CompactPCI® Connectors
In
Space Flight Applications

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CompactPCI® Connectors in Space Flight Applications[1]

I. Introduction

This report documents the current status of CompactPCI® connectors in GSFC spaceflight applications. To the extent the information is known, this report summarizes to what component quality level each NASA contractor (referred to as OEM in this report) procured the parts, and what board level and system level testing was performed. The report also provides the current status of the reliability assessment for each GSFC project based on the results of testing and FMEA (Failure Mode Effects Analysis).

This report addresses how the CompactPCI® connectors came into existence, and how these became the connector style chosen by many designers of space flight hardware. It identifies the design philosophy and the lack of robustness which has led to several known failure modes. These failure modes include fretting of connector pins during vibration, shock and thermal cycling, exposure of underplating, and increased resistance, including brief excursions to very high resistance. Each of these are signs of aging, which becomes an increasing concern for long duration orbiting space flight applications.

This report addresses the mitigation strategy to replace CompactPCI® connectors with space qualified Hypertronics 2mm cPCI connectors. The Hypertronics 2mm cPCI connectors are pin-to-pin compatible with the CompactPCI® connectors and meet all of the same technical requirements, except the ability to hot mate, and to mate directly with a CompactPCI of the opposite gender. A detailed comparison of the CompactPCI® connector and the Hypertronics 2mm cPCI connector is provided to describe the ruggedness of Hypertronics connector for space flight applications.

Finally, this report makes recommendations for flight hardware for the future missions where the hardware is yet to be built, as well as for the hardware which has already been built with CompactPCI® connectors.

[1] CompactPCI® is the name given to connectors that meet the requirements of the PICMG2.0 specification. This specification has no reliability requirements for space flight applications. The name CompactPCI® is registered to the PCI Industrial Computer Manufacturing Group (PICMG). For the purpose of this paper, CompactPCI® is the name given to all commercial/industrial connectors that meet these specifications. CompactPCI® connector is a special case of a general set of connectors called “2.0mm Hard Metric” connectors. Their mechanical and electrical performances are identical and so the same reliability issues apply to both CompactPCI® and Hard Metric connectors.

The term cPCI is often used synonymously with CompactPCI®, but cPCI is not a registered name. That being the case, in this paper, the Hypertronics connector is referred to as the 2mm cPCI connector. Hypertronics calls it the “2mm connector” and also the “Ruggedized 2mm connector”.

II. Specifications for CompactPCI® Connectors

The following two governing documents apply to CompactPCI® connectors:

1. IEC61076-4-101 Connectors for Electronic Equipment – Printed Circuit Board Connectors with Assessed Quality.
This specification is an international standard defining requirements for 2mm hard metric printed circuit board connectors. CompactPCI® is a subset of 2mm "Hard Metric" connectors. Another example of a 2mm hard metric connector is Euro-metric. This specification addresses the construction of the connectors as well as mechanical and electrical testing requirements.

2. PICMG 2.0™ CompactPCI® Specification
This specification establishes two "Standard" processor board configurations with "standard" contact assignments. The 3U configuration utilizes two 2mm connectors. The 6U configuration utilizes five 2mm connectors. This specification defines the electrical (pin assignments) and mechanical configuration requirements of the CompactPCI® connector.

It is important to note that the main focus of these specifications is to define the requirements for inexpensive high pin density (2mm pin-to-pin spacing) connectors for use in commercial/industrial applications. The emphasis is on interchangeability between different manufacturers and the ability to hot mate the connectors. The main user of these connectors is the telecommunications and data communications industries. These specifications do not mention reliability. **These specifications do not address either the short term stresses associated with Spacecraft launch or the long term reliability concerns of using these connectors in the demanding environment of space.**

Space Qualified cPCI Connector

The need for a reliable connector to replace the CompactPCI® connectors currently used by various space flight hardware builders led to a partnership between GSFC and Hypertronics to develop an alternative that would be more reliable in space flight applications. Hypertronics designed the 2mm cPCI connector utilizing a smaller Hypertac® wire basket military socket contact with known good reliability. A test plan was designed in collaboration with GSFC to determine if this connector meets the needs of space flight applications. The testing has been successfully completed by Hypertronics and the connector has been approved for space flight usage by GSFC. A NASA/GSFC procurement specification for these connectors, S-311-P-822, is expected to be released in August 2007.

III. Comparison and Interchangeability of CompactPCI® with Hypertronics Connector

Commercial CompactPCI® connectors utilize stamped fork contacts having two (2) points of contact engagement, and compliant pin terminations into PC Boards. In contrast, the Hypertronics 2mm cPCI connector employs five (5) spiral connection zones in all axes, and board terminations are soldered connections. The platings do not use pure tin, and so there is no tin whisker related risk of shorting. Also, the shell is made from a higher temperature molding material capable of withstanding soldering operations. The shell material is selected to meet NASA outgassing requirements. As a result, the Hypertronics 2mm cPCI connector is a much more reliable connector when used in harsh environments.

The purpose and design of the CompactPCI® and Hypertronics 2mm cPCI connectors are very different. The CompactPCI® connector was designed for use in the telecommunication and data communication industries where temperatures are fairly stable, and shock and vibration are far less than in spacecraft launches. Furthermore, in these industrial applications, it is common practice to swap out and upgrade cards on a periodic basis. When failures happen, there is typically no interest in determining the cause of the failure; thus, there are no data on reliability generated by these users. In spite of the lack of reliability data, these connectors have found their way into high reliability applications in demanding environments for which they were not designed. Their usage has resulted as a by-product of the designers' effort to utilize the CompactPCI® architecture in space applications, and the previous lack of a space qualified 2mm high density connector.

