DESIGN AND DEVELOPMENT OF A STANDARDIZED ELECTRONICS BOX

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The Naval Research Laboratory (NRL), in conjunction with the McDonnell Douglas Astronautics Company (MDAC), has developed a standardized electronics box that provides a simple, cost-effective structure to house various digital and analog electronic circuitry. The standard electronics box design adheres to the Lightsat principles of simple and inexpensive articles which can reliably perform various missions. This standard electronics housing design reduces repetitive design and testing costs; specifically, shock and vibration qualification testing, venting, fracture, and thermal analyses, and mass properties determination. The simple box design allows for ease of manufacture and a direct path for conductive thermal dissipation, and flexibility to handle various electronic applications. Reliability was achieved by designing the standard box to survive the repeated pressure cycling of multiple shuttle missions. While the standard housing is not a 'cure-all' design used for all purposes, it has worked well for many applications. Actual usage experience has enabled NRL to identify areas for future modifications using either contemporary or state-of-the-art technologies.
INTRODUCTION

In the past, design and fabrication of electronics boxes have been tedious, costly, and time consuming. Each box was custom designed to house the circuitry needed for a specific application, resulting in large design and production costs. In the future, technological advances will allow electronics to perform more functions in satellite operations, increasing the cost and production time.

The NRL has dealt with this problem by developing a standard electronics box. The standard box was designed to be:

1) flexible by handling both digital and analog circuitry
2) economical by reducing fabrication and analysis costs
3) reliable by surviving multiple missions if required
4) adaptable by quick fabrication to meet unforeseen requirements

Perhaps the best advantage of the standard housing design is the saving of repetitive costs associated with custom boxes. Only while developing the prototype do shock and vibration qualification tests, venting and fracture analysis, and thermal dissipation modelling need to be performed. With a standard box, mass properties can be generated sooner and with more confidence than with custom housing designs.

Flexibility required providing a suitable housing for mounting circuit cards for various electronic applications, even though the cards' components varied in height. Simplicity required creating a single standard design which allowed the largest opportunity for flexibility. The solution was to establish a standard spacing for circuit cards with average sized components, based on precluding mechanical interference during vibration and shock environments. The spacing established was .55 in. and was achieved by designing slots to insert the cards at this standard separation in the sides of the box. By fabricating boxes with differing numbers of card slots, and creating the ability to combine these boxes, enough space could be created in one box to house all the cards required.
for a specific application. Furthermore, room for cards with large components, such as relays or transformers, could be created by skipping slots. Simplicity was further enhanced by stipulating that all fasteners used in assembly were to be of the same type and dimension. Also, a consistent spacing between fasteners that attach the box to the satellite was incorporated irrespective of box length to enable ease of installation.

The NRL defines a circuit card as an assembly of these components:

1) the printed wiring board
2) the electronic components mounted to it
3) a metal backing plate, usually .062 aluminum, used as a thermally conductive plane
4) a wedge-lock mechanism that secures the circuit card assembly in its slot

CONFIGURATION

The standard housing developed at the NRL, shown in Figures 1-5, is made from 6061-T651 aluminum. It consists of two slotted side panels, two end panels, a top and bottom cover plate, and a venting assembly. The two slotted sides are made in 3-foot lengths and cut to provide the number of slots needed for a specific application. The top covers are sheared from 0.060 inch thick aluminum sheet stock, and the holes for the screws and connectors are punched. These are the only parts that vary in length depending upon the size needed. The end panels are milled and can be made with or without the vent aperture. The vent option was created to minimize fatigue stress associated with the repetitive differential pressures of multiple shuttle missions, and to prevent ingestion of foreign particles on descent. Venting is not used on these boxes for non-reusable, single-ascent applications. The vent itself is screened and baffled to reduce RF interference and lined with PVC foam as a filter for contaminants. All housing parts are assembled using only #4 NAS-1352 self-locking screws. The box is configured so the "mother-board" circuit card lies underneath and parallel to the top cover plate. The "daughter-board" circuit cards are inserted into the slots in the sides of the box from underneath, and plugged into connectors on the bottom of the mother-board. The cards are supported on silicone rubber pads that are glued to the inside of the bottom plate. These pads
provide vibrational damping to the daughter-boards’ bottom edge. Wedge-locks, inserted between the slots and the daughter-board sides, preload the circuit card in the slots providing positioning and a thermal bond. The box input/output connectors are mounted to the mother-board on stand-offs and project through the top cover. The stand-offs prevent external axial harness loads from loading solder joints, while the cover reacts external lateral loads. Locating the input/output connectors on the box top allows dense packaging of the boxes while providing good connector mating access.

