Impact Of Thermal Relief On The Cooling Of A SOT-223 Device

ABSTRACT

The term "thermal relief" describes circuit board modifications which are made to impede heat flow from copper pads during soldering (for an example, see Figure 2: Thermal relief configuration). The thermal relief copper modifications make soldering quicker and more reliable because there is less heat drawn into ground planes during pre-heating. While thermal relief is a benefit when soldering, there is a negative impact on components which use the circuit board to dissipate heat. This paper quantifies the negative impact for a SOT-223 on a single layer board.

Simulations were performed for a variety of heatsinking pad sizes, with and without thermal relief. The simulations were performed with the Sauna™ thermal modeling software from Thermal Solutions Inc. of Ann Arbor, Michigan. For a small heatsinking pad (10 mm x 10 mm), the impact from thermal relief was fairly modest (23.8% increase in $R_{junct\text{-}to\text{-}ambient}$). However, for larger copper pads, the impact was greater and the thermal relief largely removes the benefit of using a large heatsinking pad.

Study description

The SOT-223 package is a widely used package for power components. This package features an offset heatsinking tab. To remove the heat efficiently, the SOT-223 tab is usually soldered to a large copper pad (the "heatsinking pad") on the circuit board.

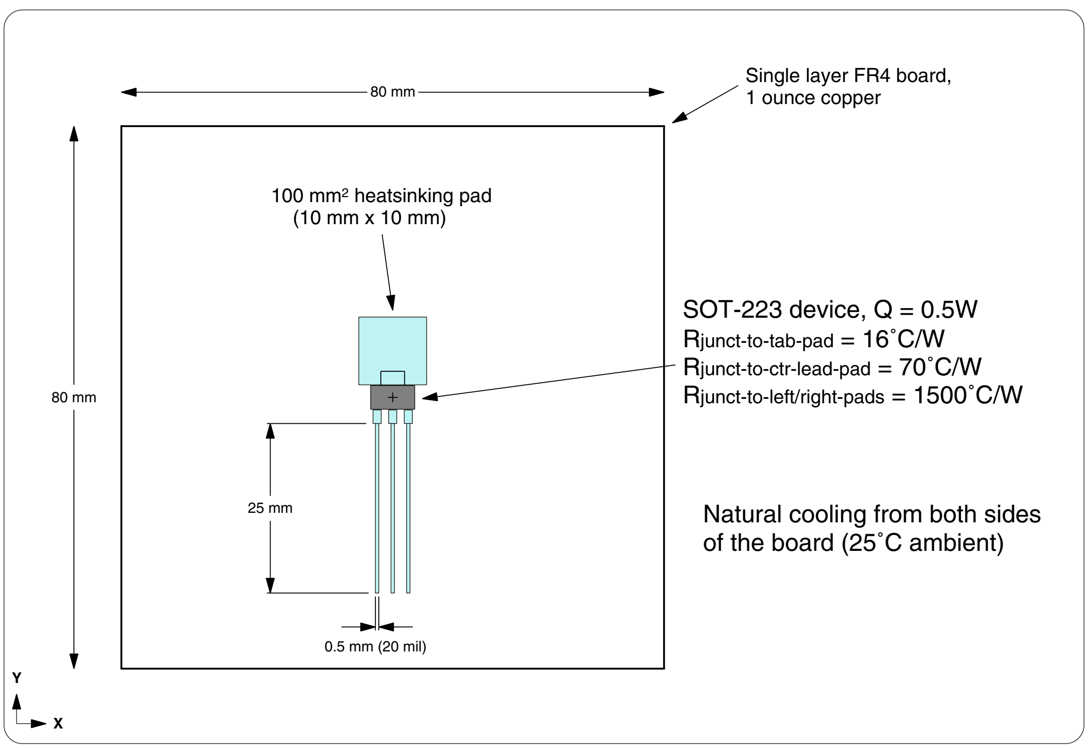

Figure 1: Study configuration (100 mm^2 heatsinking pad, no thermal relief)

In this study four different sizes of heatsinking pad were investigated: 7 mm^2 (3.5 x 2), 100 mm^2 (10 x 10), 300 mm^2 (17.3 x 17.3) , 625 mm^2 (25 x 25, about 1 in^2). The smallest pad is only slightly larger than the actual copper tab on the SOT-223 device. For the three larger pads (100 mm^2, 300 mm^2, 625 mm^2), simulations were performed with, and without, thermal relief.

The SOT-223 device was assumed to be mounted at the center of a vertical 80 mm x 80 mm circuit board (natural cooling). Figure 1 shows the configuration with a 100 mm^2 heatsinking pad. The copper weight is 1 ounce (0.036 mm thick) and there is a single copper layer.

