AIAA 2016-3697
AIAA Aviation
13-17 June 2016, Washington, D.C.
46th AIAA Thermophysics Conference

An Advanced Card Lock for Space and Terrestrial Applications

Nicholas T. Kattamis[1] and Jay C. Rozzi[2]
Creare LLC, Hanover, NH, 03755

Separable Thermal Mechanical Interfaces (STMIs) are found in advanced digital processing electronics that require conduction cooling—including space satellite systems and in-flight aerospace electronics, among other air and ground-based military systems that are sealed, have little airflow, or are used in higher altitudes. A STMI comprises an electronic card, chassis, and card lock; the card lock provides a thermal interface between a printed circuit board and the side wall of a chassis from which heat can then be removed via convection or radiation. Common, commercially-available wedge locks are limited in their ability to efficiently remove dissipated heat, limiting electronic performance and lifetime. To overcome these performance limitations, an innovative card lock has been developed that increases contact pressure and pressure uniformity, minimizes interface separation, and results in significant decrease in contact resistance. A pre-production effort has been completed to optimize the design for manufacturability. The improved card lock is a cost-effective drop-in replacement to the existing device that offers significant performance benefits.

I. Introduction

Current separable thermal mechanical interfaces (STMIs) are used in applications requiring conduction cooling in lieu of more-standard convection cooling. A STMI comprises an electronic card, chassis, and card lock; the card lock provides a thermal interface between a printed circuit board and the side walls of a chassis from which heat can then be removed via convection or radiation. In between the electronics card and the heat sink (e.g., radiator) are a number of thermal resistances that impede heat transfer. Such resistances include conduction through solid materials, heat transfer across interfaces, and the effectiveness of the heat rejection to the environment or surroundings. The specific resistance, R'_C s defined as:

$$R'_C = \frac{L\ \Delta T}{q} \tag{1}$$

wherein L (in.) is the card length, q is the total heat load (W), and ΔT is the temperature difference across the interface (°C). In the above equation, the temperature difference is typically fixed. Hence, the only way to increase the total heat transfer rate from the card to the heat rejection system is to reduce the overall thermal resistance.

Among the many thermal resistances between the electronics card and the heat rejection system, one of the largest is the contact resistance between the electronics card and the electronics chassis. Typically, electronics cards are secured to the chassis by means of a card lock. This simple device is placed in the channel groove that also receives an edge of an electronics card and imparts a force on the card that pushes it against the opposite channel wall. In doing so, it applies pressure to the card and forms a thermal connection with the chassis. The magnitude of the pressure distribution that the card lock imparts to the card-chassis interface significantly influences the overall thermal resistance of the joint.

The current off-the-shelf multi-wedge card locks (known commercially as "Wedge-Locks") utilize a series of trapezoidal wedges with 45° angles and a screw that runs through the center of the wedges to actuate the device (Fig. 1). These devices supply sufficient force and pressure to hold the cards in place during operation; however,

[1] R&D Engineer, 16 Great Hollow Rd.
[2] Principal Engineer, 16 Great Hollow Rd.

the non-uniformity of the pressure distribution and low useful contact area results in poor heat transfer performance. This is attributed to the low-stiffness wedges, which are exacerbated by slots required to accommodate the actuation screw that passes through them. The non-uniformity and relatively low magnitude of the pressure distribution results in a relatively high thermal resistance at the card chassis interface of ~1°C-in./W or more.[1] Roughly, the thermal resistance of the card chassis interface is inversely proportional to pressure.[2,3] In addition, the total thermal resistance of the joint is inversely proportional to the area of interaction between the mating surfaces.

