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THERMAL CONTACT CONDUCTANCE OF ELECTRONIC MODULES

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ABSTRACT

The thermal contact conductance of the junction between the frame guide rib and chassis card rails of standard electronic modules (SEM's) has a substantial effect on the overall thermal performance of the modules. Presently employed aluminum frames and card rails are anodized to prevent corrosion in harsh environments and to provide electrical isolation. However, the very hard, low conductivity anodic coatings greatly impede heat conduction from modules. The present investigation involved experimentally determining the thermal contact conductance of anodized SEM-E format frame guide ribs to anodized chassis card rails. Results are presented for thermal contact conductance and interface resistance as functions of module power and wedge clamp torque.

NOMENCLATURE

A	Contact area
D	Asperity slope
H	Vicker's microhardness
h	Thermal conductance
k	Thermal conductivity
R	Roughness
TIR	Flatness deviation (Total Included Reading)
t	Coating thickness
ΔT	Temperature difference
W	Waviness

Subscripts

a	Average
c	Contact or Coating
j	Junction
q	Root mean square (RMS)
s	Substrate
u	Uncoated

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INTRODUCTION

Standard Electronic Modules (SEM's) are used extensively in military electronics, with similar modular construction being employed in commercial electronics. Excessive operating temperatures of the electronics cause increased rates of thermally induced failure [1,2], as shown in Figure 1. Hence, effective cooling strategies are essential for reliable performance. Heat conduction through module structures comprises one of the major paths of heat dissipation from the electronics. However, interface resistance at junctions between components hinders the flow of heat.[2]

Roddiger and Mosby[3] measured substantial contact resistance at the junction between frame guide ribs and chassis card rails, illustrated in Figure 2. The work of Roddiger and Mosby is one of the few investigations of the contact resistance of electronic modules in the open literature. They tested bare aluminum frames and chassis, as well as bare aluminum components with such interstitial materials as thermal greases, soft metal foils, compliant materials, semi-solids, and eutectic composition liquid metals. Thermal greases, though easy to apply and effective at increasing conductance,

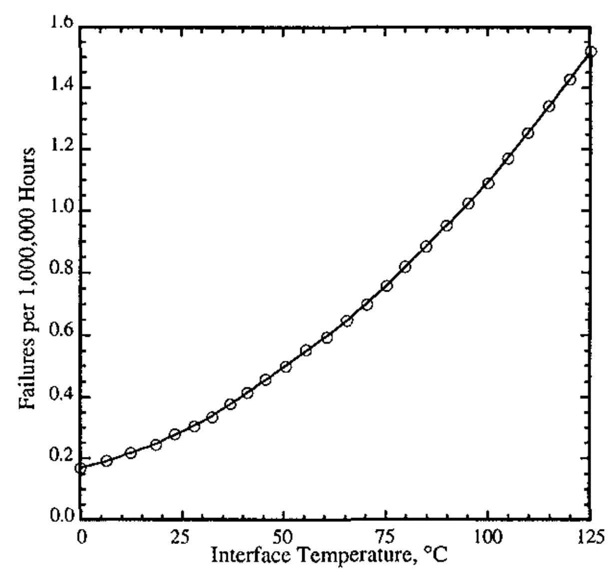

Figure 1 Influence of interface temperature on device failure (per 1000000 Hours), from Beasley[2].

