Basic Thermal Properties of Semiconductors

Three basic processes play a part in the removal of heat from the rectifier junction to the ambient air: (1) conduction (heat traveling through a material); (2) convection (heat transfer by physical motion of a fluid); and (3) radiation (heat transfer by electromagnetic wave propagation). Heat flows by conduction from the die to the package mounting surface in stud–, base–, or surface–mount pads, but it flows from the die through the leads to the mounting terminals in a lead–mounted part For case–mounted parts, convection and radiation are of primary importance in the design of the heat exchanger, which is covered in Chapter 13. For lead–mounted parts, radiation and convection from the body both play a role in removing heat from the die and are discussed later in this chapter. Transient thermal considerations and thermal runaway are often important design factors and receive treatment near the end of this chapter.

In order to simplify the analysis of heat flow, the concept of thermal resistance is used. Just as a material offers resistance to the flow of current, it may be thought of as offering resistance to the flow of heat. Resistance to heat flow is called thermal resistance and for steady–state conditions is given as:

$$R_\theta = \Delta T / P \qquad (2.1a)$$

or

$$\Delta T = R_\theta P \qquad (2.1b)$$

where:

R_θ = the thermal resistance in °C/W

ΔT = the temperature difference between points in °C

P = the power in watts.

Junction temperature of semiconductors must be held below the rating assigned to the part The junction is therefore commonly used for one of the reference points in applying Equation 2.1. The other reference point is the case for semiconductors enclosed in case–mounted packages or a specified point on a lead for semiconductors enclosed in a package intended for PCB insertion To denote the reference point, the symbols in Equation 2.1 have subscripts. Thus $R_{\theta JC}$ signifies thermal resistance, junction–to–case. While $R_{\theta JL}$ signifies thermal resistance, junction–to–lead. The corresponding temperatures are denoted ΔT_{JC} and T_{JL}, respectively.

Thermal Models

Thermal resistance may be used to form electrical models which permit calculation of the temperature rise at various points in a system. Similar to an electrical physical resistance, thermal resistance is not constant; changes in mounting, temperature, or power levels will cause some modification of values. Nevertheless, the concept provides a very valuable tool in handling thermal problems.

By use of a thermal model, complex thermal systems may be easily analyzed using electrical network theorems. The following sections discuss models for single chip case– and lead–mounted parts and for multiple chip assemblies.

Case–Mounted Rectifiers

The total thermal resistance, junction–to–ease, is composed of three identifiable thermal resistances, as shown in Figure 30. The die–bond thermal resistance is usually the largest value. Actual values are determined by the design of the device: the size of the chip, the type of the die bond, and the type and material of the package. Variations among parts from a given product line are the result of variations in the die–bond thermal resistance which is affected by the type of solder or bonding material used. As a general guide, however, thermal resistance as a function of the die area for various common diode packages using solder die bonds behaves as shown in Figure 31.

Some parts may have a piece of material inserted between the die and the package to take up stresses developed by differing thermal coefficients of expansion of the package and of the die. This technique allows a hard solder die attach technique to be used, which improves temperature cycling behavior Other parts may contain insulators that electrically isolate the chip from the package. These materials add another component of thermal resistance to the assembly.

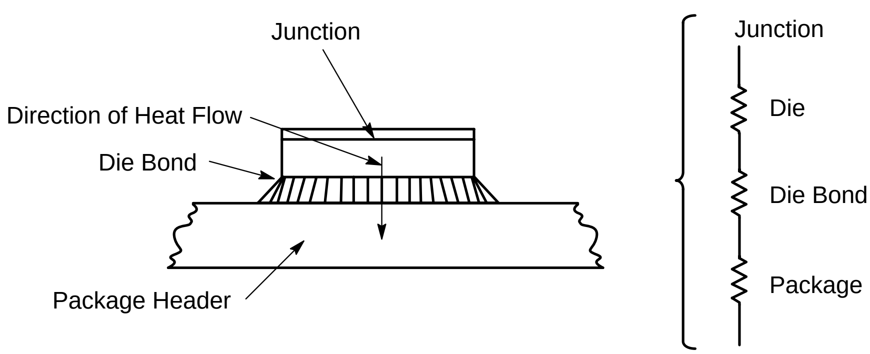


Figure 30. Thermal Resistance Components of the Junction–to–Case Thermal Resistance

