PRODUCING A LOW COST, SPACE QUALIFIED COMPUTER BY RUGGEDIZING COMMERCIAL COMPUTER CARDS

Gregory J. Dirks
Senior Research Engineer
Southwest Research Institute
San Antonio, Texas

Abstract

A low cost, space qualified computer using thermally and dynamically enhanced commercial circuit cards has been developed at Southwest Research Institute (SwRI) on an internal research program. This computer, the SC-6, has been fabricated, tested and delivered to clients for use on the upcoming Commercial Experiment Transporter (COMET) mission. Thermal enhancements provide conduction paths from the electronic components to the housing; from which the heat may be removed by conduction and/or radiation. Thermal vacuum tests confirm operation with a baseplate temperature of between -20 and +60°C. Dynamic enhancement is achieved by attaching a stiffener/damper frame directly to the circuit card to form a module, which then serves as the structural framework for the housing assembly. The structural enhancements enable the computer to survive exposure to a composite random vibration level of 14 g(rms). Electrically, the computer is implemented with multiple processors communicating over the STD bus in a master/slave configuration. This allows the user to configure a spaceflight computer with a wide variety of commercially available processor and interface cards. The current version of the SC-6 provides three CPU's; 2 Mbytes memory; and 3 serial, 64 digital and 24 differential analog channels. The computer operates on less than 10 Watts using 28 VDC spacecraft power.

I. Background

Southwest Research Institute has a great deal of experience in designing and fabricating custom, spaceflight qualified computers meeting stringent requirements for the selection of materials and electronic components. However, non-recurrent engineering costs associated with the electrical and mechanical design and fabrication of such a custom computer can be prohibitive for some potential users. Users whose mission requirements are less demanding in terms of materials and parts screening are looking for a low cost alternative to the custom computer. By removing the rigorous material and electronic component selection requirements, commercially available computer circuit cards become a viable means for producing a spaceflight computer. The use of these commercially available computer circuit cards can significantly reduce the cost of supplying a spaceflight qualified computer. Eliminating most of the non-recurrent engineering costs inherent in a custom computer is the key factor in this cost reduction.

The use of commercial circuit cards presents some difficulties. The launch environment of a spacecraft can be severe in terms of vibration and shock, and can lead to electrical failure due to cracked solder joints. The major contributing factor to cracked solder joints is the deflection of the circuit card at its fundamental resonant frequency. Commercial cards generally have large unsupported areas that result in a very low natural frequency. Since deflection is inversely proportional to the square of frequency, low frequencies generate large deflection, leading to early solder joint failure by fatigue.

Another difficulty with commercial cards is heat removal. The reliability of an electronic device can be related directly to temperature. Most commercial cards rely on either natural or forced convection effects from ambient air to cool the components. Neither of these modes of heat transfer are available in the vacuum and microgravity conditions found in spacecraft applications.

An internal research program at SwRI was conducted to address these difficulties in producing a low cost, space qualified computer using commercially available circuit cards. The goal of this program was to develop and test a packaging technique that would enable commercial circuit cards to survive the severe thermal and dynamic environments associated with spaceflight missions. This paper will detail the thermal and dynamic enhancements and present experimental results.

II. Approach

The approach to designing and testing a packaging technique to thermally and dynamically enhance commercial circuit cards for use in spaceflight is described at both the card and housing level. The main circuit card has an STD bus form factor (i.e. 6.5 by 4.5 inches). A smaller (2.8 by 3.7 inches) SBX bus daughterboard is attached to it by means of a connector at one long end and a spacer at the other. These commercial circuit cards are populated mainly by DIP electronic components, some of which are mounted into sockets. There are, of course, several discrete components such as resistors and capacitors mounted directly to the board.

The entire housing assembly contains four circuit card modules, a DC-DC converter, a filter module, and motherboard. This assembly measures 7.25"(l) x 5.25"(w) x 7.50"(h), weighs approximately 6.5 lbs. and is shown in Figure 1.