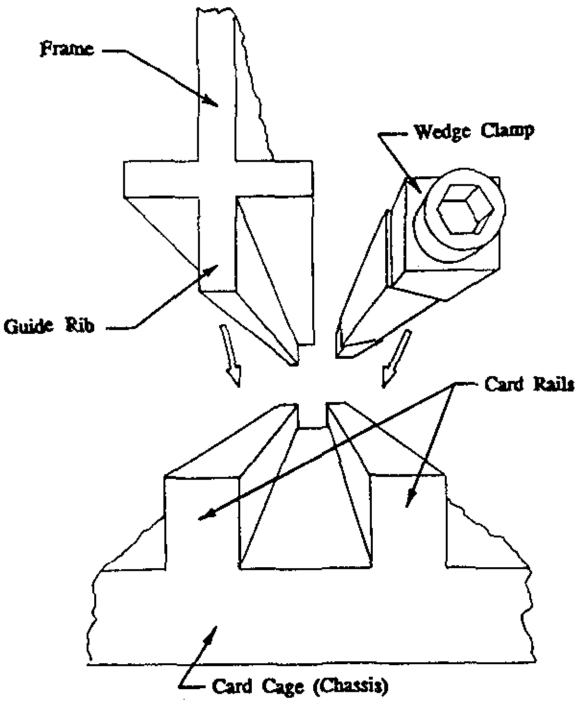

Figure 2 Exploded view of Standard Electronic Module (SEM) junction.

may migrate and contaminate electronic devices and sublime in high altitude and space environments. Soft metal foils are tediously applied and may wrinkle during insertion, actually increasing resistance. Roddiger and Mosby[3] determined that compliant materials (typically silicone elastomers) may reduce the deleterious effects of contaminants in junctions, but offer little or no improvement over clean bare junctions. They also reported that liquid eutectic alloys markedly enhanced conductance, but that their performance is severely compromised under vibrational loads (e.g., turbulence in flight), and the alloys may leak from the joint at elevated temperatures. Semisolid materials offer some advantages over elastomers and liquid metals

Fletcher[4] conducted a survey of interstitial materials for enhancing contact conductance and determined that metallic coatings offer the greatest enhancement, reliability and durability. Standard electronic module frames and card chassis are currently anodized for corrosion protection and electrical isolation. However, the high hardness and very low thermal conductivity of anodic coatings causes high contact resistance.[5] Lambert and Fletcher[6] determined that silver electroplatings can provide the necessary corrosion protection while markedly reducing contact resistance due to their relatively low hardness and very high thermal conductivity.

In addition to the thermophysical properties of coatings, thermal contact resistance is also greatly affected by surface finish, the geometry of the contacting surfaces, and the contact pressure distribution. According to Donnelly[7], contact pressure distribution is determined by the torque applied to the wedge clamp, the configuration of the clamp (i.e., 3 piece or 5 piece, etc.), and the length and thickness of the frame guide rib.

EXPERIMENTAL PROGRAM

The present investigation involves the experimental determination of the thermal contact conductance of SEM-E format frames to chassis card rails for a range of wedge clamp torques and power dissipation levels experienced by electronic modules. The coating combination tested was Type III (hard coat) anodized guide ribs to Type II (soft coat) anodized card rails. Wedge clamp torques were incremented from 0.565 to 1.582 N-m (5.0 to 14.0 in.-lb). Power levels were set at 10, 20, 40, and 80 W.

Experimental Facility

The thermal contact conductance experiments were performed with the facility illustrated in Figure 3. It consists of:

(1) a liquid, cooled simulated chassis card rail,
(2) one-half of a SEM-E format frame (cut along the centerline),
(3) a 6.60 mm wide x 5.84 mm high x 152 mm long (0.260 in. x 0.230 in. x 6.0 in.) 5-section wedge clamp,
(4) silicone pad heaters to simulate the electronics,
(5) a DC motor and gear reduction head for varying clamp torque,
(6) thermocouples for measuring the temperature drop across the guide rib/card rail junction,
(7) and a radiation heat shield which also simulates the enclosure created by adjacent modules.

Thermocouple voltages are measured to high accuracy by a Hewlett Packard (HP) 3497A datalogger.

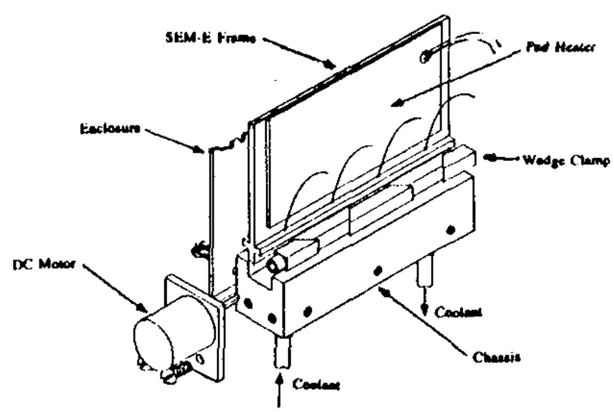

Figure 3 Schematic of experimental apparatus.

