

THE MESSENGER POWER DISTRIBUTION UNIT PACKAGING DESIGN

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Abstract

A Power Distribution Unit (PDU) is being developed by The Johns Hopkins University Applied Physics Laboratory for the **MESSENGER** (**M**ercury **S**urface, **S**pace **E**nvironment, **G**eochemistry, and **R**anging) spacecraft that will orbit the planet Mercury for one Earth year to complete the global mapping and the detailed characterization of the planet's exosphere, magnetosphere, surface, and interior. The PDU contains the circuitry for the spacecraft pyrotechnic firing control, power distribution switching, load current and voltage monitoring, fuses, external relay switching, reaction wheel relay selects, and power system relays. It also supports the Inertial Measurement Unit (IMU) reconfiguration, Integrated Electronic Module (IEM) select relays, solar array drives, propulsion thruster firing control, and propulsion latch valve control. To enable the mission to reach the distant planet, significant weight reduction for all spacecraft electronics must be achieved. This requirement has led to an advanced electronic packaging design that begins with component selection, printed wiring board design with very small feature sizes, and a compact interconnection scheme. The significant challenge in the packaging design of the PDU is how to implement state-of-the-art technologies to minimize system weight and meet the stringent reliability required by the MESSENGER power system. This paper will describe the detailed electronic packaging design of the PDU that, including the use of Metal Oxide Semiconductor Field Effect Transistor (MOSFET) devices instead of conventional mechanical relays, a high-density printed wiring board design with blind and buried

vias, and a modular packaging design to achieve significant weight reduction.

Introduction

A Power Distribution Unit (PDU) is being developed for the MESSENGER (Mercury Surface, Space Environment, Geochemistry, and Ranging) mission to flyby and orbit the planet Mercury [1-3]. The PDU design (Figure 1) consists of five power-switching boards, two 1553/analog telemetry boards, two command decoder/DC-DC converter boards, and one auxiliary board. It has an overall size of 23.4 x 22.6 x 23.9 cm and an estimated weight of 12.5 kg. In addition to the main function of providing the power switching for the MESSENGER spacecraft electronics and instruments, the PDU will collect telemetry data from the solar array, battery, and attitude and propulsion systems. This information will be sent to the Integrated Electronic Module (IEM) via the 1553 buses. Figure 2 illustrates the block diagram for the PDU.

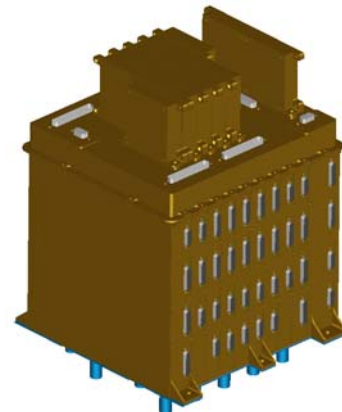


Figure 1: The MESSENGER PDU.

