HESSI
13 Deadly Sins Review

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SPECTRUMASTRO

HESSI 13 Sins Compliance Summary

HESSI

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No.	Requirement	Status
1	There must be no devices between the spacecraft separation switch and the battery, only copper; no relays and no switches.	Comply
2	A command receiver and start-up command decoder logic must be powered directly from the battery without interrupting circuitry or switching logic such that the command receiver/decoder can never be disconnected by any method.	Comply
3	The system must provide hardwired bus undervoltage detection and load-shedding circuitry, preferably in tiered fashion, to shed loads down to the essential bus only.	Comply
4	Entry through the command receiver must always be able to execute start-up commands and all basic essential functions, including computer reset.	Comply
5	One must be able to bypass the separation circuitry independently with RF commanding.	Comply
6	Only the absolute minimum number of components may be connected to the “hardwired” essential power bus, preferably only the low power front end section of the command receiver.	Comply
7	One must be able to cycle power to the computer if necessary to perform a “bottoms-up reboot” or reset or to clear latched memory conditions.	Comply
8	No fuses are used in Spectrum Astro designs.	Comply
9	The design must provide essential hardwired command decoding and telemetry encoding that does not depend on computer software command decoding or software-based telemetry encoding.	Comply
10	The TT&C antennas must provide 4Π Steradian coverage at low bit rate to insure the command access for vehicle recovery in the event of loss of attitude.	Comply
11	The on-board computer must be completely re-programmable on-orbit.	Partial Compliance
12	The vehicle must be recoverable from a complete loss of attitude control through an automatic and manual back-up recovery sequence.	Comply
13	The system should provide encryption bypass capability that is timeout-based to preclude the possibility of encryptic failure, key problems or authentication pointer loss.	Comply

1. There must be no devices between the spacecraft separation switch and the battery, only copper; no relays and no switches.

Status: Comply

- **The Battery Is Hard Wired to the Essential Bus**

Comments:

- **The Essential Bus Is Powered at Launch and Does Not Go Through Any Relays or Switches**

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2. A command receiver and start-up command decoder logic must be powered directly from the battery without interrupting circuitry or switching logic such that the command receiver/decoder can never be disconnected by any method.

Status: Comply

- **HESSI Always Has Capability to Receive and Execute RF Commands**

Comments:

- **The Command Receiver and Communications Interface Board (CIB) are Powered from the Essential Bus and Can Not be Disconnected or Turned Off by Any Method**
- **The Command Receiver Portion of HESSI S-Band Transponder is Hard-Wired to Essential Bus, While Transmitter Portion of Transponder Can Be Commanded On and Off Via the Power Control Board (PCB)**
- **The Communications Interface Board (CIB) Provides Hardware Command Decoding for Critical Functions Including Power On/Off Control of Rad 6000 Flight Processor Board (CPU)**

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3. The system must provide hardwired bus undervoltage detection and load-shedding circuitry, preferably in tiered fashion, to shed loads down to the essential bus only.

Status: Comply

- **The HESSI Power Control Board (PCB) Provides Hardwired Undervoltage Detection and Load Shedding With Three Undervoltage Setpoints.**

Comments:

- **The Undervoltage Setpoints Shed Loads in the Following Sequence:**
  - **The First (Highest) Voltage Setpoint Provides a Signal to the Payload to Go to a Low Power Standby Mode.**
  - **The Second Voltage Setpoint Sheds the CPU, Attitude Control Hardware, and the Solid State Recorder.**
  - **The Third (Lowest) Voltage Setpoint Trips off Spacecraft Heaters and Shuts Down the Instrument.**
- **The HESSI PCB Also Has Overcurrent Detection on All of the Non-essential Bus Switches Which Shed All Loads on Their Respective Buses When a Current Threshold Is Exceeded. This Threshold Is at Least 150% of the Nominal Current, and the Overcurrent Trip Is Designed Not to Trigger on Short Duration Transients Such As Component Turn-on Inrush Currents.**
- **Both Undervoltage and Overcurrent Detection Can Be Disabled by Ground Command**
- **Undervoltage Setpoint Voltages Can Be Commanded by Ground From Nominal Values to Lower Values Designed to Match a Battery With a Single Cell Failure**

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4. Entry through the command receiver must always be able to execute start-up commands and all basic essential functions, including computer reset.