Table 1 Surface Metrological, Thermal Conductivity, and Vicker's Microhardness Data for SEM-E Frame Ribs and Chassis Guide Ribs.

	RMS Roughness μm	CLA Roughness μm	RMS Waviness μm	CLA Waviness μm	TIR μm	Asperity Slope	k_s/k_c W/mK	H_u/H_c* kg/mm²
Anodized Card Rail	0.834	0.664	1.130	0.928	12.98	0.092	152.1/0.0292	128/160
SEM-E Card A	1.268	1.062	1.546	1.170	15.01	0.137	208.4/0.0292	85/280
SEM-E Card B	1.130	0.956	2.436	2.122	20.70	0.110	208.4/0.0292	85/280
SEM-E Card C	1.302	1.124	2.978	2.296	20.30	0.113	208.4/0.0292	85/280

* H_u is VHN of uncoated substrate material, and H_c is VHN of coating/substrate combination.

The facility (specifically the clamp torque and heater power) is controlled by an IBM-compatible 486-66MHz microcomputer.

SEM Frames and Chassis

SEM-E format frames 15 cm x 15 cm x 0.335 cm (6 in. x 6 in. x 0.125 in. thick) were tested, because they are one of the more commonly used formats. Those tested were received with Type III anodization. The simulated chassis was Type II anodized.

The chassis was instrumented with six 30 AWG, type K, special limit of error (1/2 normal, 1.1 K) thermocouples at 2.54 cm (1.0 in.) intervals along the side of the groove in contact with the SEM-E frame. (The other side of the groove was, of course, in contact with the clamp.) Each SEM-E frame was instrumented with nine identical type K thermocouples. Six were located at 2.54 cm (1.0 in.) intervals along the base of the guide rib (Figure 2). The other three were located at the center of the heater on either side, and at the card centerline at the front.

Presently utilized aluminum 6101-T6 SEM frames are given a Type III, Class 2 "hard coat" anodic coating, synthesized in a low-temperature sulfuric acid electrolyte. The aluminum A356-T61 chassis card rails were anodized with a Type II, Class 1 "soft coat" anodic coating, synthesized in room-temperature sulfuric acid. Types III and II anodization are U.S. Navy designations of the coating procedures[8], while "hard coat" and "soft coat" are the equivalent industrial descriptions. Class 1 is a Navy designation for undyed coatings, while class 2 indicates black dyed coatings. The anodization procedures, electrolyte compositions, thermal behavior, and related information are described in detail by Darrow[9] and by Lambert et al.[10]

Surface Measurements

The surface profiles of contacting surfaces profoundly affect their contact conductance. Thus, the contacting surfaces of the guide ribs of all SEM-E frames and of the card rail were characterized using a SurfAnalyzer 4000/5000 surface profilometer from Federal Products. Measurements include: root mean square (RMS) and centerline average (CLA) roughness, rms and average waviness, overall flatness deviation (TIR), and rms asperity slope. These surface characteristics, as well as representative material conductivity and microhardness measurements, are listed in Table 1.

EXPERIMENTAL PROCEDURE

Testing began with insertion of half a SEM-E frame and wedge clamp into the chassis. The wedge clamp was initially torqued to 1.58 N-m (14.0 in.-lb). This was done to duplicate the standard practice of exerting maximum rated torque to wedge clamps when installing SEM's. This pre-loading also helped to minimize the effects of burrs, scratches, and other small flaws on the frames, chassis, and clamps.

Next, the thermocouples were connected to the datalogger and checked for accuracy, and the coolant valve was opened. The data acquisition and control program was then executed, computing contact conductance at three minute intervals while maintaining the desired heater power. The program recorded the relevant data after steady state conditions had been achieved, and incremented the torque or the heater power as necessary.

