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Keep It Cool!

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Summary
Cooling a system is becoming an increasing challenge for a variety of industries. This problem can be attacked at low level, but usually breaks into two parts. This first is the high operating temperature of some components and the second is the high thermal cycle between a full-on and quiescent or off-state. The details will show how each of these situations represent a challenge for designers. There are lessons to be learned.

Detail
Heat is the necessary and unpleasant outcome of wasted energy within a component or circuit. The more powerful or the denser the circuitry, the bigger the problem becomes. Heat needs to be removed in order for a component or circuit to function. There are three basic ways of removing heat. These are:

1) Increase the mass of the heat sink – This is a passive approach, add bulk.
2) Increase air flow over the hot spots – This uses air as a heat sink.
3) Use liquid cooling methods - This can be both passive or active.

A series of examples will demonstrate these methods and identify strengths and weaknesses of each. Self-heating of components have a strong influence upon the reliability of the component and usually has an additional impact on the dependability of the circuit[1].

The first approach to cooling is to use more mass to a component. This usually comes in one of three ways. The first is to add material or potting to the component or circuit. In the past, power conversion modules were potted to reduce the overall operating temperature. Two advantages are that this potting cools the hottest components in the module and keeps the module components all at about the same temperature to minimize thermal drift. The two obvious disadvantages are that cooler components are heated and that rework is a problem. There are limits to this approach, so it is best said to only help a heating problem somewhat. A second approach is to add copper to a circuit board. Some dense modern components such as a QFN (quad flat pack and many similar packages) come with a copper slug on the bottom [2]. This is tied directly to a heat source such as a semiconductor die and greatly aids removal of heat from inside the package. Now add some under the package pads and the heat can be spread effectively into the circuit board. The advantage is more cooling. The disadvantage is the board heats up and adjacent components may suffer. Secondly, the area under the package can't be used for other purposes such as routing circuits and making interconnections. The third approach is to add the mass to the top of the part. We call this an external heat sink and they are usually finned and stick up into the air. The mass of the heat sink may be sufficient by itself or a little natural convention may do the job of removing heat. A few disadvantages with an external heat sink exist. This is an extra cost for the heat sink and may require a thermal pad or grease to ensure good contact. Heat sinks also stick up in the way and sometimes add stress to delicate solder joints. Most of these passive approaches are limited to dissipating about 1 to 2 Watts per square inch of board space. See Figure 1 for examples of passive cooling.

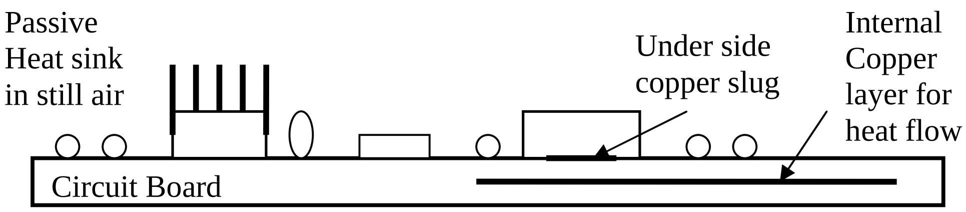

Figure 1 Passive cooling

Now**,** if we are operating in the 2 W to 10W per square inch region, a second more active approach may be required. Blow lots of air over the hot spots. This can be done selectively with baffles directing an air stream to a hot component, or it can be done just flowing lots of air over a whole circuit. There are a few disadvantages - we need to add a source of air, such as an external fan and also look at the air flow pattern to be sure no dead spots or shadowing occurs. Add a small heat sink to the hottest components and orient them in the air stream and this can often be a great solution. It is even possible to have a small fan on a single large component with thermostat control. This is often the solution selected in a lap top computer to keep the microprocessor cool. The fan runs only when needed and has the advantage of cooling nearby components. The downside is that extra energy is required to run the fan and the air flow stream can't be blocked. Thermal contact is assured by grease or a thermal pad at extra cost.