As a result of the need for a high reliability CompactPCI® connector, the Hypertronics 2mm cPCI connector was developed. The Hypertronics connector was designed for the harsh environments of space flight and the demands for long term reliability. It was also designed to be pin-to-pin compatible with CompactPCI® and to have the same PC board footprint. See Figures 1 and 2 below for a pictorial comparison of each connector. The Hypertronics 2mm cPCI and the CompactPCI® connectors are not directly mateable. However, Hypertronics offers an adapter that allows the two to mate. This is important for utilizing the support equipment that is typically used for termination of commercial CompactPCI® connectors.

One feature that the CompactPCI® connector has that is not available in the Hypertronics 2mm cPCI is the ability to hot mate – remove and install cards without removing backplane power. The CompactPCI® connector accomplishes this by staggering the lengths of the pins. The ground pins are the longest, followed by the power pins, with the signal pins being shortest. This is an important feature in the telecommunication and data communication industries, but is not necessary for normal spaceflight applications. The only possible exception may be use on the International Space Station where manned repair, while in use, may be required.

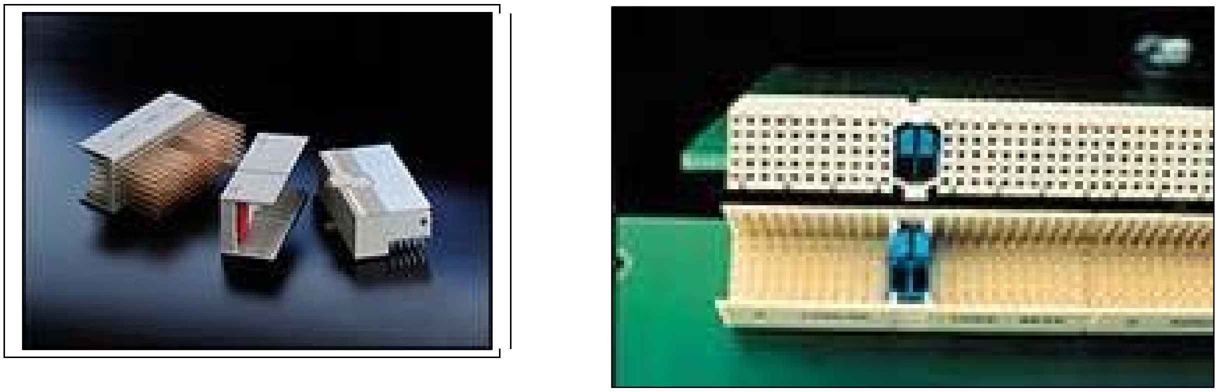

Figure 1 – Picture of commercial CompactPCI® connector

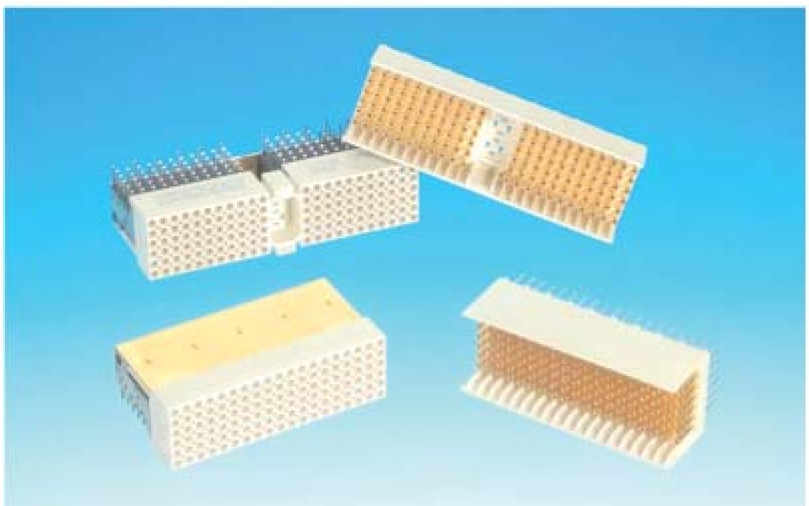

Figure 2 – Picture of Hypertronics 2mm cPCI connector

The two connectors look quite similar; however, they differ in contact construction, contact plating, shell material and PC board terminations. The following sections provide a side-by-side comparison of the two connectors in these areas.

Contact Construction

The CompactPCI® connector is designed with blade-shaped pins on the (female) “backplane connector”, and bifurcated socket tines on the right angle (male) “daughter card connector”. The contacts are typically stamped out of phosphor bronze, or in at least one case, beryllium copper. See Figure 3 below for examples of the CompactPCI® contacts. Included in Figure 3 is a cross-sectional view of the bifurcated socket tines compliments of Diane Kolos, NASA/GSFC Materials Engineering Branch.