Thermal contact conductance data for each SEM-E frame, clamp, and chassis combination were obtained for four power levels: 10, 20, 40, and 80 W. Steady-state was assumed to have been achieved when none of the ten most recent conductance measurements (taken over the preceding half hour) varied by greater than 1.0% from the average value of the ten readings. To simulate working conditions (where room temperature cards are clamped into the chassis), the heater was turned off and the chassis is allowed to cool to room temperature between each clamp torque increment.

Data Analysis

Thermal contact conductance is defined as the heat flux over the interface divided by the temperature discontinuity across the card rail-guide rib interface.

The interface temperatures of the SEM-E frame and chassis card rail are obtained by extrapolating the average temperature of the six thermocouples adjacent to the junction in the frame and the six thermocouples in the chassis to the interface. The heat flux was defined as the total power dissipated divided by the nominal contact area of one guide rib 8.32 cm^2 (1.29 $in.^2$).

UNCERTAINTY ANALYSIS

The experimentally determined thermal contact conductance results are subject to uncertainty, predominantly due to errors in the thermocouple readings. These are due to slight inhomogeneities in the thermocouple alloys and signal noise in the *instrumentation. The method of Kline and* McClintock[11] was used to estimate the overall uncertainty.

The uncertainties in the contact conductance experiments include 10% for the heat flux and 3% for the temperature discontinuity. The overall uncertainty in the conductance data, including standard deviation of repeated tests, is 11%.

RESULTS AND DISCUSSION

Roddiger and Mosby[3] measured the average interface contact pressure as a function of wedge clamp torque (Figure 4). Torque loads ranged from 0.1 to 1 N-m *(1 to 9 in-lbs), resulting in average interface pressures* of 0.05 to 0.5 MPa (10 to 60 psi). Donnelly[7] conducted a similar investigation using a pressure sensitive film to measure the actual pressure distribution over the contacting surfaces, and a calibrated load cell test facility to measure average loads on the contacting

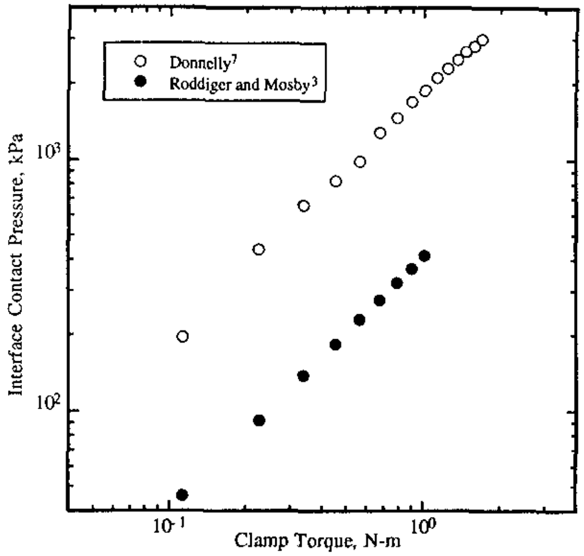

Figure 4 Comparison of the interface contact pressure as a function of wedge clamp torque from Riddiger and Mosby[3] and Donnelly[7].

surfaces between the guide rib and the card rail. These two techniques compared favorably, and are compared with results from Roddiger and Mosby[3] in Figure 4. For the same range of torque, Donnelly obtained average contact pressures of 0.2 to 3.0 MPa (30 to 300 psi), higher than those of Roddiger and Mosby. The differences between the two data sets may be attributed in part to differences in anodized coatings and surface finishes.