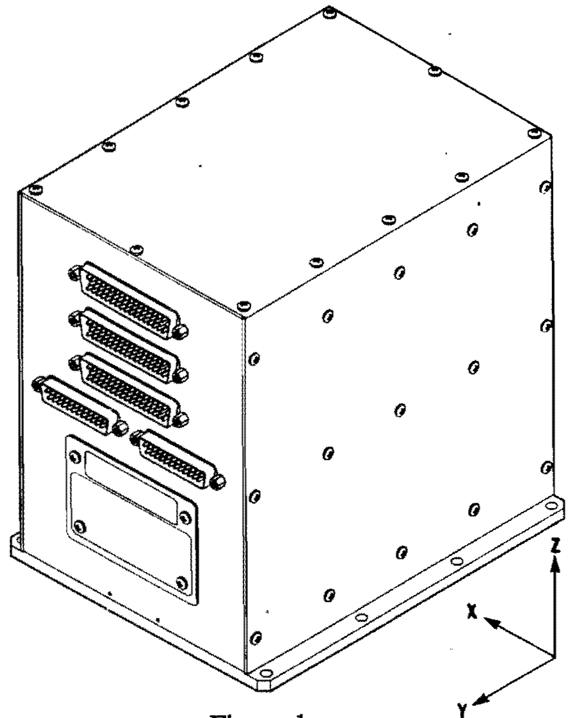

Figure 1
SC-6 Assembly

Thermal

Convection (either natural or forced) as a mode of heat transfer is not feasible in spacecraft applications due to the vacuum and microgravity conditions. Therefore, thermal enhancement are designed to provide adequate heat removal by conduction to a heat sink. Two modifications to the circuit cards are required. One is the addition of copper wire braid to connect high power dissipation component cases directly to the aluminum housing framework. As a general rule any component dissipating more than 1% of the entire heat load is connected in this manner. In practice, this means that for a 10 Watt computer all components dissipating 100 mW or more are individually conductively tied to the housing. The other modification is to bond the long board edges to the housing framework, again using a thermally conductive epoxy. These modifications allow for heat to be conducted from the electronic components to the housing and, subsequently, to a heat sink either by conduction to a coldplate or radiation to the environment.

To evaluate the effectiveness of these modifications a completely assembled computer was subjected to a thermal vacuum test. The chamber pressure was less than 1.0e-5 Torr and the temperature extremes were one hour dwells at -20°C and +60°C as measured at the baseplate of the computer. Thermocouples were used to monitor case temperatures of select internal electronic components and external housing temperatures.

Dynamic

To control vibration induced board deflections, it is necessary to increase the fundamental resonant frequency of the circuit card, fn, while decreasing the amplification factor, Q. A stiffener with an intermediate energy absorbing material (open cellular urethane) placed in contact with the back of the circuit card is the main modification. The combination of circuit card and stiffener/damper creates a sub-assembly module that is the framework for the housing. Other modifications include bonding the edges of the board to the housing frame, soldering all socketed components, and staking discrete components.

Evaluating these modifications involved vibration tests at both the board (module) and fully assembled housing levels. To characterize the circuit card response, a single module was subjected to a composite random vibration level of 14 g(rms) in the direction perpendicular to the card plane. Figure 2 shows the input PSD spectrum of this test. An accelerometer was placed at the center of the board in order to detect the first bending mode frequency. Also, a completely assembled computer was tested using the same input spectrum. Three accelerometers mounted at a top corner were used to detect the first bending mode frequency of the assembly.

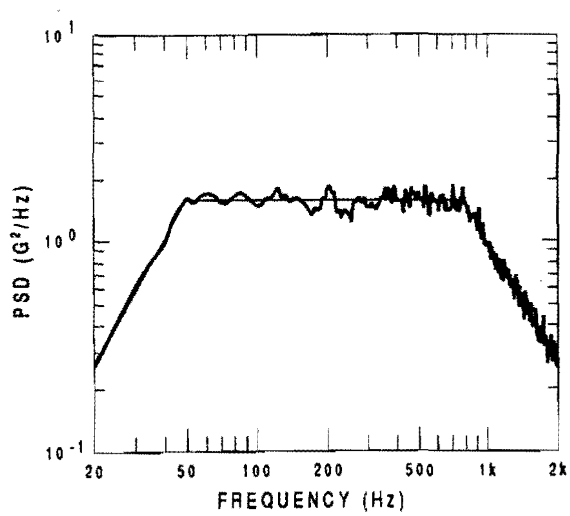

Figure 2
Random Vibration Input

III. Results

Thermal

The results of the thermal vacuum test are summarized in Table 1. This table shows the temperature gradient from the 60°C baseplate through the housing and finally to the electronic component case. High power dissipation electronic components were selected for temperature measurement in order to determine the highest operating case temperature.