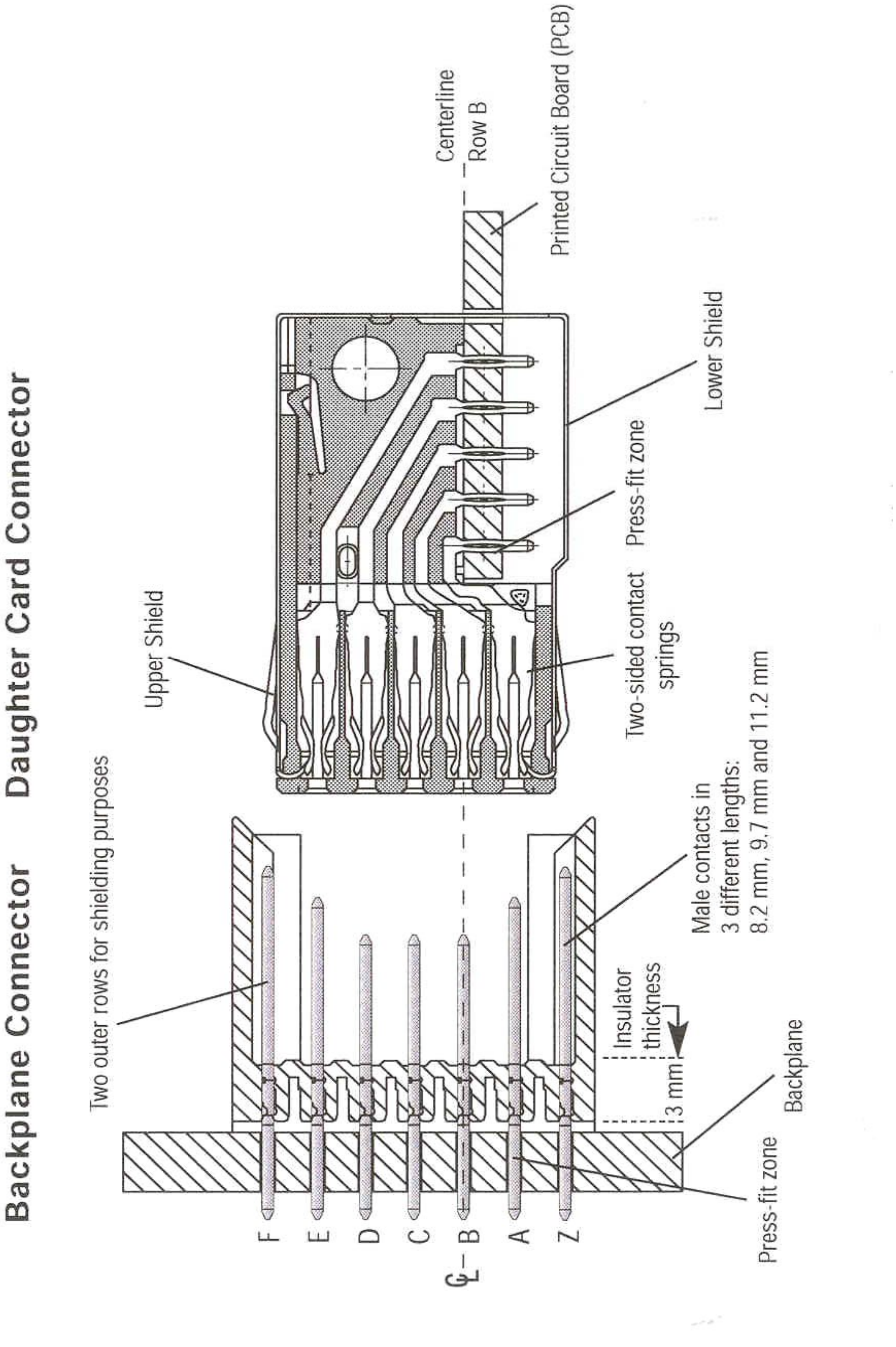

Figure 3a – Example of typical CompactPCI® blade

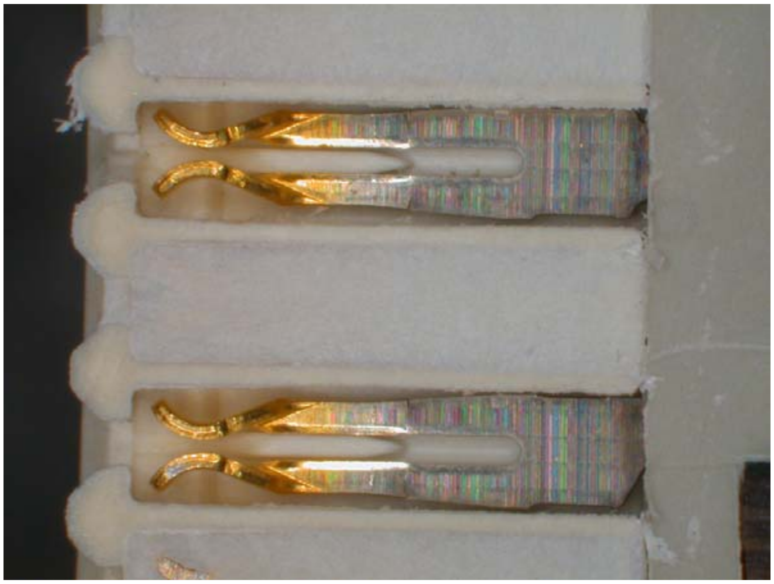

Figure 3b – Cross-Section of CompactPCI® Bifurcated Socket Tines (Diane Kolos, NASA/GFSC). Magnification is 8x.

This connection system only allows for two points of contact where the pin mates to the socket. This type of connection may cause intermittent loss of connectivity due to "**Contact Spreading**" during vibration. The analogy of a "clothes pin" describes this loss of connectivity – if one of the two sides makes a weak contact, or the side spreads apart, the connection is lost. Over an extended period, this connection design can also cause increased contact resistance as the result of "**Fretting**" and build up of fretting debris.

