CONSTRUCTION OF THE GAMCIT GAMMA-RAY BURST DETECTOR (G-056)

Michael H. Coward, John M. Grunsfeld*, Benjamin J. McCall, Albert Ratner
California Institute of Technology, Pasadena, California 91125

ABSTRACT

The GAMCIT (Gamma-ray Astrophysics Mission, California Institute of Technology) payload is a Get-Away-Special payload designed to search for high-energy gamma-ray bursts and any associated optical transients. This paper presents details on the development and construction of the GAMCIT payload.

In addition, this paper will reflect upon the unique challenges involved in bringing the payload close to completion, as the project has been designed, constructed, and managed entirely by undergraduate members of the Caltech SEDS (Students for the Exploration and Development of Space). Our experience will definitely be valuable to other student groups interested in undertaking a challenge such as a Get-Away-Special payload.

SCIENTIFIC MOTIVATION

The first report of gamma-ray bursts (GRBs) occurred in 1973 from earth orbiting satellites. GRBs are highly energetic events that are characterized by a rapid increase in the observed gamma-ray flux, at energies from tens of keV to several MeV's. The decline of such events may be a simple exponential or quite complex non-linear decay. Three gamma-ray bursts observed by the BATSE detector on the Compton Gamma Ray Observatory are depicted in Figure 1. [2]

It soon became evident that gamma-ray bursts represent one of the most energetic and violent events in the observable universe. Ever since the first detection of these phenomena, many experiments, including the BATSE experiment, have been designed to monitor them, yet their origin is still one of the great enigmas of modern astrophysics. The BATSE observations have yielded important data on the possible location of these events. By determining the coarse location of these bursts, BATSE researchers have observed an isotropic distribution of GRBs. Furthermore, from studies of the intensities of the bursts, researchers have deduced that the bursts are not distributed homogeneously, but have a definite boundary. [3] The distribution of a sample of gamma-ray bursts, observed by BATSE and showing their isotropy, is shown in Figure 2. These facts indicate that the bursts are either local to the solar system, distributed in a large halo around the galaxy, or at cosmological distances. One theory suggests that the neutron stars in binary systems are the cause. In this scenario, a normal companion star transfers material into an extremely strong gravitational potential well near the neutron star. The energy gained by this matter is converted into gamma-rays near the surface of the neutron star producing a gamma-ray burst. Other models predict that comets, or other material is accreted by an isolated neutron star or black hole producing a GRB. An interesting prediction of the former theory is that as the gamma-rays strike the atmosphere of the

---

* NASA Johnson Space Center, Houston TX 77058

companion star, some of the gamma-ray energy may be converted to visible light. If these theories are correct, then a GRB may be accompanied by an optical transient. [4]

OVERALL SYSTEM DESIGN

GAMCIT uses two standard NaI(Tl) scintillation gamma-ray detectors, combined with a 35mm film camera and film sensitive to visible light. GAMCIT is the first experiment to search for gamma-ray bursts and their associated optical transients truly simultaneously. An on-board computer triggers the camera when a burst is detected by the scintillators.

During the system design, the GAMCIT team decided to store the energy and arrival time for every gamma ray photon incident on the detectors during the mission. Most experiments to date have either stored the photon data only during gamma-ray bursts, or by the data into time and energy bins. Storing every incident photon does dramatically increase the amount of on board storage required by the payload, but it reduces the complexity of the hardware and software, and opens up the possibility of doing significant advanced post-flight data analysis.

STRUCTURAL DESIGN

The three major structural components of the GAMCIT experiment are the user lid, the main supporting structure, and the battery enclosure. The GAS lid is the attachment interface between the can and the NASA mounting plate. Since we are using a Motorized Door Assembly (MDA), a major task was designing a space facing pressure vessel lid. The concerns that were dealt with during the design process were structural integrity, thermal insulation, and maximization of gamma-ray penetration.

These concerns were dealt with using a User Designed Mounting Disc (UDMD). The UDMD was machined out of a solid acrylic disc 53 cm in diameter and has three circular cutouts for the two photo-multiplier tubes and the quartz window for the camera. In addition, it has three small holes for mounting three vacuum rated electrical feedthroughs to carry signals and power to the top of the lid. One of the challenges of the structural design was to ensure that the lid would not leak despite the components mounted in it. To achieve this goal, each component mounted in the lid had an O-ring seal. An example of these O-ring seals can be seen in figure 3.

