



Design and Development of a CPCI-Based Electronics Package for Space Station Experiments

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Summary

The NASA John H. Glenn Research Center is developing a Compact-PCI (CPCI) based electronics package for controlling space experiment hardware on the International Space Station. Goals of this effort include an easily modified, modular design that allows for changes in experiment requirements. Unique aspects of the experiment package include a flexible circuit used for internal interconnections and a separate enclosure (box in a box) for controlling 1 kW of power for experiment fuel heating requirements. This electronics package was developed as part of the FEANICS (Flow Enclosure Accommodating Novel Investigations in Combustion of Solids) mini-facility which is part of the Fluids and Combustion Facility's Combustion Integrated Rack (CIR).

The CIR will be the platform for future microgravity combustion experiments and will reside on the Destiny Module of the International Space Station (ISS). The FEANICS mini-facility will be the primary means for conducting solid fuel combustion experiments in the CIR on ISS. The main focus of many of these solid combustion experiments will be to conduct applied scientific investigations in fire-safety to support NASA's future space missions. A description of the electronics package and the results of functional testing are the subjects of this report. The report concludes that the use of innovative packaging methods combined with readily available COTS hardware can provide a modular electronics package which is easily modified for changing experiment requirements.

Introduction

In figures 1 and 2, the available envelope and location of the electronics package (referred to as the PI Box) within the CIR facility are shown. The primary electrical interface is a series of ARINC 404 rectangular connectors that mate with the CIR facility interconnect when the PI Box is installed in the facility. Forced-air cooling is provided by the facility. Air enters the PI Box near the ARINC 404 connectors and exits the enclosure through a screened hole at the top.

PI Avionics Package Envelope from Section 3.1.2.5 of FCF-IDD-CIR Combustion Integrated Rack Payload Interface Definition Document Fluids and Combustion Facility Rev. C 2/28/2005.

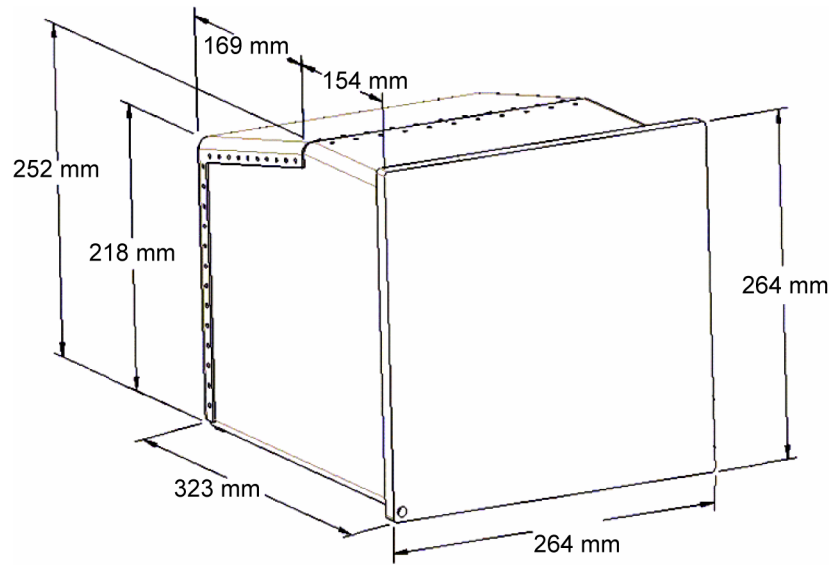


Figure 1.—Available volume for PI avionics enclosure.

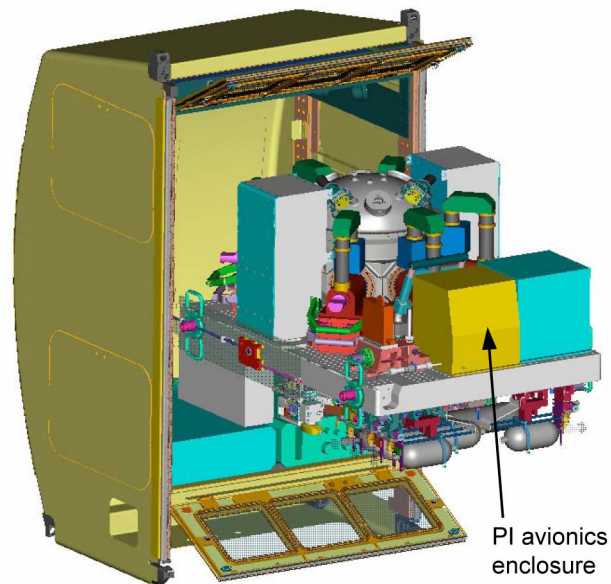


Figure 2.—Location of PI avionics enclosure.
Combustion Integrated Rack (CIR) Facility

Electronics Package Description

Figure 3 shows a transparent view of the FEANICS electronics package, termed the PI Box by the project.

