4.0 HEAT FLOW & THERMAL RESISTANCE

4.1 HEAT FLOW

Heat can be transferred from the regulator package by three methods, as described and characterized in Table 4.1.

TABLE 4.1. Methods of Heat Flow

METHOD	DESCRIBING PARAMETERS
Conduction is the heat transfer method most effective in moving heat from junction to case and case to heat sink.	Thermal resistance θ_{JC} & θ_{CS}. Cross section, length and temperature difference across the conducting medium.
Convection is the effective method of heat transfer from case to ambient and heat sink to ambient.	Thermal resistance θ_{SA} and θ_{CA}. Surface condition, type of convecting fluid, velocity and character of the fluid flow (e.g., turbulent or laminar), and temperature difference between surface and fluid.
Radiation is important in transferring heat from cooling fins.	Surface emissivity and area. Temperature difference between radiating and adjacent objects or space. See Table 4.2 for values of emissivity.

4.2 THERMAL RESISTANCE

The thermal resistance between two points of a conductive system is expressed as

$$\theta_{12} = \frac{T_1 - T_2}{P_D} \,°C/W \qquad (4.1)$$

where subscript order indicates the direction of heat flow. A simplified heat transfer circuit for a cased semiconductor and heat sink system is shown in Figure 4.1. The circuit is valid only if the system is in thermal equilibrium (constant heat flow) and there are, indeed, single specific temperatures T_J, T_C, and T_X (no temperature distribution in junction, case, or heat sink). Nevertheless, this is a reasonable approximation of actual performance.

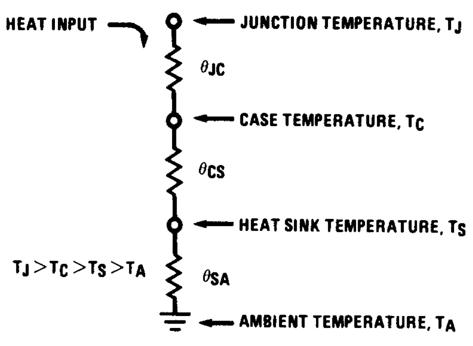

FIGURE 4.1. Semiconductor-Heat Sink Thermal Circuit

The junction-to-case thermal resistance θ_{JC} specified in the regulator data sheets depends upon the material and size of the package, die size and thickness, and quality of the die bond to the case or lead frame. The case-to-heat sink thermal resistance θ_{CS} depends on the mounting of the regulator to the heat sink and upon the area and quality of the contact surface. Typical θ_{CS} for several packages and mounting conditions are as shown in Table 4.2.

The heat sink to ambient thermal resistance θ_{SA} depends on the quality of the heat sink and the ambient conditions. A listing of approximate θ_{SA} for a number of commercially available heat sinks appears in Section 5. θ_{SA} includes effects of both convection and radiation.

4.3 BASIC THERMAL CALCULATIONS

Cooling is normally required to maintain the worst case operating junction temperature T_J of the regulator below the specified maximum value $T_{J(MAX)}$. T_J can be calculated from known operating conditions. Rewriting Eqn 4.1, we find

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \,°C/W \qquad (4.2)$$

$$T_J = T_A + P_D\theta_{JA} \,°C \qquad (4.3)$$

Where: $P_D = (V_{IN} - V_{OUT})I_{OUT} + V_{IN}I_Q$

$\approx (V_{IN} - V_{OUT})I_{OUT}$

except for TO-92 package where $V_{IN}I_Q$ must be considered important.

I_Q = Regulator quiescent current

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

Data sheets usually provide a plot of Eqn 4.3 for several heat sinks. An example for the LM340T with $T_J = T_{J(MAX)} = 150°C$ appears in Figure 4.2. Note that for the lower curve $\theta_{JA} = \theta_{CS} + \theta_{SA}$ while the upper curve is for $\theta_{JA} = \theta_{JC}$. Where the upper curve slope is zero, the limit is the arbitrary power dissipation rating instead of Eqn 4.1.

Table 4.2 Approximate Thermal Resistance, Case to Heat Sink θ_{CS} in °C/W

Package	Direct contact	Contact with silicone grease	Contact with grease and mica washer
TO-3	0.5 - 0.7	0.3 - 0.5	0.4 - 0.6
TO-202	1.5 - 2.0	0.9 - 1.2	1.2 - 1.7
TO-220	1.0 - 1.3	0.6 - 0.8	0.8 - 1.1

Normally, we impose a full load operating junction temperature T_J at 25°C (or more) below specified $T_{J(MAX)}$ at maximum expected T_A, and we need to find the required θ_{JA} from Eqn 4.2.

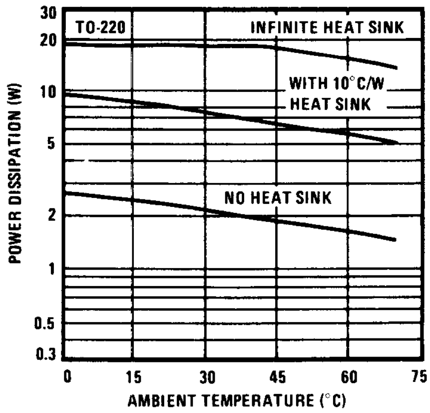

FIGURE 4.2. Power De-Rating Curves for LM340T