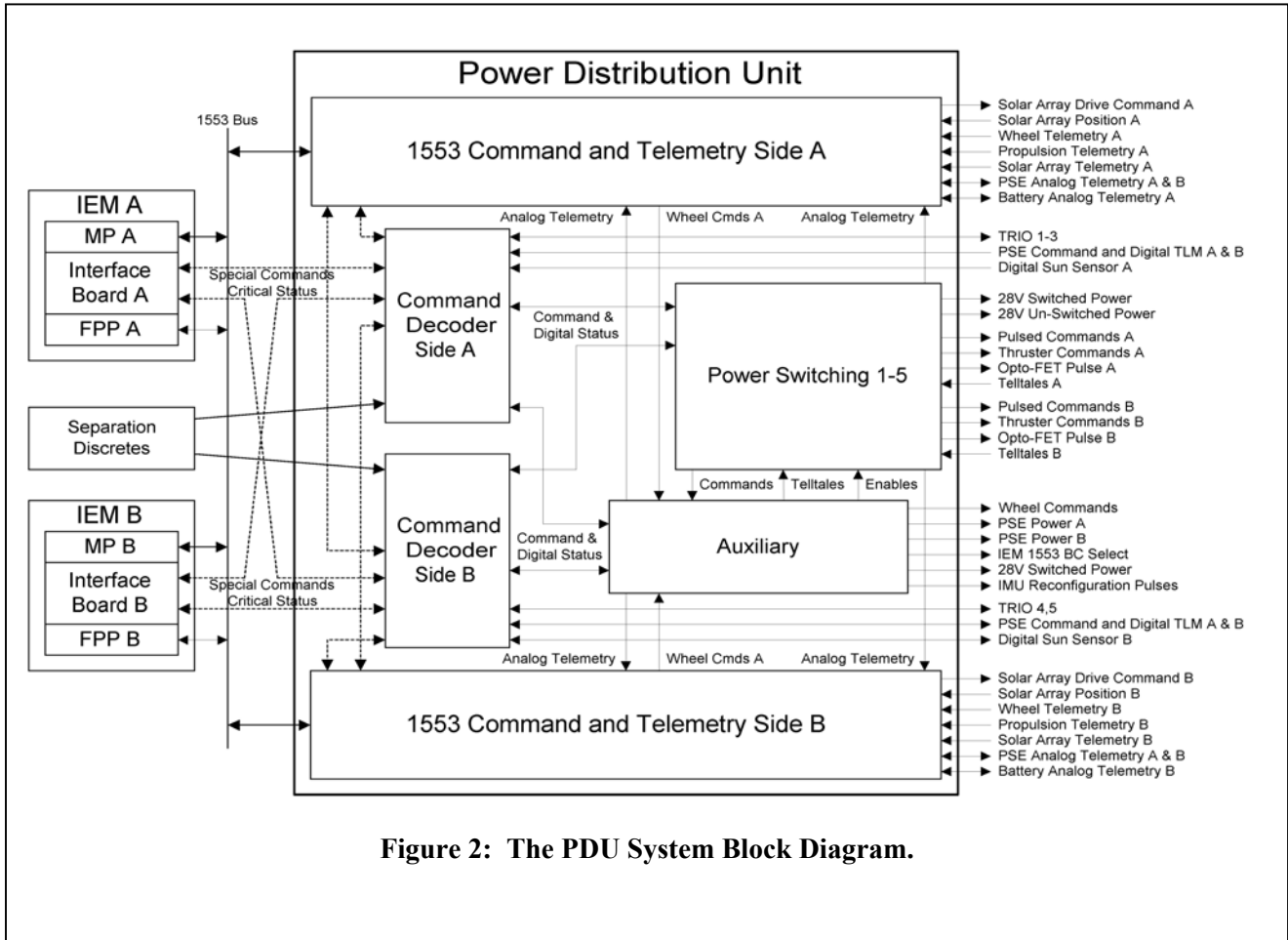


Figure 2: The PDU System Block Diagram.

The PDU Packaging Design

Modular Packaging Design

The PDU package employs a modular design where each circuit board is bolted to the chassis frame along three sides (Fig. 3). These attachment points provide the primary structural supports and thermal paths for the electronic assemblies. Additional staking material is also added along the edges of the boards with Scotchweld-2216 epoxy to ensure that resonance frequency of the electronic assemblies is above 150 Hz. The use of epoxy also enhances the thermal transfer between the circuit board and the chassis. A high resonance frequency at the board level will minimize solder joint stresses caused by board deflection during vibration. In cases where an additional thermal path is required

to reduce the maximum junction temperature of high-power devices, an integrated heat sink is added to the frame. Each electronic module (slice) plugs into the motherboard assembly located on top of the unit. The motherboard provides interconnections between the modules. It also provides interfaces for spacecraft umbilical, pyros, battery, and all fuse modules (Fig. 4). The modular design of the PDU provides the flexibility for future modification by simply replacing one or several of the modules.

Chassis Design

The chassis is of a lightweight design that uses magnesium alloy ZK60A-T5 with a nominal wall thickness of 1.5 mm. During the design process, detailed thermal and structural analyses were performed to ensure an optimized design. In addition, the frame for each module has an

interlocking capability to provide lateral support for the complete assembly.

