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Living with a Star (LWS) Space Environment Testbeds (SET) Mission Carrier Overview and Capabilities

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Abstract – NASA has initiated the Living With a Star (LWS) Program to develop the scientific understanding to address the aspects of the Connected Sun-Earth system that affect life and society. A goal of the program is to bridge the gap between science, engineering, and user application communities. This will enable future science, operational, and commercial objectives in space and atmospheric environments by improving engineering approaches to the accommodation and/or mitigation of the effects of solar variability on technological systems. The three program elements of the LWS Program are Science Missions; Targeted Research and Technology; and Space Environment Testbeds (SETs). SET is an ideal platform for small experiments performing research on space environment effects on technologies and on the mitigation of space weather effects. A short description of the LWS Program will be given, and the SET will be described in detail, giving the mission objectives, available carrier services, and upcoming flight opportunities.

1. INTRODUCTION

The Sun, the astronomical object most significant to humanity, affects the entire solar system. Because of the consequences of the Sun's dynamic behavior to the Earth and other planets and the rapidly expanding utilization of this region for human activities, a thorough understanding of the Sun's effects is becoming increasingly essential. The Sun radiates both as humans in space and on high altitude flights, and terrestrial climate change[1].

electromagnetic energy and as fast-moving electrically charged particles. The electromagnetic radiation across a broad spectrum of wavelengths originates from the photosphere, the Sun's surface. This energy proceeds unimpeded directly from the Sun to planetary atmospheres, with a majority reaching the surface of the planets. The effects of the interactions are far-reaching and have impacts on our technological systems, on

The goal of the LWS Program is to develop scientific understanding of connected Sun-Planetary systems under a program architecture that will increase the flow of scientific understanding to enabling science disciplines. Using the data and information generated by the program, enabling science will have significantly improved capability to address the mitigation of effects induced by solar variability. The purpose of this paper is to give an overview of the implementation of the SET segment of the LWS Program and to describe the details of the SET experiment carrier design.

2. LWS MISSION OVERVIEW

The SET Project is one of the three elements of the LWS Program. These three LWS elements are:

- **Science Missions** to make scientific observations of the Sun, Heliosphere, and Geospace regions. The Science Missions will collect the data required to achieve better understanding of the environment.

- **Targeted Research and Technology (TR&T)** to improve knowledge of space environmental conditions and variations over the solar cycle, develop new techniques and models for predicting solar/geospace disturbances, and develop cost-effective techniques for assimilating data from systems of spacecraft. The TR&T defines the environment in the absence of a spacecraft.

- **Space Environment Testbeds (SET) Project** to reduce the uncertainty in the space environment definition in the presence of a spacecraft as functions of location and time in the solar cycle and will minimize or accommodate the space weather effects on space hardware.

Additional information on the Living With a Star Program elements can be found in Reference [i].

3. SET PROJECT OBJECTIVE AND GOALS

The SET Project addresses the LWS goal of understanding how Sun/Planet relationships affects humanity by addressing effects of solar variability on the space environment in the presence of spacecraft, the performance of spacecraft hardware in this environment, and accommodations and/or mitigation techniques for the environmental effects. The objective of the SET Project is to improve the engineering approach to mitigate the effect of solar variability on spacecraft design and operations so that new technologies can be infused into the space missions without adding risk.

Before new technologies can be used in space, space environment effects must be defined and mitigated. This requires identification and understanding of the mechanisms of the space environment interactions, modeling of the interactions, and development of ground test protocols to qualify technologies for space. The models and ground test protocols require flight validation to decrease safety margins and assure reliability. In the past, accommodation of space environment effects relied on empirical models. As the complexity of technologies increases, models derived from physics based understanding of the effects are required.

Space environment effects that are induced by solar varying space environments are well understood (design margins < x2) for only 10-15% of the technologies used in space missions (e.g., microelectronics on CMOS down to 0.25 microns). The effects on most other technologies are poorly understood and design margins range from x5 to x10. Design margins for newer technologies, such as SiGe and "exotic" materials, are greater than x10. When margins for spacecraft design and operations are reduced, space environment "tolerant" and new technologies can be used more frequently, the fraction of spacecraft resources available for payloads can be increased or launch vehicle requirements can be reduced, and routine operations above Low Earth Orbit (LEO) (above 2000 km) can be performed at the same cost as for the LEO operations.

The goals of the SET Project are to:

- Define the mechanisms for induced space environment and effects

- Reduce uncertainties in the definitions of the induced environment and effects on spacecraft and their payloads; and,

- Improve design and operations guidelines and test protocols so that spacecraft anomalies and failures due to environment effects during operations are reduced.