The thermal contact conductance of aluminum 6101-T6 SEM-E frame guide ribs to aluminum 6061-T6 chassis card rails was measured for type III anodized

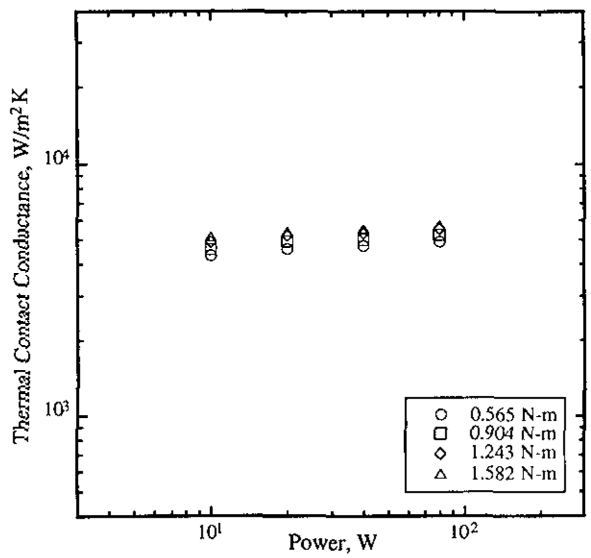

Figure 5 Thermal contact conductance as a function of module power dissipation for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

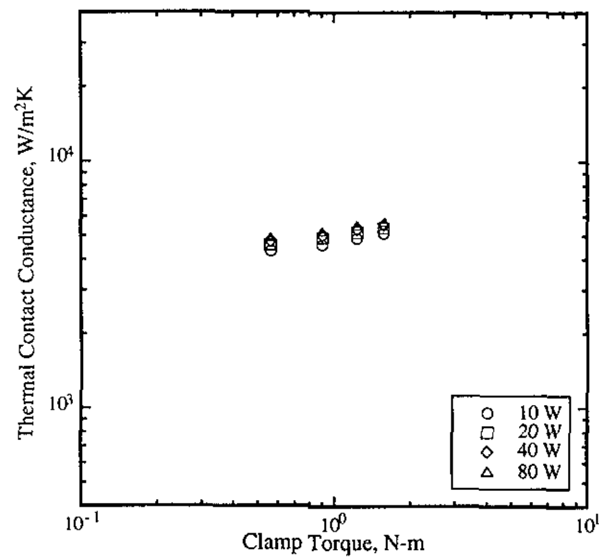

Figure 6 Thermal contact conductance as a function of clamp torque for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

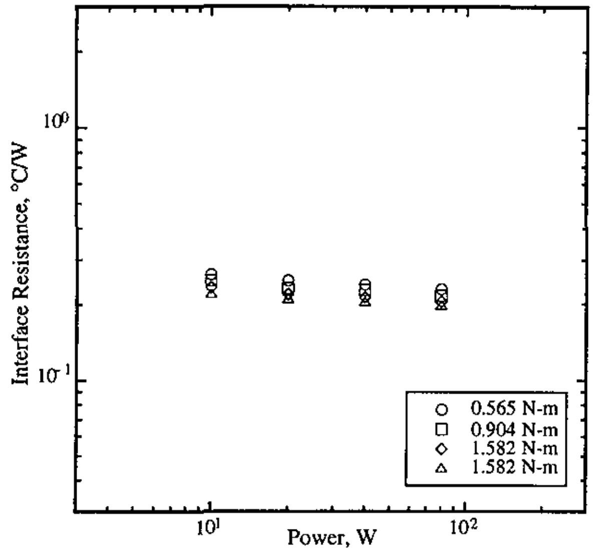

Figure 7 Interface resistance as a function of module power dissipation for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

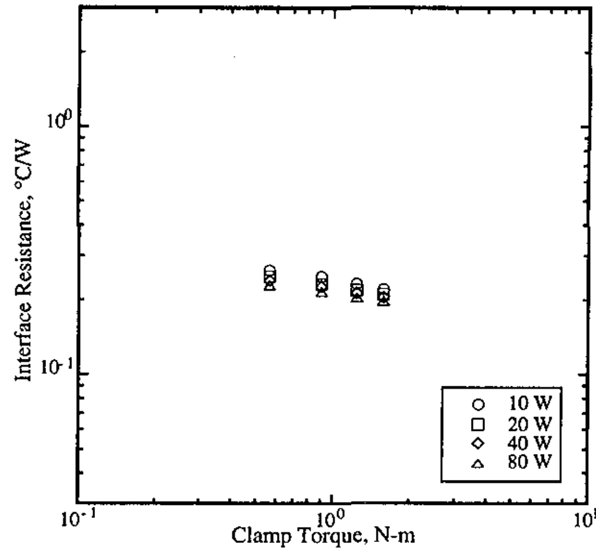

Figure 8 Interface resistance as a function of clamp torque for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