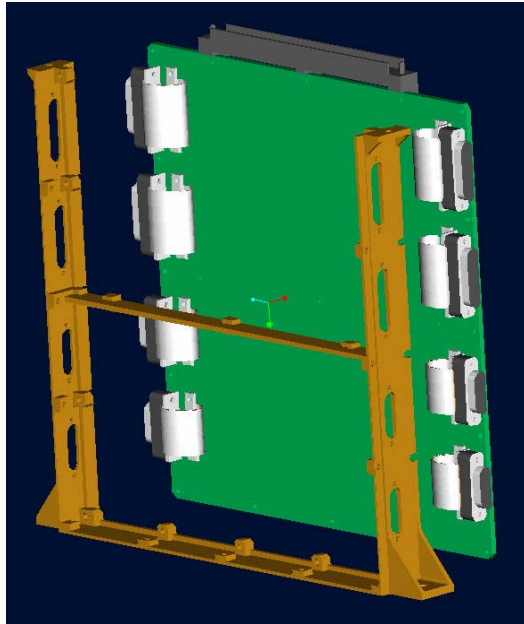


Figure 3: An Electronic Module in the PDU.

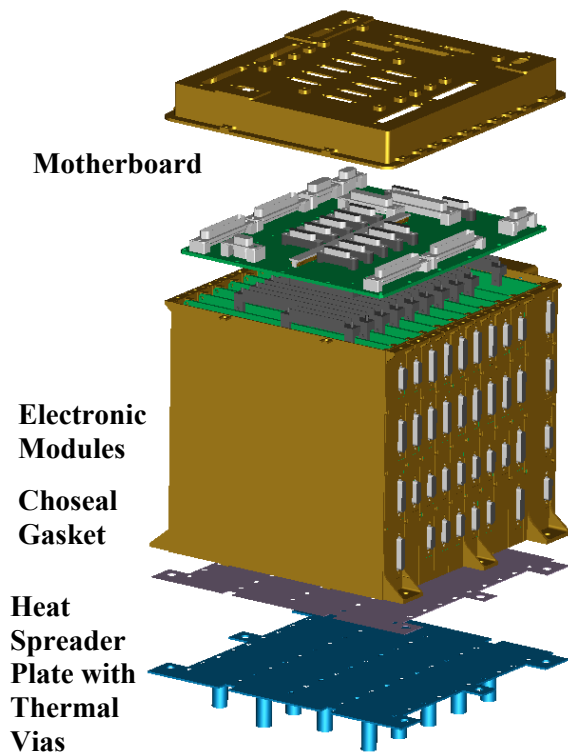


Figure 4: The PDU Modular Design.

Printed Circuit Board Design

To achieve a high-density packaging design, the electronic components are mounted on both sides of the boards (Fig. 5). The printed circuit boards in the PDU slice design have an overall dimension of 20 x 20 x 0.2 cm. They consist of 10-16 layers of interconnections with 127 x 127 μm line width and spacing for the signal lines. For the switching circuits, 2-oz copper planes and wider traces were used to accommodate the high current design. To minimize the magnetic field generated by the supplied current and return lines, cross strapping feature was included in the board layout to cancel out such effects. The board design uses polyimide with glass-reinforced material to minimize the thermal stresses caused by the high temperature of the soldering process that can reach 180°C. The material has a high glass-transition temperature (above 300°C) and a low coefficient of thermal expansion (CTE), which has a value of 12-16 ppm/°C in plane and 41 ppm/°C perpendicular to the plane of the board [4].

