APPLICATION NOTE

Use of infrared thermography in electronics

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Electronic circuits and components come in a variety of shapes and forms. All electronics operate with current flowing, which in turn leads to power dissipation. This power dissipation manifests itself primarily in the form of heat. Hence a key factor in the design, tests, verification and troubleshooting of all electronics, is heat management. With increasing circuit complexity and or reduction in size, heat management of electronics is taking on a more significant role in the design phase and also in the subsequent phases of test, verification and troubleshooting.

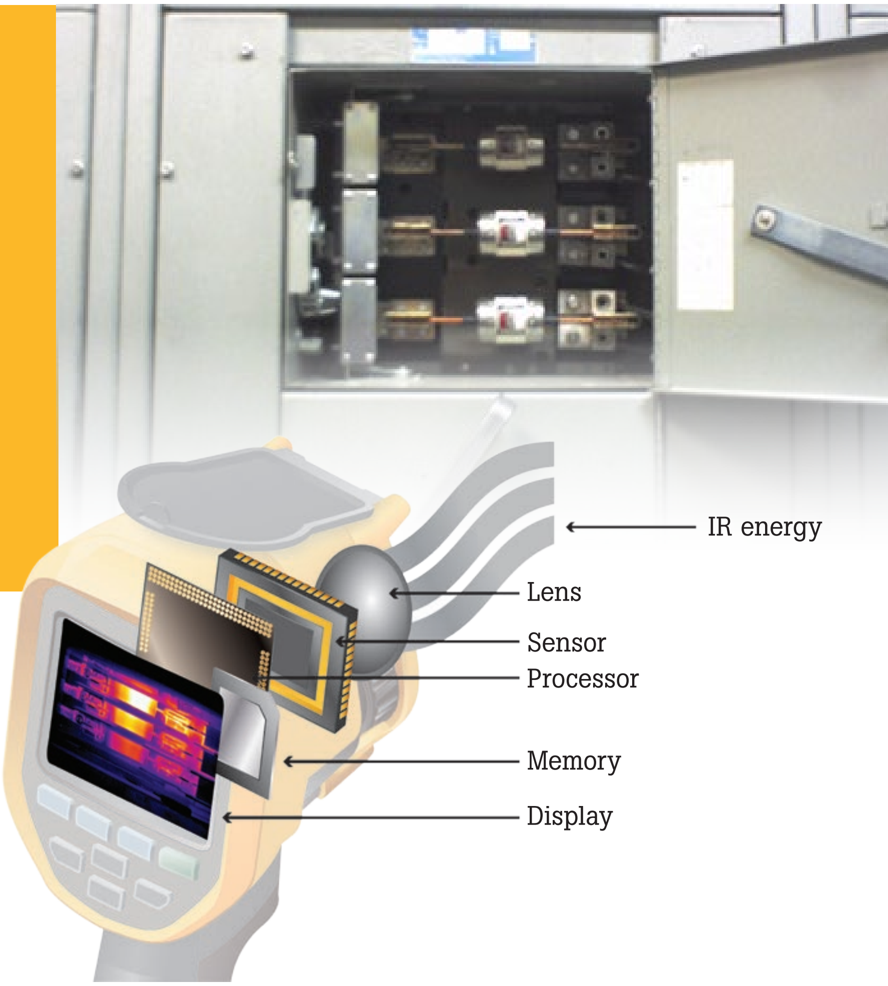


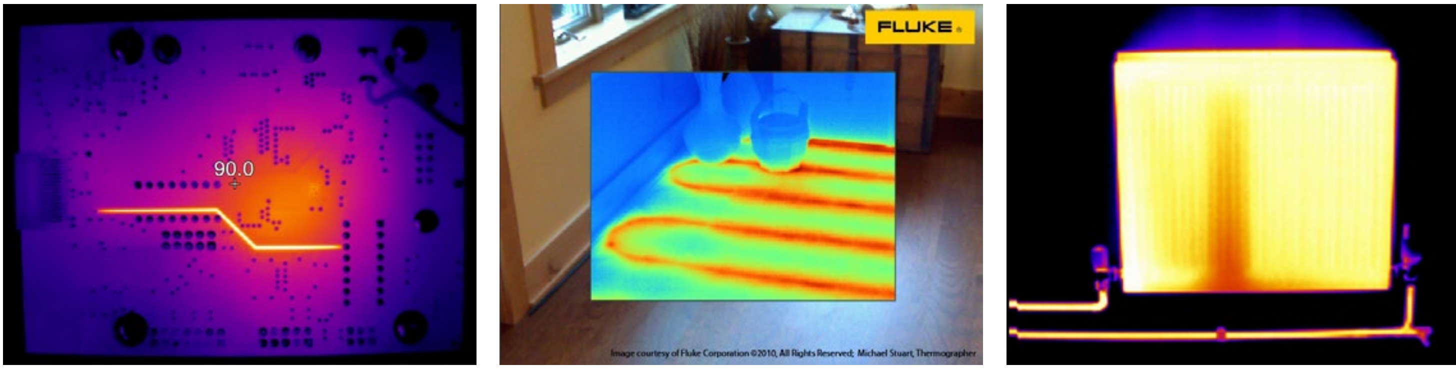
Figure 1. Anatomy of an infrared camera

Thermal imaging cameras (TI) are an ideal tool to use in mapping out the heat patterns on electronic circuits and components. Two major advantages of Thermal imaging over contact temperature measurement devices are:

1. The ability to measure temperatures without making contact with the circuit or component, thus ensuring that the temperature of the object is not affected.
2. The ability to view a large area or even the whole circuit or component, rather than measuring a single point.

What is thermal imaging?

All objects radiate infrared energy (IR). This radiated IR energy is directly proportional to the temperature of the object. So it increases as the object temperature rises. Majority of modern thermal imager cameras use a 2-Dimensional detector to detect this IR energy and convert it into an electrical signal. This data can then be stored in the electronic memory of the camera. The data can then be displayed on a screen as a heat map of the scene image by using a colour palette to represent the different temperatures. Radiometric thermal imagers are calibrated such that the IR energy can also be converted to display apparent temperature values.



Circuit board　　Underfloor heating　　Radiator

Figure 2. Examples of thermal images

What are electronic circuits and components?