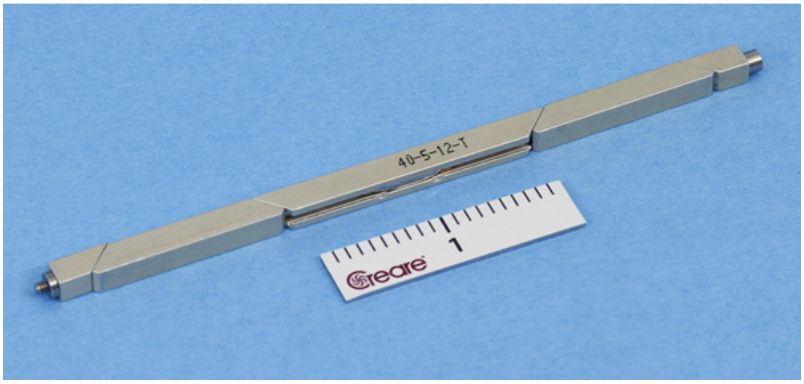

Figure 1. Current State-of-the-Art for an Off-the-Shelf Multi-Wedge Card Lock. Poor thermal performance attributed to low wedge stiffness, large trapezoid angle (45°), and low allowable actuation torque.

Overall, off-the-shelf multi-wedge card locks cannot remove sufficient heat from conduction-cooled, high-power, card-based, electronic components. In these systems the card lock is the performance-limiting component. This reduces the allowable density of electronic components per heat sink and reduces the payload capability for space satellite, aerospace, and ground-based applications. Key problems associated with these card locks include: (1) low contact interface force and (2) non-uniform contact pressure. Each of these elements is discussed in more detail below.

Low Contact Interface Force. The existing design is based on a series of wedges with 45° bevels that mate to one another. The large angle limits the amplification of screw tension to a lateral clamping force with a 1.5:1 ratio for a high-performance 3-wedge 5-inch conventional device (typical $\mu = 0.1$) based on the following equation:[1]

$$M_{Wedge} = \left(\frac{N-1}{2}\right)\left(2\frac{cos\theta - \mu sin\theta}{\mu cos\theta + sin\theta}\right) \tag{2}$$

where M is the ratio of lateral clamping force to screw force, N is the number of wedges, θ is wedge angle, and μ is the wedge-to-wedge friction coefficient and wedge-to-wall friction coefficient. In addition, the combination of wedge construction (thin walls) and small screw diameter limits the recommended screw torque and, therefore, limits the clamping force.

Small Thermal Contact Area. Per unit length, the maximum thermal contact area interface is limited by the height dimension of the wedge lock. This sets the height of the interface between the wedge lock and chassis, as any mating surfaces beyond this dimension would not be subjected to mechanical pressure. Unfortunately, the useful thermal contact area is much smaller, as it is limited by chassis stiffness. The current chassis is designed with fins that act as thin cantilever beams, which contributes to the separation of the thermal contact with increasing contact force. In the limit of high contact force, the thermal contact area transitions towards line contact, further increasing contact resistance.

Non-Uniform Contact Pressure. Non-uniformities in contact pressure are present along the length and along the height of the thermal interface. This results in non-uniformities in contact conductance and overall higher-than-desired contact resistance, electronic card temperature, and electronic component temperature.

Along the length of the thermal interface the interface pressure varies substantially, as the design of the conventional device alternates its contact between the heat sink and chassis. Moreover, the low mechanical stiffness of the device further exacerbates the contact, creating small discrete zones of high contact pressure at the wedge-to-wedge interfaces followed by large zones of virtually zero contact pressure. This effect creates a low overall contact area, which increases the effective path heat must travel to exit the electronic card and thus increases the overall card and electronic component temperature. This effect is compounded in low atmospheric conditions (e.g., satellite operating environment), the conditions for which this device has been developed. Similarly, non-uniformities in pressure exist along the height of the thermal interface, attributed to the lack of stiffness in the conventional device.

II. High-Performance Card Lock Design

Fig. 2 illustrates an exploded view of a novel, patent-pending, high-performance card lock, which consists of two wedges (traveler and fixed) and a fastener. The traveler wedge slides with respect to the fixed wedge, expanding or contracting laterally depending on the direction of travel. The fastener is captured in the fixed wedge such that it can rotate but not displace. Clockwise rotation threads the fastener into the traveler wedge, pulling the wedge toward the fastener head, and causing the lock to contract laterally in the card slot. Counterclockwise rotation expands the card lock, locking it against the electronics card and chassis.