To thermally isolate the UDMD from the Experiment Mounting Plate provided by NASA, an Experiment Thermal Isolation (ETI) consisting of an acrylic ring 50 cm in diameter and 3.2 cm in thickness was used. To further reduce the thermal conductivity between the mounting plate and the UDMD, titanium bolts were used instead of traditional steel bolts to connect the EMP, ETI, and UDMD because of their lower thermal conductivity. Figures 4 and 5 provide two views of the EMP, ETI and UDMD.

The main supporting structure is composed of three aluminum sheets which divide the GAS compartment into three pieces. The three sheets meet in the center and run along the length of the can. The sheets fit into machined slots on the UDMD and another acrylic disk on the bottom of the can. The UDMD and bottom disk are attached together by 10 rods that run the length of the can.

The battery enclosure is one of the more unusual aspects of the GAMCIT payload. In order to maximize the space available for the experiment hardware, a Tubular Battery Enclosure (TBE) was designed. Instead of the traditional battery box, the TBE consists of 21 PVC tubes, each of which holds 10 batteries. In flight configuration, only 19 of these tubes are filled due to weight considerations, but all of the tubes are identical. Each tube has a copper disk on the top and bottom, with a spring on one end, leading to a "flashlight" type of system. Figure 6 provides a view of the TBE.

DETECTOR DESIGN

The GAMCIT detector system is composed of two major subsystems: the gamma-ray detector system and the optical transient detection system. The gamma-ray detector is composed of two NaI(Tl) scintillator crystals, 13 cm in diameter, and 2.5 cm in thickness. Each crystal is coupled to a 10 stage 13 cm photo-multiplier tube (PMT). The PMTs collect the photons emitted by the crystals and convert them into an amplified electrical signal. Because of the protective aluminum shell around the crystal, the lowest energy gamma-ray photons that can be detected is about 50 keV. To extend the range down into the hard x-ray region, two experimental avalanche photo-diodes provided by Dr. Desai of Goddard Space Flight Center will be flown. [4]

The other major system is the optical camera system. The system is comprised of a professional 35mm film camera with a 250 exposure data back. The lens system is a standard 50mm f/1.2 lens available from the camera manufacturer. Since the image is to photographed at infinity, and the depth of field is unimportant, the lens may be stopped down to the lowest setting (f/1.2). The focus ring, however, must be fixed so that vibrational stress does not cause the camera to de-focus. The data back holds 250 exposures, and each burst triggers the camera for five exposures, giving us enough film for 50 bursts. This is an over-estimate of the number of real bursts that are statistically expected, however, false triggerings may significantly increase this number.

The film used is a standard ASA 3200 film which will be pushed during processing to ASA 50000. With our optical system, we can expect to see up to seventh magnitude astronomical objects.

ELECTRONICS DESIGN

The core of the electronics is an embedded 486 single board CPU. Although the team considered building a custom microcontroller board for the experiment, the use of a standard board allowed for more rapid prototyping and development of the controller. This controller is responsible for all instrument control, data handling and system maintenance functions. Figure 6 shows a block diagram for the payload.

The primary function of the controller is to identify and record a gamma-ray burst. This is accomplished by having the output current from the PMT pass through the amplification and detection electronics. The signal from the PMT passes through a charge sense amplifier that converts its current pulse into a voltage spike. This spike is then integrated to give a voltage proportional to the energy of the incident gamma ray photon. This voltage is digitized by a high-speed 12 bit analog to digital converter and is fed to the CPU.

The CPU examines the incoming photons and triggers the camera when it detects a burst. For the purposes of the payload, a burst is defined as an increase in the gamma-ray count of 5.5 sigma. When the burst is detected, the CPU will trigger the camera to take five successive frames.