Status: Comply

Comments:

- **HESSI Always Has Capability to Receive and Execute RF Commands**
- **The Command Receiver and Communications Interface Board are Hardwired to to the Essential Bus and Can Not be Disabled**
- **Hardware Decoded Commands Provide Control of All Basic Essential Functions Including Reset of the Flight Computer**
- **Hardware Decoded Commands Control the Following Basic Essential Functions**
  - **Flight Processor Power Control**
  - **Solar Wing Release Mechanism Actuation**
  - **Telemetry Transmitter Power Control**
  - **Downlink Antenna Selection**
  - **Battery Charge Control V/T Limit Selection**
  - **Downlink Data Rate Selection**
  - **PCB Undervoltage Shutdown Disable**
  - **PCB Overcurrent Shutdown Disable**

5. One must be able to bypass the separation circuitry independently with RF commanding.

Status: Comply

Comments:

- **All Functions Which Are Initiated by Launch Vehicle Separation Can Be Controlled Via Hardware Decoded RF Commands**
- **The Functions Which are Initiated by Launch Vehicle Separation Detection Include:**
  - **Deployment of the Solar Array Wings**
  - **Turn-On of the Flight Processor and Initiation of Attitude Control and Initial Sun Acquisition**
  - **Turn-On of the Telemetry Transmitter Over the UCB Ground Station (based on time delay)**
- **Start of the Initialization Functions Can Be Verified Via Launch Vehicle Telemetry Prior to Spacecraft Separation Since They Are Initiated by Pegasus Launch Vehicle Stage 2/3 Separation**
  - **If S/C to LV Separation Used to Initiate Sequence Then First Ground Verification Would Occur at First Berkeley Pass 80 Minutes Post-Separation**

6. Only the absolute minimum number of components may be connected to the "hardwired" essential power bus, preferably only the low power front end section of the command receiver.

Status: Comply

Comments:

- **The Following Components Are Hardwired to the Essential Bus:**

S-Band Transponder	(XPD)	Command Receiver Portion Only
Communications Interface Board	(CIB)	H/W Command Decoding and Downlink Data
Payload and Attitude Control Interfaces Board	(PACI)	Hardware Telemetry Encoding
Charge Control Board	(CCB)	Battery Charge Control
Power Control Board	(PCB)	Power Distribution
Auxiliary Driver Board	(ADB)	Solar Array Release Mechanism Drive
VME DC-DC Converter		Essential +5V, +15V, -15V Power for SEM Boards
CPU DC-DC Converter		+5V Power for CPU (Controlled by PCB)

- **Components Powered by the Essential Bus are All Required for Minimum Spacecraft Operation and Commandability**
- **All Other Components Connected to Non-Essential Bus Switches Which are Automatically Shut Down Upon Under-voltage or Over-current Detection**

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7. One must be able to cycle power to the computer if necessary to perform a "bottoms-up reboot" or reset or to clear latched memory conditions.

Status: Comply

- **The HESSI Rad 6000 Flight Processor Can Be Power Cycled by Hardware Decoded Ground Command or Reset by a Watchdog Timer in the Communications Interface Board**

Comments:

- **Watchdog Timer Time-out Resets Flight Computer**
  - **Flight Computer Power Cycled If Watchdog Timer Times Out Three (3) Times**
- **Because HESSI Has a Passively Stable Sun-pointing Spin-stabilized Attitude Control System It Can Survive for Extended Periods of Time With the Flight Processor Powered Off and Active Attitude Control Disabled**
- **HESSI Can Receive and Execute Ground Commands and Generate State of Health Telemetry Even With CPU Powered OFF**

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8. No fuses are used in Spectrum Astro designs.

Status: Comply

- **HESSI Has No Fuses**

Comments:

- **HESSI Has No Fuses**

9. The design must provide essential hardwired command decoding and telemetry encoding that does not depend on computer software command decoding or software-based telemetry encoding.