Fretting is the wearing down of the plating due to the relative movement of the contacts during vibration or thermal cycling. This relative motion scrubs the gold finish off of the contact mating surfaces revealing the underlying base material which is susceptible to corrosion. Figure 4 shows an example of fretting as revealed in a Ball Aerospace DPA report.

It is also worth noting that the "Stamped" manner in which the pin and socket tines are made often results in a "file-like" surface on the pin and socket interfaces. Through vibration or mating, this action "files" away the gold plating. This surface appearance can be seen in Figure 4 as diagonal striations in the plating.

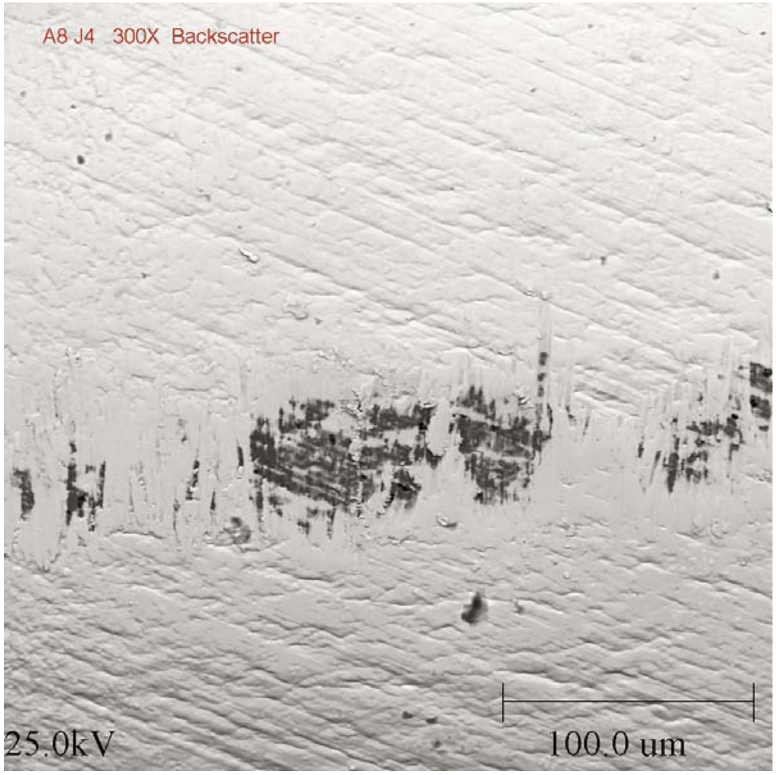

Figure 4 – Example of Fretting as reported in Ball Aerospace DPA following vibration testing. Darkened region is exposed base metal.

Corrosion (oxidation, hydration, or other reactions depending on ambient fluids) will happen as the base metal is exposed to (moist) air. Fretting can be detected electrically as an increase in contact resistance after exposure to vibration, shock, or thermal cycling; it can also be seen under inspection with a microscope, or using Energy Dispersion X-Ray Spectroscopy (EDS). ASTM B868 (Specification for Contact Performance of Electrical Connection System) states that it is a "well-established principal that contact resistance, its change with time under an appropriate life test sequence, and sample-to-sample variability are the most reliable indicators of connection quality." In other words, as the average resistance of a connection goes up, the resistance can become chaotic, making the connection intermittent.

Fretting is a significant problem observed during the vibration testing and thermal cycling of boxes using CompactPCI® connectors from various manufacturers including ERNI, VALCONN, and Tyco/AMP. Fretting is the usual cause of "wear out" of CompactPCI® contacts. In summary, two points of contact in a mated contact pair results in a weak point in the connector design due to contact spreading, fretting and the subsequent corrosion of the base metal.

The Hypertronics 2mm cPCI connector is designed using their patented Hypertac® contact. The Hypertac® contact offers many spiral connection zones between the pin and the wire basket socket sleeve; five (5) zones are used for the 2mm cPCI case. This type of contact construction virtually eliminates the potential for fretting to occur and for intermittent loss of connectivity due to vibration. See Figure 5 below for an example of the Hypertac® contact; ten zones of contact are shown in this example.

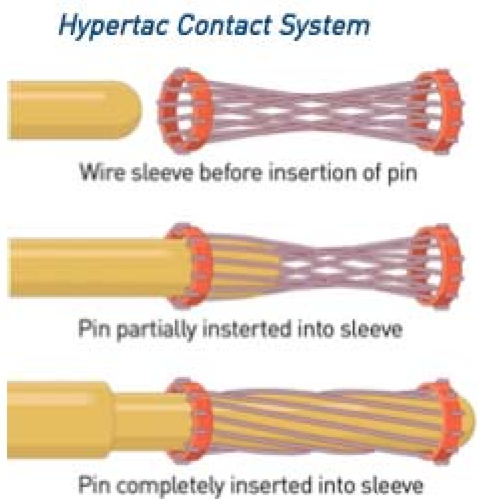

Figure 5 – Example of the Hypertac® contact system

Related to the importance of contact construction, is the importance of retaining the connectors, and therefore their respective contacts, fully seated during operation. This is one of the main causes of the fretting of the contacts during vibration. Both the CompactPCI® and the Hypertronics 2mm cPCI connectors lack a clamping mechanism to keep the connector pairs fully mated, and free of any relative motions between pin and socket larger than a few micrometers. Regardless of which connector system is used, a locking mechanism must be in place to keep the daughter card from moving relative to the backplane. This is typically accomplished in space flight applications by incorporating an edge card wedge lock to hold the board tight in the chassis. This keeps the daughter card from de-mating within the chassis, but it does not address the potential for the backplane to move relative to the daughter card. For instance, during vibration or thermal cycling the backplane will flex, causing the mated connector pair to move relative to each other. It becomes necessary to perform vibration and shock analysis to determine if additional reinforcement of the backplane is necessary to prevent excess flexing. And this testing must be carried out using items that are a faithful replica of the flight items to attain accurate duplication of the flight-like displacements.