The level of design in this electronics package is not a flight model, but instead is termed a “Fit/Functional” model by the FEANICS project. This means that the package will fit mechanically and electrically in the CIR facility and that it will function to operate the FEANICS experiment mechanical hardware. Internally, it does not have the mechanical robustness of a flight package. For example, the card guides in the card cage are inexpensive plastic guides instead of the more rugged “wedge-lock” guides that would be specified for flight. Also, no weight-saving measures, such as lightening holes, have been taken in this model.

Mechanically, the PI Box consists of three major pieces: a baseplate, card cage assembly and cover. The baseplate provides the mechanical and electrical interface to the CIR facility and attachment points for the card cage and cover. The cover fits over the card cage and attaches only to the baseplate. This way, changes to the card cage structure would not affect the cover design. The cover consists of two machined sides with a bent sheet metal center piece. The center is connected to the two sides with rivets. Figure 4 shows views of the PI Box with the cover removed. The card cage holds all the electronic devices and consists of COTS card guides and brackets. The card cage sides are custom parts that provide attachment to the baseplate. To take full advantage of the Compact-PCI specifications, the card cage is designed to accommodate an eight slot, 6U Compact-PCI backplane. In this model, a six slot backplane was used to provide room for an additional box which contains power conditioning components for the FEANICS experiment heaters. This additional box receives its 120VDC power input through the circular connector at the top of the PI Box. The connector is identical to the 120VDC connector that the CIR facility provides for delivering 120VDC to user devices. A mating cable was fabricated to connect the CIR facility and PI Box 120VDC connectors. Also of interest is the row of circuit breakers called out in figure 4. These were installed to provide over current protection for the secondary voltages (3.3, 5, ± 12 V). During testing however, it was discovered that the mil-spec circuit breakers caused an unacceptably high voltage drop

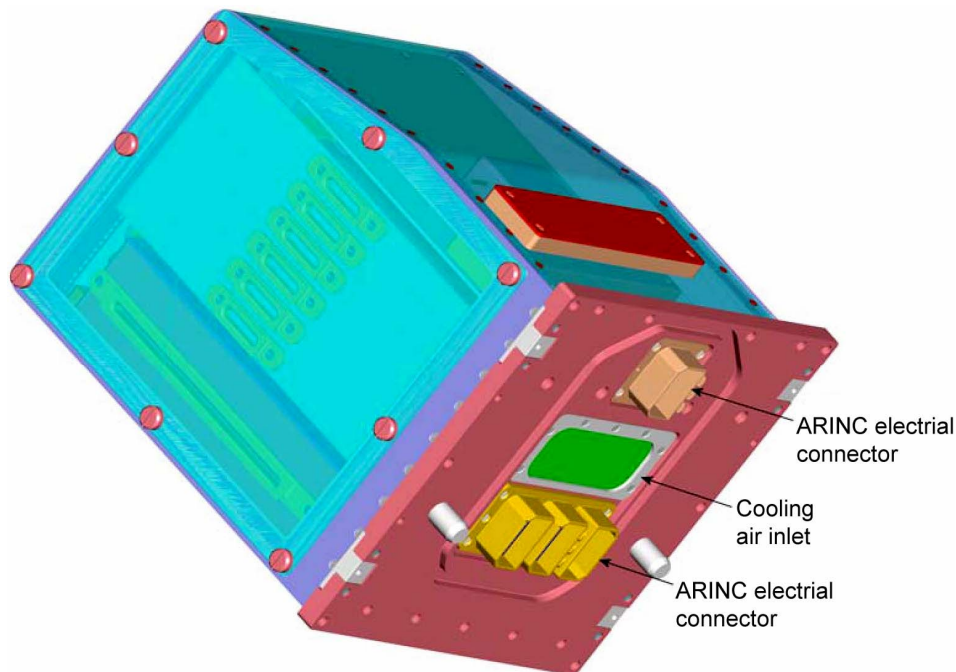


Figure 3.—FEANICS PI box electronics package.