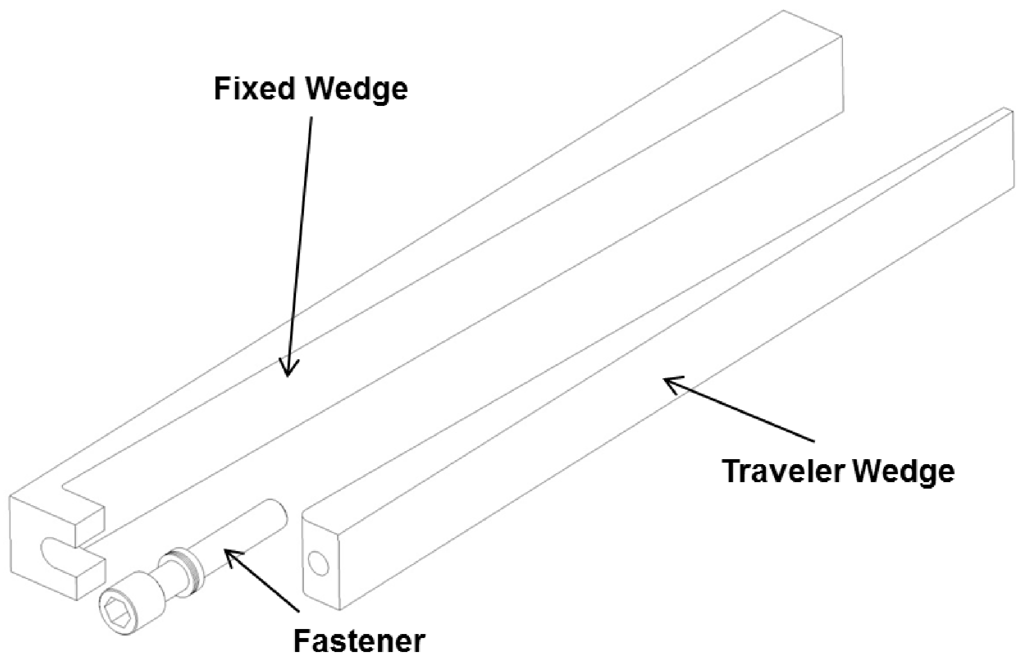

Figure 2. Exploded-View Illustration of the High-Performance Card Lock Comprising Two Wedges and an Actuation Fastener.

Estimated Performance. Solid wedges are utilized to maximize structural rigidity and robustness, which enable the application of a high and uniform pressure to the thermal interface (card-chassis). Higher pressure reduces the local contact resistance as does higher pressure uniformity, which increases the effective heat transfer contact area and reduces heat transfer path length. A force balance on the high-performance card lock yields:

$$M_{Incline} = \frac{cos\theta - \mu sin\theta}{\mu cos\theta + sin\theta} \tag{3}$$

As designed with a 2.5° angle, the high-performance card lock produces a force multiplier of 4.1 (μ of 0.1). Notably, the high-performance card lock produces a force multiplication nearly 3 times higher than the conventional multi-wedge card lock. In addition, increased rigidity of this design versus the conventional approach produces more uniform pressure, which further reduces the thermal resistance at the card-chassis interface. The rigidity of the high-performance card lock enables the applied torque to increase, further increasing the applied force between the card and the high-performance card lock relative to the conventional system. A durable coating is used to produce low coefficient of friction, contributing to the high force multiplication.

Manufactured Devices. Fig. 3 (left) provides a series of images of manufactured high-performance card locks. The card locks shown have been manufactured from stainless steel; however, successful devices have been fabricated from lower-mass aluminum alloy. Fig. 3 (lower right) shows the card locks following application of variants of the low-friction coating.