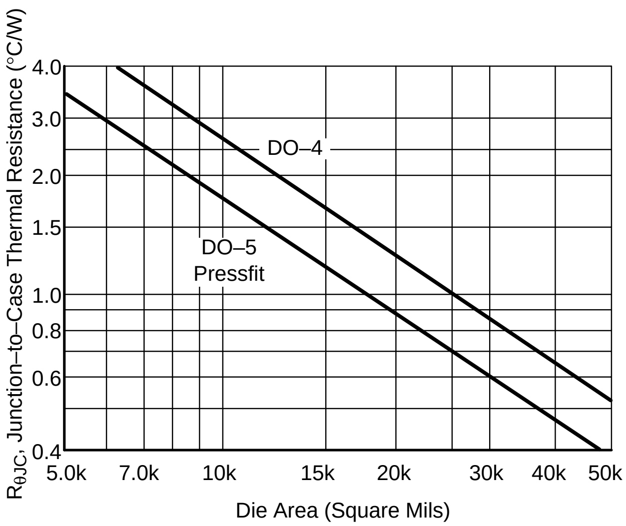


Figure 31. Typical thermal resistance of common rectifier packages having copper material in the heat flow path (data averaged from measurements at ON)

Thermal resistance (R_θ) follows the same general equation as does electrical resistance:

$$R_\theta = \rho \frac{l}{A} \qquad (2.2)$$

where:

ρ = thermal resistivity
l = length of thermal path
A = area of thermal path

The equation states that thermal resistance is inversely proportional to area; however, the data of Figure 31 does not indicate this relationship exactly. The deviation is caused because the area of heat flow through the package is not the same as the die area. As heat flows, it spreads out toward the edges of the package; consequently, as larger die are placed in a given package, the area for spreading reduces proportionally.

Lead–Mounted Parts

In the axial lead–mounted rectifier, heat travels down both leads to some kind of a heat dissipator, which is usually nothing more than a printed–circuit wiring pattern. Heat is also removed from the package by convection and radiation, which make the thermal circuit model immensely more complicated for a lead–mounted part than for a case–mounted part. However, certain lead–mounted parts are easily handled because the thermal resistance of both leads is identical and quite low compared to the package radiation and convection components which maybe neglected. Examples of parts in which this simplified approach is satisfactory are the MR750 series. Thermal resistance as a function of lead length is shown in Figure 32. Note that the thermal resistance is linearly proportional to lead length, indicating that the package heat transfer components play a negligible role in the total thermal resistance. If the package thermal resistance components were not negligible, the lines would curve as the lead length increased.

Data is often given for the case where both leads have identical lengths. However, identical lead lengths will not result in lowest thermal resistance to the mounting points since the net thermal resistance is composed of two parallel paths. The lowest net value will always occur when one of the paths is made as short as possible. For example, suppose a mounting situation is encountered where the leads must take up a 1 inch span. If each lead were 1/2 inch long, the thermal resistance (from Figure 32) is l3°C/W maximum. However, the device could be mounted with one lead 1/8 inch long and the other 7/8 inch long. The thermal resistance from junction to the end of each lead is 4°C/W for the 1/8 inch lead and 23°C/W for the 7/8 inch lead. The net thermal resistance of the parallel combination is 3.4°C/W. The reduction from 13°C/W is quite significant but to take advantage of this reduction the mounting terminal must have a low thermal resistance to the ambient As the span becomes less, the advantages of asymmetrical mounting become less significant.

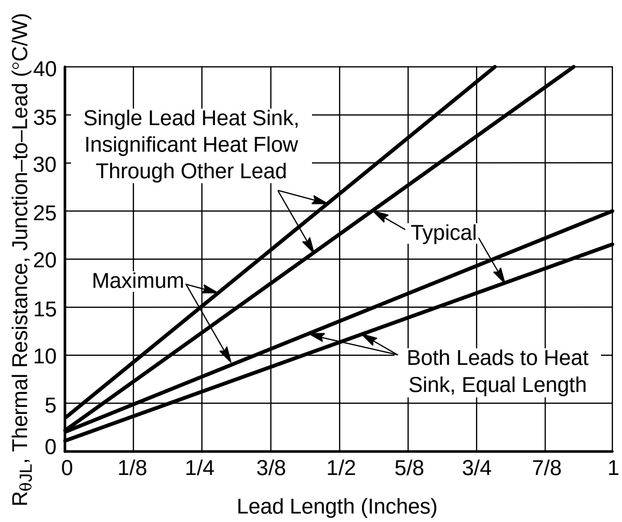
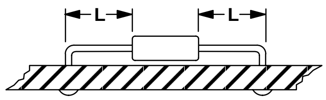