The CPU also stores the incoming time and energy of every time to the data storage subsystem. It consists of an array of 5 800 megabyte hard disk drives. The drives were originally designed for use in laptops, and as a result, are both low power and rugged, with shock and vibration specifications well in excess of the Shuttle launch and landing specifications. To reduce power, the drives will be powered down for the majority of the flight, and will only be powered up for short intervals to write the accumulated data. To buffer the data, a 32 megabyte static ram array is attached to the processor to reduce the number of times that the drives must be powered up.

To achieve accurate time stamping of incoming gamma-ray photons and to allow for accurate position information, a Global Positioning unit (GPS) is used. Because of the doppler shifts caused by the speed of the Shuttle, traditional GPSs would be unable to acquire enough satellites to obtain a position and time fix, but the GPS manufacturer has provided special software to enable it to acquire in a low earth orbit. When the GPS acquires, it provides a pulse every second which is accurate to within a microsecond. The CPU uses this pulse to establish an accurate time of arrival for every photon that is seen by the PMTs.

POWER MANAGEMENT

One of the primary concerns of the GAMCIT team was the power source selection, since all Get-Away-Special payloads must be totally autonomous from the Space Shuttle Orbiter expect for the crew activated relays. Thus, upon drawing up a power budget, it was our task to determine which type of power source was the most appropriate to our application requirements. After a careful consideration of the products currently available on the market, and of those that fell within the NASA safety margins, we decided on standard commercially available alkaline D-size cells. The cells have a nominal voltage of 1.5 V with a rated capacity of 14.25 Amp-hours.

The major problem one encounters with alkaline cells is the less than ideal discharge characteristic. In general, such cells discharge linearly with time from their nominal voltage (1.5 V) to the rated cut-off voltage (0.8 V). In order to overcome this difficulty, we were forced to use a DC-DC converter. The DC-DC converter that we chose has an input voltage range from 7-35 VDC, and three output terminals: two at 12 VDC and 0.7 amperes maximum, and one terminal at 5.1 VDC and 5.0 amperes maximum.

The actual battery setup is configured as 19 packs of 10 batteries each, for a total of 190 batteries. Each pack of batteries provides 15 VDC nominally, discharging to the cut-off voltage of approximately 8 VDC. Each parallel leg of the total battery power supply is protected by a Schottky diode to prevent circulating currents which would lead to mission failure. In addition, the whole power supply is protected by a 6 Amp fuse, chosen in accordance with NASA regulations, on the ground leg.

The electronic system is fully powered through the DC-DC converter, expect for a two clocks, one on the GPS, and one on the CPU, powered by small watch type silver-zinc cells.

CONSTRUCTION

GAMCIT has been under design and construction for about four years. In the summer of 1993, GAMCIT was able to offer stipends to five students to work for ten weeks on the project. During the summer, most of the design details were hammered out, and prototyping began. Construction continued during 1994, with the bulk of construction taking place during late 1994 and early 1995. As construction progressed, new ideas continued to surface, and the design slowly evolved. Some of the changes were driven by component availability, with the most notable being the crystal size and shape. Originally, GAMCIT was to have two pie shaped crystals with plastic light integration cones connecting them to the PMTs. When the crystals became unavailable, two standard cylindrical crystals were substituted and it was decided to directly couple the PMTs to the crystals. Other changes were driven by ideas for better ways to solve the problems presented by the experiment, with the best example being the substitution of the Tubular Battery Enclosure instead of a conventional battery box.

INTEGRATION

In May 1995, the GAMCIT team brought the payload to Kennedy Space Center for integration onto STS-69. During a routine leak check, a vacuum was pulled inside the can and the resulting reverse pressure on the lid was enough to fracture it. A replacement lid could not be fabricated in time, and the payload was pulled from the flight. The GAMCIT team is currently machining a new lid, and we hope to fly the payload in late 1995 or early 1996.

CHALLENGES

The GAMCIT project at Caltech has been driven entirely by undergraduate students since its beginning. GAMCIT is a spin-off of the Caltech Students for the Exploration and Development of Space (SEDS), a student group with over one hundred members (over 6% of the student body, graduate and undergraduate). The sponsorship of SEDS has been essential to the success of the project, in terms of drawing in interested students, facilitating support from Caltech's administration, and bringing in start-up funds from aerospace corporations.