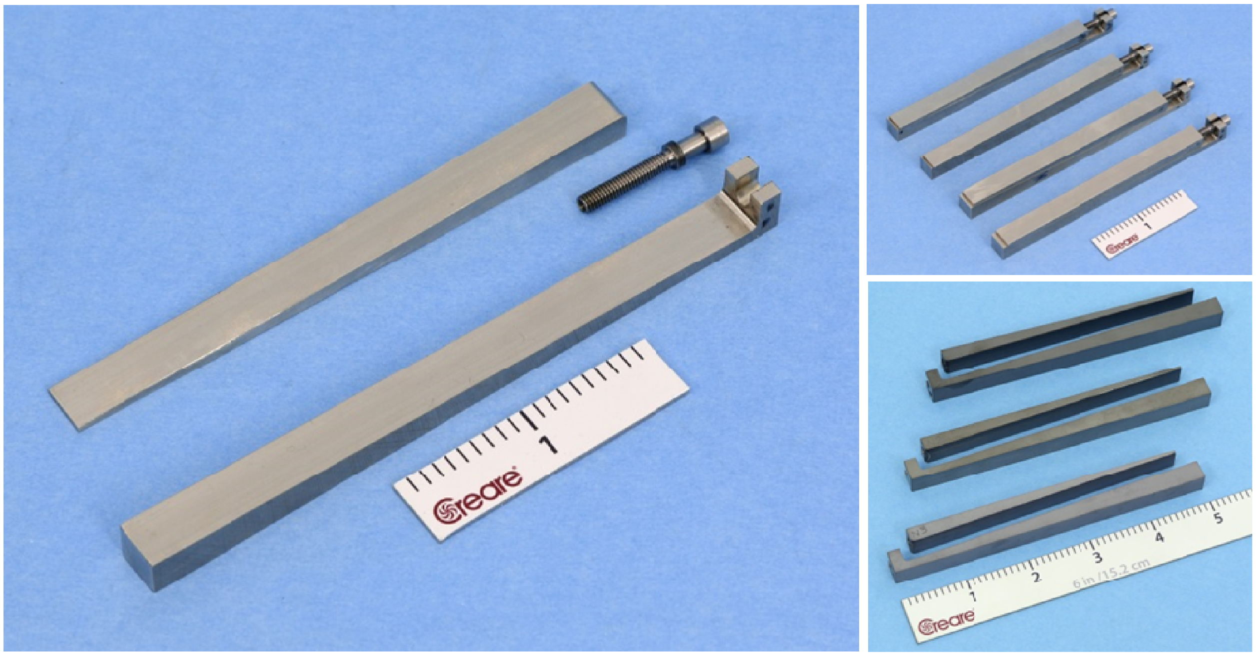

Figure 3. Manufactured High-Performance Card Locks.

III. Results: Performance Comparison

Mechanical Pressure at the Thermal Interface. Measurements of pressure were conducted at the thermal interface to quantify the pressure distribution for the high-performance card lock. For performance comparison, tests were duplicated for the conventional device. Fig. 4 shows a schematic view of the setup that included a standard electronic chassis, card lock, and electronic card with pressure sensitive film at the thermal interface. Tests were conducted at the manufacturer recommended torque value for the conventional device and the design torque value (high-performance card lock) using three sets of pressure films having differing sensing ranges. These included a low pressure film having a sensing range of 28 to 85 psi, medium pressure film having a sensing range of 70 to 350 psi, and a high pressure film having a sensing range of 350 to 1400 psi.