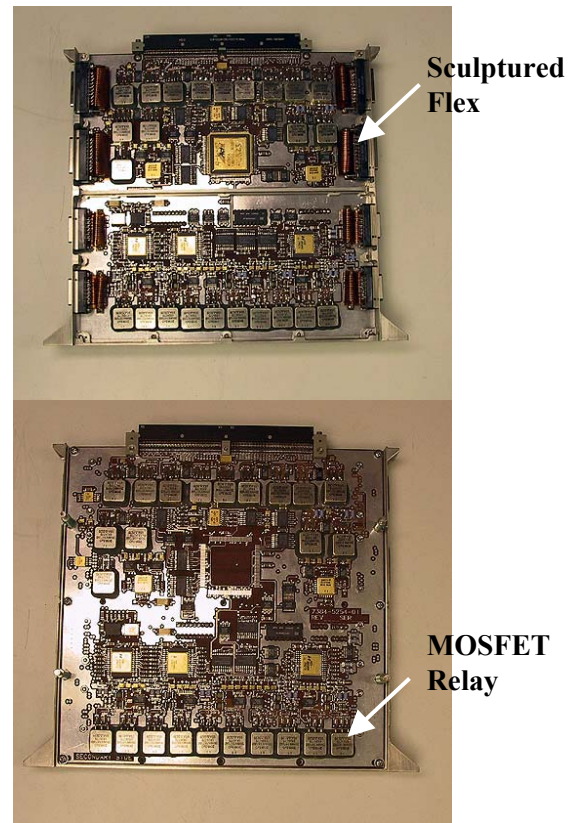


Figure 5: Photograph of the Power Switching Engineering Model Slice (front and back).

There are several technologies used in the PDU circuit board designs: sculptured-flex circuits, blind and buried vias, and CTE compliance for leadless ceramic chip components.

Sculptured-flex technology

Sculptured-flex circuits used in the power-switching circuit board design (Figs. 5 and 6) are based on proprietary process developed by the Advanced Circuit Technology Corporation. They provide high current capacity support for all switching circuits from the rigid multilayer boards to the micro-D connectors. The sculptured-flex circuit technology permits the use of much thicker copper material, up to 0.6 mm. The advantage of the sculptured circuit is that the circuitry can include built-in terminations, allowing the exposed pins be soldered directly to the board.

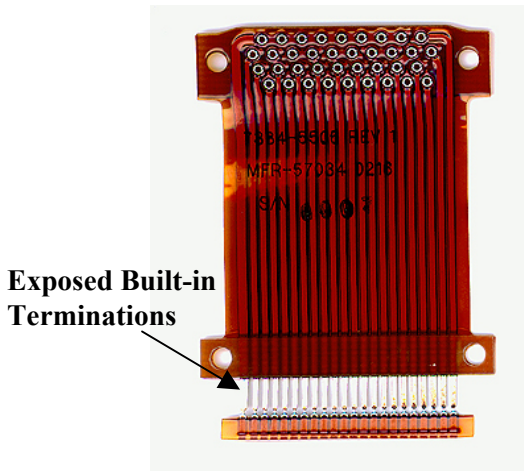


Figure 6: Photograph of a Sculptured Flex Circuit Board.

Blind Via and Buried Via Technology

Blind and buried vias are used in several circuit board designs in the PDU. They provide the interconnections between layers without occupying the real estate area on the other side of the circuit board (Fig. 7). This design feature accommodates higher component population per unit area to support miniaturization. In the PDU circuit board design, the aspect ratio of the drilled via size versus the depth of the blind vias has been carefully selected to ensure a reliable copper plating process.

Le et al. [5] reported that blind and buried vias with an aspect ratio of 1 or less performed well in harsh environments.

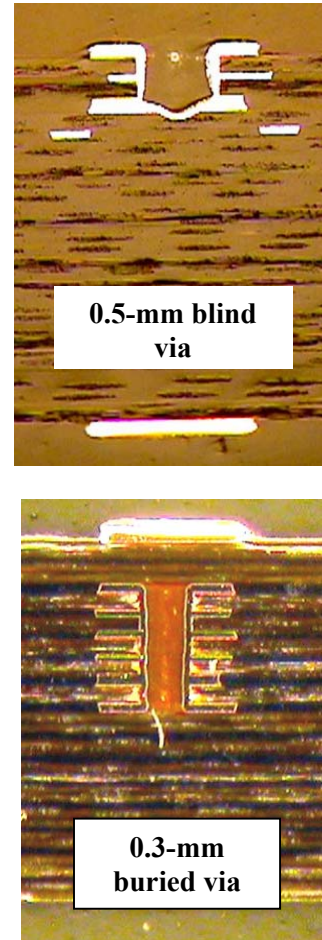


Figure 7: Photograph of a Microsection of the Power Switching Circuit Board with Blind and Buried Vias.

