ABSTRACT

Infrared thermography has become an essential tool for design verification of electronic assemblies. This paper will discuss how infrared thermography is used within IBM to identify and alleviate design problems early in the hardware prototype stage of electronic power assemblies. Several examples of the types of problems found in power assembly designs will be discussed. Infrared thermography has been used within IBM since 1983. It has been used on IBM designed power assemblies, as well as supplier designed power assemblies for IBM products. Enhancements to thermal images and the evolution of electronic mail has simplified tremendously the task of communicating thermal problems to a worldwide design team and supplier base.

Keywords: computers, electronic assembly, design verification, problem prevention, power assemblies, problem communication

1. INTRODUCTION

The computer industry has undergone an enormous amount of change over the past twenty years. Beginning with the advent of the IBM personal computer in 1981, computers have started to etch their way into almost every daily task for many businesses and households. Computers are becoming ubiquitous, and computing power is growing tremendously. Customers demand as much computing power, storage, memory, and function as possible in a given space. Technology advances have paved the way for greater levels of integration and denser packages. But with the increase in density, the thermal layout and design of the computer system becomes much more important.

2. POWER SUPPLY

One of the components of the computer system is the power supply. The function of the power supply is to take an input voltage, which may be an AC or DC, and generate the useful output voltages required by the components of the computer system. A typical computer system requires several different power supply output voltages since each component has unique input voltage requirements. For instance, a hard file typically requires +12V and +5V to power it, logic typically requires +5V and +3.3V, and processors have been rapidly requiring lower input voltages. For instance, the IBM copper technology microprocessors operate at an input voltage of +1.5V.

Power supply technology has changed considerably in the past twenty years to keep pace with the product needs and consumer demands. In the early 1980’s, IBM midrange systems such as the System 38 and System 36 used ferro resonant power supply technology. These power supplies consisted of large transformers operating at line frequency, 50 Hz or 60 Hz. These transformers provided the input isolation and several step down voltage taps which could be rectified and filtered into the useable output voltages for the system. The ferro resonant transformers and filter assemblies were physically very large and heavy assemblies.

Beginning in the early to mid 1980’s, there was a need to begin utilizing switch mode power supplies (SMPS). These power supplies operate at higher switching frequencies, allowing the transformers to be much smaller and lighter. Today, typical SMPS operate at frequencies between 200 kHz to 500 kHz. With the advance of power technology, power supplies became smaller sized and increased in power density. Thermal aspects of power supplies have become very critical in ensuring a reliable design. As computers have advanced into ever increasing critical customer applications, customers are less tolerant of any downtime on their computer systems. A very reliable power system design is required. Fig. 1 is a block schematic of a switching power supply.
3. POWER ASSEMBLY DESIGN VERIFICATION

To guarantee a reliable design, all power supplies within IBM go through a qualification process. This process reviews several aspects of the power supply. One of the key elements of the design verification testing is the thermal analysis of the power supply. The purpose of this analysis is to identify layout or component power dissipation concerns early in the development process.

Beginning in the early 1980’s, the thermal measurements were obtained by epoxing thermocouples to every component in the power supply assembly. Monitoring every component in the assembly using thermocouples is a labor intensive process since typical power supply designs have over two hundred components. Often times it is difficult mounting thermocouples on components due to the physical layout of the assembly. Also, several power components are quite large, and it requires experience to choose the best location to mount a thermocouple. Sometimes thermocouples would come loose and cause invalid and/or erratic results. Around 1983, thermal imaging began to be utilized by IBM to verify the thermal designs of power supplies. The first imager IBM used was a Hughes Probeye and it required argon gas to help cool the detector. The camera immediately became useful in identifying thermal hot spots in power designs, as well as being a useful failure analysis tool. For example, it proved useful in identifying where shorts were occurring in flex cables used in the first IBM developed 5-1/4” hard files. Since the camera lacked sufficient resolution and analysis capability and the equipment was quite bulky, the main method in obtaining power supply temperature measurements continued to be thermocouples.

In 1990, an Inframetrics 760 camera with ThermaGram analysis software was obtained. The camera’s resolution and analysis capability was sufficient to identify hot components and analyze the thermal images of power assemblies. The reasons for using thermocouples on all components were eliminated, and after several verification tests, it was decided to mainly rely on the thermal images and only thermocouple certain components which could not be adequately viewed by the camera.

In 1996, two Inframetrics PM250 cameras were obtained by IBM to upgrade the thermal imaging capabilities. The advantage of having two cameras is that two separate test setups can be measured concurrently, and when one camera is being calibrated, the other camera may be used. The camera's hardware and software has made obtaining thermal images and analyzing the images in reports much easier than its predecessors. This has assisted IBM significantly to communicate problems with our suppliers and design teams which are located all over the world.