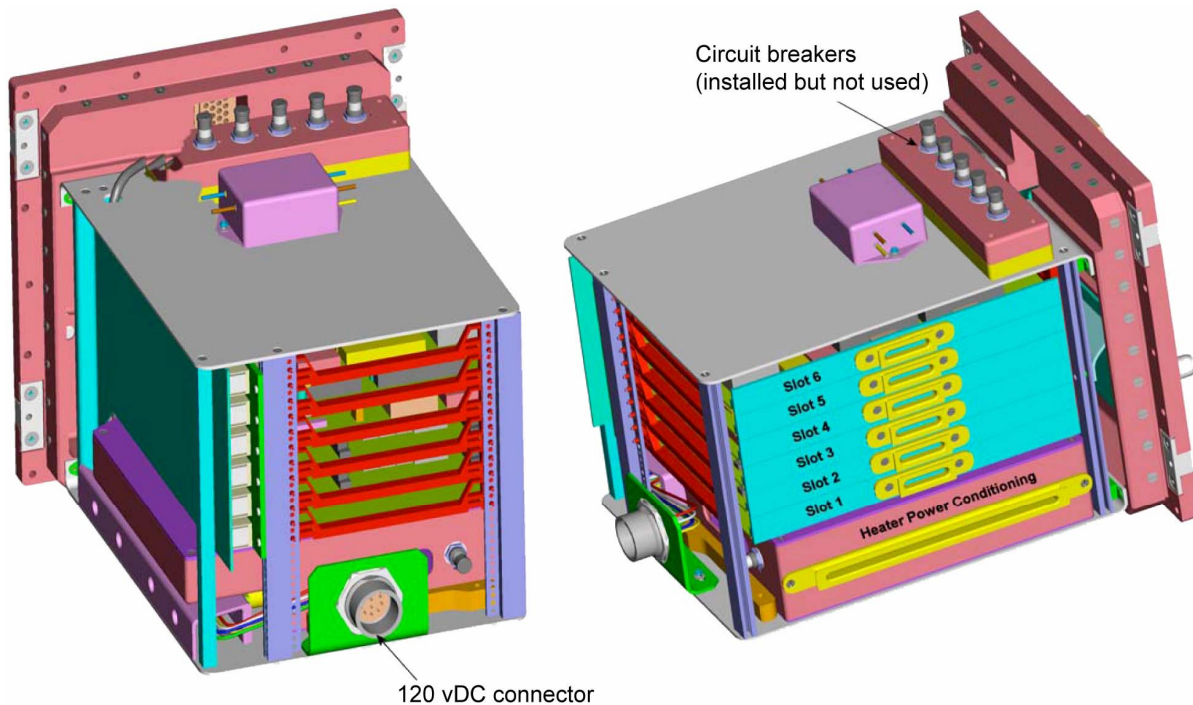


Figure 4.—FEANICS PI box assembly with cover removed.

for the secondary voltages. They were replaced with fuses for this prototype. For the flight configuration, over current protection provided by the CIR facility would be utilized.

Figure 5 is a block diagram of the PI Box electrical system. The electrical and electronic components in the PI Box operate the FEANICS experiment mechanical hardware through software commands. There are six PC boards in the Compact-PCI card cage that accomplish this function. To maximize system flexibility, Industry Pack (IP) modules were chosen to provide generic input and output capabilities. There are two IP carrier boards which each hold four IP modules. The complement for this PI Box is shown in table 1. The advantages of using Industry Pack Modules are twofold: First, there are many IP module manufacturers making a variety of module types. This provides longevity and flexibility for changing experiment requirements. Second, the Industry Pack specifications make full use of the “User I/O” contacts which are part of the Compact-PCI backplane. This greatly simplifies wiring within the PI Box by allowing a flexible circuit to be employed for the internal interconnect.