Electronic circuits and components come is a variety of shapes sizes and form. Components include, passive devices like, resistors, capacitors, and inductors and active devices like transistors, and diodes. Integrated circuits are single monolithic devices where an electronic circuit built on using active and passive devices. Hybrids are circuit usually constructed of ICs and components, especially if the components, like inductors or high value capacitors are too big or cannot be fabricated on a monolithic IC. Printed circuit assemblies (PCAs) are defined as Printed circuit boards (PCB) where electronic components are mounted on to it to create an electronic circuit. PCAs can also have hybrid devices mounted on them. Majority of electronic circuits tend to be PCAs. Surface Mount Technology (SMT) is a method where components are mounted directly on a PCB rather than the traditional method of connect to the PCB through holes. Such components are known as Surface mount devices (SMD) and tend to be much smaller. Although there is a huge variety in components and circuits types, as previously mentioned, they all dissipate heat when operating and therefore require heat management.

What are the sources of heat in electronics?

The power input to any electronic or electrical circuit is dissipated as heat. This heat dissipation will cause a rise in temperature above ambient. The temperature rise depends on a variety of factors. The primary factor will be the thermal resistance of the device; other factors include any thermal management, heat sinks, forced air cooling etc. Excluding the other factors lets us consider an example of thermal resistance only. A resistor is dissipating 300 mW (0.3 W) of power. Its thermal resistance is rated at 150 K/W. Then this will give lead to a temperature rise of 0.3 X 150 = 45 °C. Assuming ambient of around 20 °C means that the temperature of the resistor will be around 65 °C. If the resistor has an operating temperature range, of, for e.g., -55 °C to +155 °C, a component temperature of 65 °C may not be an issue. However on other components, the combination of the power dissipation and the thermal resistance may well bring the operating temperature closer to its specified operating range.

In addition we also need to consider other sources of heat in an electronic circuit. Shorts circuits; High speed switching, especially where the device is overclocked.

