ENHANCING RELIABILITY IN A MULTI-FUNCTION CALIBRATOR USING THERMAL DESIGN

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Abstract

The failure rates of semiconductor devices have been directly related to junction temperatures. Thus, the reliability of a semiconductor device can be enhanced by lowering its junction temperature. In a complex electronic instrument where substantial amounts of power are dissipated, temperature control becomes necessary. For this to happen, however, thermal design must be incorporated into the system design of the instrument from the very start. To treat thermal problems after the fact can create real problems in electrical, mechanical, and scheduling areas of the project. This paper describes the thermal problems in the design of a complex multifunction calibrator and a solution methodology that was used to reduce the device junction temperatures in the instrument.

Introduction

The failure rates of semiconductor devices have long been tied to the Arrhenius equation that relates failure rates to device temperatures [1], [2]. The lower the device temperature, the lower the failure rate. In the design of complex instruments that act as voltage or current sources, considerable power is generated inside the instrument itself. Without proper cooling, the internal temperatures can easily increase the device failure rates by factors of 30 or more. In most large calibrators, internal cooling (usually with air) is absolutely necessary. However if this cooling is to be effective it must be designed in right from the beginning. Adding the cooling as an afterthought can lead to hot spots in the instruments and lower reliability. This paper discusses the solution to this cooling problem in the design of a multifunction calibrator manufactured by the John Fluke Mfg. Co., Inc.

The Cooling Problem in a Multifunction Calibrator

A multifunction calibrator has, by its nature, a large amount of heat generated inside. Most need to use linear supplies for high isolation and low noise. However, these are not energy efficient supplies and they generate more heat than the more efficient switching supplies. For low distortion, amplifiers must be operated Class A. These are less energy efficient than Class A-B or B. Thus, more heat is generated inside the instrument. The multifunction capability leads to more built-in inefficiencies. Since there are several functions, each of these must use some "bias" power to keep them warmed up in case they are called for by the operator or controller. In a large calibrator, such as the one in development at Fluke, this standby power is on the order of 135 watts. The full-load power is approximately 205 watts. If this energy is not efficiently transferred to the ambient environment quickly, the internal temperature will increase to the point that the components are thermally stressed and their reliability will decrease substantially. Another thermal problem associated with the multifunctionality of this instrument is the division into functions of the internal circuitry. There is a common power supply, but the wideband function has its own power amplifiers, as do the AC, DC and High Voltage. Thus the power dissipating components are spread throughout the chassis. It is very difficult to keep the functions isolated and have all the power dissipated in the same section of the chassis. So we had two problems to solve: 1) we had a lot of heat to get out of the chassis and 2) the heat generating components were spread out inside the chassis.

Thermal Design Solutions

For electronic applications, the two most effective modes of heat transfer are conduction and convection. Radiation is less effective for most electronic component temperatures. To determine whether we could get by with conductive and natural convective heat transfer from the chassis directly to the ambient, we calculated the amount of heat that could be transferred out of the chassis by conduction to the outside, assuming a 20° C average internal temperature rise. This was approximately 65 watts; far below that needed for conduction and natural convection to be the sole cooling mechanisms. Clearly, additional forced air cooling would be necessary. For general test equipment applications, air is the preferred coolant and vane axial fans are the preferred movers of air. Several approaches were tried, but the one with the most promise was the concept of tuned airflow. This involved using the mechanical structure to act as a ducting system to get air where it was needed and to limit the airflow where it was not needed. By "tuning" the airflow, the cooling became much more effective. Air wasn't wasted on low power circuitry. It could be applied directly to the components that needed cooling air. To appreciate this concept, refer to Figure 1. This shows the arrangement of the printed circuit cards inside the calibrator. The stars represent the areas of high heat dissipation. If we didn't use internal ducting, but just let the air flow as it will, the air velocities in the areas of the stars would be insufficient to provide adequate cooling.

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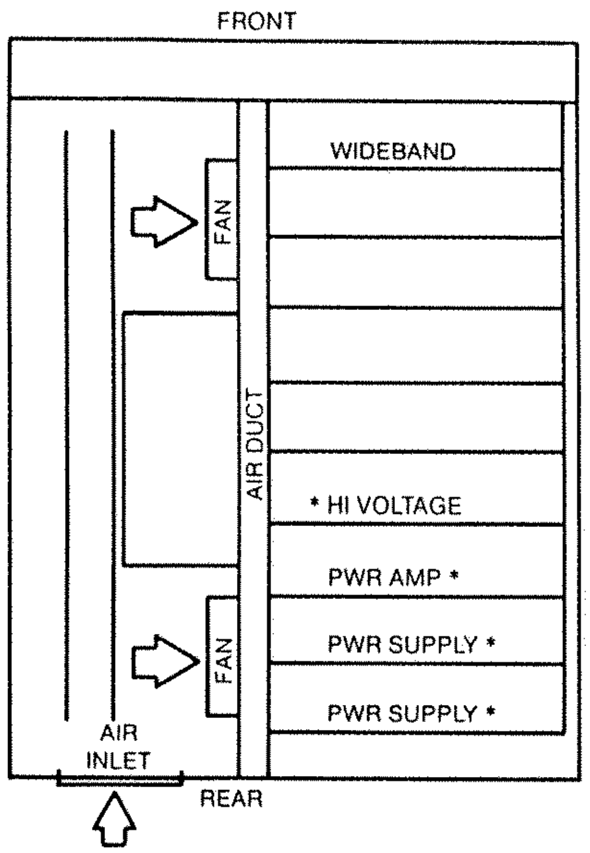