TABLE 1.—FEANICS PI BOX COTS INPUT AND OUTPUT CAPABILITY

System input and output function	Vendor and module part number	Number of available channels
Analog input	Acromag IP340 (3 modules)	48
Timer/counter	Acromag IP482	10
Combination analog input and output	SBS IP-OPTODAQ12-ET	8 in and 8 out
Isolated digital output	Acromag IP445 (2 modules)	64
Isolated digital input	Acromag IP440	32

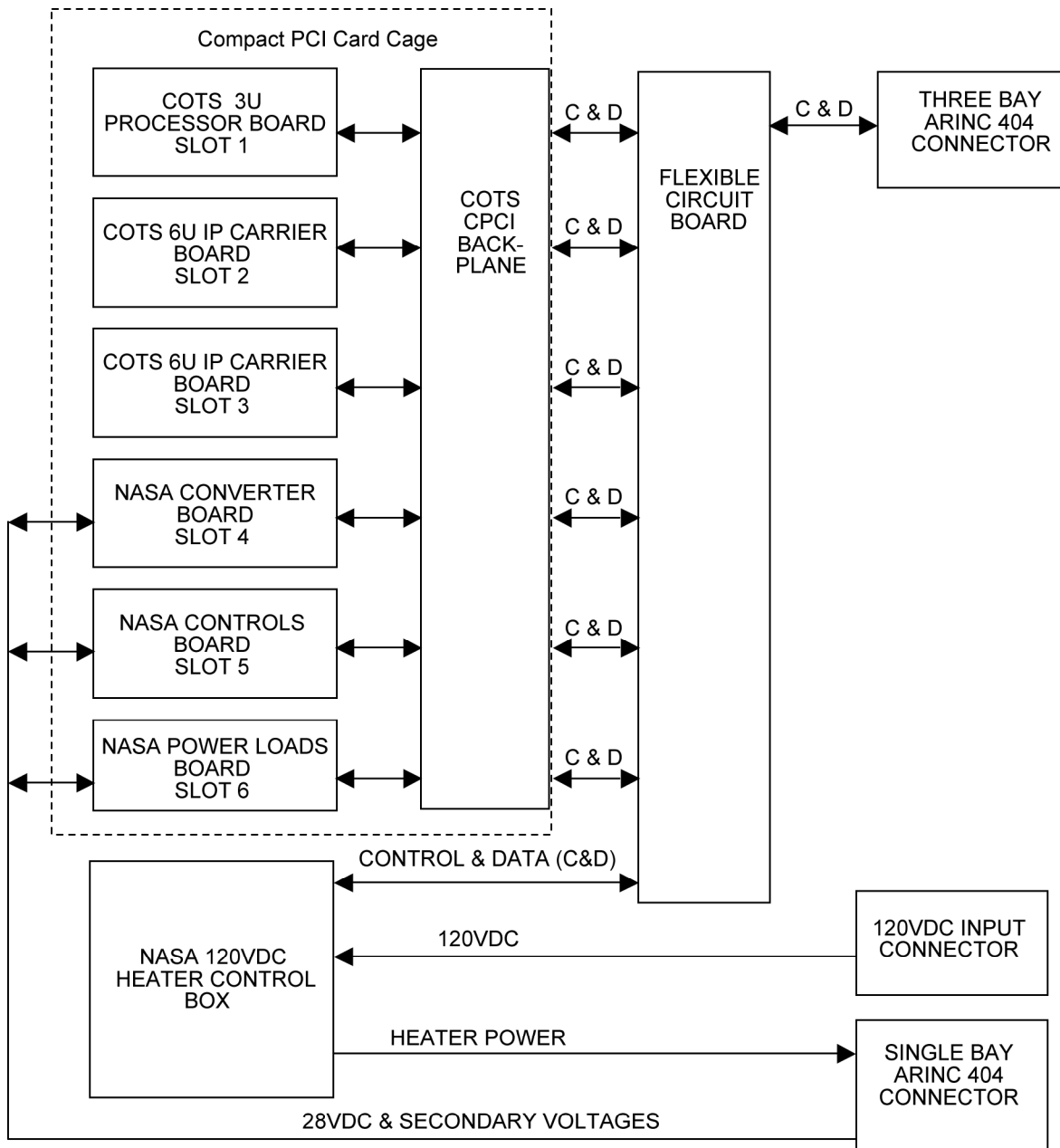
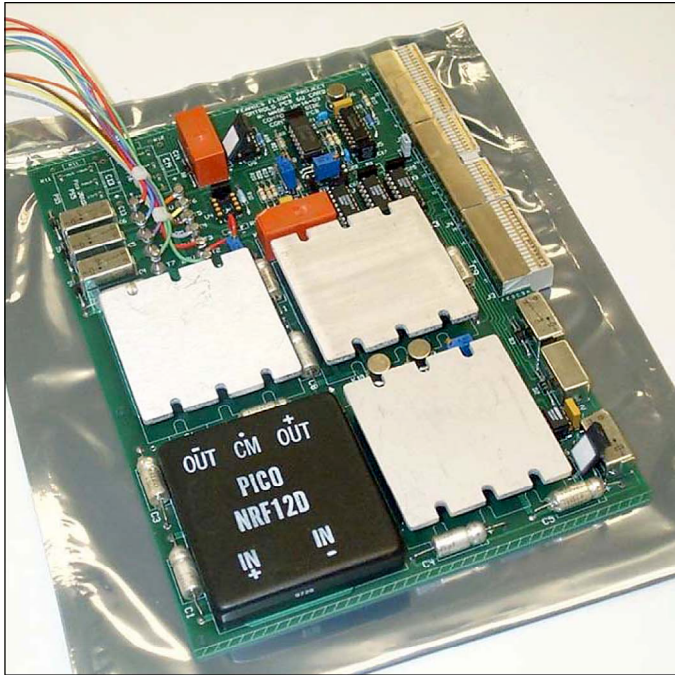