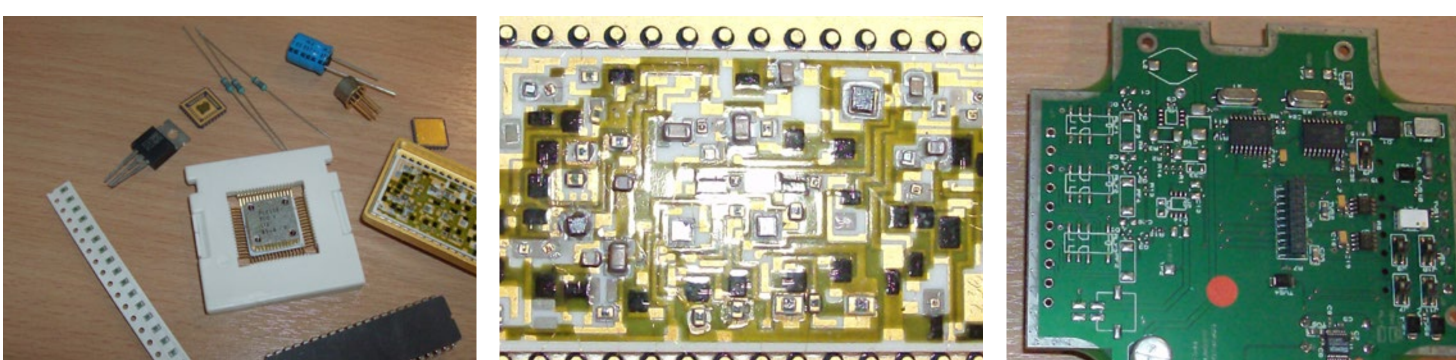


Figure 3. Examples of electronic components, hybrids and PCAs.

Why heat matters?

It is generally accepted that operating components at higher temperatures leads to higher stresses on components and circuits. This in turn can lead to increase in leakage currents, greater voltage drifts, increased propagation delays, increased chemical reactions in the material. All of these factors will lead to:

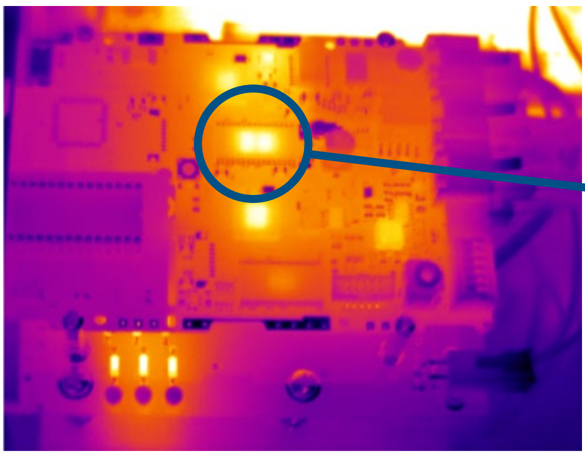


Figure 4. Thermal image of a PCA

Shorter lifetime: There is significant data that the lifetime of electronic parts is reduced by an increase in temperature. Whilst Reliability engineering offers many tools to estimate the lifetime of products, life is reduced with an increase in temperature referred to as mean time to failure (MTTF) or mean time between failures (MTBF), the temperature of the product is a key and vital parameter in these calculations. Whilst there is a great deal of debate and discussion on the effect of modelling used to establish reliability based on the Arrhenius equation, what is certainly true is that elevated temperatures do affect lifetime. The general quick rule of thumb is that an increase of 10 °C reduces lifetime by half.

Greater risk of failure: Like shorter lifetime, there is also significant data that increased temperatures also increases the risk of failure. An example of this on joints. The different metals will have different thermal coefficients: thermal cycling can then lead to strains and crack in joints.

Possible reduced performance: An increased temperature can also affect the overall performance of an electronic circuit. Increased switching times, reduced resistances, increased leakage currents, all these factors can be enough to alter the overall performance of an electronic circuit.

Possible safety concerns: The combination of greater risk of failure, reduced performance and a higher component temperatures can also potential lead to possible safety concerns.

Operation of thermal imagers

With the advances in infrared camera technology over the past 15 years, prices of thermal imagers have dropped significantly. It is also well recognised that modelling and CAD/CAM design has progressed significantly over the last 30 years. However true verification of a design still requires a working circuit. The thermal analysis of electronic circuits can now be carried out easily and rapidly at affordable prices.