PROTOTYPE TESTING

A prototype box was assembled and tested to determine whether it would withstand qualification level launch environments, and to define a worst-case environment for the electronic components inside. Random vibration, thermal-vacuum, and internal pressure tests were conducted to meet these ends. Random vibration levels measured during system level acoustic testing were compared to the individual box base input level to determine adequacy. The acoustic levels tested to are given in Figure 6.

The prototype housing was a six-slot box with five cards mounted in it. Three of these circuit cards had 10 watt power resistors attached to them. The other two cards had 1 watt resistors. A 1/2-inch hole was drilled in the top and bottom covers to allow the passage of internal transducer wires. Ten accelerometers were placed on the test box: one on each of the five circuit boards, two on the motherboard, and a triaxial accelerometer on the box side containing the vent (Figure 7). The devices used as edge supports were Calmark card locks, a wedging mechanism that secures the cards in the slots the same way bicycle handlebars do in frames (see Figures 4&5). Each card lock tightening screw was torqued to 6 in-lbs.

TEST RESULTS

The random vibration test was carried out in three axes using the spectrum shown in Figure 8, each axis being tested for two minutes. The maximum acceleration experienced by any card in the box was 135g’s at 330 Hz in the direction perpendicular to the circuit card face, however, the data was not repeatable in two later tests. Since the test box was identical for each test, it was concluded that the discrepancy came from the circuit card edge supports providing an inconsistent degree of fixity.
For the thermal-vacuum test, thermo-couples were attached to the two center cards. One card was inserted with thermal grease as a medium between the card and the box. The other was inserted without grease. The NRL designed the box to use conductance to the mounting surface as its sole heat release into the satellite. To eliminate radiant coupling for the test, the box was covered in a thermal blanket and mounted to a temperature controlled baseplate in a vacuum chamber. The chamber subjected the box to 10⁻⁵ Torr, and baseplate temperatures of -20 C, 10 C, and 60 C. The box power was set at 9.6W, 19.2W, and 32W for each baseplate temperature. Most of the tests were performed without the use of thermal grease as a conducting enhancement at the box/baseplate interface since the box was meant to perform as specified without its use. However, for the highest settings, 32W at 60C, the interface of the box with the baseplate was varied to determine the amount of difference thermal grease, and the number of mounting bolts, made in conductance. The results are displayed in Figure 9.

**FIGURE 9**

<table>
<thead>
<tr>
<th>Baseplate Temperature = 60°C</th>
<th>Box Power = 32W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Mounting Condition</strong></td>
<td><strong>Card Temp., Greased</strong></td>
</tr>
<tr>
<td>8 bolts, Greased</td>
<td>86</td>
</tr>
<tr>
<td>8 bolts, No Grease</td>
<td>89</td>
</tr>
<tr>
<td>4 bolts, Greased</td>
<td>87</td>
</tr>
<tr>
<td>4 bolts, No Grease</td>
<td>92</td>
</tr>
</tbody>
</table>

As expected, the combination of thermal grease and maximum bolt count provided the best conductance, while the poorest performance was provided by no grease and minimum bolt count. However, the difference between the extremes was insufficient to warrant the extra effort to use the grease. To model each box thermally for future use without having to test it, a relationship that defined the maximum card temperature given the baseplate temperature, the total card power, and the total box power was developed. This relationship is expressed in Figure 10 and in equation form below:

\[ T_c = T_p + Q_c/G_{cb} + Q_b/G_{bp} \]
Where:

\[ T_c = \text{Center temperature of card} \]
\[ T_p = \text{Temperature of baseplate} \]
\[ Q_c = \text{Total card power} \]
\[ Q_b = \text{Total box power} \]
\[ G_{cp} = \text{Conductance between card center and box side} \]
\[ G_{bp} = \text{Conductance between box side and baseplate} \]

The values for \( G \) depend on the type of interface and the distance that the heat must travel. Also, since \( G_{bp} \) is affected by the box size, it is necessary to know the length of a side in inches. The values for \( G_{cb} \) and \( G_{bp/\text{in.}} \) are presented in Figure 11.

