



The Heat Is On – High-Power Surface-Mount Resistors

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SCOPE

The heat is on for the passive electronic components industry, as it is seeing an increase in new surface-mount high-power devices, especially resistors. This is exciting, as it creates opportunities to reduce the overall size of electronics. Unfortunately, we must still abide by the laws of physics. Resistors generate heat as a result of the properties they create. When more power is applied to a resistor, more heat is generated. If this heat is not properly transferred from the part, the part may shift in value and eventually fail.

There are new technologies utilizing aluminum nitride (AlN) ceramics in place of aluminum oxide that boast extreme power ratings, such as > 100 W in the 1206 case size. The AlN ceramics have a much better thermal conductivity than that of aluminum oxide, approaching that of beryllium oxide. At first glance this is very exciting and impressive, until one considers how they are going to transfer the massive amount of heat away from the device and the rest of their circuit. Applying 100 W to a 1206-size resistor will heat up the resistor rapidly to temperatures in excess of 500 °C, which will melt solder joints and potentially damage most electrical components, especially active devices, if not properly dissipated.

Why do these resistors have these ratings? The devices themselves are capable of running at these power ratings due to the higher thermal conductivity of the substrate and the ability to transfer the heat away from the device. The challenge is where that heat gets transferred. Manufacturers include footnotes in the datasheets indicating active thermal management, elaborate heat sinks, or simply that the user must maintain a given temperature for the device, such as 155 °C.

Is it easy or cost-effective to implement the necessary thermal management for these high-power resistors? No. This article is not intended to overwhelm the reader with thermodynamics and complex equations. The intent is to discuss a few techniques to manage the heat that is generated by high-power surface-mount resistors and the effects they will have on design space, complexity, and cost

BACKGROUND

There are two main types of heat transfer with high-power surface-mount resistors. The first is conduction through the substrate and conductors to the board and traces. The second is convection to the surrounding environment.

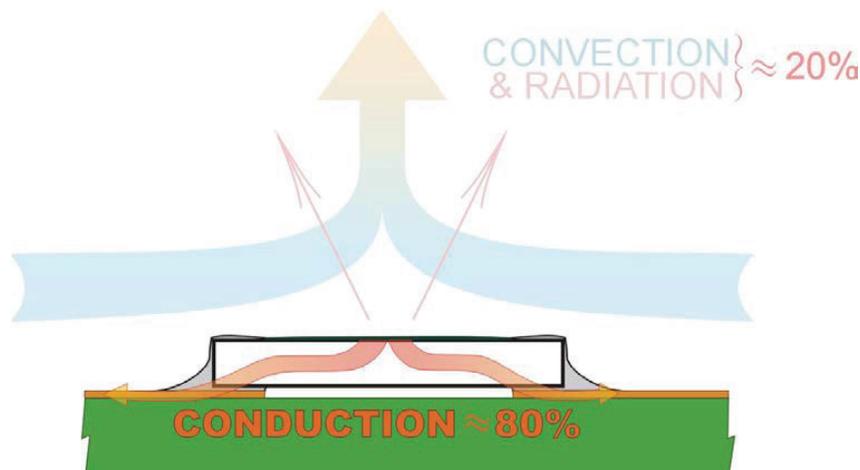
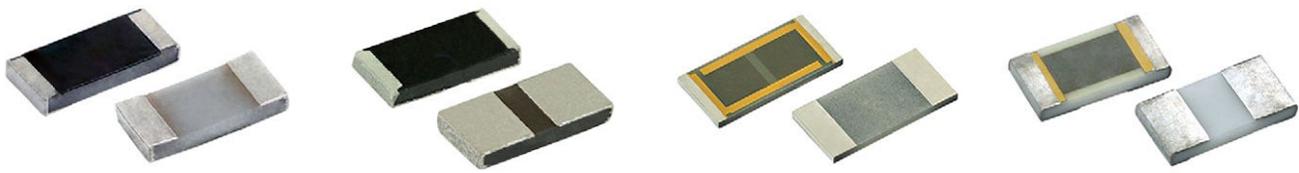


Fig. 1 - Predominant Types of Heat Transfer for High-Power Surface-Mount Resistors

The Heat Is On – High-Power Surface-Mount Resistors

Conduction is the predominant means of heat transfer and thus many manufacturers will provide a thermal resistance for their device. Thermal resistance gives a first order approximation of how well the device transfers heat to the board and traces as power is applied, i.e. °C/W. This rating lacks many details, the main issue being the properties of the test card used to establish it. For example, the amount of copper employed on the test card will significantly affect the resulting thermal resistance of the device. Some manufacturers provide the details about how their devices were tested to establish the power rating or the thermal resistance. However, in many cases the techniques employed are not practical in application.