4. SET PROJECT IMPLEMENTATION

In order to achieve its goals and objectives, the SET Project has chosen an implementation comprised of two key components:

- **Flight Investigations.**

  - Collect data in space to validate the performance of new technology vulnerable to the effects of the solar varying environments and instruments for LWS science missions o Collect data in space to validate new and existing ground test protocols or mechanism models for the effects of solar variability on emerging technologies and components

- **Data Investigations.**

o Improve, develop, and validate engineering environment models, tools, and databases for reliable spacecraft design and operation

The SET Project will accomplish its goals by acquiring investigations through NASA Research Announcements (NRAs) and partnerships. A series of science workshops with scientists and technologists are held to discuss current investigation needs, and to assist in defining requirements for NASA Research Announcements for future SET Flight Investigations and Data Investigations opportunities. The Workshop participants have defined the following five categories for SET investigations:

1. Characterization of the space environment in the presence of the spacecraft;

2. Definition of the mechanisms for materials' degradation and the performance characterization of materials designed for shielding from ionizing radiation;

3. Accommodation and/or mitigation of space environment effects for detectors and sensors;

4. Performance improvement methodology for microelectronics used in space; and,

5. Accommodation and/or mitigation of charging/discharging effects on spacecraft and spacecraft components.

The NASA's Office of Space Science (OSS) solicited the first flight investigative mission through NASA Research Announcement, NRA-02-OSS-04 in 2001. Current funding supports seven experiments with Phase B development beginning in May 2004. A second NRA release for flight investigations is scheduled for October 2004. Implementation responsibility for LWS and SET is assigned by OSS to the LWS Program (Code 462) at GSFC.

SET experiment opportunities are open to U.S. industry, universities, Federally Funded Research and Development Centers (FFRDC), NASA Centers, other U.S. Government agencies, and non-U.S. organizations.

The SET Project implementation concept calls for space investigations to be flown as secondary payloads in "piggyback" mode aboard various host spacecraft. The flight investigations require the development of a carrier avionics that will serve as an interface between the host spacecraft and the experiments. The objective of the carrier development is to provide the technology research community an ongoing program that will provide investigators quick access to space thereby accelerating the infusion of new technologies into space programs. The carrier is currently under development at NASA, Goddard Space Flight Center preparing for first flight opportunity in 2007. The missions and associated carrier will support the following:

- Mission duration is 1 to 2 years;

- The carrier and associated experiments will fly as a piggyback secondary attached payload;

- Each mission will support up to 16 individual experiments. Experiments may be 3U cards, 6U cards, or individual box experiments; board experiments may utilize up to 4 W power and box experiments to 10W;

- Board and box experiments are provided 6 regulated voltages, unregulated power from the host spacecraft (typically 28V), a command and telemetry interface, a clock signal, and analog lines for dosimeter, thermal, and other telemetry monitoring;

- Experiment command and telemetry interface are provided at 1 Kbits per second.

- Specifications for the experiment interface, communication protocols, and flight requirements are defined and available in NASA provided documentation.

5. SET CARRIER CONCEPT & CAPABILITIES

The SET concept has evolved from previous and similar architectures implemented on missions such as Space Technology Research Vehicles (STRV), and Microelectronics and Phortonic Test Bed (MPTB) testbeds. Significant contributions to the design and mission concept of SET carrier were originally developed by the Johns Hopkins University (JHU) Applied Physics Laboratory (APL), during 2001-02, then the Project was transitioned an in-house development at GSFC in 2002, building upon the APL architecture.

Flight Investigations will be hosted in or through a carrier system that will interface to host spacecraft providing a ride opportunity. The SET carrier system is designed to be fail-safe, flexible, modular, and scalable, to meet the requirements of most host spacecraft, while standardizing the interface to the flight investigations. Operationally, SET is low-impact to a host due to its non real-time, autonomous payload operation. Power, serial communication, bi-levels, and analog services are available to each experiment. The carrier electronics are housed in the lower portion of a standard mechanical enclosure with the flight investigations on the top section of the enclosure with up to 170 degree field of view (FOV) to the space environment. A system block diagram is represented in Figure 5-1.

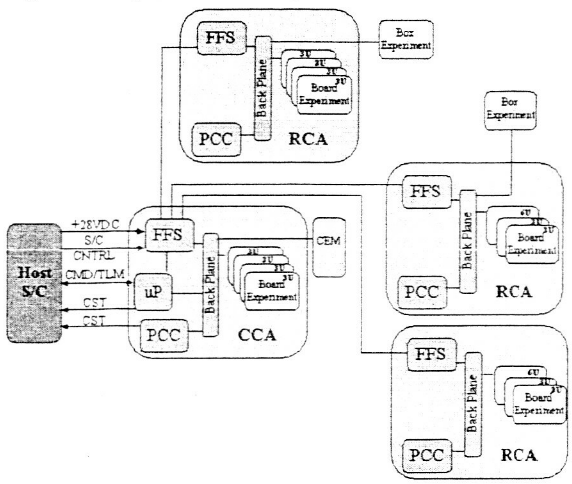

Figure 5-1 SET Carrier System Block Diagram

The carrier design incorporates a generic-style interface to a host, including; redundant +28VDC input power, host initiated bi-levels, a RS-422 serial command and telemetry communication interface, and hard-line analog carrier status telemetry (CST) monitors. This generic interface would typically meet most spacecraft bus designs for payload or instrument accommodations. Mission specific unique requirements or changes would be designed into the carrier generic interface section, or incorporated in a mission specific card when a host spacecraft is identified, or during requirement definition.