4. THERMAL ANALYSIS PROCESS DESCRIPTION

The process of obtaining a thermal image of a power assembly which correlates with what will actually be seen in the final application is not an easy task. The first issue is how to allow an infrared camera to look into the power supply chassis to identify hot spots. The second challenge is how to mimic the system level cooling, preheat, and back pressures without having to use all the system hardware. The third challenge is defining the input voltage conditions and output loading conditions which are relevant to test.
5. ISSUE ONE

The problem of allowing the camera to view inside the power assembly chassis is resolved by cutting surfaces of the power supply chassis which otherwise are solid surfaces. Care must be taken to ensure that the airflow through the power assembly is not modified during this process. IBM uses a laser cutter to cut the chassis. Then the surface is smoothed and the cutouts are replaced with a transparent sheet of window covering material. IBM has determined that in most cases the material found in window insulator kits (such as 3M's catalog number 2140) works quite well. The material is clear, may be fitted tightly to the chassis window opening, and does not distort the infrared transmission (see Fig. 2).

In most power supplies, when the chassis solid surfaces are replaced by clear viewing windows, about 80% of the components become visible. For those components which remain out of view of the camera, alternate techniques must be used. One solution is to apply thermocouples to the components which cannot be viewed. A second solution may be to modify the mechanical structure of the power supply or power supply card assemblies to allow the hidden components to be viewed. The best solution is dependent on the particular power assembly being tested and the final application.

6. ISSUE TWO

The system cooling, back pressures, airflow directions must be understood. Typically in IBM specifications for power assemblies, the airflow may be specified as a cubic feet per minute (CFM) rate or as a linear feet per minute (LFM) airflow rate once the system cooling is defined. These figures however are sometimes hard to verify by measurements. For example, an anemometer which measures linear flow rates is very position dependent, and depending upon the orientation of the transducer, it may provide readings which vary by as much as an order of magnitude from actual flow rates. A better technique is to monitor the pressure drop from input to the power supply to output of the power supply. This can be compared to readings made in the system.

In many cases, a blower or fan assembly will be used to generate the air flow, and then baffling is used to direct the airflow across the power assembly unit. The complete airflow subsystem along with the power assembly can then be tested to determine pressure drop (airflow) versus voltage applied to the fan or blower assembly as shown in Fig. 3. The curve generated from this analysis can then be used during the thermal testing to set up the proper airflow rates.

Figure 2: Power supply with viewing windows cut

Figure 3: Typical thermal setup
7. ISSUE THREE

Determining the input source and output loading conditions to apply to the power supply must also be identified. The IBM power supply engineering specification will specify the input voltage range and minimum and maximum loads for each output voltage. The thermal design verification must analyze the power supply under the most extreme cases which may occur during system operation. Some investigation into the system operation is required to define these conditions.

Often times, the worst case operation conditions will occur at minimum low line input voltage and maximum output load test case. During this test case, the boost section of the power supply is operating at high input currents, and the output rectifier and filter is also operating at high current stresses. At times, however, the maximum input line voltage can identify parts which are stressed due to input voltage.

Many power assemblies also develop auxiliary output voltages. These output voltages are always on as long as the power supply has input voltage applied to it. The unique requirement of the auxiliary output voltages is that they need to remain cool with convection cooling. Since the system may not be enabled when the auxiliary circuits are regulating and providing power, the system fans or blower assemblies are not helping to cool these circuits.

The specification and an understanding of the system is used to determine which thermal test cases should be performed on a particular power assembly. Some power assemblies have more potential operating modes than others, and so there may be many thermal test cases which must be analyzed to guarantee the design of the assembly.

8. CRITERIA OF POWER ASSEMBLY THERMAL ANALYSIS

The criteria used in determining potential problem areas in power assembly designs is an evolving guideline and requires some engineering judgment. Some of the problems may be based on past experience, while others are based on component ratings and reliability expectations. For several years, Military Standard 217-F and Bellcore standards have been used for predicting assembly failure rates based on the electrical stress and thermal stress on electronic components making up the assembly. These documents provide a good starting point for analyzing thermal results of electronic assemblies.

For power supply assemblies, the following technique is used to evaluate potential problem areas.