The design and construction of devices can aid in the conduction of heat, enabling higher power ratings. Replacing aluminum oxide substrates with aluminum nitride significantly improves the conduction of heat. Some resistive products that utilize aluminum nitride substrates are Vishay Dale's RCP and PCAN. The devices' aluminum nitride allows heat to be more rapidly dissipated throughout the entire resistor — by carrying more heat away to the board and the surrounding environment — thus allowing much higher power levels to be achieved. Another method used to improve conduction of heat is to increase the size of the backside terminations. These are available on both the RCP and PCAN and also on the PHP, which utilizes the traditional aluminum oxide substrate. The larger backside conductor increases thermal conduction to the board traces via an increased thermal contact area and reduced distance between the resistive film and the board traces.



RCP (standard)

RCP (wide)

PCAN

PHP

Convection is an important factor to consider, especially if a board is enclosed. The heat that is radiated can quickly increase the ambient temperature to unsafe and damaging levels. If a board is encapsulated, it can be detrimental to the high-power component and surrounding components as it prevents transfer of heat by means of convection. It is highly recommended that high-power resistors not be encapsulated.

Some manufacturers' power ratings assume an infinite heatsink. An infinite heatsink is one that can carry an infinite amount of heat away from the device. This is not realistic and thus may limit the amount of power that can be applied to a component.

THERMAL MANAGEMENT TECHNIQUES

Heavy Board Traces:

Adding surface area and volume to board traces is an easy technique to employ. Since most of the heat transfer from these devices is through conduction, it is also a common technique. An example is shown in Figure 2. There are two options in employing this technique: Increase the width of the traces and / or increase the thickness of the traces.

The Heat Is On – High-Power Surface-Mount Resistors

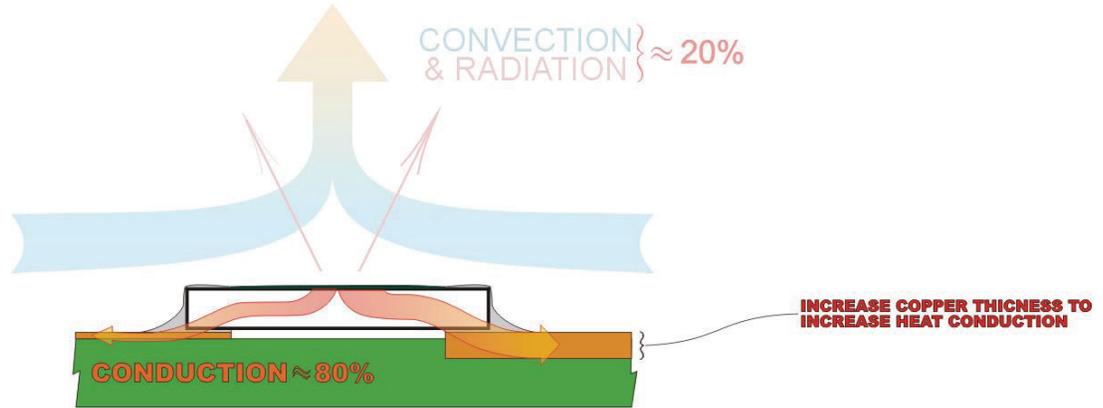


Fig. 2 - Example of Implementing Heavy Board Traces

This technique spreads the heat generated by the resistor to the entire board, which increases the area over which the heat is radiated to the surrounding environment. The challenge occurs when a steady state is reached. If active thermal management techniques are not included in the design, the board and the surrounding environment eventually reach a peak temperature that may exceed safe operating temperatures.

This technique is typically low-cost. However, there are still higher costs involved due to the amount of metal used for the traces, typically copper. In addition, there is added weight and an increased board size to accommodate the heavy board traces.

Thermal Back Plane:

A similar technique, which is more robust, is to employ a thermal back plane. This technique uses a larger copper plate on the backside of the board to transfer the heat away from the circuit. As with the heavy board trace technique, the heat is spread over a large thermal mass, which will increase the area to transfer heat by convection and radiation. An example is shown in Figure 3. Note that if active thermal management is not employed, the board and surrounding environment may exceed safe operating temperatures.