The experiment mechanical, electrical, and thermal interfaces are standard and documented in accordance to the SET Experiment Accommodations and Requirements Specification (SEARS) document. Experiments may consist of printed circuit boards (PCBs) in the 3U or 6U form factor, or as individual standalone instrument box. Cards are supported internally to the carrier mechanical enclosure, and box experiments through external harnessing, and mission specific mechanical accommodations on the host spacecraft. Seven switched power voltages services, analog monitoring, clock signal, bi-levels, and RS-422 command and telemetry data are available to each experiment on an 80 pin connector.

The carrier modular design consists of a Central Carrier Assembly (CCA) and Remote Carrier Assembly (RCA). The CCA and RCA are identical in mechanical configuration except that the CCA contains the carrier Processor Card (PC), or carrier command and data handling system (C&DH). One CCA and 3 RCAs will accommodate up to 16 experiments, but unique mission specific wiring can accommodate different levels of experiments.

The carrier system provides passive cooling and active thermostatic heater control, which maintains payload and experiment operational temperatures between –15C and +55C.

5.1 Carrier Mechanical Systems

The mechanical system consists of an aluminum 6061-T6 machined enclosure with covers/lids for the carrier backplane, and experiment bays. Figure 5.1 illustrates the conceptual design, showing 3U cards, with slot 3/4 able to accommodate a 6U card. Board experiments are mounted on the top, while carrier system cards are mounted underneath. Experiment boards are mechanically supported along the edge with several fasteners, and each bay is machined to provide a Faraday cage to reduce the propagations of Electromagnetic Interference (EMI).

Orientation of the enclosure on the host spacecraft can be either vertical or horizontal to minimize the mounting footprint requirements, increasing the potential for accommodations when surface space on a host is restricted.

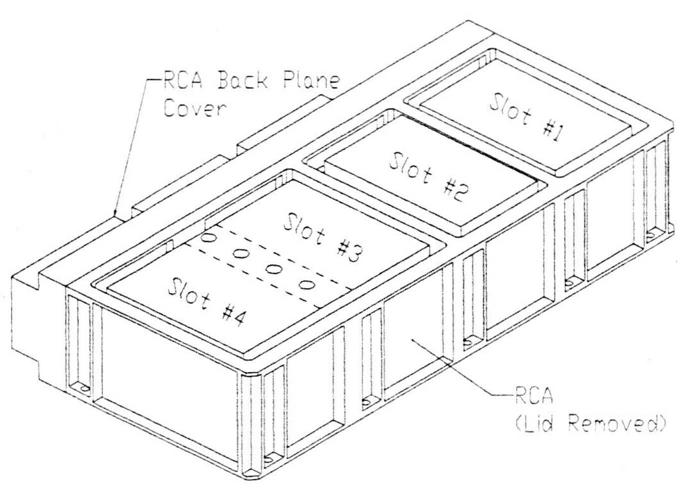

Figure 5.1 – Mechanical Enclosure

Each experiment bay includes a standard 200mil thick aluminum cover, provided by the carrier, which provides experiment thermal protection and mechanical containment, while minimizing shielding of the radiation environment.

5.2 Carrier Electrical Systems

The carrier electrical system consists of power control distribution electronics and a central processing card. The power electronics in each CCA or RCA, consists of a Fusing, Filter, and Switching Card (FFS) that interfaces to the spacecraft power bus, and a Power Control Card (PCC) that receives power from the FFS and provides power distribution and analog telemetry services to experiments. The FFS can be generic, but can customized for each specific spacecraft while the PCC is generic in nature, providing standard power and analog telemetry interfaces to experiments.

The Processor Card (PC), housed in the CCA, provides the control function of the Carrier, operating as the spacecraft data interface, as the master controller for all of the power subsystems, and as the command and telemetry processor for all experiments. All communication to and from the PC is accomplished through point-to-point RS-422 serial ports. Similar to the PCC, the PC design is principally generic, providing a standard data interface for all carrier subsystems and experiments. It is capable of supporting up to 4 PCCs and 16 experiments.

