Don't Be Sunk by Heat Sinks

— a painless introduction to heat-transfer physics

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Application

Find the right heat sink for an LM309K voltage regulator IC. The maximum input voltage is 10 volts, the output voltage is to be held at a constant 5 volts, and the maximum current to be drawn from the supply is 1 Amp.

Step 1: Write down the formula:
$R\theta_{SA}(max) = (T_J - T_A)/P_D - R\theta_{JC} - R\theta_{CS}$.

Step 2: Calculate P_D:
$P_D = (Vin - Vout) \times I(max)$
$P_D = (10\ V - 5\ V) \times 1\ A = 5$ Watts

Step 3: Find T_J(max) and derate by 50° C. The data sheet gives us a figure of 125° C for the absolute maximum operating junction temperature; derating that figure by 50° C gives us 75° C for T_J(max).

Step 4: Find T_A(max). The maximum ambient temperature is 25° C, 5° C above room temperature of 20° C.

Step 5: Find $R\theta_{JC}$. Keep in mind that the LM309K is an IC, not a transistor. The data sheet reveals a figure of 3.0° C/W for $R\theta_{JC}$. For transistors, Table 1 is fairly accurate, but for ICs, watch out!

Step 6: Find $R\theta_{CS}$. Since the case is ground on the LM309K used as a fixed 5-volt regulator, we will not need an insulating washer. To improve the heat transfer between the device and the heat sink, we will use some heat-sink compound. From Table 2 we obtain a value of 0.1° C/W for $R\theta_{JC}$.

Step 7: Plug the values into the formula:
$R\theta_{SA}(max) = (75°\ C - 25°\ C)/5\ W - 3.0°\ C/W - 0.1°\ C/W = 6.9°\ C/W$.

Step 8: Pick a suitable heat sink. Choose the next lower value for a TO-3 type case. The RCA-SK KH3423 looks suitable with a $R\theta_{SA}$ value of 5° C/W.

For years I have been resorting to B.F.I. (Brute Force and Ignorance) when designing transistor projects. Mainly, this meant using the biggest heat sink I could afford or watching my project go up in smoke. After the loss of a few precious power transistors, I set out to find out all about proper heat sinking. The principle behind picking the right heat sink is rather simple.

In this article, we will explore heat-transfer physics, interfaces, and practical heat-sink choices. First, let's look at how heat sinks work.

Theory

Heat-transfer physics is a scary-sounding phrase for something that some hams don't think they know about, although they know of something similar: basic electricity. Fig. 1 shows the analogy between thermal resistance and ohmic resistance.

In electrical circuits, whenever there is a difference of voltage between

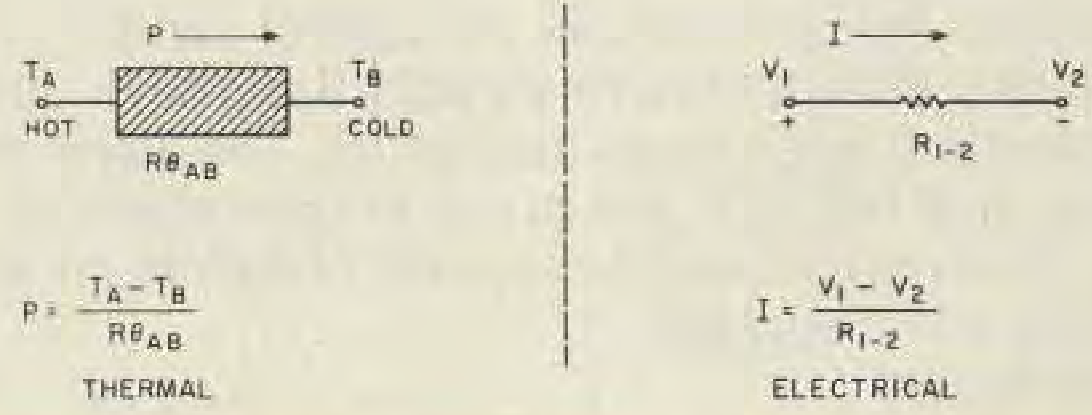

Fig. 1. The electrical analog of heat transfer.

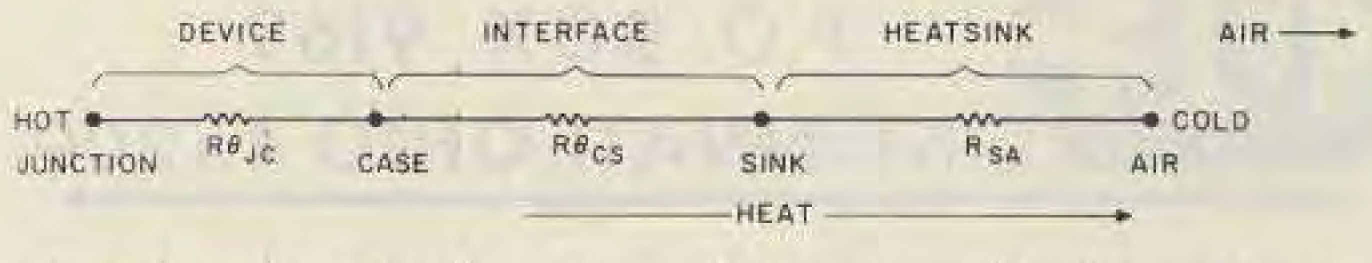

Fig. 2. The electrical analog of heat transfer from the junction of the semiconductor to ambient air ($R\theta_{JA} = R\theta_{JC} + R\theta_{CS} + R\theta_{SA}$).

two points, or nodes, current is said to flow from the more positive node to the more negative node. The amount of current that flows is inversely proportional to the resistance between the two nodes.