The CompactPCI® approach for the telecommunication and data communication industries is to have card locks at the ends of the PC board that push the daughter card connector into its mate on the backplane. With card locks on, PC boards and daughter cards are likely to return to their nominal installation position after the “mild” vibration exposures experienced in telecommunication applications.

Material Selection

Neither of the two governing CompactPCI® documents, IEC61076-4-101 nor PICMG 2.0, defines what material should be used for the shell. That being the case, the shell material selection is completely up to the discretion of the manufacturer. This material was not selected for its robustness to harsh environments, and in particular, stability under soldering temperatures (since soldering is not part of the design for this connector). It was selected based on cost and commercial experience (ease of manufacture, yield etc.). A contractor reported an experience to NASA which states that during operation, two examples of the plastic shell of a CompactPCI® connector (which was solder installed) split from end-to-end.

The Hypertronics 2mm cPCI connector was designed for high reliability applications including space flight use. It was designed to be soldered onto a PC board, and the shell material was selected appropriately. Since NASA was involved in the development process of this connector, Hypertronics selected an insulator material that not only meets NASA temperature requirements, but also meets NASA outgassing requirements.

Termination

The manner in which the connectors terminate to the PC board is another key difference between these two connectors. The CompactPCI® connectors are designed with compliant pin terminations. The terminations are designed bulged out, similar to the eye of a needle, so that as the connector termination lead is pressed into the PC board the termination leads are scored into the plated through-hole barrels on the PC board. A problem that can occur, and contractors have confirmed, is that the termination leads can bend over as the connector is forced onto the board. If this occurs, then both the board and connector most likely will need to be scrapped. Bent contacts can be detected by visually inspecting the connector location from the bottom-side of the PC board. If you cannot see a pin in each hole you probably have a bent over termination. Another way to check for bent over terminations is through pin-to-pin continuity checks.

NASA discourages the use of press-fit or compliant pin terminations in flight hardware. NASA prefers that all components should be soldered in place; plated-through barrels are to be 100% filled with solder. However, soldering press-fit or compliant pin terminations in place has raised a number of problems. The terminations do not have a solderability requirement, and some terminations are not wet by the solder. The large thermal mass of this high density connector, and the large thermal mass of the accompanying PC boards, impose a long time for heating to soldering temperatures, and opens the risk of thermal degradation of the heat-treatment of the work hardened pins and of the plastic shell; it also can exacerbate damage to the PC board that may have been initiated by insertion of the compliant pin. The close fit of the compliant pin into the plated-through barrel and any non-wetting character to the pin interferes with solder filling the plated-through barrel: fills to as little as 30% have been seen, and fills of 50% to 60% are the norm. X-rays can be used to determine the fill-fraction, but cannot determine whether the solder is wetting the pin.

Knowing the preference of the space community for soldered terminations, Hypertronics designed the 2mm cPCI connector with solderable terminations and high temperature molding material. The additional heat of soldering process is not an issue, as is the case with commercial CompactPCI® connectors. Proper attention to removal of solder flux remains necessary.

IV. Industry and NASA Experience

NASA has flown a few spacecraft, with CompactPCI® connector quantities ranging from a few to as many as 30. These missions have lasted a few months to a few years, with rather benign environments with regard to thermal cycling. So far, these missions have experienced no operational problems that have been assigned to the used of the CompactPCI® connectors.

In addition, their performance in the telecommunication and data communication industries has been generally successful, although we must keep in mind that these connectors are used in "hot swap" situations that allow replacement of entire boards when any fault is noted, and the failing boards are rarely subjected to a failure analysis to assign the cause of the failure: these industries do not generate rigourous failure rate data for any of the parts they use. Still, there have been several situations, well-known to community, of selected parts-types that have demonstrated unacceptably poor performance in the field (e.g., aluminum electrolytic capacitors, counterfeit circuits, quartz crystal wristwatches made using 99.5% tin and 0.5% copper solder): generally poor performance becomes known, and that is not yet the case for CompactPCI® connectors, over their typically several years of use.

Based on this experience, and on estimates of the rates of degradations caused by the mechanism discussed above, the extent of degradation is estimated low during preparations for space flight applications.

The extent of degradation is expected to increase sharply as the mission duration increases since there are several degradation mechanisms that each accelerate with time. The degradation mechanisms that cause contact resistance to increase in CompactPCI® connectors, and that lead to bursts of brief excursions to high resistance, accelerate with time. If contact fretting of the gold plated contact surface occurs during the spacecraft thermal cycling, shock and vibration testing, then oxides/corrosion will develop, and increase contact resistance, as well as increase the frequency of bursts of brief excursions to very high resistances. And relaxation of the compliant pins in the plated-through barrels also results in an increasing connection resistance: this causes increased joule heating in low-power lines (carrying up to a nominal ampere of current) and this heating can increase the rate of relaxation throughout the neighborhood of this pin. As contact resistance increases with extended time, the likelihood of failure increases as well. Since CompactPCI® connectors have only been used in space flight applications for short durations (few months to 2 years, and in missions like STEREO and Deep Impact for which the amplitude of thermal cycling is very low, relative to many Earth-orbiting missions) there is no significant data showing potential reliability past this point. There are, however, significant indicators (i.e., fretting corrosion, intermittance, contact resistance increase) during very limited testing performed on flight and flight-like hardware that imply potential problems for longer missions. The growth of dendrites in delaminated PC boards, and of tin whiskers on pins whose tin coating contains less than 0.5% of lead, are also delayed failures, for which successful operation during ground testing offers sharply limited evidence of continued successful operations into the future.