Note that the model includes pads on both sides of the SOT-223 component. Sometimes a simplified modeling approach is used which only looks at the heat flow through the SOT-223 tab. But this is an oversimplification which would lead to errors. As shown in the figure, $R_{junct\text{-}to\text{-}tab\text{-}pad}$ = 16°C / W and $R_{junct\text{-}to\text{-}center\text{-}pad}$ = 70°C / W. The $R_{junct\text{-}to\text{-}tab\text{-}pad}$ value can be found on a datasheet. The value of 16°C / W is typical of SOT-223 packages. The $R_{junct\text{-}to\text{-}center\text{-}pad}$, on the other hand, is usually not found on the datasheet. However, since the center lead is generally an integral part of the leadframe, a thermal resistance can be estimated with reasonable confidence.

For the other two pads on the "leaded" side of the component, it was assumed that $R_{junct\text{-}to\text{-}lead\text{-}pad}$ = 1500°C / W. This should be considered a conservative estimate. (For a power MOSFET, one of the leads will be a high current path and would be expected to have fairly low thermal resistance.)

The thermal modeling was performed with the Sauna™ thermal modeling software from Thermal Solutions Inc. of Ann Arbor, Michigan. Sauna's component model lets the user apply a specific thermal resistance between the junction and each lead pad. The component model also allows for heat transfer from the top of the component body, as well as down into the circuit board. It is essential that the simulation capture heat flow in all directions as the heat flow through the tab is only a portion of total heat flow. If the analysis only focuses on the tab and heatsinking pad, the negative impact of the thermal relief would be exaggerated.

Thermal relief configuration

The term "thermal relief" describes circuit board modifications which are made to impede heat flow from copper pads during soldering. As shown in Figure 2, thermal relief involves creating

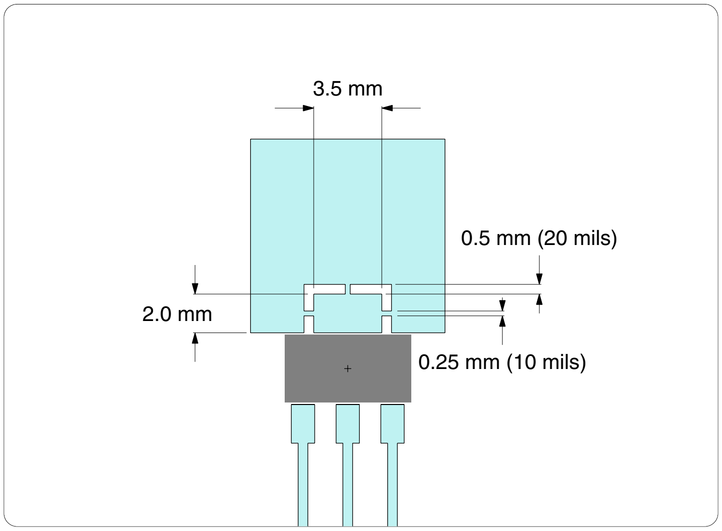

Figure 2: Thermal relief configuration

a break in the copper, sometimes referred to as "thermal moat" or "thermal dam". Examination of Figure 2 shows that the study used a moat of 0.5 mm (20 mils) and three "drawbridges" of 0.25 mm (10 mil) width. This a typical configuration for thermal relief used by industry.

Results

The results of the study are summarized in Figure 3. The figure shows $R_{junct\text{-}to\text{-}amb}$ (R_{ja}) for a range of heatsinking pad sizes, with and without thermal relief.