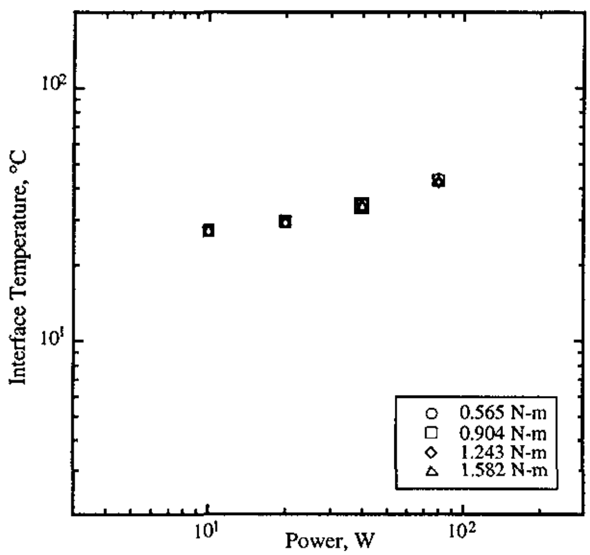

Figure 9 Interface temperature as a function of module power dissipation for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

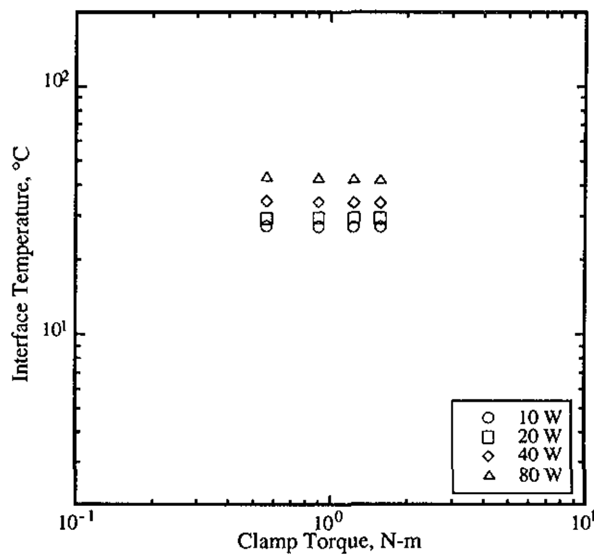

Figure 10 Interface temperature as a function of clamp torque for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

guide ribs to type II anodized card rails. Testing was performed for clamp torques ranging from 0.565 to 1.582 N-m (5.0 to 14.0 in.-lb) at four power dissipation levels: 10, 20, 40, and 80 W.

Figures 5 and 6 show the thermal conductance as a function of module power dissipation and wedge clamp torque. There is little change in the conductance as a function of power dissipation at all torques. However, there is a slight increase in the conductance as a function of wedge clamp torque. Clearly, increases in torque result in increased contact conductance.

The interface resistance is shown as a function of module power dissipation and wedge clamp torque in Figures 7 and 8. The interface resistance decreases slightly with increases in power dissipation, and increases slightly with increases in wedge clamp torque.