It should also be noted that the approach of extending data obtained on flight-like hardware using CompactPCI® connectors to flight hardware using CompactPCI® connectors has a very significant flaw: these connectors have no manufacturing lot specific inspections or traceability requirements, and even connectors from the same Lot Date Code (LDC) can have entirely different materials and fabrication processes. On the other hand, if testing is performed on the flight hardware, we can be certain that we are consuming the life of these connectors before launch. **Hence, this is a connector system for which we cannot "screen in" reliability, or even estimate it, in the usual ways.**

GSFC Flight Project Usage

CompactPCI® connectors were designed for commercial/industrial applications. Since 1999, designers have adopted the compact PCI standard processor board lay-out, and these connectors became their choice for backplane connectors by default since no space qualified CompactPCI® connectors were available. Their usage has occurred in several NASA/GSFC projects including STEREO, AIM, GLAST and NPP. Below is a summary of the CompactPCI® connectors used and the experiences each project had with them. Although several of GSFC projects have been allowed to launch with flight hardware using CompactPCI®, this should not be considered precedence for future missions. Future missions should use the space qualified Hypertronics 2mm cPCI connector.

STEREO

The SECCHI instrument on the STEREO spacecraft uses a VALCONN CompactPCI® connector on its RAD750 Single Board Computer. The on-board computer for the STEREO spacecraft uses an AMP CompactPCI® connector. Also, the Obervatory uses AMP CompactPCI® on IEM and Valconn CompactPCI® on SEB. Twenty-seven CompactPCI® connectors in all are used on the STEREO spacecraft. Since there are two STEREO spacecrafts flying, 54 CompactPCI® connectors are in space flight.

STEREO testing revealed bursts of brief excursions to high resistance during thermal cycling. This is documented in a STEREO cPCI Qualification Summary / Anomaly Investigation presented by A. Jacques and M. Jones (2003). A decision to launch STEREO without replacing these connectors was based on detailed FMEA analysis that verified there were no signals passing through these connectors during launch that would cause serious problems for the mission. And the Sun-orbits of the two STEREO spacecraft sharply limit thermal cycling to several degrees at most.

AIM, SORCE, and GALEX

The AIM spacecraft used one CompactPCI® connector pair on the RAD6000 Single Board Computer. The project approval to launch with the RAD6000 was based on the heritage of this board on SORCE, GALEX, and Orbview-4, and 1,000 hours of operation in box and spacecraft test by the OEM. Note that 1,000 hours does not speak to "wear out" --- this data has no place in evaluating against such a threat; instead, it only gives us hope that there is no "infant mortality".

NASA launched the SORCE satellite on 25 January 2003. The satellite flies at an altitude of 640 km in a 40-degree-inclination orbit around the Earth. On board SORCE are four instruments. Thus, there is the potential for "age" --- it has been around for four years now, and is still sending back data at a great pace --- however, the on-board computer experienced an anomaly on 14 May 2007, placing the spacecraft in safe hold. The spacecraft was fully recovered on 20 May, and is now operating normally. The root cause is still under investigation by LASP and OSC, but there is no announcement of any finding, and there is a suggestion that none may be forthcoming. The question is whether a CompactPCI® connector burst of brief duration high resistances could have driven this safe hold.

GALEX was launched 28 April 2003 from Cape Canaveral Air Force station by a Pegasus XL rocket into an orbit of 690 kilometers (428 miles) above Earth. The planned mission duration is 29 months. It is still working --- there has been down time caused by a high voltage problem, but it is not likely that the down time was related to a CompactPCI® connector.

GLAST

The GLAST project has ERNI CompactPCI® connectors on the backplanes and RAD750 boards on the spacecraft and instruments. A total of approximately 50 CompactPCI® connectors in all are used on the spacecraft. These connectors were soldered onto the boards to minimize the negative effects of vibration. Radiographic inspection revealed that the solder fill of the terminations ranged from 40% to 60%. However, x-rays cannot tell whether the solder has wetted the pin. To further investigate the extent of the CompactPCI® problem, the GLAST project performed a powered vibration test on the assembled connectors. The FMEA analysis revealed that any signals which passed through these connectors during launch would not cause a loss of mission.

The GLAST project is using two RAD750 boards on the spacecraft, and only one is needed for successful mission operation. The LAT instrument is using five RAD750 boards. Three of these boards are in the EPU (Event Processing Unit) and two are in the Spacecraft Interface Unit (SIU). The EPU needs two of the three units, and SIU needs one of two units for the science to meet mission requirements. The GLAST project has decided to launch with the existing flight hardware using the RAD750 boards with CompactPCI® connectors. This decision was based upon several factors, including the cost and schedule impact of replacing these connectors with the recently available space qualified Hypertronics 2mm cPCI connectors. The removal of existing connectors from a flight board introduces potential damage to the board, therefore downgrading the boards to non-flight. The project's decision to launch with the existing flight hardware took this concern into consideration as well.