While the sponsorship of a large student group is very beneficial, our experience has proven that projects such as ours cannot succeed without faculty and staff support. Dr. John M. Grunsfeld served as our first advisor for the GAMCIT project, and was instrumental in obtaining recognition and laboratory space for the project, as well as in the preliminary design work. After Dr. Grunsfeld left Caltech to become an astronaut, the students of GAMCIT approached Dr. Maarten Schmidt of the astronomy department to serve as a faculty advisor. Dr. Schmidt's assistance has proven invaluable in securing financial support from Caltech and outside organizations to continue the project. It is also worth noting that securing course credit for work on the project has been very helpful in recruiting new members to the project team.

However, the challenges involved in the GAMCIT project go far beyond those of politics. Because our "engineers" are all undergraduates, the project's participants have faced quite a learning curve in all areas of the science and engineering of the payload. While this makes for a much slower timetable than projects in industry might enjoy, it also serves to provide a hands-on experience for undergraduates that is seldom available in standard university curricula.

As in any other workgroup, leadership, responsibility, and personal relations are critical issues to the success of a project such as ours. However, these problems are exacerbated by having an all-undergraduate working group - students are students first and space experimenters only in their "spare time." Offering course credit can serve as a limited incentive to get things done, but ultimately the motivation must come from the students' own sense of involvement in the project, which is in turn dependent in large part on the leadership and group dynamics of the project.

The challenges and pitfalls involved in a project such as ours, staffed entirely by students, are indeed distinct from those faced in similar projects in industry or the military. While the pitfalls are many, the rewards of a student-run project are even more plentiful. We welcome correspondence from present, past, or potential student groups who are interested in Getaway Special projects.

CONCLUSION

The GAMCIT experiment has been a rewarding experience for all involved in its design and construction. GAMCIT also provides an almost guaranteed return, because any gamma-ray data collected can be correlated with similar observatories currently on ULYSSES, the Pioneer Venus Orbiter and the Compton Gamma Ray Observatory. A single optical transient correlated with a gamma-ray burst would provide a stringent constraint on burst theories.

REFERENCES

1. McCall, B.J. et al.: The GAMCIT Gamma-Ray Burst Detector. 1993 Shuttle Small Payloads Symposium, NASA CP-3233, 1993, pp. 47-56.

2. Fishman, G.J., Meegan, C.A., Wilson, R.B., Paciesasm, W.S., Pendelton, G.N., The BATSE Experiment on the Compton Gamma-Ray Observatory: Status and Some Early Results, NASA CP-3137, 1992, pp. 26-34.

3. Meegan, C.A., Fishman, G.J., Wilson, R.B., Paciesasm, W.S., Pendelton, G.N., Hornack, J.M., Brock, M.N., and Kouveliotou, C., Spatial Distribution of Gamma-ray Bursts Observed by BATSE, Nature, 1992, vol. 355, pp. 143-145.

4. Stewart, A.C., and Desai, U.D.: New Room Temperature High Resolution Solid-State Detector (CdZnTe) for Hard X-Rays and Gamma-Rays. 1993 Shuttle Small Payloads Symposium, NASA CP-3233, 1993, pp. 25-32.