The PC does have customizable features in firmware and software that allow it to be configured for different spacecraft data interfaces. Additional custom cards may also be implemented for reconfiguration of the spacecraft data interface, or for additional onboard data storage. The generic PC has 1 Mbyte of onboard storage to handle multiple experiment burst rate data requirements during solar events.

In addition to the power and data interfaces to the spacecraft, the PCCs and PC are capable of providing health and carrier status telemetry via several bi-level signals and analog voltages directly to spacecraft housekeeping electronics. Operating modes, error conditions, temperatures, currents, and heater states are all available this telemetry.

A picture of the breadboard processor board (3U size) and PCC (9U size) are shown in Figure 5.2-1 through 5.1.3

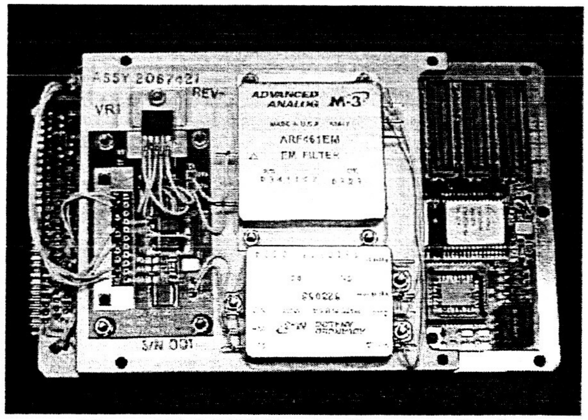

Figure 5.2-1 SET Carrier Processor Card

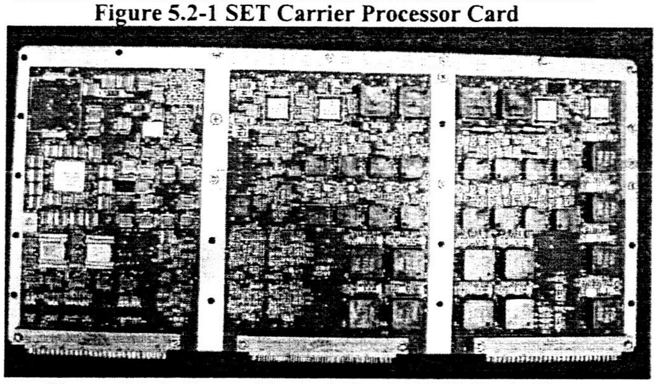

Figure 5.2-2: Power Control Card (PCC) Backside

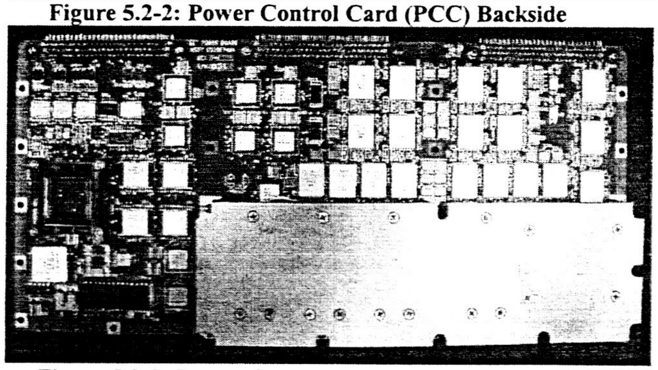

Figure 5.2-3: Power Control Card (PCC) Front Side (Board dimensions: 13.41 x 6.3 x 0.092 inches)

The carrier provides payload level hardware monitoring for over-current and under-voltage protection in case of carrier or experiment faults. System hardware and software watchdog timers provide health status checks on system parameters, and execute appropriate automated responses and safing operations.

5.2.1 Parts

The carrier flight electronics is comprised of EEE, Grade 3 parts (in accordance with GSFC's EEE-INST-002) that meet radiation requirements of 100 Krads-si for Total Dose, 37 MeVcm^2/mg for single event effect (SEE) soft errors and 80 MeVcm^2/mg for SEE hard errors. Exceptions are evaluated on a case-by-case basis.

SET investigations/experiments are required to select EEE parts that will ensure their mission success (i.e., design will function in space long enough to gather enough data to meet mission success objectives). The use of plastic, commercial devices is prohibited, unless approved by SET Project. Specific launch/orbit information is unknown at the time of award; therefore, to optimize launch opportunities, experimenters are encouraged to use parts selection guidelines similar to the Carrier. The total dose requirement could be less than 100Krads-si if mission success objectives can be achieved by collecting data in a relatively short period (a few months vs. 2 years) or other mitigation steps are incorporated into the design.