NPOES Preparatory Project (NPP)

The NPOES Preparatory Project (NPP) is using CompactPCI® connectors throughout the project. The spacecraft is using CompactPCI connectors manufactured by ERNI and Tyco/AMP. The VIRS, CRIS, and OMPS instruments are all using Tyco/AMP connectors.

The NPP spacecraft procured both ERNI and Tyco/AMP CompactPCI® connectors. The ERNI connectors were procured by a Ball Aerospace SCD that called out screening and qualification testing per 311-INST-001A for printed circuit connectors. However, at the time of procurement, no testing guidelines were available for CompactPCI® connectors to guard against the known failure modes. The AMP connectors were used on the single board computers supplied by BAE system. Additional testing requirements for the AMP connectors are unknown. Ball also installed these connectors in oversized holes on the PC board to allow for better solder fill as the connectors were mounted to the PC board. Coupon analysis was performed by NASA/GSFC on samples sent by Ball Aerospace. The analysis revealed solder fill less than 70%; this does not meet the NASA PWB assembly specification. At the date of this report, Ball Aerospace has not yet performed 100% radiographic inspection as requested by NASA/GSFC Code 300. Intermittancy in the contact connections was identified at functional testing. There was no data lost by any of the operating flight units during thermal cycling and vibration testing.

The NPP/VIRS instrument, which is being built by Raytheon, is using Tyco/AMP CompactPCI® connectors with compliant pin terminations that were subjected to supplemental solder on the Honeywell Single Board Computer, and Tyco/AMP compliant pin connectors for all other assemblies. The connectors were procured with limited screening and qualification testing. NASA/GSFC has reviewed both environmental and vibration testing data packages on the single board computer boards and the results are acceptable. There are still a few open issues to close out. For the compliant pin connectors, Raytheon contracted Amphenol to install these connectors. Amphenol has a history of installing these connectors for the US Navy. No additional testing was performed to verify the acceptability of these parts.

The NPP/CrIS instrument, which is being built by ITT Fort Wayne, is using Tyco/AMP CompactPCI® connectors with supplemental soldered terminations. Examination of the connectors used on the engineering model revealed fretting wear through the gold plating exposing the under-plate material. The fretting and exposed under-plating were observed after limited environmental testing. As a result of these observations, the OEM ordered the flight CompactPCI® connectors with a thicker gold plate, but holds the actual thickness as proprietary information. No testing has been performed on the flight model connectors to confirm if the thicker gold plating was successful in preventing the exposure of under plating. Evidence from articles researched revealed that thicker gold plating can sometimes lead to flaking of the gold.

The OMPS instrument, which is manufactured by Northrop Grumman Space Technology (NGST), uses Tyco/AMP and Samtec CompactPCI® connectors on the backplanes. Following supplemental wave soldering of press fit terminations, cracks were identified in the sides of some of the connectors. This was likely caused by the temperature induced by the wave solder machine, and the choice of a plastic without a design-need to tolerate this temperature. NGST, along with Ball Aerospace, has agreed to replace all cracked connectors and closely monitor the wave solder process.

SDO, LRO and JWST

For the SDO, LRO, and JWST projects, the Hypertronics 2mm cPCI connector has been selected as the only cPCI connector to be used for flight applications. Since the soon-to-be-released NASA/GSFC S-311-P-822 procurement specification was not available at the time of procurement, the SDO, LRO and JWST projects procured the cPCI connectors to the Hypertronics part numbers. The Hypertronics part numbers are equivalent to the S-311-P-822 specification.

The vendor supplying the Single Board Computer RAD 750 has been required to use Hypertronics 2mm cPCI connectors in place of the CompactPCI® connectors for SDO, LRO and JWST. It has been confirmed that SDO and LRO single board computers both use Hypertronics connectors, as will JWST when the procurement is placed. The RAD 750 built for NPP, GLAST and some earlier projects employed the CompactPCI® connector.

V. Reliability Issues and Mitigation Strategies Employed by NASA Space Flight Hardware Builders

The two point contact construction strategy employed in CompactPCI® connectors, coupled with the lack of a clamping mechanism to hold the mated pair together, leads to the intermittent loss of connectivity during vibration. Furthermore, fretting of the plating materials due to the relative movement of the blade shaped pins and bifurcated socket tines leads to an increase in contact resistance. Increased contact resistance directly correlates to a decrease in the quality of the electrical connection. The amount of increase in contact resistance which will significantly impact the reliability of a circuit can only be established by analysis of that circuit's requirements, and not inspection of the connector. It is circuit-application dependent. It should be noted however that any increase in contact resistance is a warning sign that the quality of the connection has begun to degrade. A number of space flight hardware builders have observed the onset of increased contact resistance during the vibration testing of flight or flight-like hardware employing these connectors, and also during thermal cycling.

It should also be noted that it is only the average contact resistance that is typically measured. It is now reported in many places that an increase in the average contact resistance correlates with the onset of an increasing frequency of brief excursions to very high resistance. The frequency of these excursions, and how they impact each signal in the application, needs to be evaluated before a decision to use these connectors or to launch the existing hardware with these CompactPCI® connectors is made. These are observed to happen under thermal cycling, as well as under vibration and shock.