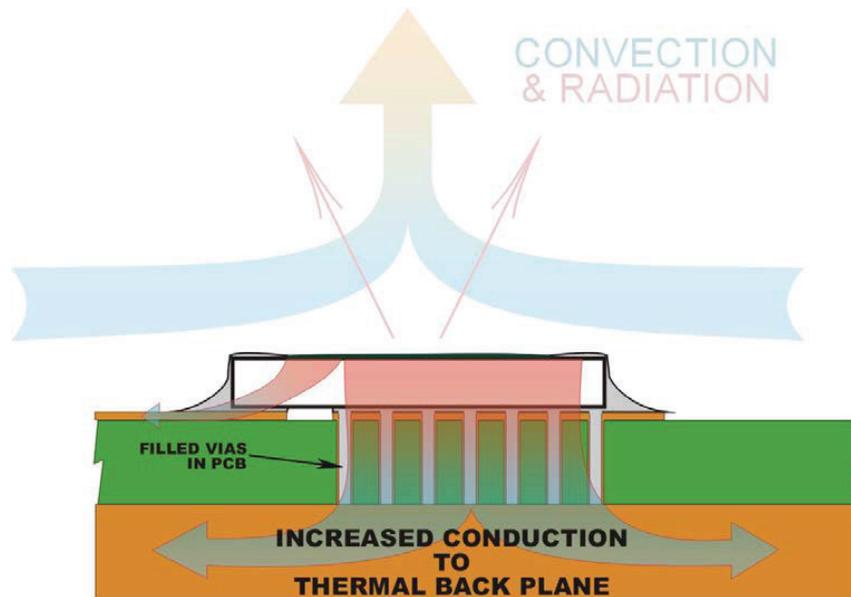


Fig. 3 - Example of Implementing a Thermal Back Plane

This technique adds higher costs, as the back plane is typically made of heavy copper. In addition, this technique will add weight

The Heat Is On – High-Power Surface-Mount Resistors

to the design and complicate board design and costs.

Oil Submersion:

Submersing a board into oil is an effective method to carry heat away from the board and attached components. Since the oil is in direct contact with every surface of the board, the conduction of heat is very efficient. An example is shown in Figure 4. A couple of challenges with this technique are oil contamination and material compatibility. The oil must have very good dielectric properties. If the oil becomes contaminated, the dielectric properties may be decreased and lead to arcing and thus failure of the device or the board. The oils used are typically custom materials and may not be compatible with the materials of the high-power resistor, other components, or even the solder.

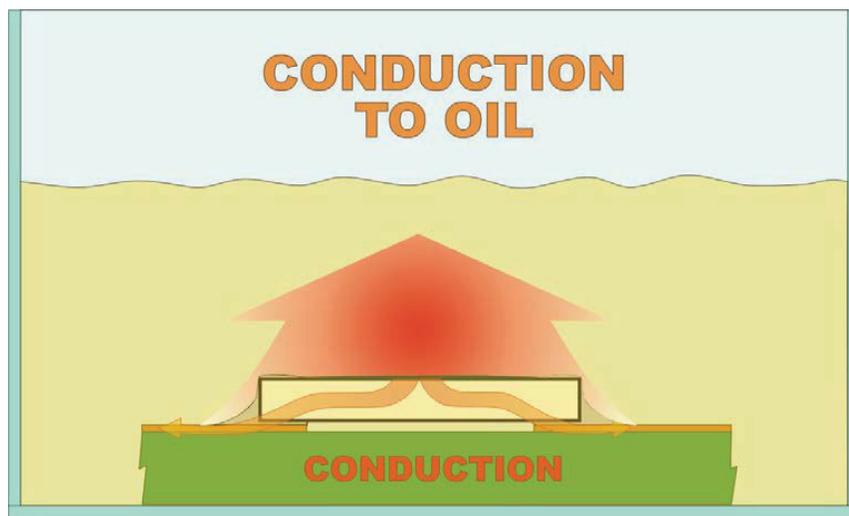


Fig. 4 - Example of Implementing a Thermal Back Plane

This technique again is limited at the steady state if active thermal management is not employed. The fixed volume of oil will eventually reach a peak temperature, which may exceed safe operating conditions.

This technique adds significant costs, as the oils are typically more expensive and there must be some type of vessel to contain them. In addition, in many cases gold contacts / terminations are employed to avoid reaction with the oil, adding very high costs.

