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High Reliability System Design Experience with the Gamma Ray Large Area Space Telescope

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***Abstract*—The Large Area Telescope (LAT) is the primary instrument on the Gamma Ray Large Area Space Telescope (GLAST), a space based observatory which is scheduled to launch late this year. The LAT traces its heritage from the particle physics community and represents a large departure in design and capability from previous space based experiments. Similarly, power, communication, and physical access limitations of a space based platform place strict requirements on the design and reliability of both the LAT and its Trigger and Dataflow (T&DF) system. The resulting T&DF system consists of a hierarchical trigger with both Level 0 and Level 3 components, distributed event processing, and slow control. We describe our experiences developing and testing the T&DF system in the context of a space mission, and we report the performance and status of the system as GLAST approaches launch.**

I. INTRODUCTION

The Gamma Ray Large Area Space Telescope (GLAST) Observatory consists of two scientific instruments as well as a spacecraft bus. The primary instrument is the Large Area Telescope (LAT), a pair conversion telescope which is sensitive to gamma rays in the energy range from 20 MeV to 300 GeV. With its large acceptance (greater than 2 sr field of view), the LAT will scan the entire sky every three hours (two orbits). The second instrument is the GLAST Burst Monitor (GBM). It detects gamma rays in the energy range from 10 keV to 30 MeV, and has a 9 sr field of view. When a gamma ray burst is detected by the GBM that is outside the LAT field of view, GLAST Obeservatory can autonomously slew to bring the burst into the LAT field of view. The spacecraft bus controls the pointing of the observatory, is responsible for the thermal survival of the instruments, and stores science and housekeeping data between ground contacts. The GLAST mission is scheduled as a five year mission with a ten year goal.

II. LAT DESIGN

A pair conversion telescope detects gamma rays when they interact in high-Z conversion foils located within a tracking volume. The tracks of the conversion products are used to point back to the origin of the gamma ray. These products are subsequently stopped in an electromagnetic calorimeter where their energy is measured. The entire detector is surrounded by an anti-coincidence detector which can be used to veto events resulting from the passage of charged particles. In addition to these detector subsystems, there must also be a trigger and data acquisition system, and a control and monitoring system which are under the control of a flight software system.

The LAT tracker (TKR) is precision silicon strip detector which consists of 16 modules of 36 layers each with 1536 silicon strips. Each pair of orthogonal strip layers is separated by a tungsten conversion foil. The data provided by the TKR are the hit strip addresses for position measurement and a time-over-threshold measured by each layer end to provide a rough pulse height. In addition, each TKR layer end provides one trigger bit indicating a hit in that half layer. Buffering for four events is provided in the front end.

The LAT calorimeter (CAL) consists of 16 modules each containing a hodoscopic array of cesium-iodide crystals arranged in 8 layers of 12 crystals. These are read out by photodiodes on each end of every crystal. The data provided by the CAL are pulse heights from each crystal end in one or all of four ranges. Each CAL layer also provides a high energy and a low energy trigger signal.

The LAT anti-coincidence detector (ACD) is a system of 89 plastic scintillator tiles which are read out by photomultiplier tubes. The data provided by the ACD are the energy deposited in each of the tiles, and two trigger signals. A low energy trigger signal is used to veto the passage of light charged particles and a high energy trigger signal is sensitive to heavy ions. These heavy ions are used to calibrate the CAL.

The Trigger and Dataflow (T&DF) system consists of several components. Each of the 16 CAL and TKR modules are assembled into a tower along with a Tower Electronics Module (TEM). Each TEM is responsible for the aggregation of trigger signals, configuration, and environmental monitoring of the corresponding CAL and TKR. Each TEM is connected to the Global Trigger ACD Signal distribution Unit (GASU) which contains, as the name implies, the Global trigger Electronics Module (GEM) and the electronics module responsible for readout, monitoring, and configuration of the ACD (AEM).

The GEM recieves the trigger signals from each of the TEMs and AEM. These are sampled on each tick of the 20 MHz system clock. Combinations of trigger signals can initiate different types of acquisitions such as non-zero suppressed or CAL 4-range readout. The GEM is also responsible for measuring the livetime of the LAT and assigning the event time for each event. The orbit averaged trigger rates are expected to be 3-4 kHz, with peaks of 10-13 kHz.

In addition to this, the GASU also contains the event builder.

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Once the event contributions from the TEMs and AEM have been assembled by the event builder, they are forwarded to one of two Event Processor Units (EPUs). The EPUs are responsible for the level 3 event filter and data compression. The average event size is 1-2 kBytes/event uncompressed and the FSW is able to achieve data compression factors of 3-4. Events which pass the event filter are then send via the GASU to the solid state recorder on the spacecraft bus to await transmission to the ground.