5.3 CARRIER FLIGHT SOFTWARE

The SET Flight Software provides a Consultative Committee on Space Data Systems (CCSDS) compliant telemetry and command interface with the host spacecraft and a Time Data Multiplexed experiment serial interface. Experiments provide predefined Command Sequences that issue experiment science or power mode change commands and request telemetry. The experiment data that is returned to the SET Flight Software is packetized and queued for output to the host spacecraft. Command Sequences must be constant for the majority of the mission. However, Command Sequences can be configured to 1) execute at periodic intervals (up to a 1 Hz frequency), 2) execute in chained sequences, and 3) be preemptive and execute when environment monitors detect specific radiation levels or experiment safety parameters exceed specified limits. These features allow the experimenter the ability to obtain, format and respond to science data without implementing their own microprocessor and its associated code within their experiment.

The carrier embedded flight software is resident on UTMC UT80196KDS. The electrical and FSW development teams performed a trade study between several available processors. The device identified as the best candidate was the UTMC UT80196KDS as the central microprocessor in the Processor Card design of the Carrier. This selection was recommended by the hardware and software design teams after evaluating trade studies completed by other systems and agencies for this application including researching and evaluating other known processors. Radiation hardness, required processing bandwidth and functionality, size, power consumption, part availability, cost, flight heritage, and software design tools and operating system availability and cost were the considered criteria.

Of the processors considered, the UT80196KDS, the UT69RH051, the RAD6000, and the RAD750 are the only devices that meet the minimum radiation requirements and have development tools readily available. Among these devices, the UT69RH051 was eliminated due to insufficient processing capability. The UT80196KDS was then chosen over the RAD6000 and RAD750 do to lower power, size and parts cost. Additionally, UT80196KDS has greater built peripheral functionality, potentially reducing hardware development.

5.4 CARRIER THERMAL SYSTEMS

The carrier thermal subsystem utilizes active and passive control. The carrier subsystems or payload elements can be either coupled or isolated from the host spacecraft, depending on host requirements. The flexible design has been modeled over a variety of potential orbit environments, maintaining a thermal environment from –15C to +55C. Thermostatically controlled heaters with 12.5 watts of energy are provided in each CCA and RCA, and up to 4 watts to a box experiment.

5.5 CARRIER CORRELATIVE ENVIRONMENT MONITOR (CEM)

Every SET mission will include one or more Correlative Environment Monitors (CEM) as part of the payload complement, and is considered part of the carrier system. CEM's are the primary mission space environment detectors for the detailed measurement of the on-orbit radiation environment. The CEMs selected for each payload complement will be tailored to provide the environment measurements required to validate the exposure of the payload to the space environment.

5.6 EXPERIMENT SERVICES

The SET carrier provides an assortment of standard electrical, mechanical, and thermal interfaces to an experiment, with the potential of optional services. Optional services include; providing EEE parts, carrier command and telemetry simulation tools, modeling, and environmental test support. An experiment can consist of a circuit board in the 3U or 6U envelope, or a box experiment that meets criteria for electrical power, mass, and data requirements.

5.5.1 Experiment Interfaces

Experiment electrical interfaces are provided via a standard 80 pin connector within the CCA/RCA enclosures. Through this interface a vast array of standard electrical services for each experiment are provided. These services include power, serial command and telemetry, and various analog services as shown in Figure 5.5-1. Each experiment has the option of using any service, which best meet their experiment requirements.

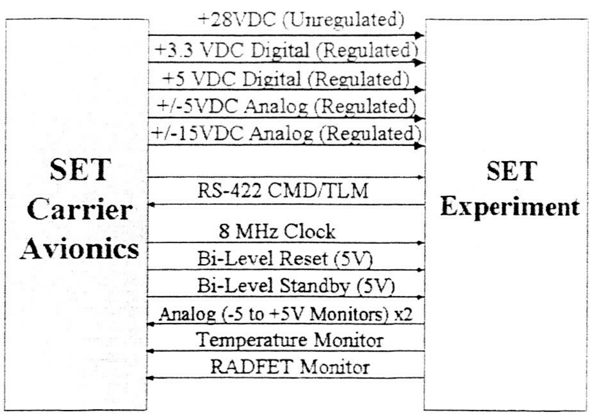

Figure 5.5-1 SET Carrier to Experiment Electrical Interface

Power is provided as individually switched, filtered and regulated +3.3V, +5V, +/-5V and +/-15V services. Experiment latch-up mitigation exists on these regulated services via an under-voltage, over-current detection and reset circuit implemented within the carrier Power Control Cards. Additionally, switched, filtered and fused +28V spacecraft power is also available. Power limits for each experiment are 4 watts for a 3U card, 8 watts for a 6U card, and 10 watts for a box experiment.

Analog Telemetry Services consist of 4 analog to digital (A/D) measurement ports. Two ports are dedicated to measuring temperature and radiation exposure via a thermistor and dosimeter respectively. The two other A/D's are experiment specific, and have a differential +5V to -5V input range with 12 bit resolution.

