

IMPROVING HEAT TRANSFER IN A VXI CHASSIS USING BLACK BODY RADIATION TECHNIQUES

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Abstract – As in any test system, cooling of the electronics is a major concern. In larger rack systems individual components are often separate 19" units (e.g., a signal generator, oscilloscopes, spectrum analyzers, etc.). These modules tend to have low-density electronics with separate cooling systems. Vendors usually do a good job of ensuring that their boxes do not overheat.

Density increases at a high rate as test stations are required to do more in smaller spaces (this trend is the same for almost all electronics). However, when the density increases (such as with VXI, VME, or compact PCI), the manufacturer cannot always control the cooling of their card. Heating from other cards, card placement, airflow in the cabinet, use of adapters, etc., all affect the cooling for a given card. The vendor, however, can only supply guidelines to the end user. It is up to the user to understand the cooling needs of the system as a whole.

Proper cooling is extremely important and is not just a function of airflow to a given card. In fact, for dense electronics (conductive or convective), air cooling may not even be the primary mechanism for heat removal.

BACKGROUND

High operating temperatures and good component reliability do not mix. Semiconductors are usually more susceptible to long term failures under prolonged, elevated temperatures. Every rise by 10° C in junction temperature cuts lifetime in half. Currently, there is no easy way to verify the internal case temperatures in a VXI chassis.

A box might have a Programmable Interface Controller (PIC) temperature sensor that can be polled from the bus. However, in general, vendors rarely take this data, and opening the box to take internal temperature readings voids the warranty.

However, with some reasonable temperature assumptions, an end user can work backwards to explain high failure rates in the active components. When the failure data closely matches manufacturer's data sheets for high temperature failures, the assumptions are known to be accurate. Of course the only way to verify temperatures in a working unit is to have a sea of thermocouples tied to critical hot spots.

Thermal imaging photos of a VXI module in an open-air chassis can provide some insight. The absolute temperature readings are meaningless, but the photos do show where heat is generated.

Figure 1 shows the left side of a VXI radio after being allowed to warm up for 30 minutes. Those viewing the photo in black and white may have trouble distinguishing the harm spots on the side panel. They are at the bottom middle and the upper left corner. These spots show as lighter shades in black and white.

The right side of the device (Figure 2) operates at a much lower temperature, with few sources of heat on the right side of the box. This does not mean that the parts on this side do not get hot. It only means that there are no significant heat sources on this side that the camera can see. In fact the upper right corner does show some heat, probably absorbing it from the warmer devices on the other side of the cabinet.

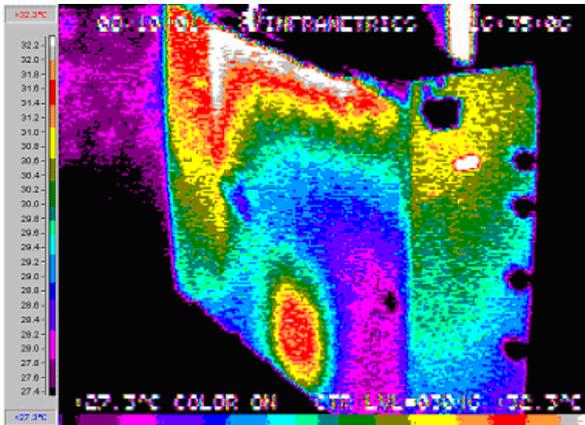


Figure 1. Left Side View of a VXI Module

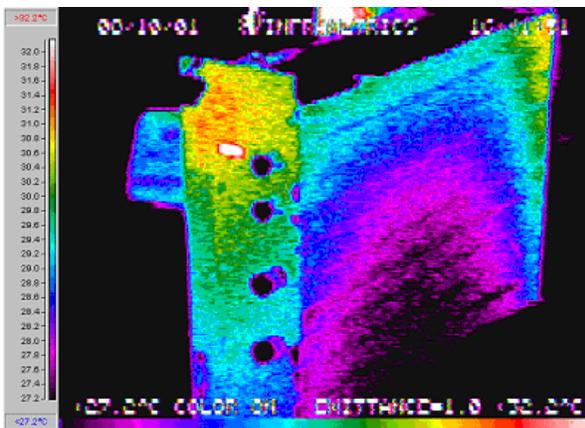


Figure 2. Cool Side of the Box, the Right Side

In both photos the differences from these warm spots are not large. Still, they are plainly visible to the camera. Therefore, the box does have hot spots and does not have a uniform temperature.