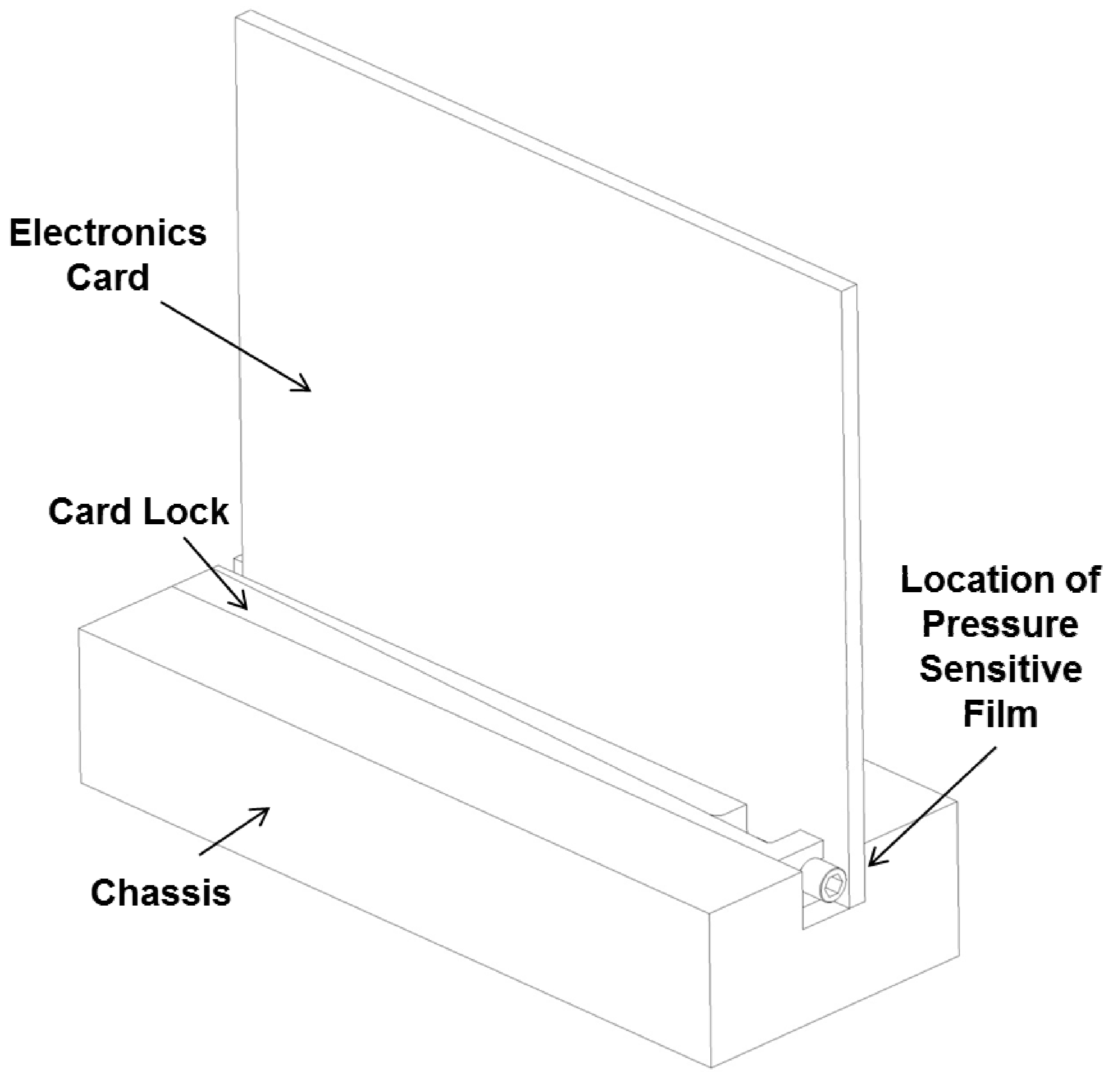

Figure 4. Top View Schematic of Setup Used to Characterize Pressure Distribution at the Thermal Interface.

Fig. 5 shows the pressure distribution results for the conventional device (left) and the high-performance card lock (right). When viewing the medium pressure-sensitive film, the high-pressure card lock increases pressure uniformity along the thermal interface both in the height and length directions and increases the contact area. Side-by-side comparison of both approaches results in a 275% increase in active contact area and a 350% increase in net contact force. Since thermal contact resistance is approximately inversely proportional to contact area and contact force, the high-performance card lock reduced the card-chassis thermal resistance by a factor of 10 or more.