Leadless Ceramic Chip Component

The 100V, 4P-channel radiation-hardened power MOSFET from International Rectifier, a 28-pin leadless ceramic chip component (LCCC), is being used in the power switching circuit boards. Use this device raised an initial concern about the CTE mismatch between the circuit board and the component. Careful investigation of circuit board materials and the device modification were carried out early in the development of the PDU design. The use of polyimide/thermount with matching

CTE and NAS-compliant pins were baselined to accommodate this device in the PDU design.

The polyimide/thermount (Arlon RT85) is a non-woven aramid reinforcement in polyimide resin used in printed circuit board development for CTE mismatch control [6]. The laminate material

without copper has a CTE in the range of 7-9 ppm/°C. This value will change with the copper and the resin contents (Fig. 8). Measurement of the actual power switching board with 16 layers of copper yields a CTE value of approximately 12 ppm/°C.

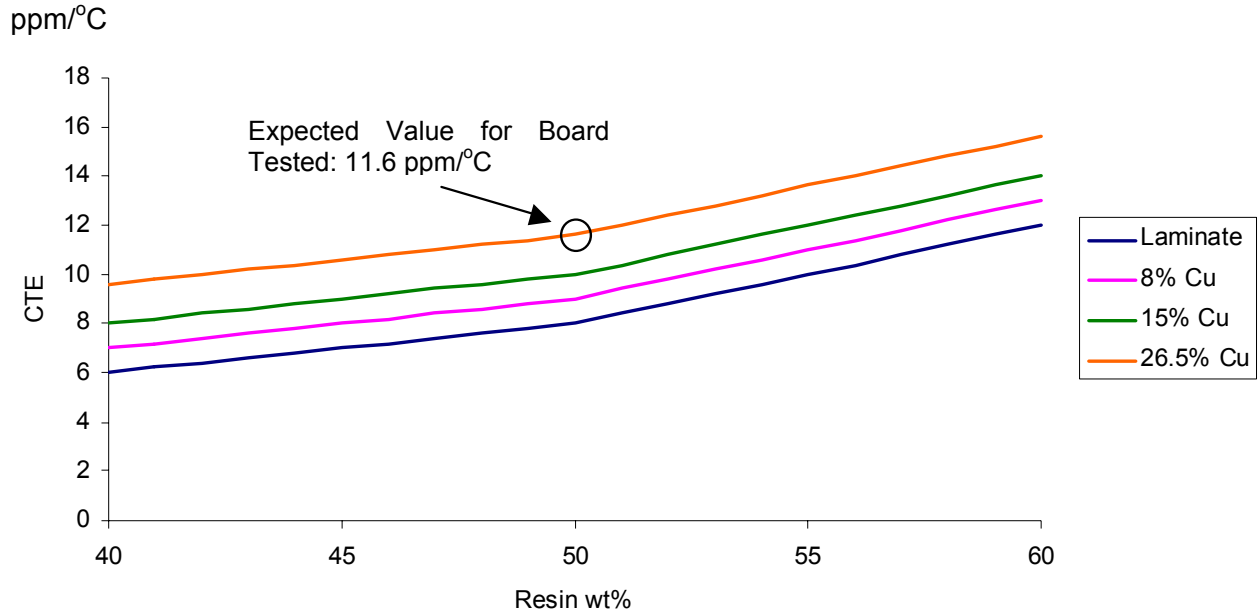


Figure 8: CTE of Polyimide/Thermount Printed Circuit Board.

The NAS/Interplex compliant pin, part number of CC17AA-S00W, has an S-shape that can be added to existing LCCC devices with high-temperature material (Sn₉₆ Ag₄). This eutectic solder material has a melting temperature of 221°C that is higher than the standard Sn₆₂ Pb₃₆ Ag₂ (179°C) used in the assembly of the PDU electronic modules. The S-shaped pins provide thermal strain relief for the solder joints during temperature fluctuations.