BLACK BODY RADIATION

Black body radiation refers to the situation where a heat source with no other way to expel its heat will continue to rise in temperature until it can radiate this heat to its surroundings. Since there are no heat sinks bonded to the lids in the figures above, most of this heat must be transferred via black body radiation. If it were mostly convection, the hot spots would be larger and less pronounced. The amount of this radiation changes with the temperature of the bodies, the area of each exposed to the other and the surface of each body.

Using relationships for heat transfer between two “grey” bodies, the heat transferred between the two is given in (1) and (2) [1].

$$Q = \sigma f e A (T_1^4 - T_2^4), \text{ where } Q \text{ is in watts} \quad (1)$$

or

$$T_1 (\text{in } ^\circ\text{C}) = ((0.239 * Q)/(\sigma f e A) + T_2^4)^{1/4} - 273 \quad (2)$$

T_2 is the environment temperature of the system in K° ; in this example it is the chassis or case lid. T_1 is the device temperature. T_1 will climb until the device temperature is in equilibrium. This is, for instance, the primary method of heat transfer in a light bulb, since there is no air inside the envelope.

$A * f$, in equation (1) is the common area viewed by the two bodies. A is the area in cm^2 . In this analysis the goal is to change as little as possible. Therefore, spacing between parts and their areas (adding a big spreading heat sink, for example) will not be changed. What can be changed is the term e . This is the emissivity of the material. Emissivity is just another way to state the fraction of the black body radiation, generated by a heated body, that leaves the surface in question. Emissivities range from 0 for a perfect radiation reflector to 1 for a perfect absorber.

Remember that this is the emissivity of black bodies where almost all of the energy is below the visible spectrum. Color, therefore, is not a variable. In general, however, if the body’s surface is shiny and reflective, it has poor emissivity compared to dull surfaces—that is, how can it radiate its own heat if it reflects everything?

SAMPLE CALCULATION

An example of emissivity can be seen in the following sample calculation. The assumptions used in this calculation are that the hot, digital chips have a good view of the case lid with some minor blockage, $f = 0.9$; the part is a big digital chip with 4cm^2 of surface area which dissipates a 100mW of power on the top surface; and the lid is a brushed aluminum surface with poor emissivity of 0.15. The poor emissivity is known from inspection of the VXI unit’s lid material.

The e used in calculations is the combination of the two surfaces given in (3).

$$e = 1/(1/e_1 + 1/e_2 - 1) \quad (3)$$

From equation (3), the total emissivity is no better than the worst emissivity. Table 5.3 [1] shows emissivity ranges from .06, for highly polished aluminum or steel, to 0.95 for water or painted surfaces. Since many digital chips these days have black plastic encapsulation, a value of 0.5 will be used for e_1 . A sealed compartment has only black body radiation to transfer heat from the cavity.

Using equations (2) and (3) with $\sigma = 1.355 \times 10^{-12}$ cal/sec-K⁴-cm² and 0.239cal/sec per watt results in a temperature of 193° C. This number significantly exceeds the ideal, hot working temperature. Clearly, even a small amount of heat in a confined area can overheat the electronics. In actual use, there would also be additional heat transfer from the convection currents and the bonding leads. A chip could not run at 193° C, so another heat transfer mechanism must exist. Note: Heat will not radiate from the back of the chip unless there is good emissivity. The shiny surface of a copper PWB has low emissivity and little heat would radiate through it. If the case has a thermal bond to the circuit card, which is usually the case, the part would run much cooler. Remember that the temperatures are raised to the fourth power in (2). It does not take much of a change in power or emissivity to get large temperature changes.

CLASSIC EXAMPLE

The classic black body radiation problem is the incandescent light bulb. There is virtually no thermal connection between the filament wire and the outside world. In a vacuum, there is no moving air, yet the filament does not melt. The only way the heat can transfer from the filament to the outside is by radiating its energy. The filament temperature climbs until it is in equilibrium with the outside world. But the emissivity is poor, so the temperatures are high. For a 100-watt bulb, even the glass envelope—much cooler than the filament (over 2000° C)—is too hot to touch. This is the same mechanism that the sun uses to transfer energy to the earth since there is nothing in space to conduct its energy.

GET THE HEAT OUT

If the same situation, as in the example above, exists with better radiant heat transfer, the temperature rise drops. As shown in Table 1, a thin coat of white paint, or any color other than

silver, on both surfaces will raise the emissivity of each to 0.94. If you like black use a flat black. Steinberg's data shows that the coating should be about 1mil (.001") to give the desired effect [1]. Increasing the coat by.05 mils only raises e to 0.20. Thick paint makes an insulator!