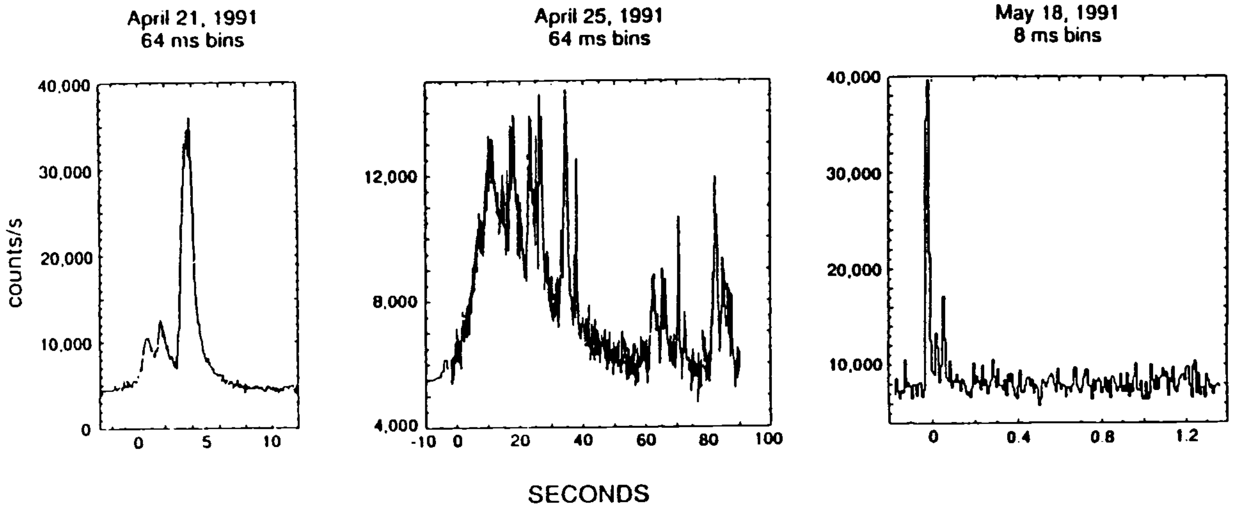

Figure 1 - A sample of gamma-ray bursts as observed by the BATSE instrument on the Compton Gamma Ray Observatory (reproduced from [2]). These burst profiles show the wide variety of structure and varying time durations of gamma-ray bursts, from milliseconds to 100s of seconds. The energies of the gamma-rays in these plots range from 60 keV to 300 keV.

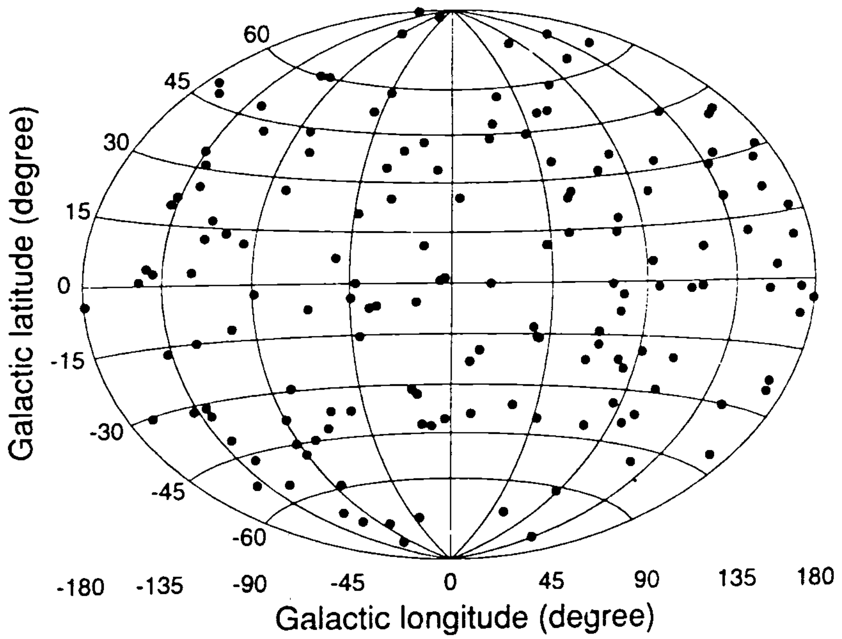

Figure 2 - The angular location of gamma-ray bursts in Galactic coordinates as observed by the BATSE instrument on the Compton Gamma Ray Observatory (reproduced from [3]). The observed distribution shows no significant deviation from isotropy. In particular, no enhancement along the Galactic plane (latitude=0) is seen, as would be expected if the sources of gamma-ray bursts had the same distribution as the stars in the Galaxy.