The serial command and telemetry interface to each experiment is a single, full duplex, RS-422 serial port. All experiment serial ports are time multiplexed, interfaced to the PC on a 40 millisecond (ms) time slot, over a 1 second period. Within the 40 ms slot, an experiment can receive commands from the carrier and send telemetry for downlink. Communication is handled in a Bus Controller/Remote Terminal fashion, with the carrier initiating all communication. The carrier provides a standard format for command and telemetry in the form of a simple High-level Data Link Control (HDLC) encoding that provides for variable length data, boundary detection, and error detection. The carrier is also easily configurable for fixed length packet formats customizable by each individual experiment. For experiments with simple command and telemetry requirements, customized packets are often preferred.

5.5.2 Carrier Simulation

To assist flight investigators in their development, testing tools are provided to each experiment in the form of a carrier simulator (CS). The CS system consists of a software application program, generated using the Labview Virtual Instrument tools, and complemented by either a PCI or PCMCIA RS-422 hardware card. The CS application program is installed on an experiment standard personal or laptop computer from the SET Project supplied compact disc (CD). The CS application provides a GUI interface to the experiment developers, which generate experiment commands with the appropriate carrier protocol headers, to the input/output of the RS-422 card.

5.5.3 Structural/Thermal Modeling

On a case-by-case basis, the SET Project may provide assistance to experiments in the form of performing mechanical and/or thermal modeling of their experiment system. The rationale for this is, that some institutions or private investigators (PI's) may not be equipped or familiar with the requirements for delivering these products in a cost effective way. Consequently, for each payload mission, an integrated payload structural and thermal model is provided to the host spacecraft for integration to the spacecraft model.

5.5.4 Environmental Test Support

Similarly, GSFC modeling expertise may be complemented by testing support to validate models, and assist flight investigations with the necessary space qualification or acceptance testing through the process of environmental testing. EMI/EMC, vibration, and thermal vacuum are potential tests that could be supported with the carrier Engineering Test Unit (ETU) or breadboard systems, at GSFC. Test plans will be prepared by GSFC to scope the effort, and establish roles and responsibilities. The experiment would be delivered to GSFC as an "in-progress" flight experiment, and must have completed system level comprehensive functional testing with acceptance tested FSW at the investigators facility. The experiment board or box would be integrated to the carrier ETU system, potentially with other experiments, and GSFC will executed the test plan for each of the environmental tests. Experiments will be required to support each test, as established in the test plan, and to review experiment science data before, during, and after each test.

6. SET HOST ACCOMMODATIONS

Since SET missions rely on host spacecraft for flight opportunities, the carrier must have reliable, fail-safe, and fault tolerant interfaces to eliminate the associated risks for fault propagation to the host. The SET carrier to host electrical interface design is flexible to meet typical host spacecraft interfaces, but can be tailored to meet specific host requirements, by developing a separate 3U host interface card. The generic carrier to host interface supports a redundant 28V +/- 7V input power, and RS-422 serial data interface, and Carrier Status Telemetry (CST) lines as shown in Figure 6-1.

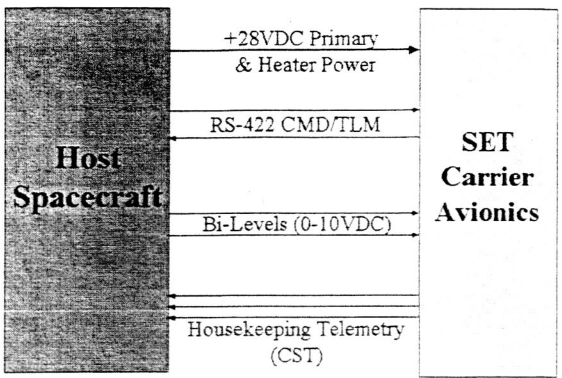

Figure 6-1 SET Carrier to Host Electrical Interface

Carrier input power lines to the CCA's and RCA's are fused at 5A, with a de-rating for maximum power at 2.5A. Input power is daisy chained via harnessing to each downstream RCA module. Each power line is filtered at the input connector and the power is diode-ored on the FFS. The power service is recombined, followed by series master Field Effect Transistor (FET) switch that is bi-level activated by the host spacecraft. A master power switch, and individual power switches are provided to the host spacecraft for activation of carrier electronics, and thermal control system, as shown in Figure 6-2.

The modular mechanical design allows for CCA's and RCA's to be integrated to a host spacecraft either independently as boxes, or as part of a integrated CCA/RCA complement mounted on an adapter plate. Structural analysis and verification through vibration testing is performed on the flight configuration for every mission.