Status: Comply

- **HESSI Can Receive and Execute Ground Commands and Generate State of Health Telemetry Even With CPU Powered OFF**

Comments:

- **Hardware Commanding:**
  - **RF Receive Antennas Provide Near 4p Steradian Coverage**
  - **Command Receiver and Communications Interface Board (CIB) Powered by Essential Bus**
  - **CIB Has Hardware Command Decoder Function**
- **Hardware Telemetry**
  - **PACI Encodes and Formats Hardware State of Health (SOH) Telemetry Packets From Analog and Digital Inputs**
  - **PACI Sends SOH Telemetry to CIB at 1 Hz or 8 Hz Rate (Selectable by Hardware Decoded Command)**
  - **SOH Telemetry Transmitted to Ground Whenever Telemetry Transmitter is On**
  - **Transmitter Turned On and Transmit Antenna Selected by Hardware Decoded Commands**

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10. The TT&C antennas must provide 4p Steradian coverage at low bit rate to insure the command access for vehicle recovery in the event of loss of attitude.

Status: Comply

Comments:

- **The Two HESSI Receive Antennas Provide Nearly 4p Steradian Coverage for Command Uplink. The Antennas Are Located at the Sun-facing and Anti-sun-facing Ends of the Spacecraft and Are Connected to the Command Receiver Input of the Transponder Via an RF Combiner. Combining the Signals From the Two Antennas Results in Some Antenna Nulls at Certain Aspect Angles, but the Ground Station Transmitter Can Provide Enough Power to Achieve Positive Link Margin in Nearly All Cases.**
- **The HESSI Transmit Antennas Are Also Located on the Sun- and Anti-sun-facing Ends of the Spacecraft. To Ensure Positive Link Margin at the Nominal 4 Mbps Downlink Data Rate an RF Switch Is Used to Select Between Transmit Antennas. The Switch Eliminates Nulls in the Antenna Pattern Because the Two Antennas Can Not Produce Signals Which Interfere With Each Other. Normally the Antenna Selection Is Done by Time-tagged Command Sequences Loaded by Ground Control. Each Individual Transmit Antenna Has >2p Steradian Coverage.**
- **In a Contingency Scenario the Ground Can Always Command the HESSI Spacecraft. The Commands to Turn on the Telemetry Transmitter and to Select the Downlink Antenna Are Hardware Decoded Commands Which Do Not Require the CPU to Be on. The C&DH Subsystem Generates Hardware Encoded Telemetry Data (Including Voltages, Currents, Temperatures and Hardware Status) at All Times Without Requiring the CPU to Be on.**

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11. The on-board computer must be completely re-programmable on-orbit.

Status: Partial Compliance

- **Flight Software Runs From RAM on Rad6000 CPU Board and Can be Modified in Flight, But Reset of CPU Reverts Back to EEPROM FSW Image Which is Read-only in Flight**

Comments:

- **Rad 6000 Has Two Distinct FSW Images**
  - **Primary FSW Image in EEPROM; Jumped Read-Only Before Launch**
  - **RAM Image Is Used for Operational Stored Telecommand Sequences and to for modified uploaded FSW Image**
- **Booting FSW Image**
  - **EEPROM FSW Image Is Always Default Boot Image**
  - **Boot From RAM Image Only Via Ground Telecommand**
- **Reprogramability**
  - **FSW Image Is Partitioned for Reprogrammability in Flight**
  - **Partitioning Allows a Single Part of RAM FSW Image to Be Replaced in Flight**
  - **FSW Bootloader Manages Loading the Partitioned Image**

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12. The vehicle must be recoverable from a complete loss of attitude control through an automatic and manual back-up recovery sequence.

Status: Comply

Comments:

- **HESSI Has Passively Stable Sun-pointed Spin Stabilized Attitude Control. HESSI Has No Thrusters or Momentum Wheels Which Could Perturb the Sun-pointing Attitude. The Only Attitude Control Actuators Are Magnetic Torque Rods.**
- **Once HESSI Achieves Sun Pointing Attitude Control the Nominal Configuration Is More Robust Than the Typical Safe Hold Mode of Other Spacecraft.**
- **The Primary Response to a Failure in the Attitude Control Subsystem Is to Disable Torque Rod Drive and Allow the Ground to Diagnose and Recover the Spacecraft. Without Active Torque Rod Control HESSI Will Remain Inertially Pointed and Power Positive for up to 60 Days (With the Payload in Standby Mode)**
- **Because of the Low Control Authority of the Magnetic Torque Rods, the Initial Sun Acquisition After Separation From the Launch Vehicle Is Critical. Simulation Results Show That HESSI Can Successfully Acquire the Sun With Worst-case Tip-off Rates and a 180° Initial Pointing Error at Separation.**

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13. The system should provide encryption bypass capability that is timeout-based to preclude the possibility of encryptic failure, key problems or authentication pointer loss.