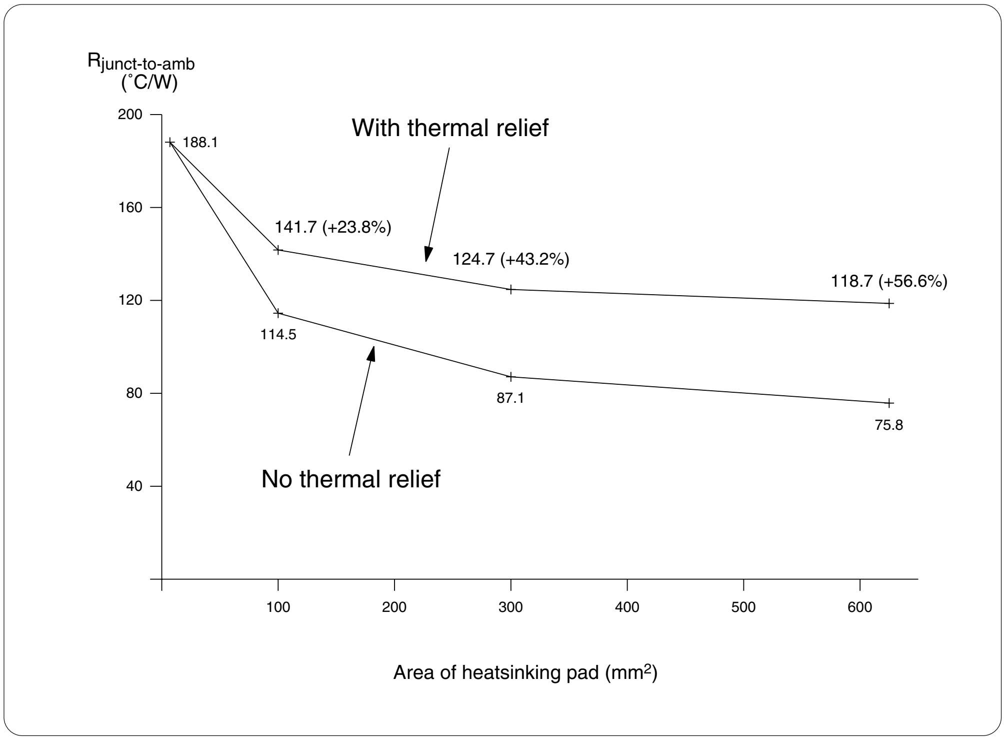

Figure 3: Results

For the small pad of 10 mm x 10 mm (400 mil x 400 mil), the impact of thermal relief is fairly modest. R_{ja} does increase by 23.8% relative to the no thermal relief case. However, the 100 mm^2 pad still provides a clear benefit when compared with the minimal 7 mm^2 pad, as R_{ja} decreases from 188.1°C / W to 141.7°C / W. Consequently, for components which use small heatsinking pads, such as PLCC-2 and PLCC-4 packages for LED's, thermal relief will likely have a limited effect.

For larger pads, the negative impact is significantly greater. With the 300 mm^2 pad, thermal relief causes an R_{ja} increase of 43.2%. For a 625 mm^2 pad, the increase is 56.6%. For Q = 0.5W, the increase in $T_{junction}$ would be 21.4°C with a 625 mm^2 pad, an appreciable increase.

The graph shows that thermal relief greatly limits the benefit of using a large heatsinking pad. When thermal relief is present, an increase in pad size from 100 mm^2 to 625 mm^2 only reduces R_{ja} from 141.7°C / W to 118.7°C / W, which is only a 16.2% decrease. The impact is even more dramatic when comparing with and without thermal relief. The R_{ja} for a 100 mm^2 pad without thermal relief (114.5°C / W) is largely identical to the R_{ja} for a 625 mm^2 pad with thermal relief included (118.7°C / W). Thermal relief can have a substantial negative impact for some situations.

Commentary

The results show that thermal relief can be detrimental. But that does not mean that thermal relief should not be used at all. Rather, thermal relief should be used intelligently by looking closely at components under thermal stress. Rather than simply removing the thermal relief, the moat could be moved further away from the component, or perhaps additional drawbridges added. Where necessary, the heatsinking tab could be hand soldered. There are many possibilities and thermal simulation can play an important role in the evaluation of different options.

One particular concern during reflow soldering is "balancing". If solder melts on one side of the component but not the other, the component can shift or turn upward ("tombstoning"). Besides adding thermal relief for the heatsinking pad, another approach is to enlarge pads on the opposite side of the component. This will also improve cooling of the part. Again, thermal simulation can be used to evaluate different alternatives.

There's much more to be investigated. The SOT-223 package is just one of many power packages. Similar studies should be performed for other common power packages such as the DPAK, D2PAK, PLCC, etc. Just as important, there needs to be an investigation for multilayer boards with vias. Once again, this is something that can be done with the Sauna program.

Finally, note that higher junction temperatures can lead to failure in several ways. First, most obvious, an excessive $T_{junction}$ can lead to a catastrophic device failure. Second, just as important, an increased junction temperatures means that the temperature cycling magnitude is increased. This in turn can lead to solder joint failures, an equally bad outcome. While uniform and repeatable manufacturing is an important goal, a product which is reliable in the field is also very important. ■

Please contact Thermal Solutions if you have comments or questions.

Written by:
Mike Naughton
Thermal Solutions Inc.
3135 S. State St., Suite 108
Ann Arbor MI 48108
734-761-1956
www.thermalsoftware.com, miken@thermalsoftware.com
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