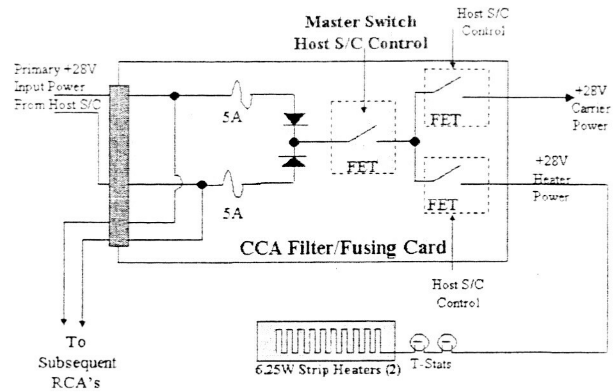

Figure 6-2: Host Spacecraft to Carrier Power Distribution

6.1 SET-1 Mission: ST8

Piggyback opportunities for ridesharing are continuously sought by the NASA Headquarters Program Executive, who represents SET, matching the available and future SET flight investigations to a potential spacecraft mission.

The first SET flight opportunity is planned for the New Millennium Program (NMP), Space Technology Mission 8 (ST8), scheduled for launch in 2007. The SET payload complement aboard ST8 would consist of up to 8 investigations housed in one CCA and one RCA, plus a CEM. . NASA is negotiating payload accommodations, and system power/mass resources, which result in a Memorandum of Agreement (MOA).

6.2 Future Missions

Subsequent SET missions are dependent upon the future identification of potential piggyback opportunities. NASA Headquarters is responsible for pursuing these opportunities, which include both US and foreign spacecraft, and launch vehicles.

7. PAYLOAD INTEGRATION & TEST (I&T)

Payload integration and test (I&T) begins with the carrier boards completing fabrication, assembly, and card-level functional test. Circuit cards are integrated with the carrier mechanical enclosure, and a system level performance test is completed. Once the carrier avionics has successfully demonstrated system level performance with mission specific, acceptance tested FSW, experiment cards are integrated with the carrier. Isolation, continuity, power, analog calibration, and signal integrity, are all measured and verified. Payload (carrier and experiments) command and telemetry mnemonic specifications are verified using the ground data system, and science data quality checks are performed by each of the experiment ground support computers. Once all mission experiments are integrated and verified operationally correct, an end-to-end mission simulation is performed to verify payload self-compatibility, through all planned experiment power and data management profiles.

Once payload level comprehensive testing is successful and complete, an environmental qualification/acceptance test is performed. Sine sweep, random vibration, & acoustic tests, electromagnetic interference/compatibility (EMI/EMC), and thermal vacuum are performed to demonstrate system level flight environment compatibility, and compliance with host spacecraft requirements.

During all phases of flight integration, flight assurance will be active in assisting the experiment, and carrier test teams with maintaining accurate flight logs and paperwork documentation of all work activities during the I&T process.

7.1 Experiment Integration

Experiment integration is performed after an experiment board or box experiment has completed a pre-ship review with GSFC. Following delivery, a post-ship functional test will be performed, including a data quality check to demonstrate that an experiment as a standalone element meets the science requirements and intended measurements. After post-delivery verification, each experiment will be integrated to the carrier through an extender break-out-card, which has a similar function of a break-out-box. Power isolation and continuity measurements are performed to verify proper power path, and grounding configurations between the carrier and experiment. Signal quality waveforms are measured across all RS-422 interfaces, and analog channels to characterize any noise. Once all interfaces have been characterized, the extender break-out-card is removed and the experiment is mechanically integrated to the carrier enclosure in flight configuration. When a box experiment is integrated, a mission unique harness will be built between the carrier enclosure and the experiment. A break-out-box will be used to perform the integration.

7.2 Ground Data System (GDS)

The ground data system (GDS) used during carrier ground testing, payload integration, and mission operations, is the Integrated Test and Operations System (ITOS). ITOS is a commercially available flight proven ground system that was originally developed at GSFC for the Small Explorers (SMEX) Program in the early 1990's. It has supported many flight missions over the years, and offers a wide array of test tools, a user friendly command/telemetry database, real time plotting, supports CCSDS standards, and includes industry standard script languages for automated functional testing.

7.3 Mission Simulations

Mission simulations begin in the I&T phase, and continues through launch site operations. Several simulated mission operational tests are performed between the payload and various ground segments, which validate end-to-end system performance and modes of operation. Rehearsal of these mission phases validates the GDS and mission planning tools with the flight payload. Mission launch and early orbit rehearsals, simulations, and end-to-end ground system testing with host spacecraft control centers are jointly conducted. Experimenters actively participate in the simulations to verify that their science data is provided correctly through all systems.

7.4 Launch Site Operations

Spacecraft and launch vehicle integration at the host spacecraft facility, or launch site is determined after a ride opportunity is formally negotiated. A launch site test plan is produced to document the roles and responsibilities of each organization. Experiment participation during launch preparations is minimal, but does require review of science data each time an experiment test is jointly performed with the carrier. Access to experiment flight hardware is restricted with the exception of removal of "remove before flight" covers.