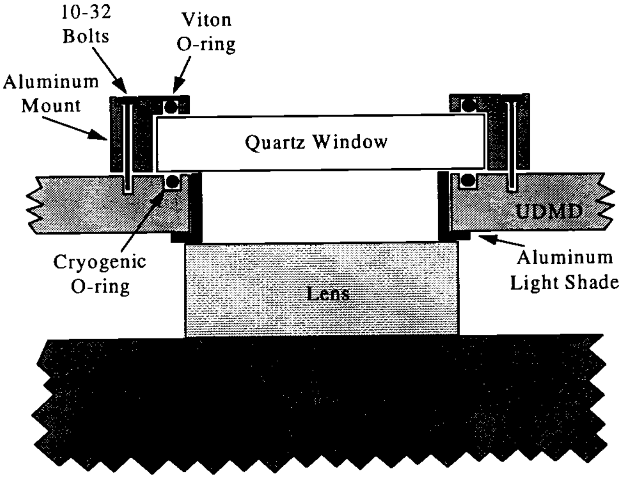

Figure 3 - O-ring seal on quartz window for Camera

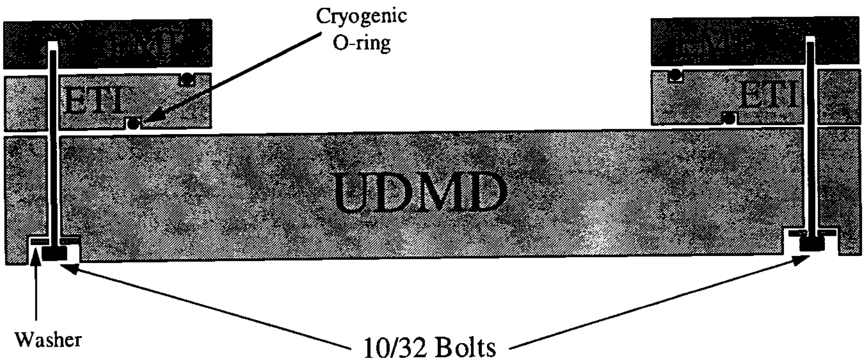

Figure 4 - Side view of UDMD (User Designed Mounting Disk), ETI (Experiment Thermal Isolator), and EMP (Experiment Mounting Plate)