The average interface temperature as functions of module power dissipation and wedge clamp torque is shown in Figures 9 and 10. The average interface temperature increases moderately as power dissipation increases, and appears to be independent of wedge clamp torque (Figure 9). These trends are also apparent

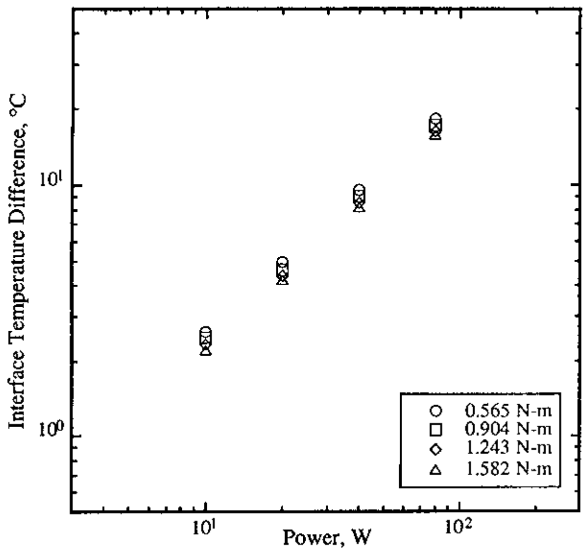

Figure 11 Interface temperature difference as a function of module power dissipation for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

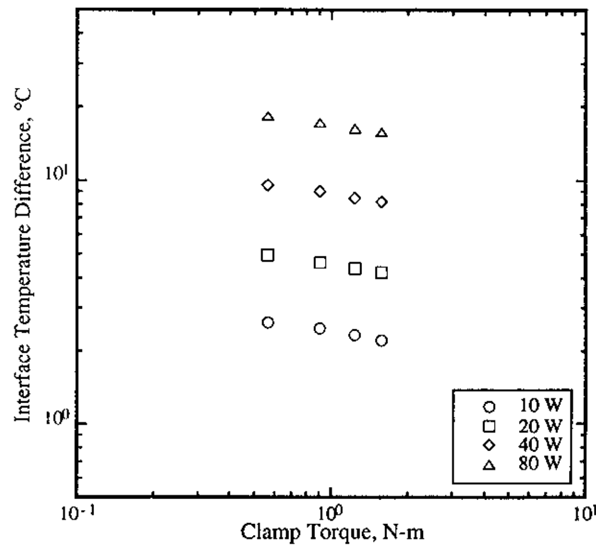

Figure 12 Interface temperature difference as a function of clamp torque for Type III anodized SEM-E frame guide rib to Type II anodized chassis card rail.

in Figure 10, which demonstrates the independence of torque.

While the variation of thermal contact conductance, interface resistance, and average interface temperature with power dissipation and wedge clamp torque has been limited, the effect of module power dissipation on interface temperature difference is significant, as shown in Figures 11 and 12. There appears, however, to be little effect of wedge clamp torque on interface temperature difference.

The rate of electronic device failure was shown to be a function of interface temperature in Figure 1. The level of interface temperature is dependent upon the interface temperature difference, which is (in turn) a function of the interface resistance. Clearly, a reduction in the interface resistance can be accomplished by increasing the actual area of contact between the guide ribs and the card rail.

The area of contact is dependent upon the mechanical and thermophysical properties of the contacting surfaces and the average load or pressure on the interface. Current coating specifications for Standard Electronic Modules and rails (Type II and Type III anodization) preclude an optimum area of contact and the thermophysical properties of the coating materials increase the interface resistance. On the basis of the forgoing assessments, it appears that the primary way to decrease the average interface temperature and associated module operating temperature is to increase the interface pressure.

CONCLUSIONS AND RECOMMENDATIONS

The thermal contact conductance and interface resistance between Standard Electronic Module guide ribs and card rail chassis has been determined for a range of module power dissipation levels and wedge clamp torques. Power dissipation ranges from 10 to 80 W and torques range from 0.565 to 1.582 N-m (5.0 to 14.0 in-lb). Results of these studies indicate that the thermal contact conductance is a weak function of power dissipation and torque. The interface resistance and interface temperature are only slight functions of power and torque. The interface temperature difference, however, is a strong function of module power dissipation, but only a modest function of torque.

Based on this experimental study, it appears that the module operating temperature could be decreased by increasing the area of contact between the module guide rib and the card rail chassis. Increases in the area of contact could be accomplished by using softer, more conductive surface coatings, or by significantly improving the uniformity of the contact pressure.

ACKNOWLEDGEMENTS

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