Compliant pin terminations have been seen to rupture barrels and to induce delaminations between layers in PC boards. Delaminated PC boards have grown dendrites between traces, causing leakage paths and even short circuits, carrying tens of milliamperes of current without clearing. Attempts to augment the joint by introducing solder does not heal the delamination, rather, it tends to extend it. On the other hand, ruptured barrels relax the compression between pin and barrel, and sharply increase the electrical resistance, as well as permitting ambient gases to enter the contacting zone, allowing corrosion which further increases contact resistance. In this case, introducing solder can preserve the joint somewhat.

One of the strategies employed by NASA space flight hardware builders to reduce the potential for connectivity loss through these compliant pin connectors is to solder the terminations after pressing them in. Although soldering the terminations to the PC board is preferred for high reliability applications, including space applications, there are concerns regarding the impact of soldering on the engagement socket tines employed in CompactPCI® connectors. Soldering heat can potentially relax the "work hardening" manufactured into the phosphor bronze spring that enables press fit. When stress relieved, the spring can plastically deform. This reduces the contact pressure exerted on the pin, increasing the contact resistance.

In addition, the shell material used in CompactPCI® connectors has been found to be deformed by the temperatures reached during the soldering process. The evidence of cracking which resulted from thermal exposure to the soldering process is alarming. And, the use of components that crack under soldering temperature is a serious concern for the existing flight hardware using CompactPCI® connectors. Also, soldering heat has caused the plastic shell to retract from the part of the pins next to the pc-board, allowing pin-to-pin visibility: this can allow tin whiskers to bridge between pins, should they grow. (Some pins have been measured to have less than 0.5% of lead by weight, and this opens to possibility of whisker growth.)

Another problem that was identified with the soldering of CompactPCI® connectors is the removal of solder flux. Because the connector sits flush to the PC board, there is no visibility to remove flux. There have also been instances where solder flux has wicked up into the connector shell itself. Thirdly, if board delamination occurs, flux can enter this area. All of these examples can result in pin-to-pin shorting with resistances ranging from 3 ohms to being short.

Another option employed by space flight hardware builders to make the soldered connections has been to oversize the plated through holes, in the expectation of improving solder flow, and then to solder the terminations in place. This has only been marginally successful, and has its own reliability concerns. Inspections at GSFC has shown absence of adequate wetting of the terminations, and failure to get solder to wick up into the plated barrels to the desired 100%. Consequently, NASA has permitted a relaxed supplemental solder barrel-fill target of 70%. The solder barrel-fill in the x-rayed boards has been in the range of 30% to 70%. In addition, increasing the hole size reduces the press fit contribution to termination.

It should also be mentioned that the contacts of the CompactPCI® connector are prone to damage when probed for contact resistance measurements or connectivity checks. When probing is required it should be performed on a mated pair. If probing is required on one side of the mate, special equipment is needed, and care should be taken to avoid pin bending.

Hypertronics space qualified 2mm cPCI connector shall be used for meeting the requirements of a highly reliable connection for a long period of time in demanding applications. The connection system used by Hypertronics is far superior; the Hypertac® technology has a proven history and appropriate materials are used. Taking all of this into consideration, currently, Hypertronics is the only manufacturer qualified to build a 2mm high density connector for space flight hardware.

VI. Recommendations

The following summarizes the recommendations for the future missions as well as the existing flight hardware that require or employ high density (2mm) Hard Metric connectors (including CompactPCI® connectors, VME, Hypertronics, etc.).

Future Missions

- Do not use compliant pin or press-fit technologies for space flight applications.
- Use connectors with three or more points of contact per socket.
- Use only space qualified connectors such as Hypertronics 2mm cPCI connectors when a CompactPCI®-like connector is needed.

Existing Flight Hardware

- Replace CompactPCI® connector with Hypertronics 2mm cPCI connector.
- If a CompactPCI® connector is already installed, and the application is such that a Hypertronics 2mm cPCI connector cannot be substituted, the following strategies must be employed.
    - Vibration and thermal cycling tests on Engineering and Qualification samples should be performed in such a way to ensure that sufficient gold contact is present at the end of the mission in flight hardware.
    - If terminations are soldered, verify that the soldering process is reliable and non-destructive of other properties. For example, ensure that the soldering heat does not stress or crack the plastic shell. Soldering verification should be performed on a sample basis with the sample being representative of flight board configuration and thermal mass.
    - Inspection
        - At every mate/demate, inspect the socket tines with a magnifier and the pins with a flashlight to verify that the contacts have not been bent.
        - Train handlers in the importance of CompactPCI® inspection. Also train the handlers in how to perform this inspection.
        - Probing has caused damage to the sockets. Use a mated pair when probing.
    - Any anomalies in performance that occur during flight verification testing, that could be attributed to a connector showing high resistance or intermittent opens, should be documented and dispositioned.
    - All critical connections should be routed through two (or more) lines for redundancy.
    - **Perform a detailed FMEA to evaluate the risk associated with the failure modes outlined in the report. If FMEA was performed earlier, but did not take into account the condition outlined below, it must be performed again. Specifically, the FMEA should address failures caused by:**
        - **Increased contact resistance (10 to 100 ohms) and brief excursions to open circuit (0.2nS to 10's of mS) due to fretting.**
        - **Pin-to-pin shorting (resistance short to 3 Ohms) that could be caused by solder flux, board delamination, or tin whiskering.**

Evaluate each application to identify critical connections. FMEA, as a minimum, should be performed on all critical connections.

VII. References

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Appendix A

Quantitative Reliability of CompactPCI® Connectors in Spacecraft

By Henning Leidecker