Figure 1. Top View of Calibrator

Suppose we look at a particular assembly, for example, the power amplifier (see Figure. 1). This assembly has a heatsink that must dissipate 40 watts worst case. Additionally, the heatsink must be small to allow room for all the components on the board and to fit in the allotted volume, which also gave a height constraint. The air flowing across the heatsink could not flow across any of the critical temperature sensitive components. Thus, the heatsink had to mount on the outboard side of the chassis so air could flow across it and then promptly exit the instrument. Heat transfer between a metal heatsink and the surrounding air can be described by the relationship [3].

$$q = hA \left\{ T_w \quad T_\infty \right\} \tag{1}$$

where q = heat transferred,
h = convection heat transfer coefficient,
A = surface area,
T_w = metal surface temperature, and
T_∞ = temperature of the air moving across the heatsink

The factor h is a non-linear function of the air velocity. The higher the velocity, the higher the value of h [3], [4]. Thus, to increase the heat transfer from a heatsink, we need to increase the velocity of air across the heatsink. The amount of air moving across the pcb cavity (see Figure. 1) is not as important as the velocity of the air moving across the heatsink. To make the fans effective at a distance we used small air ducts mounted on the circuit board to duct the high velocity air coming off the fan right to the heatsink (see Figure 2). The use of this duct gave us twice the velocity across the heatsink with a resultant decrease of 16° C at the transistor junctions. For the temperatures we're looking at, this translated into an increase in reliability by a factor of approximately 3.3.

This design technique was used on the wideband assembly, the power supply assembly, the high voltage assembly and the power amplifier assembly. In all cases the velocity of the air coming off the fans is sufficient for cooling the assemblies. Holes of certain shapes and position were placed in the duct and this allowed air to come blasting in to cool components with high heat dissipation, while providing just enough air for the low power components on the assemblies. By controlling the size and shape of the holes in the duct, we were able to control the flow of air to each assembly. So each assembly gets the airflow it needs to keep the device temperatures low.

Additional airflow tuning was done with fans. Normally, the fan is mounted on the rear of the chassis and either pressurizes the chassis, with air exiting in the rear or on the sides. Or the fan reduces the pressure inside the chassis and air flows in through an opening in the rear of the chassis or through openings in the sides. We looked at both of these alternatives and decided to use a slightly different approach. By using two small fans, instead of one large one, we were able to balance the airflow better inside the chassis. One fan is mounted towards the rear and the other is mounted near the front. Both are mounted on the "air duct" formed by the structural sheet metal (refer to Figure 1). This tuning gave us the necessary airflow in the front of the instrument to cool the wideband assembly.

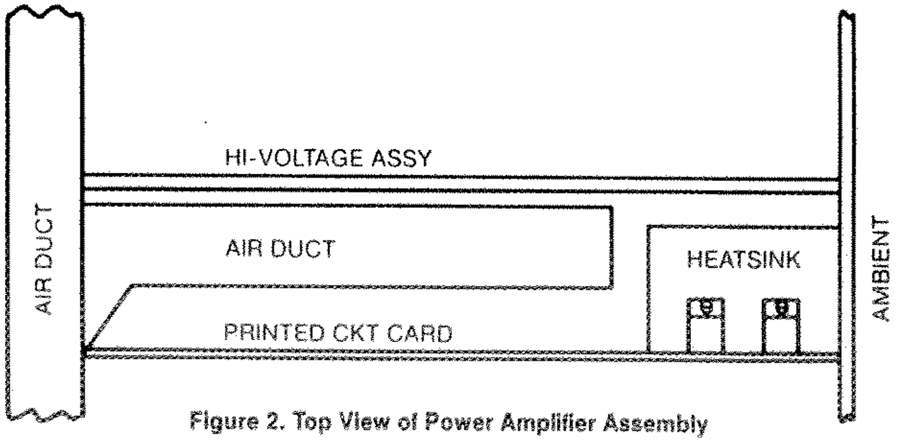

Figure 2. Top View of Power Amplifier Assembly

Conclusion

In a large instrument such as a multifunction calibrator, there is a definite thermal design problem. If this is recognized at the start of the project, then the mechanical design and printed circuit board designs can accomodate thermal design. This cannot be done as an afterthought because the mechanical changes can make thermal design seem insignificant in the later stages of a large project. By incorporating thermal design into the design cycle, significant reductions in device temperatures can be achieved. This produces an accompanying increase in instrument reliability and that's important to our customers.

This concept of tuned airflow can also be applied to the systems level. Many instruments are designed to have free access to surrounding ambient temperatures. When systems of instruments are mounted inside racks, it is important to incorporate thermal design into the construction of these systems. Proper thermal design can reduce failure rates of instruments mounted in system racks as well as inside the instruments themselves.

References

1. National Semiconductor Corporation, "The Evaluation of Reliability Data," Reliability Report G8301002, Santa Clara, Calif.
2. Turner, T., "IC Failure-Rate Calculations Evaluate Components Realistically," EDN Magazine, April 15, 1981.
3. Holman, J.P., Heat Transfer, 3rd Ed., McGraw Hill, N.Y., 1972.
4. Ellison, G., Thermal Computations for Electronic Equipment, Van Nostrand Reinhold Co., Inc., N.Y., 1984.