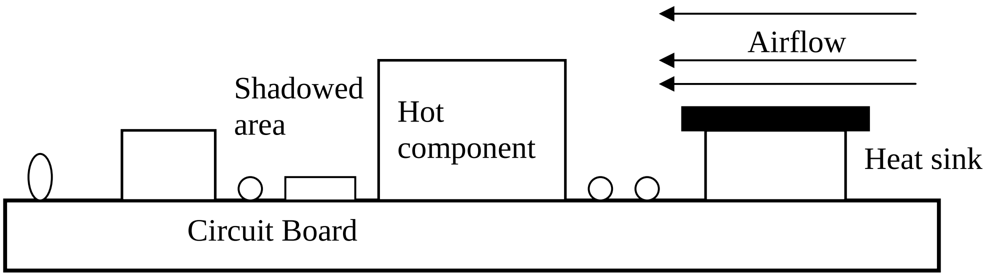

Figure 2 Airflow involved

What happens when forced air cooling is impractical or inefficient? The third solution may be required. Add liquid to the cooling solution. Two ways will be mentioned. This first is a small enclosed evaporative cooling system. This has a liquid that evaporates on the hot surface which is attached to the component. The cool side is usually in an air stream. This is a closed system, so there are cooling limits, but the system is still somewhat passive. There is no extra energy required to run it beyond the energy required for the moving air. Another disadvantage is that the cooling system must be mechanically attached to the component. A thermal pad is usually required and this leads to risk of damage from the compression required to assure good contact. The last solution is to add a large cold plate with a liquid flowing through internal channels. This is alike an automobile radiator and requires a fluid handling system and pump. This system is capable of handling up to 50W per square inch, but is expense to implement. Large cold plates may cost more than $1000, and require more exotic liquids rather than a water and antifreeze mix. Advantages are great cooling combined with a way to help make large circuit board more rigid. This extends not only to the hottest components that may be directly connected to the cold plate, but also those that don't touch the plate, but are cooled by proximity. The disadvantages are the extra cost for the cold plate, the pump and liquid connectors as well as the chiller needed to generate cool liquid. In addition is the fact that there is often flexing of the circuit board when mating and unmating the cold plate**,** causing damage to the circuit board or components. There is an extra cost for rework, a thermal pad under the cold plate and special tools and training to make it all happen. Board layout also takes a hit, since all test points have to be on the side away from the cold plate. Component height must be carefully controlled and depressions are sometimes carved into the cold plate to accommodate tall components. This solution is the most expensive, but also permits the most energy dense circuitry. This is often the solution of choice for power converters, power supplies, high-powered large ASICs or RF devices. Heat removal can be as large a challenge as circuit design.

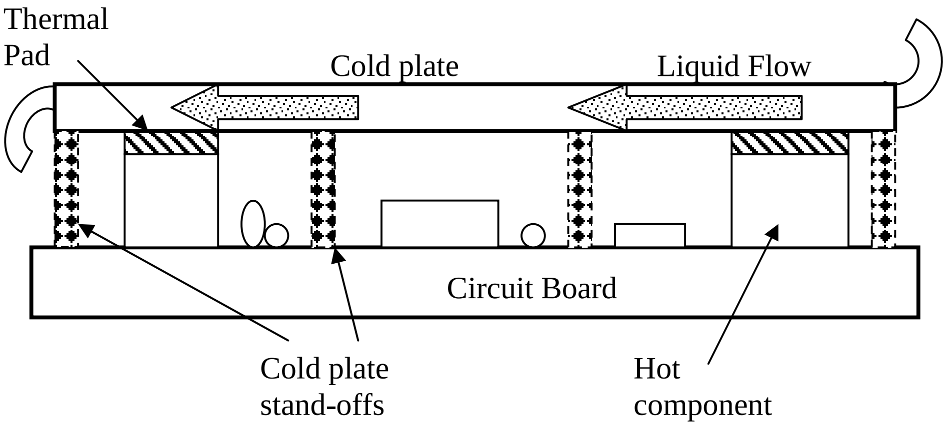

Figure 3 Cold Plate Applications

There are other cooling solutions that have been avoided here. These include thermal electric coolers, direct cooling of hot components with focused air streams and the use of extensive air handling manifolds. All have a place in the bigger cooling picture, but are more limited in their applications.

References

[1] Tian, X. and Palusinski, O., Reliability, Thermal Analysis and Optimization Wirability Design of Multilayer PCB Boards, RAMS 2002, pp 392-398, Seattle

[2] Jawaid, S. and Nesbitt, T., Accelerated Reliability Tests; Solder Defects Exposed, RAMS 1999, pp 43-50, Washington