An accelerated life test is being performed on polyimide/thermount boards with LCCC devices and on polyimide/glass boards with compliant pins

added to the LCCC devices. Early results indicate that both design configurations met the lifetime requirement for the MESSENGER spacecraft. We selected the compliant pin for the final PDU design because of some difficulties found during the manufacturing of circuit boards with polyimide/thermount material. The problem is due to the low resin content of the prepreg material and the heavy copper thickness (2 oz) in the power switching design. Figure 9 shows voids found in a polyimide/thermount board during microsection examination.

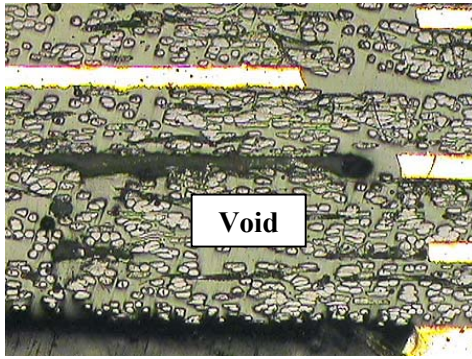


Figure 9: Void Found in the Polyimide/Thermount Power Switching Circuit Board.

Structural and Thermal Design

The structural decks of the MESSENGER spacecraft are composite panels with Graphite/Cyanate Ester laminate material. This material has a lower CTE value than that of the magnesium PDU chassis. The differences in the CTEs can introduce excessive stresses at the mounting inserts during temperature fluctuations. To avoid this problem, slip joints are used for mounting the PDU to the spacecraft deck. The slip joint design consists of four washers with NEDOX SF2 coating at each mounting foot of the box. NEDOX is a proprietary polymer-infusion-surface enhancement process developed by General Magnaplate Corporation [7]. The material has been accepted by NASA and has been used in several space programs to increase corrosion/abrasion resistance and lubricity in harsh environments. It is electrically conductive and can withstand a wide range of temperatures, including cryogenic environments. The typical thickness of the coatings is approximately 10 μm . Proper torque will ensure that the unit will shift only when there is a significant change in temperature and not during vibration.

An overarching goal in the structural design of the PDU has been to develop, wherever possible, the lightest structure to meet the launch and mission requirements. The structure design of the PDU is governed by the stiffness design. A detailed NASTRAN finite element analysis with a model

having approximately 13,000 elements was developed during the conceptual design phase of the PDU to optimize chassis design. With this analysis guide, the PDU structure was able to make use of magnesium alloy ZK60A-T5. The PDU design was analyzed for strength and stiffness in the launch environment (Table 1). A strength analysis was performed based on the specified quasi-static load of 25 g's in each of the three mutually orthogonal axes of the instrument. A normal-mode analysis was also performed on the PDU in order to verify that the natural frequencies of the instrument do not couple with the launch vehicle dynamics. The first resonance frequency of the PDU is 102 Hz and corresponds to rocking motion of the chassis. All printed circuit boards have first resonance modes above 200 Hz (Fig. 10).

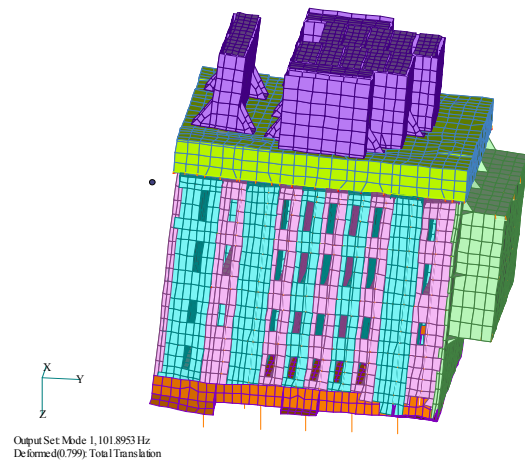


Figure 10: PDU First Resonance Mode Shape.

Table 1: Random Vibration Environment.