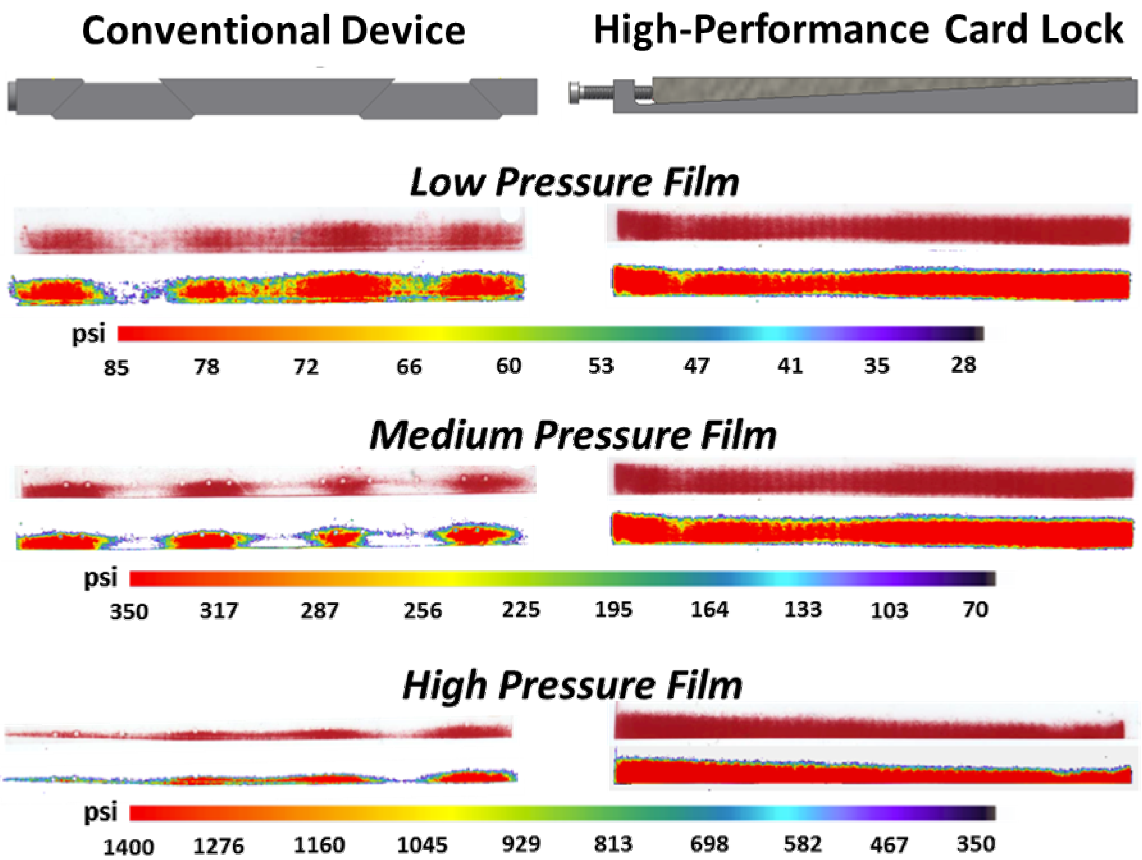

Figure 5. Measurements of Pressure Distribution at the Thermal Interface. The high-performance card lock provides a 275% increase in thermal contact area and 350% increase in contact force.

Pressure uniformity can be quantified by calculating the ratio:

$$\frac{A_{INT}(P)}{A_{MAX}} \tag{4}$$

where AINT(P) is the measured area of interaction between the lock and the card, which is a function of the applied pressure, and AMAX is the maximum area of interaction between the lock and the card, which is a function of only the geometry and is independent of applied pressure. Using the pressure data from Fig. 5, the variation of this ratio can be plotted as shown in Fig. 6. For a highly uniform pressure distribution that minimizes the contact resistance at the thermal interface, the above ratio should be as close to 1.0 as possible. The high-performance card lock maintains a ratio near 1.0 up to about 350 psi, decreasing to approximately 0.7 at 1400 psi, as the torsional rigidity limit of the design is reached. Conversely, the conventional device has a ratio near or below 0.5 at low pressure (i.e., < 350 psi) that decreases still further to approximately 0.1 at 1400 psi. Thus, the high-performance card lock provides substantially better pressure uniformity at all applied pressures and therefore minimizes the joint thermal resistance.