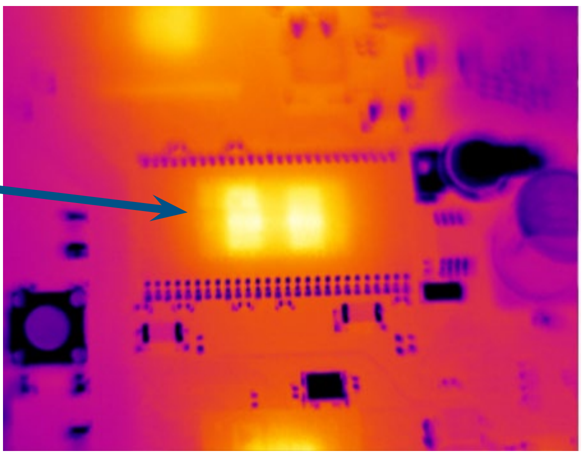


Figure 5. Close up of an IC device on the PCA

Typical ways to image

As thermal imaging cameras detect infrared radiation, which in turn is electromagnetic radiation, the key aspects of imaging are very similar to visible cameras.

The combination of the lens used and the detector resolution will largely dictate the image we get. The total field of view, the spatial resolution we can achieve. In Figure 4 below, the image is of the complete circuit board. However the IC (circled) appears to show some distinct heat pattern. When we either use a different lens or arrange to view it from a closer distance we can now see, as shown in Figure 5, two clear heat patterns. This is in fact due to this device having two memory blocks.

Effects of emissivity

As explained earlier all objects radiate infrared energy. Which in turn is proportional to the object temperature. However different materials and surface finishes can affect the amount of IR energy emitted. For e.g. Figure 6 at right is a visible image of an unpowered electronics board. The different materials and finishes will emit different amounts of infrared energy at the same temperature. To illustrate this effect Figure 7 to 9 shows the thermal image of the same unpowered board at three different ambient temperatures. In Figure 7 it is at normal ambient temperature. In Figure 8 the board was cooled by placing it in a refrigerator. In Figure 9 the board was heated up in an oven.

In all three images the temperature scale used is different and was adjusted to provide a good visible image. The actual scale used in each case is shown on the right hand side of the image. However three temperature measurement points are selected in each image to illustrate effects of emissivity.

1. On the right hand side of each image (19 °C) is the ambient temperature of the background.
2. The component in the bottom right hand corner is a SD card holder with bare metal covering. Bare metal has a low emissivity.
3. The component on the middle left hand side is a ferrite core. The finish is a matt finish with a relatively high emissivity.

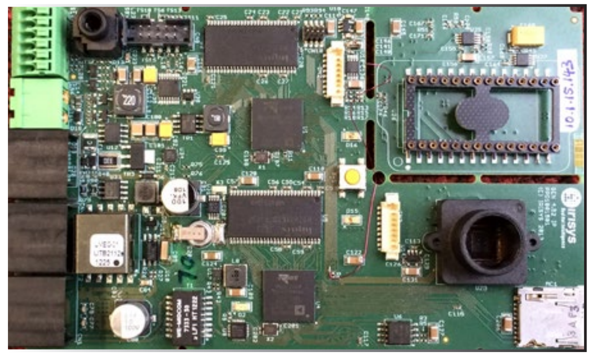


Figure 6. Visible image of a PCA

In Figure 7, under ambient temperature conditions there is very little temperature variation in the electronic board. A spread of only 3 degrees.
In Figure 8 where the board was cooled down, we now see the ferrite core has a temperature 4 °C whilst the low emissivity, SD holder is just under 18 °C. Just over a degree cooler than ambient.
In Figure 9 where the board was heated up, the high emissivity ferrite core is once again at a high temperature (40.2 °C) whilst the SD holder cover at just under 21 °C, is only under 2 °C warmer than the ambient. So the high emissivity surfaces are closer to their actual temperature. Whilst low emissivity surfaces are difficult to measure. Bare metals are particular hard to measure in these circumstances and as such users should avoid trying to get meaningful data from such surfaces.