Frequency (Hz)	Normal to Mounting Plane	In Plane
20	0.0063 g^2/Hz	0.0031 g^2/Hz
20-80	+6 dB/Oct	+6 dB/Oct
80-800	0.1 g^2/Hz	0.05 g^2/Hz
800-2000	-9 dB/Oct	-9 dB/Oct
2000	0.0065 g^2/Hz	0.0032 g^2/Hz

In addition to minimizing weight and complexity, a design goal for the thermal control system was to maintain the PDU electronics to within their de-rated operating temperatures. The PDU thermal control has a passive thermal conduction design where each electronic module has an independent thermal path to the heat sink. The PDU is designed to operate with a base plate temperature that varies from -34°C to $+65^{\circ}\text{C}$. It dissipates 26 W in the worst-case condition. Except for the command decoder/DC-DC converter board, all PDU circuit boards rely on internal copper layers to transfer heat generated from the electronic components to the heat sink. The command decoder/DC-DC converter board requires an additional 1-mm-thick magnesium heat sink integrated into the chassis design. To enhance the thermal transfer between the slices and the heat spreader, a layer of Choseal 1285, 0.5-mm-thick gasket [8], is added between the electronic modules and the heat spreader (Fig. 4). The heat spreader also has thermal vias that connect the chassis to the spacecraft heat pipes located beneath the structural decks. Figure 11 illustrates the interface between the PDU and the spacecraft thermal control using heat pipes. Figure 12 provides temperature profiles of the PDU circuit boards predicted by COSMOS finite element analysis.

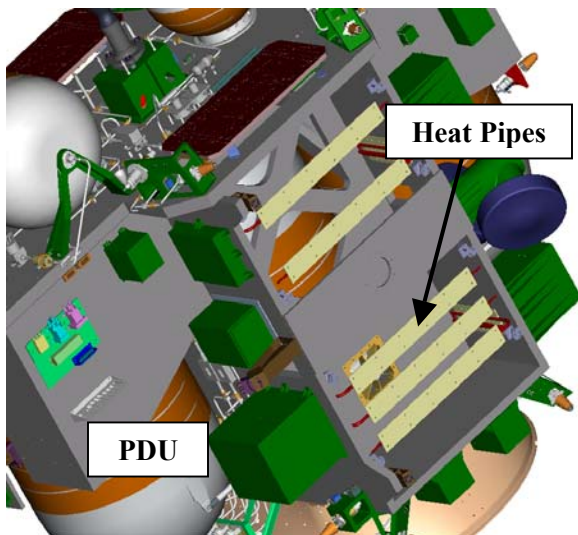


Figure 11: Thermal Interface between the PDU and Spacecraft Heat Pipes.

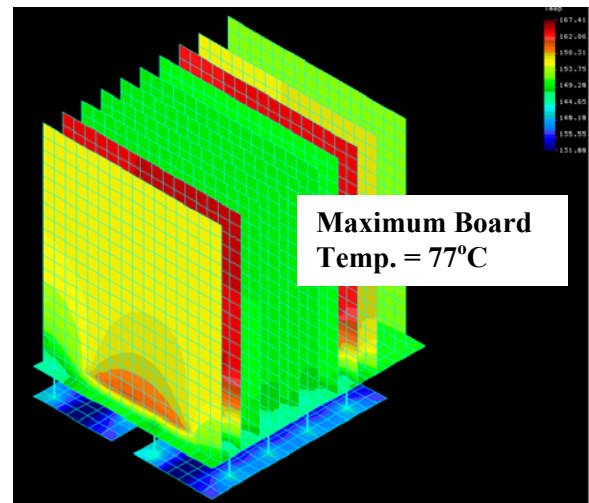


Figure 12: Predicted Temperature Distribution of the PDU Electronic Modules.

Summary

The PDU design for the MESSENGER power system is a very challenging task. It requires careful selection and implementation of miniaturization technologies in the printed circuit board and in the chassis designs to eliminate any potential risk to the program while achieving lightweight electronic packaging design. The design is progressing for launch in March 2004.

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