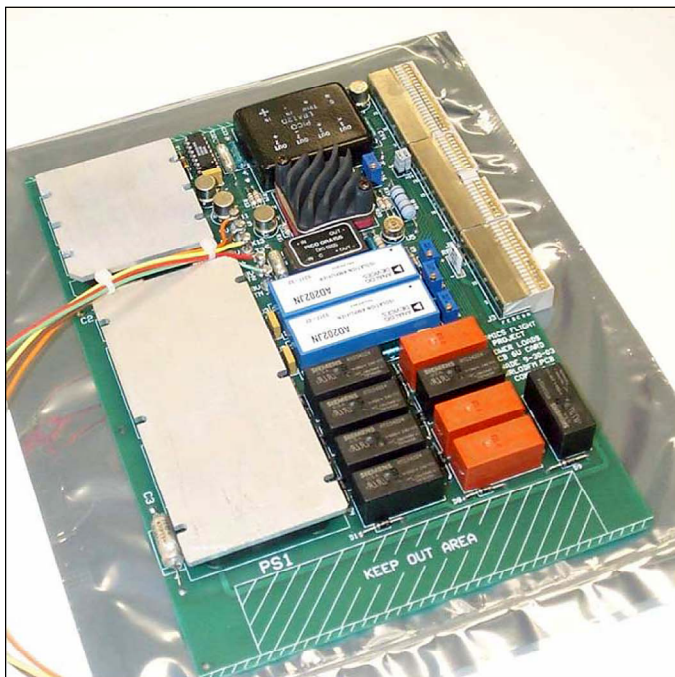
Figure 5.—FEANICS PI box electrical block diagram.

Three of the PC boards in the Compact-PCI card cage are NASA custom boards designed to perform specific control, power and instrumentation functions for the FEANICS experiments. They are shown in figures 6 through 8 along with a description of each.



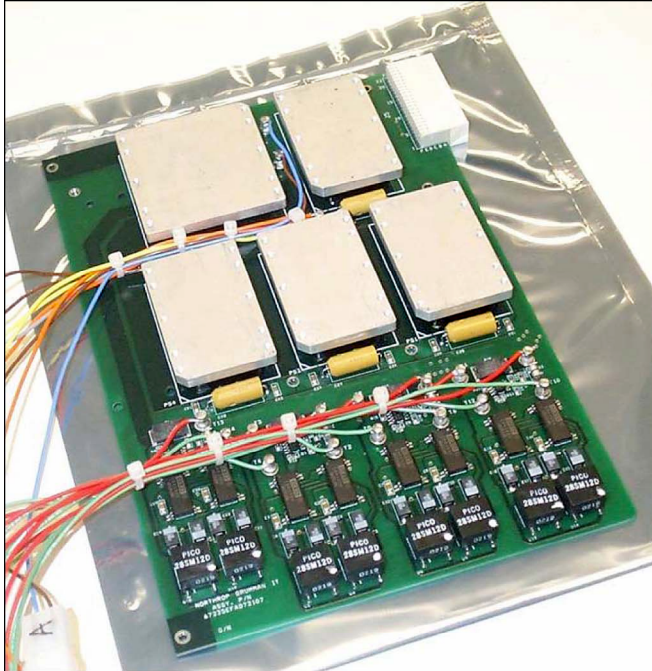
Controls Board located in Card Cage Slot 4. It's primary role is to house eight custom circuits which include LED variable lighting, chamber mixing fan control, smoke wire controls, a 15 V power supply for the 120 V isolation amp, O₂ sensor variable controlled (12 to 6.25 V) power supply, tunnel air flow blower control, ±12 V O₂ sensors power supply, and substrate heater control circuits.

