximum power handled by a particular device and the temperature of the transistor junction are related since the power dissipated causes an increase in temperature at the junction of the device.
- Example: a 100 W transistor will provide more power than 10 W transistor.
- Proper heat sinking techniques will allow operation of a device at about one-half its maximum power rating.
- There are two types of bipolar transistors
  - Germanium
    Junction temperature: 100 – 110°C
  - Silicon
    Junction temperature: 150 – 200°C
- Silicon transistors provide greater maximum temperature
- Average power dissipated may be approximated by
  \[ P_D = V_{CE}I_C \]
- This power dissipation is allowed only up to a maximum temperature.
• Above maximum temperature, device power dissipation must be reduced (derated) so that at higher temperature, power handling capacity is reduced.
• The limiting factor in power handling by a particular transistor is the temperature of the device’s collector junction.
• Power transistors are mounted in large metal cases to provide a large area from which the heat generated by the device may radiate.
• Even then the device power rating limited.
• Instead if the device is mounted on the heat sink power handling capacity is increased.
• The derated curve for silicon transistor given by

\[
P_D(\text{temp}1) \equiv P_D(\text{temp}0) - (\text{Temp}1 - \text{Temp}0) x
\]

derating factor
Numerical:

Determine what maximum dissipation will be allowed for an 80W silicon transistor rated at 25 degree C. if derating s required above this temp by derating factor of 0.5W/degree C at case temp of 125 degree C.

Solution:

Using the above formula

Power derated is 30W

Thermal analogy of power transistor

• $\theta_{JA}$ → total thermal resistance (jn to ambient)
• $\theta_{JC}$ → transistor thermal resistance (jn. To case)
• $\theta_{CS}$ → insulator thermal resistance (case to heat-sink)
• $\theta_{SA}$ → heat-sink thermal resistance (heat sink to ambient)

• Using electrical analogy
• $\theta_{JA}= \theta_{JC}+ \theta_{CS} + \theta_{SA}$

• This analogy can be used in applying kirchoff’s law as

$TJ = PD \theta_{JA} +TA$

• The thermal factor $\theta$ provides information about how much temp drop( or rise) for amount of power dissipation .

• Eg: $\theta_{JC}=0.5$ deg C/W means that power dissipation of 50W. the difference between junton temp and case temp is given by

$TJ-TC = \theta_{JC} PD = 0.5 \times 50 = 25$ deg C.

• Value of thermal resistance from junction to free air (using HS) → 40 deg C/W

• For this thermal resistance only 1W of power dissipation results n junction temp 40 deg C greater than the ambient.
• A HS can now be seen to provide a low thermal resistance between case and air much less than 40 deg C/W value of case alone. Using HS having
• $\theta_{SA} \rightarrow 2$ deg C/W
  And insulating thermal resistance (case to HS)
• $\theta_{CS} \rightarrow 0.8$ deg C/W
• Finally for transistor
• $\theta_{JC} \rightarrow 0.5$ deg C/W
• $\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$
  $= 2.0 + 0.8 + 0.5$
  $= 3.3$ deg C/W
With HS thermal resistance between air and the junction is only 3.3 deg C/W compared 40 deg C/W for transistor operating directly in to free air

### Numerical:

A silicon power transistor s operated with a HS $\theta_{SA} = 1.5$ deg C/w. the transistor rated at 150W(25 deg C) has $\theta_{JC} = 0.5$ deg C/W and the mounting insulation has $\theta_{CS} = 0.6$ deg C/W. what s the max power dissipated f the ambient temp s 40 deg C and TJ max s 200 deg C
• Solution : $p_d = (T_J - T_A) / \theta_{SA} + \theta_{JC} + \theta_{CS}$
  $= 61.5$W
Class C and Class D amplifiers

Class C
• The circuit is biased to operate for less than 180 deg of input cycle. The tuned circuit in the load provide a full cycle of output signal for fundamental frequency of tuned LC circuit. This type of operation is thus limited to one fixed frequency as in communication systems.
• Not suitable for power amplification

Class D amplifier
• Class D designed to operate with digital or pulse type signals
• Efficiency of 90% can be achieved.
• Desirable for power amplifiers.
• Necessary to convert any input signal in to pulse type wave before using to drive a large power load and to convert the signal back to sinusoidal type signal to recover the original signal.
- Here class – D amplifier we can also consider D stands for Digital since that is the name of the signal provided to the class D amplifier.

**Block diagram of class D**

- Most of the power applied to the amplifier is transferred to the load the efficiency of the circuit is typically very high.