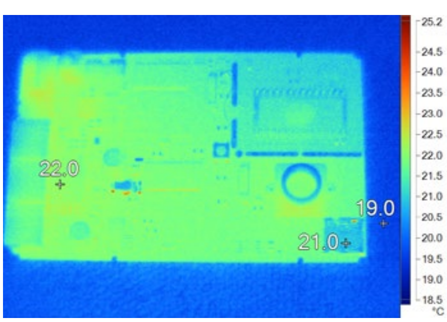


Figure 7

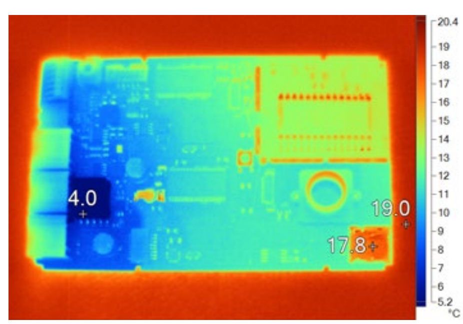


Figure 8

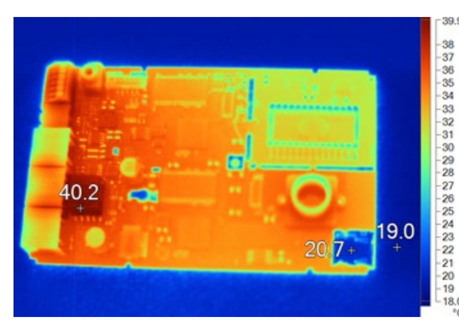
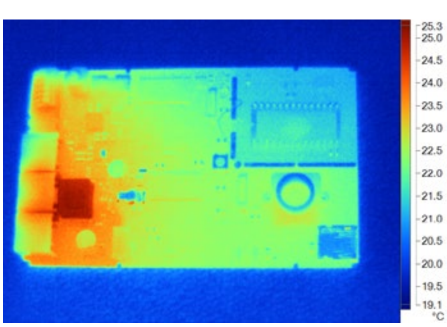
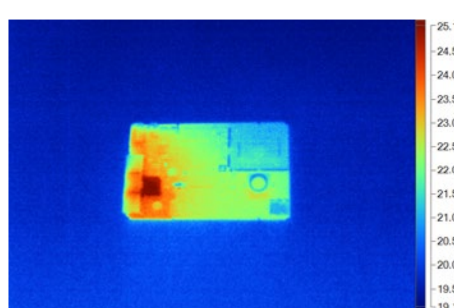