**FIGURE 11**

<table>
<thead>
<tr>
<th>Card/Box Interface</th>
<th>No. of Samples</th>
<th>( G_{cb} , \text{W/}^\circ\text{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Grease</td>
<td>16</td>
<td>0.480 ± 0.027</td>
</tr>
<tr>
<td>No Grease</td>
<td>16</td>
<td>0.282 ± 0.022</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Box/Plate Interface</th>
<th>No. of Samples</th>
<th>( G_{bp/\text{in.}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Bolts, Greased</td>
<td>3</td>
<td>1.06 ± 0.042</td>
</tr>
<tr>
<td>8 Bolts, No Grease</td>
<td>9</td>
<td>0.582 ± 0.038</td>
</tr>
<tr>
<td>4 Bolts, Greased</td>
<td>1</td>
<td>0.828</td>
</tr>
<tr>
<td>4 Bolts, No Grease</td>
<td>3</td>
<td>0.552 ± 0.095</td>
</tr>
</tbody>
</table>

The internal pressure test was designed to simulate a failure of the box's venting option. The approach was to show that the box could structurally survive more than twice the maximum operational differential pressure of 14.7 psi. For this test, the internal transducers were no longer needed, therefore, the top and bottom plates with 1/2 inch holes were replaced with un-cut plates. The box was pressurized through an air fitting attached to a hole drilled into one of the slotted sides. The results of the test showed that a pressurization of as much as 30 psig created a maximum deflection of only .038 in. The strength of this six-slot test box at twice the differential pressure seen during launch implies that the design would survive the repeated compression and decompression of a multi-launch lifespan with a venting failure.
With testing it was determined that the box would perform the function for which it was designed, but it was left to determine whether it was financially beneficial to produce. It is difficult to do an itemized cost comparison between a standard box and one that is custom built, because of the variety of custom box designs, costs, and methods to produce them. However, by looking broadly at the entire spectrum of tasks necessary to create, fabricate, and prepare a box for flight, the value of the standard box’s design becomes apparent. In terms of machining, depending on the design of the custom box, the standard box may be more expensive. However, a larger quantity of the same standard design will be produced, allowing these designs to be stored for repetitive input in a N.C. milling machine, driving production price down. Manufacturing of many articles of the same design yields a lesser price per article. Even more money can be saved in updating the drawings of successive standard boxes by using a CAD system. The drawings for a certain size box are called up and modified to handle the new connectors and their placement on the top plate, as opposed to developing an entire set of drawings for each part of a custom box. The main advantage of the standard box design is the savings of non-recurring costs that are recurring for a custom design. In terms of testing, if it is known that a specific box qualifies for a given launch vehicle, only acceptance testing may be needed for future boxes. Integration activities are also reduced, because by knowing the amount of slots needed, the weight of the box can be determined to a fair degree of accuracy, (see Figure 12) and an accurate footprint obtained for component placement earlier in the project.

Now that the NRL has put the standard box to use, the "bugs" are being discovered and a list of desirable modifications is being developed. Some of them are listed below:

1. Since RF, analog, and digital electronics have such differing size, power, and dissipation requirements, separate standard boxes should be created for each category.
2. The NRL's standard box was designed for a mission where size and weight were not at a high premium. For future uses this may not be the case, therefore optimization of thermal conductance, weight reduction and volume should be considered.

3. For large scale production, the slotted sides of the box can be made by casting, reducing cost further.

4. Removal of separate circuit boards after integration with the satellite involves detaching the box because the cards must be extracted from the bottom. Future boxes should provide the ability to retrieve cards from the top, without detachment from the spacecraft.

5. There were times when the design could not be used due to height requirements. Perhaps boxes that use 3X7 instead of 5X7 cards can be developed to supplement the choices with boxes that aren't as tall.

6. In an effort to reduce the weight of the box and tailor the thermal conductive paths, metal matrix composites could be implemented.

CONCLUSION

The NRL understands that it is impossible to develop a cure-all standard electronics box. However, it is desirable to have a design on hand to start with while creating an electronics box. Every standard box used is money and time saved by not having to start from scratch.
ACKNOWLEDGEMENTS

Thanks is given to the engineers of NRL and McDonnell-Douglas who provided advice and insight into this paper, especially: H. Edward Senasack, Jr., Mark Wilkins, Daniel Clark, Paul Van Horn, Bernard Ryon, Leon Zakian, Denis R. Mahony, Thomas R. Mc Birney, Ralph E. Ruth, George L. Bernard, and Michael Brown.
FIGURE 1
OVERVIEW - NRL STD. HOUSING
FIGURE 6

ACCEPTANCE ACOUSTIC ENVIRONMENT
FIGURE 7
ACCELEROMETER PLACEMENT
FIGURE 8
DESIGN AND QUALIFICATION TEST LEVEL

random vibration

Frequency (Hz)  Level
20   0.05  G²/Hz
20-80  +6  dB/octave
80-280  0.8  G²/Hz
280-2000  -8  dB/octave
2000  0.0043  G²/Hz

G_{RMS} = 17.6
Duration = 120 Seconds/Axis
3 Mutually Perpendicular Axes
STANDARD BOX THERMAL RESPONSE

FIGURE 10
FIGURE 12

NRL Standard Box
Weight Chart