8. MISSION OPERATIONS

Mission Operations is segmented into 6 phases as follows:

- Launch
- Early orbit and checkout of the host spacecraft
- Carrier and experiment activation
- Normal operations
- Anomaly recovery (if required)
- Flight software patches/uploads (if required) and
- Experiment and carrier deactivation

During launch, all carrier systems and experiments will be un-powered unless the SET Project negotiates power services to thermal subsystem for survival heaters.

Following spacecraft orbit insertion, and obtaining a stable power positive attitude, the carrier and experiment activation will follow, or be incorporated with the early orbit checkout of the host spacecraft. Once activation begins, the carrier will progress through its activation sequences as described in Section 8.1. When carrier and experiment activation is complete, the payload will transition to normal operations. During normal operations the carrier will support power, command and telemetry services for the experiments, through the use of on-board command sequences.

In the event of an anomaly, carrier and experiment system faults are managed by hardware and software system watchdogs, which can trip sequences to safe experiments or the carrier electrical systems. Fault records are stored within the carrier on-board memory and telemetered to the ground, for analysis, troubleshooting, and recovery operations. Ground procedures are developed during integration and test to manage faults, and recovery operations.

Following the completion of all payload activities the experiments and carrier will be deactivated. In some case this may occur long before the host spacecraft completes its primary mission.

8.1 CARRIER MODES OF OPERATION

Boot Mode

When carrier electrical power is applied, or the carrier is reset via command from the spacecraft, or by a carrier command, the payload enters Boot Mode. This is a predefined state that initializes the carrier by loading flight software from non-volatile memory, and resetting all parameters to default values, and performing built-in carrier health tests. After initialization, the carrier nominally transitions to Safe Mode. If a boot mode fault is detected during boot diagnostics, the carrier will automatically transition to Maintenance Mode.

Safe Mode

The carrier avionics enters Safe Mode after Boot Mode operation is complete, or enters Maintenance Mode based upon a system malfunction. Safe Mode is a predefined, minimum power safehold configuration in which power to experiments is removed and carrier functionality is minimized. The carrier maintains minimal, but sufficient capability to communicate with the spacecraft, maintains critical health and safety parameters (such as operating temperature and volatile memory retention), maintains watchdog timer diagnostics, and is able to transition to other operating modes. If a safety critical anomaly is detected during Operations Mode, or if the spacecraft requires non-essential power reduction, the carrier may be commanded to this mode.

Operations Mode

Operations Mode is the only mode where experiments are powered, active in science data collection, and providing science telemetry to the carrier. Normally, experiments are operated in a deterministic mode, where pre-determined command sequences and tables are pre-stored in the carrier and are executed in a time division, multiplexed fashion control by the carrier FSW.

Within Operations Mode, Experiments may be placed in *Experiment Normal Mode* or in *Experiment Standby Mode.* Operations Mode can only be entered by command from Safe Mode. In Operations Mode, default operating parameters can be modified by command.

Maintenance Mode

Maintenance mode is dedicated for patching or loading FSW from the ground, and for performing carrier system diagnostics. Maintenance Mode may be entered by command from Operational or Safe mode or automatically if a boot fault is detected in Boot Mode.

8.2 EXPERIMENT MODES OF OPERATION

"Experiment Normal" and "Experiment Standby" are the two valid operating modes for experiments, and are supported while the carrier is in Operational Mode. Experiment Normal Mode defines all the modes, and sub-modes for an experiment, that do not exceed allocated electrical power and data limits. Experiment Standby Mode is defined as minimum power mode of not to exceed 100 milli-watts, and is primarily used when the entire payload level power must be minimized. Experiments are commanded by the carrier to enter the Standby Mode, or may elect to be unpowered.

8.3 FAULT AND ANOMALY RECOVERY

Carrier and experiment system faults are managed by hardware and software system watchdogs, which can trip sequences to safe experiments or the carrier electrical systems. Fault records are stored in carrier on-board memory and telemetered to the ground, for analysis, troubleshooting, and recovery operations. Ground procedures are developed during integration and test to manage faults, and recovery operations.

9. CONCLUSION

The SET carrier is a modular and scaleable avionics system, which provides a standard mechanical, electrical, and thermal interface for a variety of science experimenters, while also providing a flexible design for typical host spacecraft interfaces. Experiments can be designed, built, tested, and integrated with the carrier prior to ever establishing a launch opportunity.

10. WEBSITE & POC INFORMATION

For Project information, please utilize the following websites with associated points of contact;

Living With A Star website: http://lws.gsfc.nasa.gov

Space Environment Testbeds website: http://lws-set.gsfc.nasa.gov

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12. REFERENCES

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