Figure 6.—Controls board.



Power Loads Board located in Card Cage Slot 6. It's primary role is to house four custom circuits which include high and low power igniter control with voltage and current monitor, laser diode driver control, and the ±12 V isolated multiplexer and radiometer power circuit.

Figure 7.—Power loads board.



DC-DC Converter Board located in Card Cage Slot 5. The primary role of this board is to produce secondary voltages of 3.3, 5, ± 12 V, and filtered 28 V. The secondary voltages are used to power the Compact-PCI card cage and field devices. This board also provides voltage and current monitoring of the four 28 V input channels supplied by the CIR Facility.

Figure 8.—DC-DC Converter board.

One of the greatest challenges of designing this electronics package was creating the necessary internal interconnect wiring. Since the card cage occupies most of the available volume, a compact method of wiring is desirable. Also highly desirable is an interconnect that could be easily modified and documented for future changes to the experiment requirements. A large, flexible circuit board satisfies this need. This 14 layer board is completely passive containing only connectors and traces to maximize reliability. It allows the design to make full use of the Compact-PCI “User I/O” connections which are available on the back of the commercial backplane. As shown in figure 9, the flexible circuit board plugs into the back of the backplane and is flexed at a right angle to bring the connections to the baseplate. The two outside layers of the flexible circuit contain the higher current traces. Next are two ground plane layers. The middle layers contain the low current control and signal traces. The 269 contacts of the large ARINC 404 connectors are soldered directly to the flexible circuit board. To make this possible, it was necessary to procure custom PC board tail contacts for the ARINC 404 shell. These contacts replaced the standard crimp contacts. Figure 9 shows a model of the flexible circuit board and card cage. Figure 10 shows the flexible circuit board installed in the FEANICS PI Box.

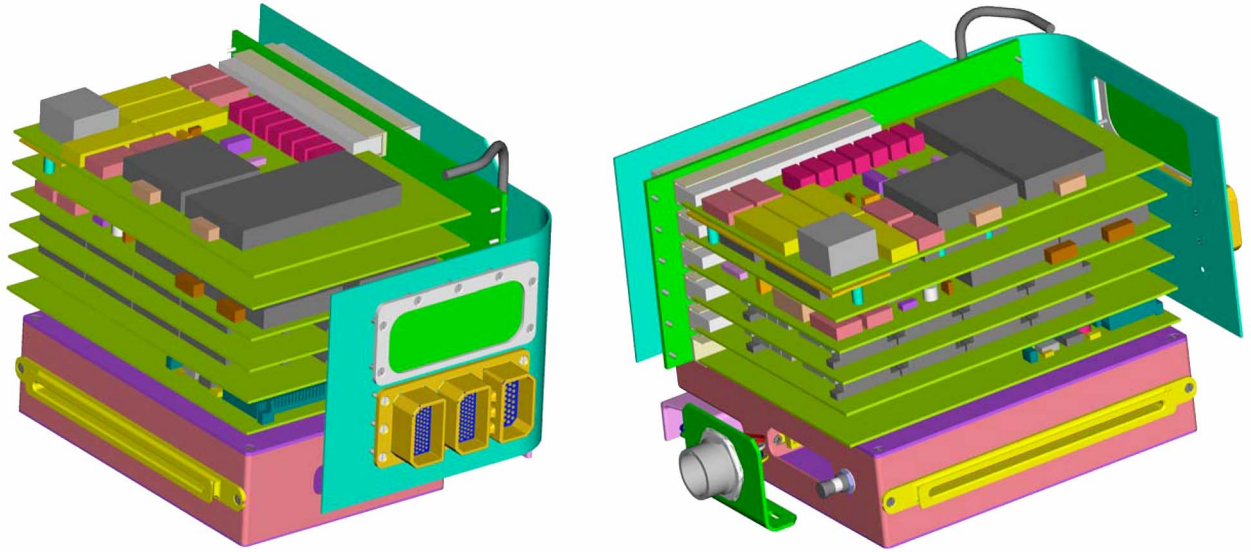


Figure 9.—FEANICS PI box electrical components assembly showing flexible circuit.