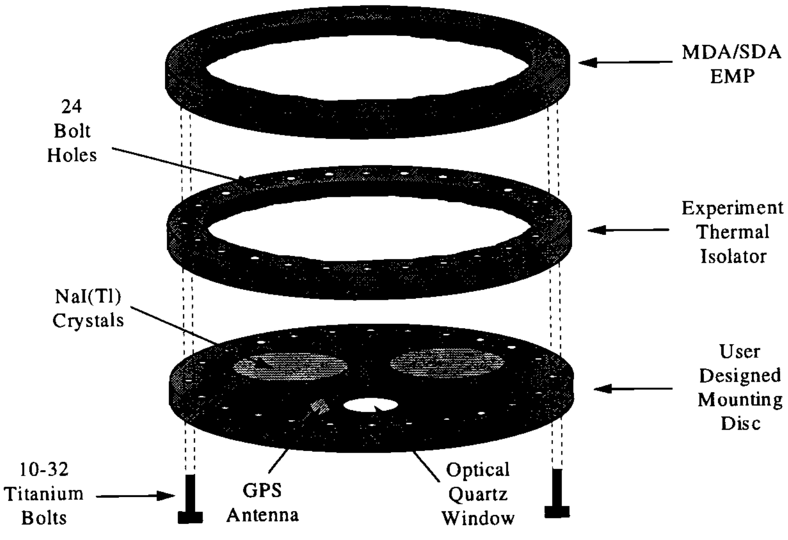

Figure 5 - Exploded view of EMP, ETI, and UDMD

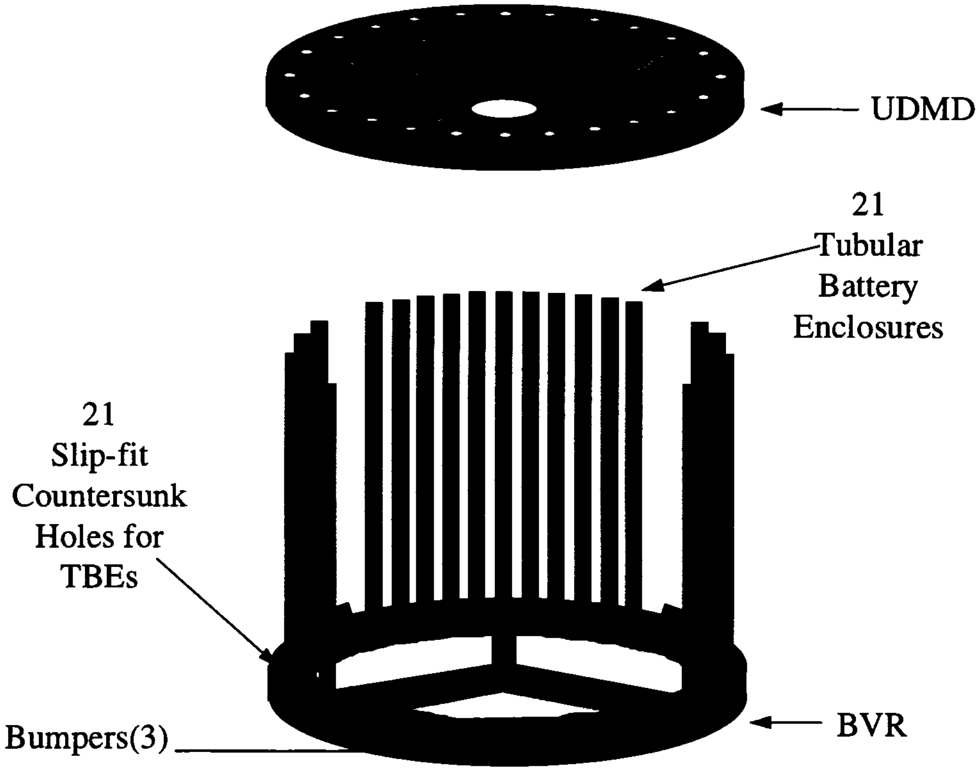

Figure 6 - Tubular Battery Enclosure

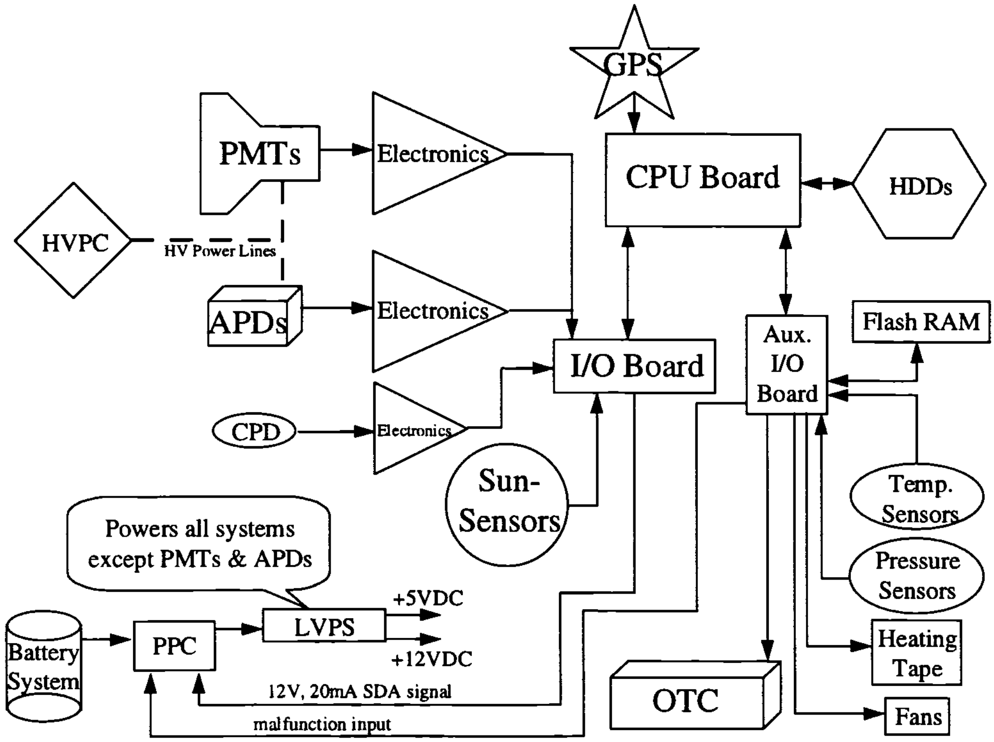

Figure 7 - Block Diagram of the Electronics Subsystem