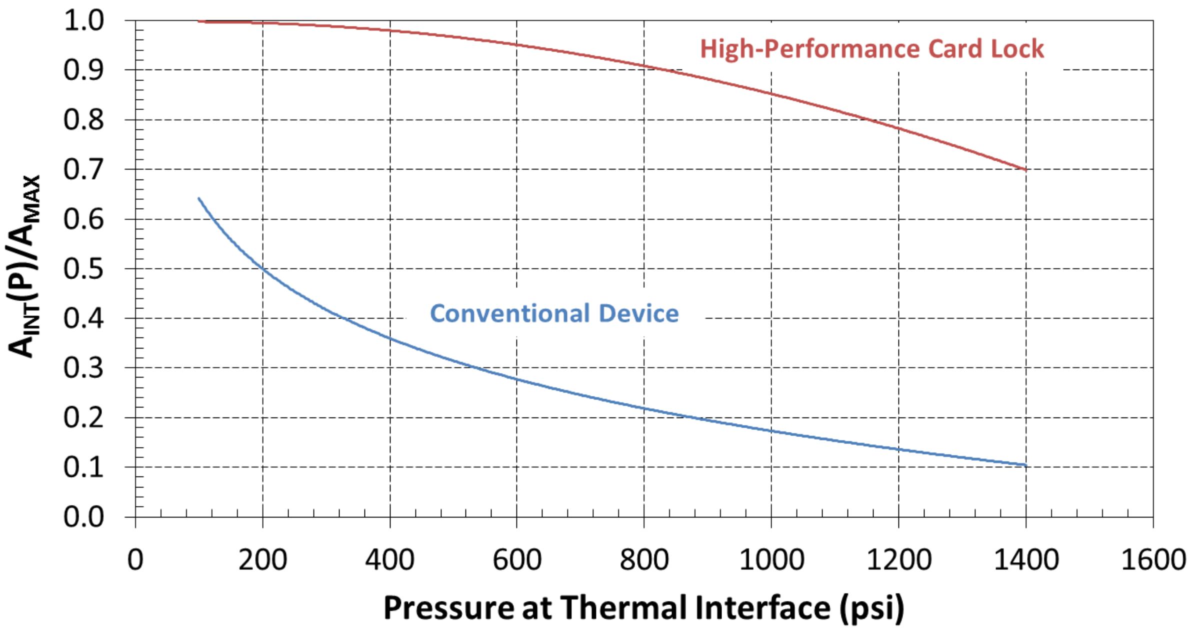

Figure 6. Pressure Uniformity Quantification Based on Fig. 5 and Defined as the Measured Interaction Area Divided by the Maximum Interaction Area.

Contact Resistance at the Thermal Interface. Fig. 7 (left) shows the comparison of contact resistance along the thermal interface for the conventional device and the high-performance card lock for a variety of applied torque values. Fig. 7 (right) shows the corresponding average thermal contact resistance along the thermal interface. Test results correspond to a 20 W/inch heat input to the card (100 W total), a cold plate temperature of 22°C, and un-plated and plated thermal interfaces. The electronics card and card cage heat sink used for the evaluation was of similar form, fit, and function to those used in space satellite and terrestrial applications.

The conventional device produces the most non-uniformity in contact resistance along the thermal interface relative to the high-performance card lock, which dramatically reduces non-uniformity along the thermal interface at all test conditions. Large variability in the conventional device is related to periodic contact and low mechanical stiffness, both of which are inherent in the design and construction of the device, and result in an average 0.39°C-in./W contact resistance. The high-performance card lock results in a dramatic reduction in the variation in contact resistance due to the stiffer and more durable design. Specifically, an average 0.11°C-in./W contact resistance, which is a factor of 3.5 reduction from the baseline approach, and a factor of 10 below the industry standard for conventional wedge-lock style technology (~1.0°C-in./W) was achieved. When accounting for the experimental uncertainty of our test facility, which includes uncertainties of the thermocouple measurements and the heater current and voltage, the uncertainty on the reported contact resistance values for the conventional device is +/-6.7% and for the high-performance card lock is +/-23%. The relatively small variation in performance for the high-performance card lock with increasing torque is related to the experimental uncertainty of the temperature measurements, which are used to calculate the thermal contact resistance.