Figure 10.—View of PI box showing flexible circuit board.

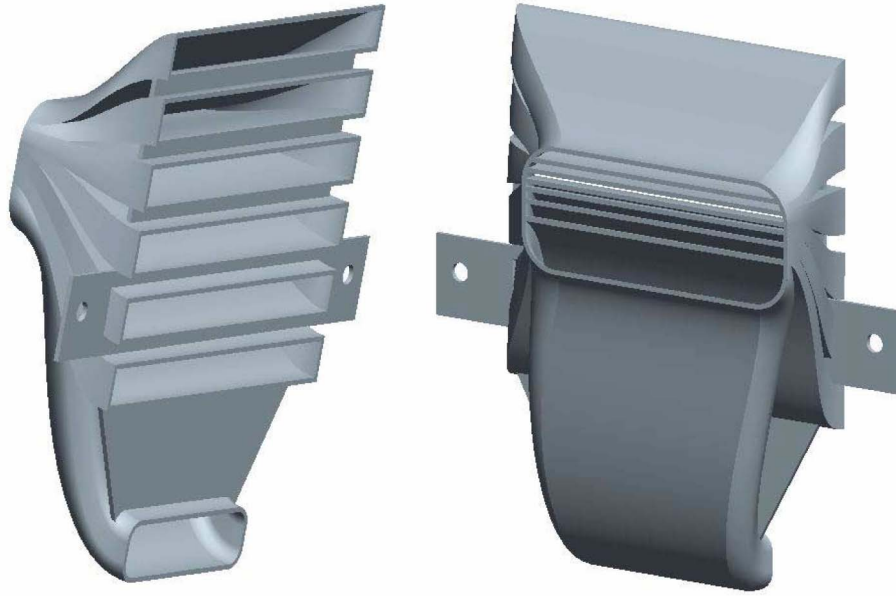


Figure 11.—Cooling air manifold.

Another area of concern during design of this package was the method of distributing cooling air within the enclosure. For this version of the hardware, a cooling air manifold was fabricated using stereo lithography rapid prototyping. This plastic manifold was installed in the baseplate to distribute cooling air to the six card cage slots and the 120VDC heater power conditioning box. During testing, a number of thermistors were installed to monitor the air temperature within the PI Box. The cooling air manifold is shown in figure 11.

Testing

The FEANICS PI Box was tested as part of stand-alone experiment hardware testing and with the CIR Engineering Development Unit. The testing was done throughout 2005 at NASA-Glenn Research Center.

Figure 12 shows the PI Box installed in the FEANICS Test Station which was developed to facilitate testing and troubleshooting of FEANICS experiment hardware and software. The FEANICS PI Box (1) was installed in the Test Stand (2). The Test Stand replicates the mechanical and electrical connections of the CIR Facility and simulates the forced-air cooling of the facility with an internal fan. The PI Box is connected to the FEANICS experiment hardware through the Test Box (5). The Test Box provides access to the approximately 300 electrical connections between the PI Box and the FEANICS experiment hardware for troubleshooting and signal measurement. A commercial DC Power Supply (4) powers the PI Box. The computer hardware on the Test Station provides communication with the processor board in the PI Box and loads the processor board with software to operate the experiment hardware. The FEANICS hardware is operated with a laptop computer (8) which issues commands to the PI Box.