Similarly, in thermal circuits, whenever there is a difference of temperature between two bodies (T_A and T_B) or between two portions of one body, heat (P) is said to flow in a direction from higher to lower temperature. This heat flow is expressed in Watts. The amount of heat which flows when a given change in temperature is applied will be found to vary with what is called the thermal resistance of the material ($R\theta$). The lower the thermal resistance of the material, the greater the heat it transfers. Thermal resistance can be expressed in terms of degrees centigrade per Watt (°C/W).

Applying the Theory to Heat Sinks

In semiconductors, heat is produced at the junction of the differently-doped silicon materials. To escape the semiconductor, heat travels from the junction through the case, the interface, and the heat sink into the ambient air. The heat sink dissipates the heat into the surrounding air by means of radiation and convection. The whole system can be represented by the electrical equivalent circuit shown in Fig. 2.

The total thermal resistance from junction to air is the sum of individual thermal resistances: junction to case ($R\theta_{JC}$), case to sink ($R\theta_{CS}$), and sink to air ($R\theta_{SA}$). Applying the analogy found previously, we can say that $P_D\ (max) = [T_J(max) - T_A(max)]/R\theta_{JA}(max)$, where P_D is the maximum power dissipated by the device in Watts, T_J is the maximum junction temperature in °C, T_A is the maximum ambient temperature in °C, and $R\theta_{JA}$ is the maximum thermal resistance from junction to ambient air in °C/W. With a little algebra, we can combine the two formulas found above and get a very useful equation for finding the correct heat sink. In this equation, $R\theta_{SA}(max) = [(T_J - T_A)/P_D] - R\theta_{JC} - R\theta_{CS}$.

Although manufacturers list maximum junction temperatures of 150°-200° C, it is a good design practice to operate the device at a much lower temperature. To ensure plenty of leeway and extend the useful life of the device, use a maximum junction temperature of 50° C less than the manufacturer's listed maximum junction temperature.

There are several ways of obtaining the maximum power dissipated by the device. A simple way of calculating the power dissipated is: $P_D(max) = P_{input} \times (1 - eff)$.

Another way of calculating the power dissipated is: $P_D(max) = I(max) \times E(max)$.

In some cases, the actual power dissipated may be less than these values, but keep in mind this is a worst-case figure.

The thermal resistance from the junction to case ($R\theta_{JC}$) depends mostly on the type of case that the device is packaged in. Although it is best to obtain the value from the data sheet for the transistor or semiconductor device, Table 1 shows some typical values if the data sheet is unavailable.

The thermal resistance from case to sink ($R\theta_{CS}$) depends on a handful of factors: the type of washer used (if any), the tightness of the transistor or semiconductor device against the heat sink, and whether or not silicone thermal paste or heat-sink compound is used. Some approximate values are shown in Table 2.

Case	$R\theta_{JC}$
TO-3	1.5
TO-5	30.0
TO-18	150.0
TO-36	0.7
TO-39	35.0
TO-66	7.0
TO-92	125.0
TO-220	4.0

Table 1. Typical values for $R\theta_{JC}$ for common case styles.

Washer	Paste	No Paste
none	0.1	0.2
beryllia	0.2	0.4
alumina	0.3	0.5
mica	0.4	0.8

Table 2. Approximate values for $R\theta_{CS}$.

It should be fairly obvious why thermal joint compound is important. These zinc oxide and silicone oil mixtures reduce the high thermal resistance of the air gap between the case and the heat sink. But be sure to use it sparingly; the paste has a large thermal resistance and it is important to keep the layer as thin as possible.

A list of commonly available heat sinks and their thermal resistances ($R\theta_{SA}$) is shown in Table 3. The thermal resistance of heat sinks can be improved or lowered by improving the heat-sink-to-air interface. When the ambient air moves, it more readily accepts heat; thus, some benefits can be gained from a fan blowing across the fins of the heat sink. Also, a change in color can decrease the thermal resistance of a heat sink. A thin coat of flat black paint (such as barbecue black) sprayed over a shiny aluminum heat sink lowers the thermal resistance by about 25%. For a real application, see box.

Conclusion

Although calculations in finding the right heat sink can be much more complicated, this article was written to simplify heat transfer physics as much as possible for the amateur or radio experimenter. Hopefully, the reader will be able to pick the right heat sink for the right job with the guidelines presented here. ■

For More Information:

International Electronic
Research Corp.
135 West Magnolia Blvd.
Burbank CA 91502

Thermalloy, Inc.
PO Box 340839
Dallas TX 75234

Wakefield Engineering
60 Audubon Road
Wakefield MA 01880

Brand	Stock	$R\theta_{SA}$	Fits these cases
Calectro	J4-866	23*	TO-220
	J4-878	11	TO-3
	J4-880	2.25	(2) TO-3,TO-36,TO-66, and TO-220
Radio Shack	276-1361	2.25*	(2) TO-3,TO-36,TO-66, and TO-220
	276-1363	20*	TO-220
	276-1364	13*	TO-3
RCA-SK	KH3413	80	TO-1,TO-18,TO-72,TO-104, and TO-92
	KH3415	52	TO-5 and TO-39
	KH3417	20	TO-220
	KH3421	15	TO-66
	KH3423	5	TO-3
Thermalloy	6011	60	14 and 16 pin DIP ICs
	6087	25	40 pin DIP ICs
	6038	10	TO-220
	6017	8	TO-66
	6013	8	TO-3
	6157	0.9	Circuit board or external mounting
Wakefield	502	1.3	TO-36
Engineering	641	3.5	TO-3

*The $R\theta_{SA}$ values for these heat sinks were found experimentally by the author.

Table 3. Typical values for $R\theta_{SA}$.