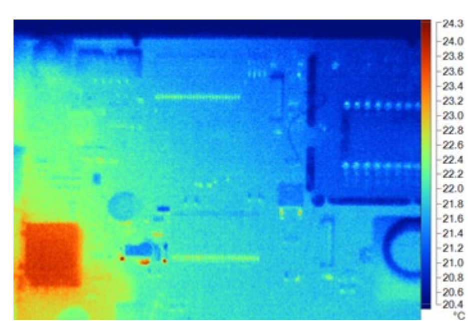
Figure 9



Standard lens



Wide field of view



2x telephoto lens

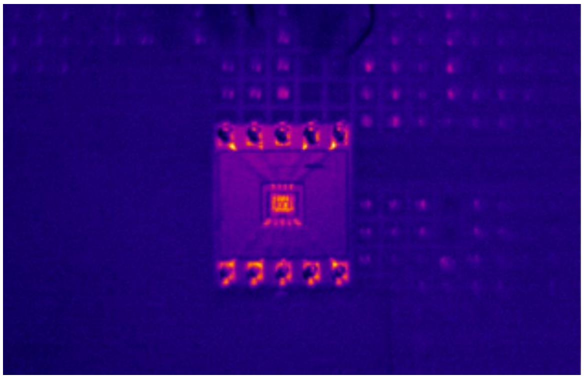


Figure 10. Unpowered Resistor set

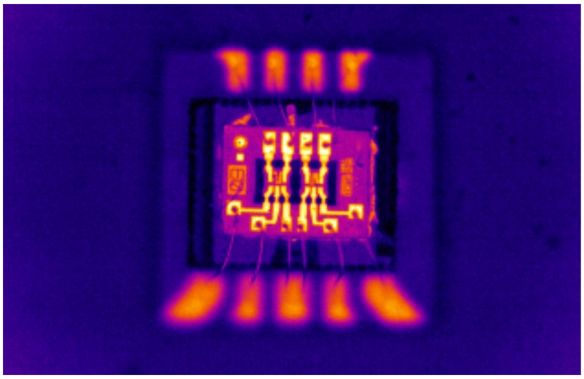


Figure 11. Unpowered resistor set with macro lens

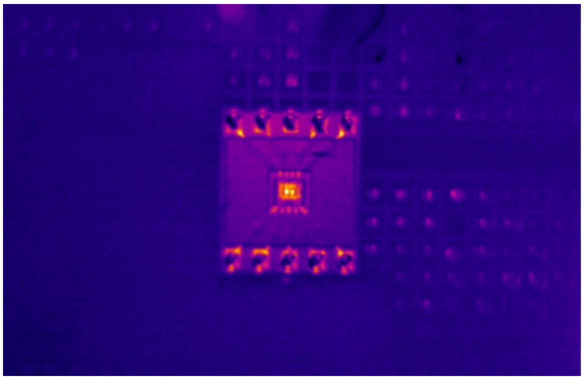


Figure 12. Powered resistor set

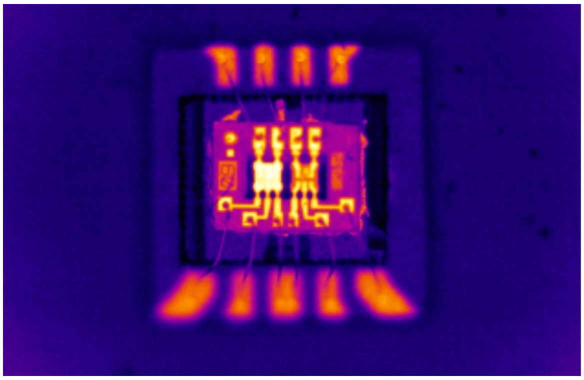


Figure 13. Powered resistor set with macro lens

Effect of Lenses

In analysing electronics using thermal imagers it can also be useful to be able to have different views. In addition to altering the distance between the board and the camera this case the use of different lenses can be provide more details and data easily.

The images below are of the same board taken with a standard lens, a wide field of view lens and a telephoto lens. In addition a macro lens can provide high level of detail.

Case study: Use of thermal imaging in the design phase

Electronic component vendors all must test their products to ensure that they perform as expected under specified conditions and to determine their typical performance life. For example, a manufacturer of surface mount resistors would want to ensure the performance, reliability, and typical life expectancy of the components it supplies. The best way to accomplish that is to test the resistors at key points during design and development stages. A resistor is primarily a device that limits current or voltage and dissipates heat depending on the currents and voltages applied. Viewing the typical thermal patterns of a resistor under test with an infrared camera equipped with a macro lens allows a manufacturer to obtain extremely useful data about the design of the resistor and its behaviour as it dissipates heat energy. Those thermal patterns can indicate manufacturing related issues.

For example, Figure 10 shows an unpowered 400 ohm resistor on an AC/DC converter captured with a standard lens. Figure 11 shows the same component captured with a 25 micron macro lens. As you can see, the macro image provides much more detail about the resistor, even without power. Next we powered up the converter and scanned it first with the standard lens (Figure 12) and then with the macro lens (Figure 13). The image captured with the standard lens doesn't show any obvious problems. However, the much more detailed image captured with the 25 micron macro lens shows that the right side of the resistor is drawing far less current than the left side. This then indicates room for further investigation. Either one of the pair of resistors is drawing too much current or the other one is drawing too little current. Temperature measurements are vital in calculating expected lifetime. The heat patterns of the resistor can be detailed enough to indicate hot spots. Such hot spots are very likely outside the specified working temperature of the component and can accelerate stresses in the material leading to early failure. With the information gained from the thermal images, the engineer would be able to change the design or the manufacturing process to mitigate the stress points that are creating the hot spot.

Case study: Use of thermal imaging in verification

A sensor company had a PCA designed to provide the high level of data processing required for its sensors. During the verification stage checking the PCA was inspected with a thermal imager where a hot spot was noted on a small component. On further investigation this hot spot was on a device and was around 85 °C. (Figure 14) With the exception of the power supply devices and processor devices, which had heat sinks attached, the rest of the components on the board were all around 65 °C or less.