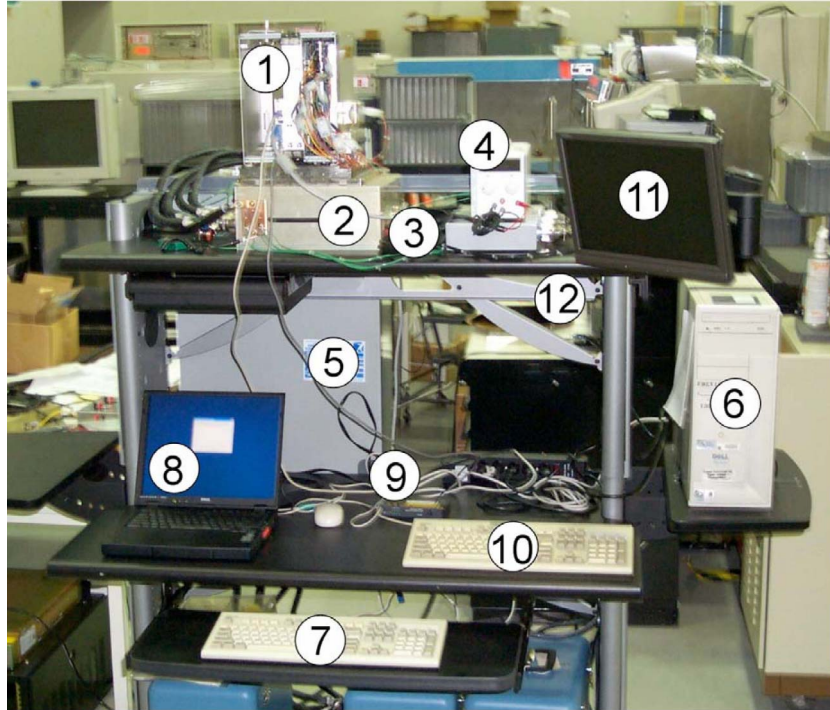


Figure 12.—FEANICS PI box test station.

1. PI Box
2. PI Box Test Stand
3. Test Stand Fan Power Supply
4. DC Power Supply (provides 28VDC to PI Box)
5. Test Box
6. Desktop PC
7. Desktop PC Keyboard
8. Laptop PC
9. Ethernet Hub
10. PI Box Processor Board Keyboard
11. LCD Monitor
12. Monitor A/B Switch

Figure 13 shows the FEANICS PI Box installed in the CIR Engineering Development Unit. During the summer of 2005, FEANICS/CIR integrated testing was performed to verify the functionality of the FEANICS hardware in the CIR facility. The FEANICS PI Box was operated for over 100 hr in the CIR Engineering Development Unit without thermal or electrical failure.



Figure 13.—PI box (highlighted) installed in cir engineering development unit.

Future Enhancements

As stated previously, this electronics package was built and tested to verify the fit and functionality of the original FEANICS PI Box design. During this time, some ideas for enhancements to the package were generated. While the flexible circuit was used for internal control and data connections, power connections were still done as point-to-point connections between card cage boards. Replacing the wire bundle with a power PC board, would continue the same modularity provided by the flexible circuit. All the power interconnect wiring is between the NASA designed boards in slots 4, 5, and 6 and the single bay ARINC connector in the baseplate. A three slot “power foreplane” could be located in front of the commercial Compact-PCI backplane to provide the required power connections. The NASA designed boards would plug into the power foreplane eliminating the point-to-point wiring between boards. The shape of the NASA designed boards would have to be changed to accommodate the power foreplane, but they are custom boards anyway and can be changed as needed.

Concluding Remarks

A Compact-PCI based electronics package for controlling space experiments was designed and tested as described in this report. A major goal of this project was to successfully test the package, the FEANICS PI Box, in the Combustion Integrated Rack (CIR) Engineering Development Unit by having the package operate the FEANICS experiment hardware. This was accomplished in the summer of 2005 when the PI Box was operated for over 100 hr without thermal or electrical failure. The use of innovative packaging methods combined with readily available COTS hardware can provide a modular electronics package which is easily modified for changing experiment requirements.

APPENDIX—FEANICS PI BOX COMMERCIAL PARTS MANUFACTURERS

Type of Part	Manufacturer	Website
Industry Pack Modules and Compact-PCI Carrier Boards	Acromag	www.acromag.com
Industry Pack Modules	SBS	www.sbs.com
Processor Board	Kontron	www.kontron.com
Card Cage Guides and Hardware	APW	www.apw.com
Compact-PCI Backplane	Bustronics	http://www.bustronic.com/cpci/cpci_overview.html
ARINC 404 Connectors	Radiall	www.radiall.com
PC Tail Contacts for ARINC 404 Connectors	Arizona Connector	http://www.azconnector.com/
Flexible Circuit Board Fabrication	Proto Circuit Inc.	http://www.protocircuit.com/
Compact-PCI Connectors	ERNI	http://www.erni.com/2mm-hard-metric-connectors.htd

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