Active Cooling:

Actively cooling a board can be very effective but at a much higher cost. One common technique is to employ a chiller, which circulates coolant. This can be used with a thermal back plane where the coolant circulates through channels in the plane or tubing that is thermally connected to the surface of the plane. An example is shown in Figure 5. This method can also be used with the oil bath, where the oil is circulated continuously through the chiller. Both of these techniques “pump” heat away from the thermal back plane or the oil bath.

The Heat Is On – High-Power Surface-Mount Resistors

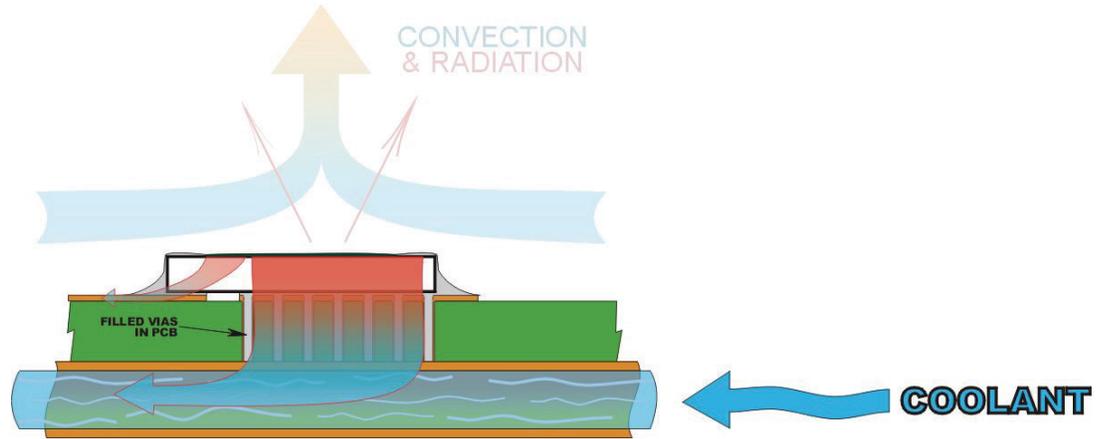


Fig. 5 - Example of Implementing Circulated Coolant Through a Thermal Backplane

Another technique is to employ forced air, whether conditioned or unconditioned. Applying forced air to a board is relatively easy and can be achieved at a reasonable cost. The effectiveness of this technique is limited, as it relies on convection and the surface area of the high-power resistor. An example is shown in Figure 6. There are high-power resistors that are encased in heatsinks, which aid in the cooling process by significantly increasing the thermal mass and surface area. To employ this technique requires adequate free space surrounding the board to properly circulate the air. The air typically must be filtered to prevent contaminants from degrading the performance of the electronics.

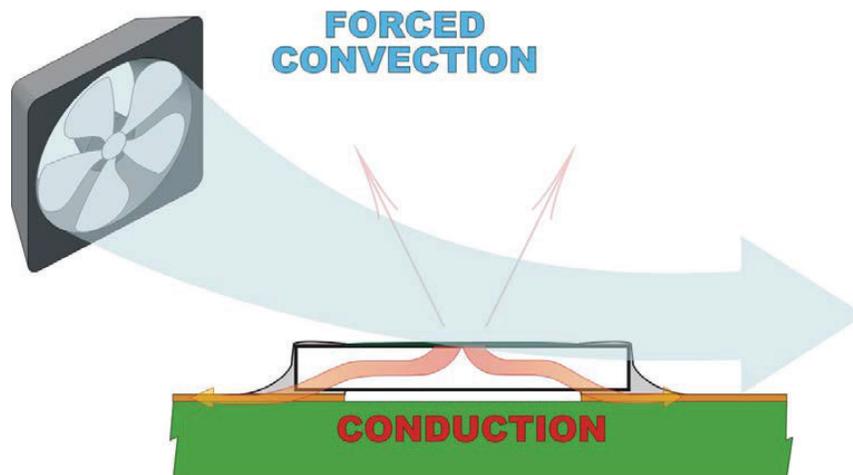


Fig. 6 - Example of Implementing Forced Air Cooling

CONCLUSIONS

High-power surface-mount resistors offer increased power capabilities, even with standard board mounting techniques, due to the reduced thermal resistance of the substrates (e.g. AlN), which is typically two to three times that of standard chip resistors. In order to achieve higher power levels, more elaborate techniques must be employed, as discussed in this article. Designers must be very careful when selecting high-power surface-mount resistors. If a datasheet claims extremely high power levels, the burden is on the designer to maintain certain criteria, e.g. maximum surface or terminal temperatures, that are typically noted in the fine print.