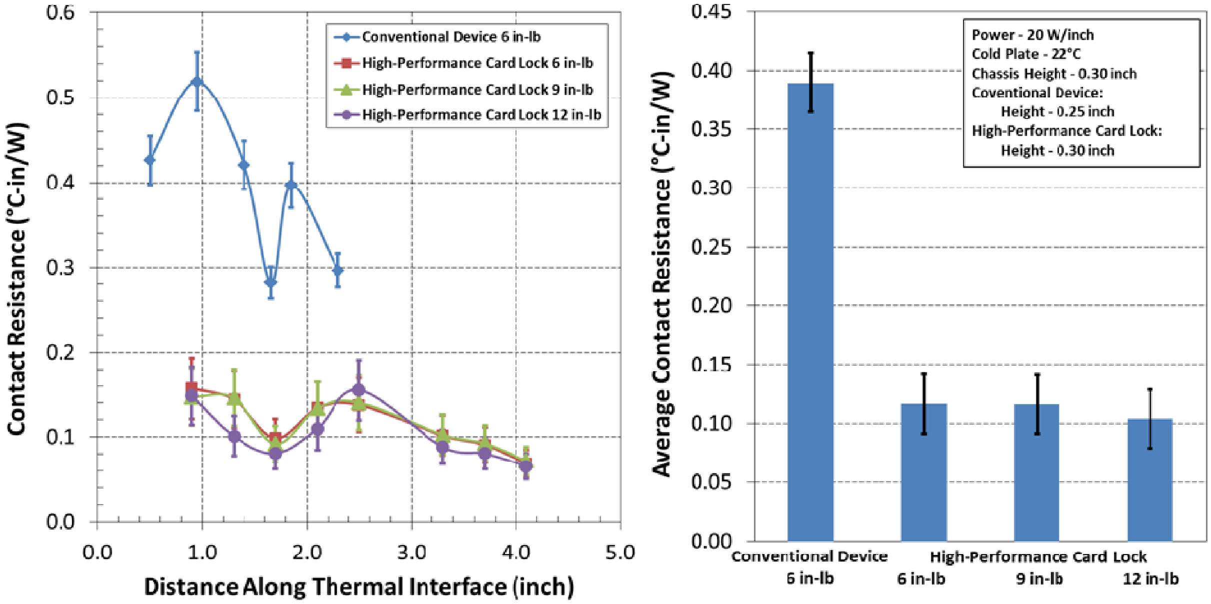

Figure 7. Contact Resistance Measurements at the Thermal Interface. The high-performance card lock outperforms the conventional device through reduced and less variable contact resistance.

IV. Conclusion

A high-performance card lock has been developed for conduction-cooled electronic applications that require a separable thermal mechanical interface. In comparison to the industry-standard conventional device, the high-performance card lock exhibits a 3.5x increase in thermal contact force and a 2.75x increase in useful thermal contact area, all of which result in an order of magnitude reduction in contact resistance. The increased contact resistance uniformity of the high-performance card lock increases the flexibility of the electrical system designer. Previously, non-uniformities associated with the conventional system constrain the placement of high heat-dissipating electrical components on the card near positions of low thermal contact resistance. The high-performance card lock eliminates this constraint. Finally, the high-performance card lock has been designed as a drop-in replacement to the conventional approach, enabling its use in space satellite systems and in-flight aerospace electronics, among other air and ground-based military systems.

Acknowledgments

We gratefully acknowledge the continued support of the SBIR program (Contract No. FA9453-14-C-0296) and specifically that of our technical monitor, Brenton Taft, at Kirtland Air Force Base in Albuquerque, NM.

References

[1]Pentair Technical Products, Birtcher Product Catalogue: Rugged Printed Circuit Board Hardware, pg. 81–82, Vol. 2, 2010.

[2]Bloom, M. F., "Thermal Contact Conductance in a Vacuum Environment," Missile & Space Systems Division Douglas Aircraft Company, Douglas Report SM-47700, 1964.

[3]Lambert, M. A., and Fletcher, L. S., "Metallic Coatings for Enhancement of Thermal Contact Conductance," *J Thermophysics and Heat Transfer*, Vol. 8, No. 2, Apr. 1994, pp. 341–348.