Table 1
Thermal Vacuum Test Data

Baseplate	Side Panel	Comp. Case	Comp. Case	Comp. Case
60.0	65.3	89.7	87.9	87.7

In addition to measuring component temperatures, functional testing of the computer was conducted during the hot and cold dwells of +60°C and -20°C respectively. This functional test confirmed successful operation of the computer at the specified temperature extremes.

Dynamic

The results of the random vibration tests are presented graphically in Figures 3 and 4. Figure 3 shows the response at the circuit card level whereas Figure 4 shows the response at the housing.

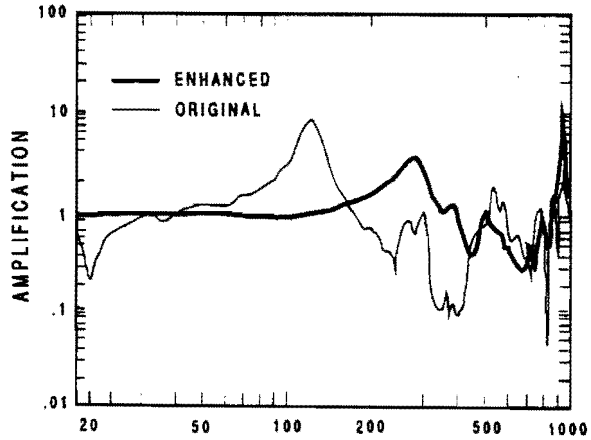

Figure 3
Circuit Card Response Transfer Function

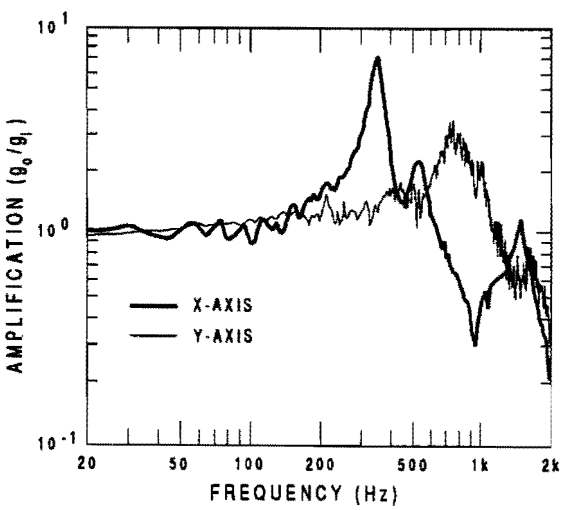

Figure 4
Housing Response Transfer Function

Table 2 numerically summarizes the data presented in the previous two figures.

Table 2
Vibration Test Data

Response Location	Natural Frequency		Amplification	
	X-Axis	Y-Axis	X-Axis	Y-Axis
Circuit Card Unmodified	---	123	---	9.13
Circuit Card Modified	---	280	---	3.80
Housing Assembly	350	750	7.20	3.60

In addition to dynamically characterizing the computer assembly, the computer was functionally tested at the end of a one minute per axis vibration test. The result of this functional test was the successful operation of the computer.

IV. Conclusions

A packaging technique has been developed and tested allowing commercial computer circuit cards to be used successfully in the severe thermal and vibration environments encountered in some flight missions. Extensive testing of the packaging technique confirms operation at temperature extremes of -20°C to +60°C, as measured at the baseplate, and operation after exposure to a composite random vibration level of 14 g(rms) for one minute per axis. The quantitative data from these tests indicate that the thermal and dynamic enhancements have successfully ruggedized the commercial circuit cards by keeping parameters within acceptable limits. A patent for the packaging technique has been applied for.

The use of commercially available circuit cards significantly reduces the cost of supplying a computer to a user group able to waive some of the standard material and electronic component selection requirements. The low cost is achieved mainly by reducing non-recurrent engineering costs associated with a custom design computer.

Not only has a computer using commercial circuit cards been developed and tested, but five units have been produced for use on the upcoming Commercial Experiment Transporter (COMET) mission.

Acknowlegdements

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