Given that this particular component was a power supply controller chip, with all of the large currents passing through external components, it is not expected to dissipate much power at all. It was then necessary to investigate what was causing such a high power dissipation in a part which was expected to require very little power.

Given that the measured package temperature of 85 °C was at about 23 °C ambient, then the part would be expected to be reach 122 °C at 60 °C ambient. This would then be very close to the specified maximum 125 °C junction temperature for this device.

The design team then requested all the testing parameters used. Once this information was available they requested the tests to be repeated at 12 V. The device now no longer got as hot measuring 42 °C. Highest temperatures on the board were also now under 60 °C, which was much more reasonable. Unfortunately the end product cannot be operated from 12 V, as the system uses 24 V power supply.

Having identified the issue, various options were considered to resolve this matter. A redesign of the board was ruled out due to a combination of time, resource, cost and operation–cost both of the redesign and component changes that would be required. In addition was no suitable alternative to the "culprit" device. The major deciding factor was that the modelling carried out clearly indicated that it would be difficult to get the desired lower temperatures by redesign only.

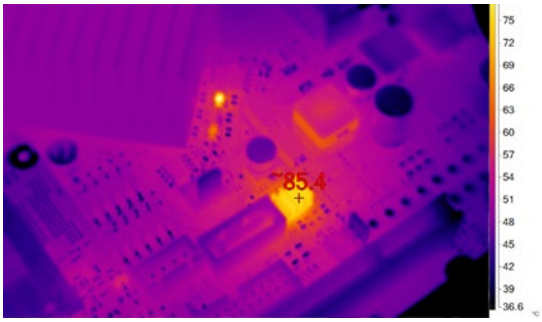


Figure 14. Power controller chip at around 85 °C

Figure 15. PCA running at 12V power supply

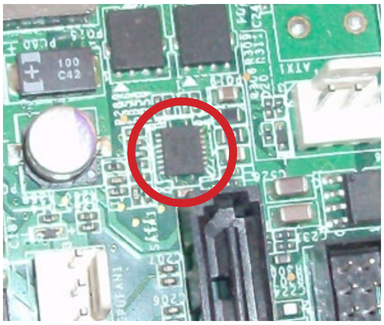


Figure 16. Without heatsink

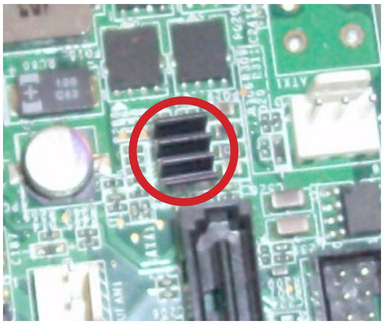


Figure 17. With a heatsink

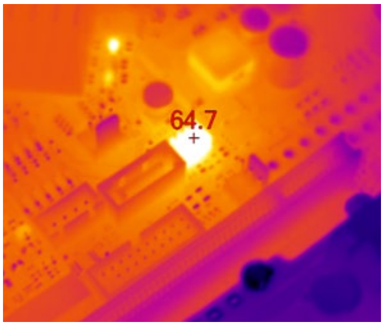


Figure 18. Operation with heatsink

The other major solution then was to consider the thermal management of the PCA. As there was only one device of concern, it was decided to attach a heatsink to it.

The addition of a heat sink now increased the cooling effect giving a lower overall package temperature.

Conclusion

The two case studies described above illustrate the power of using thermal imaging in the thermal management aspect of electronics. In both instances using contact temperature measurement would have been cumbersome and very time consuming. In addition in the case of the unbalanced current flow in the resistors the small size meant this could would not have been identified. In the second case the effect of the probe touching the small IC may well have led to some cooling effect which in turn could easily report a slightly lower temperature. This lower value could have been enough to assume that this is not as critical.

With the decrease in component sizes and increased performance demands, heat management of electronics devices and circuits is becoming more significant and important. Thermal imaging is proving to be an ideal tool in helping in the design, verification and troubleshooting of electronics.

Sat Sandhu is a Thermography Services Manager for Fluke, covering Europe, the Middle East and Africa (EMEA) and Asia Pacific. Sandhu has worked in electronics design and thermal imaging for over 36 years.