The FSW system is responsible for configuring the LAT, controlling data taking, performing charge injection calibration, and performing onboard science processing. FSW runs on the EPUs as well as the Spacecraft Interface Unit (SIU). The SIU is responsible for overall control and monitoring of the LAT and, as the name implies, provides the interface to the spacecraft bus. The EPUs and SIU are identical cPCI based crates controlled by a 750 class Power-PC processor board.

III. LIMITATIONS OF THE SPACE ENVIRONMENT

There were a number of constraints placed on the design of the LAT based on the limitations of the launch vehicle (a Boeing Delta II, heavy configuration). The limited size of the fairing (1.8 m) restricted the lateral dimension of the LAT. The total weight of the LAT needed to be less than 3000 kilograms to allow insertion into orbit at an altitude of 550 kilometers. Though this weight limit affects the design of the LAT in many respects, the largest impact is by limiting the depth of the calorimeter. This limits the energy measurement of gamma rays whose interaction products are no longer contained in the LAT calorimeter. The need to survive vibrations experienced by the LAT throughout the launch also affects the design of the instrument. These vibrations are transferred mechanically and acoustically to the LAT. This requires the LAT to pass mechanical and acoustic vibration tests.

There are also a number of constraints placed on the LAT by its environment on orbit. The total power budget of the LAT (650 W) is set not by the ability of the solar array to generate electricity, but by the ability of the thermal radiators to dissipate the heat generated by the LAT. The limited power most constrains the LAT design by limiting the number of silicon tracker channels and the amount of processing power available to the FSW. This constraint also resulted in the use of custom Application Specific Integrated Circuits (ASICs) in the place of the more flexible Field Programmable Gate Arrays (FPGAs). Thermal stability is also required to maintain the alignment of the the detector towers. To ensure the LAT's ability to cope with the on orbit environment, the LAT was required to undergo extensive thermal vacuum testing.

An even larger departure from ground based experiments is the lack of access to the instrument both physically and in terms of communication. Contact with the observatory is limited to 10 to 12 minute contacts, about 6 times per day. This limits the science data bandwidth to an orbit average of 1.2 Mbits/s. This sets the necessary level of background rejection and data compression. Lack of physical access to the instrument requires the design to be tolerant of single point of failures. In addition, all components were required to undergo flight qualification testing (FQT). This is a series of tests which help to ensure that each of the components, both hardware and software, are capable of surviving in low Earth orbit.

IV. LAT RELIABILITY FEATURES

Each of the LAT subsystems are provided with features to enhance reliability. In the T&DF system, this is often achieved through the use of cold spares, which are duplicate components that can be swapped in should the primary component fail. To this end, the T&DF components: GASU, SIU, and EPUs each have a designated cold spare.

In the case of the detectors, where it is not sensible to have unused, duplicate detector elements, redundancy is achieved through the configuration of multiple data paths. For example, each layer of each TKR module is normallly read out and controlled from both sides, half from one side, half from the other. If a front end component should fail, each TKR layer can be reconfigured to exclude the failed part, thus preventing the loss of an entire layer. Similarly in the case of the CAL, the science requirements can still be fulfilled should the readout electronics fail on one crystal end. In the ACD, each of the scintillator tiles is read out by two separate photomultiplier tubes, housed on separate chassis, to eliminate the loss of any tile data due to a single point failure.

In addition to redundant design, flight qualification is required for each component of the LAT. In the case of components without space heritage, this entails a detailed series of tests to ensure that the component will survive on orbit. In the case of programmable units, not only must the device be qualified, but its program as well. For example, though the FPGAs used (Actel RT54SX series) had space heritage, the 15 different designs used in the LAT were required to undergo FQT. Similarly, there were 9 ASIC designs which underwent FQT, but as they all were fabricated using the same process, that process only needed to be qualified once.

To qualify the FSW, the LAT team used the LAT Testbed which is a complete T&DF system constructed from engineering model units. In the place of detector components, the Testbed includes a Front End Simulator (FES). This allows the input of test data samples that are not available on the real instrument in a repeatable and deterministic fashion. These include both diagnostic patterns and high fidelity Monte Carlo simulated signal and background scenarios. The FES is capable of storing and entire simulated orbit's data. During the operations phase of the mission, the Testbed will continue to be used to refine FSW and will be indispensable in anomaly resolution.

V. CONCLUSION

All of the LAT subsystems have been integrated and successfully tested. At the time of writing, the LAT and GBM have been integrated with the spacecraft and environmental testing of the GLAST Observatory has begun. The LAT has performed superbly to this point and we anticipate a successful launch in late 2007.