1. For each thermal test case, identify all components which have reached 50°C or greater while operating at a room ambient of 23°C.
2. Analyze the stresses and airflow on components which have exceeded 50°C to determine if the thermal measurements make sense.
3. Analyze the printed circuit board temperature. For standard FR-4 printed circuit boards make sure that the temperature will not exceed 105°C under worse case operating temperatures.
4. If there are hot components, such as power resistors, which are rated to operate warm, make sure they are lifted off from the printed circuit board surface.
5. Verify that the temperatures of the magnetic components are within their insulation class ratings with at least 10°C margin under worst case operating conditions.
6. Review surface mount components for temperatures above expected values. For example, a temperature rise of 30°C or more on a ceramic capacitor is a concern and possibly a less lossy dielectric material or a leaded capacitor should be chosen instead.
7. Check that electrolytic capacitors are not being heated due to abnormally high ripple currents or due to adjacent heat producing components.
8. For semiconductor devices such as MOSFETs and diodes, calculate the junction temperature of the device. Make sure the junction temperature of the device does not exceed its maximum junction temperature rating. In addition, for reliability reasons, allow a derating from the maximum junction temperature rating. For most power semiconductor devices, it is recommended that the junction temperature remains at or below 110°C when operated at worst case conditions. The junction temperature can be calculated by:

\[ T_j = T_c + P_d \times R_{j-c} \]

Where:
- \( T_j \) is the junction temperature of the semiconductor
- \( T_c \) is the measured case temperature of the semiconductor package
- \( P_d \) is the power dissipated in the device
- \( R_{j-c} \) is the thermal resistance from junction to case of the package
9. EXAMPLES OF POWER ASSEMBLY THERMAL ANALYSIS

IBM has been performing thermal analysis on power assemblies for several years. Thermal analysis has helped produce better designs in many occasions and has become an important step in the design verification process. In most power designs, the designers spend a considerable amount of time ensuring the main power train components remains sufficiently cool. The main power train contains all the switching MOSFETs and rectifier diodes and power transformers. Most designs are made from building blocks or designs which are similar to the custom power requirements needed for the application. Sometimes due to schedule pressures or due to oversights during the design phase, the powertrain cooling is not reevaluated and thermal problems may occur.

More frequently, however, is the situation where components not directly in the power train are getting hot. Surface mount components are often overlooked. The parts are not dissipating a lot of power; yet they often are placed in areas which do not receive much if any airflow. Another area often overlooked is the printed circuit board itself. As the voltage requirements for processors and memory IC's becomes lower, higher currents are being passed through the printed circuit boards. The printed circuits boards are not always reviewed to ensure they have enough copper.

Example 1

Fig. 4 illustrates an example of a relatively simple supplier designed flyback power supply. The power supply is a full input range (90VAC-264VAC) power supply which generates +5V at 15 amps and +12V at 1 amp. This particular power supply had some initial thermal problems. The power supply contained pin through hole components on the top side of the printed circuit board, and surface mount components on the bottom side.

The power supply used convection cooling. Under full load conditions, there were some power train components getting relatively warm as shown in the thermal images of Fig. 5. Of most concern were the diode packages D11 and D13 on the component side, and the surface mount resistors on the solder side of the power supply board assembly. To correct these particular problems, the power supply's layout was changed, a better heat sink was designed for D11, a less lossy diode was used for D13, and the surface mount resistors were changed to pin through hole components.

Figure 4: Supplier designed flyback design (component side and solder side views)

Figure 5: Thermal images of power supply
Example 2

Fig. 6 is an example of an IBM designed power supply which contains several output voltages. The power supply is a full input range power supply (90VAC to 264VAC) and generates several output voltages: +5V @ 45 amps, +3.5V @ 56 amps, +12V @ 13 amps, -12V @ 1 amps, +2.6V @ 50 amps, +2.0V @ 60 amps, and +5Vsb @ 2 amps. The power supply contained several pin through hole components as well as surface mount components and some daughter card assemblies.

![Figure 6: IBM designed power supply assembly (component and solder side views)](image)

In the system application, this power supply received 30CFM of airflow. The thermal images of this power assembly showed that the printed circuit board was getting very hot (>130°C) near the output current shunt (see Fig. 7 left image). The problem was due to the fact that not enough copper was used to connect to the through hole for the current shunt used on the +2V @ 60 amps output. A change was made to the printed circuit board to add more copper to this connection point in the next pass. Also the shunt value was lowered in half to reduce the power dissipated in the shunt to half of its previous value.

Another problem noticed from the thermal images was that the snubber for the +5Vcs output were getting very warm (see Fig. 7 right image). The snubber resistors were surface mount components located on the solder side of the board and not getting much airflow. The surface mount components were reaching about 115°C at room ambient operating conditions. The snubber circuit was redesigned to lower the power in the snubber resistors, and the component temperatures were reduced to 60°C under worst case conditions.

![Figure 7: Thermal images of power supply](image)
10. CONCLUSION

Thermal imaging has been a beneficial tool in the design verification phase of switching power supply assemblies. The process has identified many types of problems early in the development cycle and has led to better power supply designs with increased reliability. The improvements in infrared thermal cameras, the analysis software, and global e-mail capabilities has significantly ameliorated the process of identifying and resolving problems with a global design and development team. In each of the examples mentioned above, the supplier, development team, and design verification group were located several thousands of miles apart. Even so, several problems were identified and resolved efficiently because of the tools available. The goal to design reliable power supplies was achieved.

REFERENCES


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