4.31 TRANSISTOR TEMPERATURE CONTROL BY HEAT SINKS

In power amplifiers, power transistors are employed which are to handle large currents. Because of heavy current these transistors are heated up during operation. As transistor is a temperature dependent device, we have to apply some method to dissipate this excessive heat produced in it and to keep the temperature of the transistor within the permissible limits. The device used for this purpose is called **heat sink.**

Heat sink *is just a sheet of metal which improves the heat dissipation ability of *power transistor and keeps its temperature within the permissible limits.*

The quantity of heat to be dissipated depends upon the surface area of the heat sink. Therefore, heat sinks are designed in various shapes. However, the modern trend is that power transistors are mounted on the chassis or body. The chassis or body acts as a heat sink.

**Heat sinks are not only used with power transistors but they are also used with other electronic devices like SCRs, Triacs etc. to improve dissipation.*

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Mathematical analysis

The permissible power dissipation of the transistor is very important term for power transistors. The permissible power rating of a transistor is determined from the expression :

$$P_{total} = \frac{T_{j(max.)} - T_{amb}}{\theta} \quad \text{... (50)}$$

where, P_{total} = total power dissipated within the transistor in watts.

$T_{j(max.)}$ = maximum permissible junction temperature *i.e.*, 90°C for Ge and 150°C for Si transistors.

T_{amb} = ambient temperature *i.e.*, temperature of surroundings air in °C.

θ = thermal resistance *i.e.*, resistance to heat flow from junction to the surrounding air. Its units are °C/watt.

The value of θ is usually given in the transistor manual. Low value of θ means heat flows easily from junction to surrounding air *i.e.*, more dissipation and smaller rise in temperature. In fact, heat sink reduces the value of θ appreciably resulting in increase in power dissipation.

Example 4.26. *A transistor AC 128 is used as medium power transistor. Its thermal resistance is 0.29°C/mW when no heat sink is provided. The maximum junction temperature is 90°C. If the ambient temperature is 25°C, find*

(i) the maximum power dissipation that can be allowed ;

(ii) the maximum power dissipation that can be allowed with aluminium heat sink of 12.5 cm² area which reduces the thermal resistance θ to 0.08°C/mW.

Comment on the results.

Solution. (*i*) When no heat sink is used

$$T_{j(max.)} = 90° ; \quad T_{amb} = 25°C ; \quad \theta = 0.29°C/mW$$

$$\therefore \quad P_{total} = \frac{T_{j(max.)} - T_{amb}}{\theta} = \frac{90-25}{0.29} = \mathbf{224\ mW.}$$

(*ii*) When heat sink is used

$$T_{j(max.)} = 90° ; \quad T_{amb} = 25°C ; \quad \theta = 0.08°C/mW$$

$$\therefore \quad P_{total} = \frac{T_{j(max.)} - T_{amb}}{\theta} = \frac{90-25}{0.08} = \mathbf{812.5\ mW.}$$

Comments : The results of the above example show that the maximum power dissipation allowed with the heat sink is nearly 3.6 time (*i.e.*, 812.5/224) in comparing to that when no heat sink is used. In practical terms, we can say that a transistor, with the given maximum power dissipation rating, can handle much larger (3.6 times) collector current when used with the heat sink.

For instance, if V_{CC} = 12 V, then

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Without heat sink :

$$I_{C(max.)} = \frac{224 \text{ mW}}{12 \text{ V}} = 18.67 \text{ mA} \quad (\because P_{total} = V_{CE} \times I_C)$$

With heat sink ; $$I_{C(max.)} = \frac{812.5 \text{ mW}}{12} = 67.7 \text{ mA}$$

Thus, the same transistor can work at ***much higher collector current*** *when used with* ***heat sink.***

Example 4.27. *An Si transistor dissipates 2 W during working. If maximum junction temperature is 150°C, find*

(i) *the maximum ambient temperature at which it can be operated. Assume value of θ for the transistor with its heat sink to be 0.02°C/mW.*

(ii) *If in place of this transistor another equivalent Ge transistor having $T_{j(max.)} = 90°C$ is applied, at what temperature it can be operated ? Comment on the result.*

Solution. (*i*) When Si transistor is used ;

$$P_{total} = 2 \text{ W} = 2000 \text{ mW} ; \quad \theta = 0.02°\text{C/mW and } T_{j(max.)} = 150°\text{C}$$

Now, $$P_{total} = \frac{T_{j(max.)} - T_{amb}}{\theta}$$

or $$2000 = \frac{150 - T_{amb}}{0.02}$$

∴ Ambient temperature, $T_{amb} = 150 - 2000 \times 0.02 = \mathbf{110°C.}$

(*ii*) When Ge transistor is used ;

$$P_{total} = 2000 \text{ mW} ; \quad \theta = 0.02°\text{C/mW and } T_{j(max.)} = 90°\text{C}$$

∴ $$P_{total} = \frac{T_{j(max.)} - T_{amb}}{\theta}$$

or $$2000 = \frac{90 - T_{amb}}{0.02}$$

or, Ambient temperature, $T_{amb} = 90 - 2000 \times 0.2 = \mathbf{50°C.}$

Comments : The results clearly show that a silicon transistor can be operated at higher ambient temperature. In other words, we can say that if equivalent Si and Ge transistors are to be operated at the same ambient temperature then Si transistor can handle larger collector current (or power).

From this example, it is also clear that Si transistor needs smaller heat sinks as compared to the Ge transistor.

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Example 5.15. *A circuit contains a coil of inductance 100 μH and resistance of 15.7 Ω. It is connected in series with a capacitor of 253.3 μμF, find (i) resonant frequency, (ii) voltage drop across R, L and C at resonance. Assume the impressed voltage to be 0.157 volts. Comment on the result. Also find the quality factor Q of the coil.*

Solution. Here, $L = 100\ \mu H = 100 \times 10^{-6}\ H$; $C = 253.3\ \mu\mu F$

$$= 253.3 \times 10^{-12}\ F\ ;$$

$$R = 15.7\ \Omega.$$

(*i*) Resonant frequency,

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{100 \times 10^{-6} \times 253.3 \times 10^{-12}}} = 1\ \text{MHz}$$

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(*ii*) Current at resonant frequency,

$$I_r = \frac{V}{R} = \frac{0.157}{15.7} = 0.01 \text{ A}$$

Voltage across $R, V_R = I_r \times R = 0.01 \times 15.7 = \mathbf{0.157\ V}$

Voltage across $L, V_L = I_r \times X_L = I_r \times (2\pi f_r L)$

$$= 0.01 \times 2 \times \pi \times 10^6 \times 100 \times 10^{-6}$$

$$= \mathbf{6.283\ V}$$

Voltage across $C, V_C = I_r \times X_C = I_r \times \frac{1}{2\pi f_r C}$

$$= \frac{0.01}{2\pi \times 10^6 \times 253.3 \times 10^{-12}} = \mathbf{6.283\ V}$$

Quality factor, $Q = \frac{X_L}{R} = \frac{2\pi f_r L}{R} = \frac{2\pi \times 10^6 \times 100 \times 10^{-6}}{15.7} = \mathbf{40}$

Comments : It may be seen from the results that $V_L = V_C$ which is 40 times to that of voltage across the resistor at resonance.

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