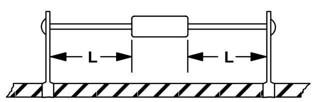
Figure 32. Thermal Resistance as a Function of Lead Length for MR751 Series Axial–Lead Rectifiers

As a design guide, when using lead–mounted pans, Figure 33 shows typical data for three popular case types. The data should not be taken as absolute because junction–to–ambient thermal resistance cannot be regarded as a design constant. The factors involved are discussed in depth in Chapter 13.

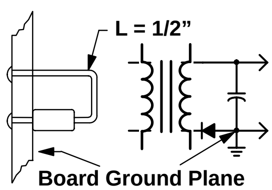
Parts with asymmetrical lead conduction and/or significant convection and radiation from the case requite use of a complete thermal model. Figure 34 shows a satisfactory approximation.



MOUNTING METHOD 1
P.C. Board Where Available
Copper Surface area is small



MOUNTING METHOD 2
Vector Push–In Terminals T–28

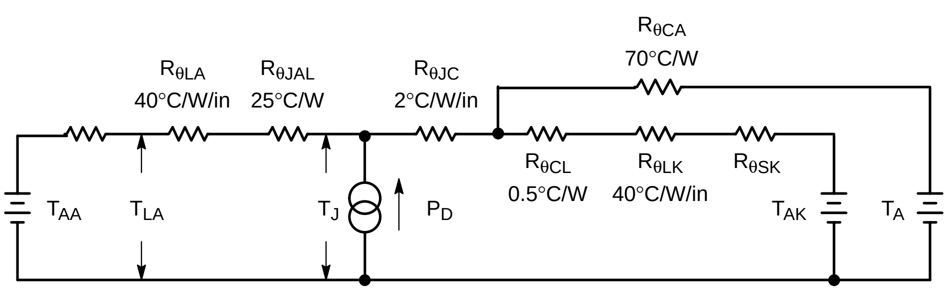


MOUNTING METHOD 3
P.C. Board with
Copper Surface of Area A

CASE #	MOUNTING METHOD	LEAD LENGTH L			
		1/8″	1/4″	1/2″	3/4″
59 (DO–41)	1	65	72	82	92
	2	74	81	91	101
	3	40°C/W (L = 3/8″, A = 2.25″ ^{2})			
60	1	–	55	–	58
	2	–	65	–	68
	3	25°C/W (L = 5/8″, A = 6.25″^{2})			
267	1	50	51	53	55
	2	58	59	61	63
	3	28°C/W (L = 1/2″, A = 6.25″^{2})			

Data shown for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

Figure 33. Typical Values for $R_{\theta JA}$ in Still Air



Use of the above model permits calculation of average junction temperature for any mounting situation. Lowest values of thermal resistance will occur when the cathode lead is brought as close as possible to a heat dissipator, as heat conduction through the anode lead is small. Terms in the model are defined as follows:

TEMPERATURES

T_A = Ambient
T_{AA} = Anode Heat Sink Ambient
T_{AK} = Cathode Heat Sink Ambient
T_{LA} = Anode Lead
T_{LK} = Cathode Lead
T_J = Junction

THERMAL RESISTANCES

$R_{\theta CA}$ = Case to Ambient
$R_{\theta SA}$ = Anode Lead Heat Sink to Ambient
$R_{\theta SK}$ = Cathode Lead Heat Sink to Ambient
$R_{\theta LA}$ = Anode Lead
$R_{\theta LK}$ = Cathode Lead
$R_{\theta CL}$ = Case to Cathode Lead
$R_{\theta JC}$ = Junction to Case*
$R_{\theta JAL}$ = Junction to Anode Lead (S bend)

*Case temperature reference is at cathode end.

Figure 34. Approximate Thermal Circuit Model for a Case 60 Part