Table 1. Emissivity of Common Metal Surfaces Along with Paint

Surface of Lid	Emissivity	T(C)
Silver, polished	0.01	567
Gold	0.02	437
Aluminum, brush	0.15	181
Black Lacquer .24mil	0.48	103
Polished Steel	0.53	99
Anodize Aluminum	0.81	82
White Paint 1mil	0.94	77

With the power dissipation still at 100mW, the part reaches equilibrium at 78° C, which is adequate. The power must be raised to 600mW to get comparable temperature rises with the higher emissivity surfaces.

If the outer lids are anodized and the hot part painted, the temperature rise goes from 78° C to 84° C, which is warm but still significantly better than the 193° C in the original case.

If the body of the heat source has good emissivity (0.95), Table 1 shows the temperature rise that results when the cover surface changes. Very low emissivity numbers easily explain the temperature of the light bulb filament.

TEST RESULTS

The simplest way to prove this theory is to improve emissivity in an existing box without changing anything else. Since most boxes have brushed aluminum lids, this is an easy place to start. Brushed aluminum has $e = 0.15$ or less, which is a good heat reflector—so paint the inside of the lid! Any heat radiated from the internal parts will now be absorbed by the lid and spread to the case. The air cooling of the rack now has a mechanism to extract the heat.

Equation (3) shows that it is best to improve emissivity on both sides of the problem. However, Figure 3 shows that the components will overheat

if one side (the lid in this case), has very poor emissivity. Clearly, it is easier to paint the inside of the lid before doing anything to the circuitry.

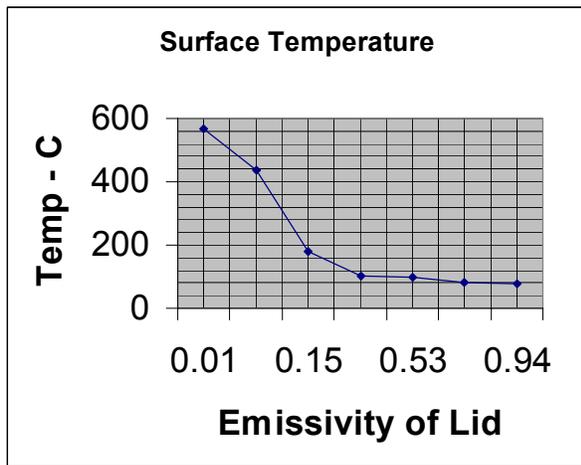


Figure 3. Temperature Profile in a Poorly Vented box when Emissivity of the Lid is the only Variable (Plot of Table 2).

Table 2 shows a significant improvement in heat transfer after the inside surfaces are painted. The exhaust temperature, for example, rose by 7° C, to 67° C. Previously, that heat was trapped in the VXI module. Heat transfer to the outside has increased almost 70%. Note the drop in case temperatures of some of the larger heat sources (power resistors and power supply modules). Airflow, in this example, did not change. A larger percentage of the heat radiating from the internal components now soaks into the case instead of being reflected back into the box. Once the heat transfers to the main chassis, the air cooling works. No matter what size fan is used in the system, the electronics will continue to overheat if that heat cannot radiate to the outside surfaces of the chassis.

Table 2. Temperature Changes Inside a VXI Module after Painting the Inside Surfaces of Box Lids with Flat Black Paint

Location	Before	After	Change
Rack Air Temp	52.2	58.3	6.1
Power Resistor 1	94	89.5	-4.5
Power Resistor 2	96.7	93.7	-3
Power Resistor 3	89.6	88.3	-1.3
Outside Cover Power Supply	57.4	52.2	-5.2
Exhaust air port 1	60	67	7

SUMMARY

Although assumptions had to be used for power dissipation and surface areas, the general principle in this paper is sound. The data shows that heat in a chassis is a problem. The thermal imaging photos also show definite hot spot areas. Therefore, parts are running above their recommended temperatures.

Lowering the emissivity of the outer lids, which are usually shiny aluminum, decreases the temperature. A thin coat of non reflective, flat paint on the inside and outside surfaces of the lids, and a thin coat on the hot parts will allow almost six times the amount of power to radiate from the box for the same component temperature rise. Therefore, the box will run cooler. Anodizing the lids works almost as well, provided the anodized surface is about .001" thick. Reliability will be greatly increased with no change to the electrical or mechanical design of the VXI module.

REFERENCES

[1] D.S. Steinberg, *Cooling Techniques For Electronic Equipment*. New York, Wiley Interscience, pp. 128-165.