Status: Comply

Comments:

- **HESSI Has No Encryption on Command or Telemetry.**

HESSI Design Overview

SPACECRAFT BUS OVERVIEW

Mission

- Investigate physics of particle acceleration and energy release in solar flares
- Hard X-ray imaging spectroscopy
- Gamma-ray spectroscopy
- Fourier-transform imaging with 9 bi-grid modulation collimators
- Cooled germanium detectors

Thermal Control

- Passive, cold-biased system using local radiators
- Thermostatically controlled heaters designed with 25% control authority margin
- Standard Kapton etched foil strip heaters

Attitude Control

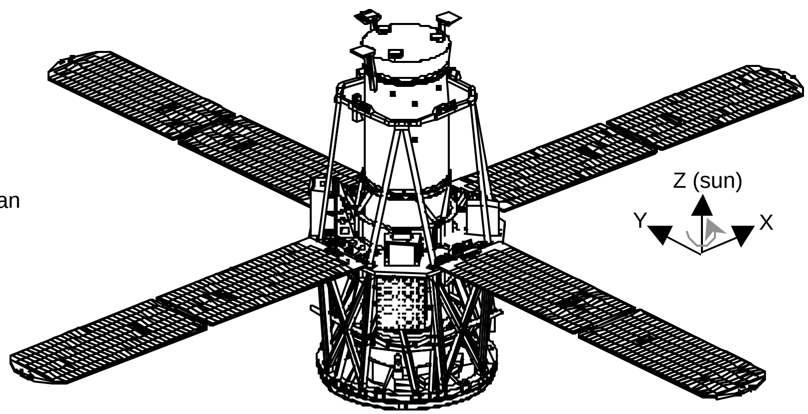
- Autonomous sun acquisition using 4π steradian coarse sun sensors and magnetometer
- Spin stabilized at 15 RPM
- Sun pointing knowledge of 0.09° or better
- Closed loop rate and pointing control
- Instrument SAS provides backup pointing

Telecommunications

- S-band telecommunications
  - 2.0 kbps uplink at 2040 MHz
  - 4.0, 1.0 Mbps and 125 kbps downlink at 2215 MHz
- All omni antennas
- Downlink antennas are switched to allow selection of optimal antenna and eliminate nulls due to antenna interference
- 8.7 Gigabits of science data downlinked per 24 hour period

Spacecraft Mass

Spacecraft Bus CBE	136.2 kg	
Implementation Margin	8.2 kg	(6.0%)
Spacecraft Bus	144.4 kg	
Instrument CBE	125.3 kg	
Implementation Margin	27.7 kg	(22%)
Instrument	153.0 kg	
Spacecraft	297.4 kg	
Pegasus Capability	331.3 kg	
LV Contingency	33.9 kg	(11%)



Command & Data Handling

- Flexible, flight-proven, VME-based architecture
- Rad6000 processor
- 20 MHz CPU
- 4.0 Gigabyte Solid State Recorder
- Commanding and SOH telemetry available without CPU

Mission Parameters

- Mission Life = 3 years
- Altitude = 600 km
- Inclination = 38°
- Orbit Period = 96.68 minutes
- Max eclipse = 35.5 minutes
- $0° < \beta < 61°$
- Approximately 17,000 eclipse cycles

Launch Vehicle

- Designed for compatibility with Pegasus XL
- Mass margins consistent with Pegasus XL

Structure & Mechanisms

- Open structure allows access to components
- Al honeycomb/Al facesheet deck structure
- Imager support ring, central cylinder, and strut system provide load path to LV adapter
- Inertia mass located on solar array wing tips to achieve Is/It > 1.1
- Inertia adjustment devices used on orbit to align principal axis with instrument axes

Electrical Power

- (4) deployable, non-articulationg solar array wings
- Si solar cells with 5 mil coverglass
- 1.27 cm [0.50"] Al honeycomb/Graphite facesheet substrates
- Solar array produces 505 W at 3 years
- Single CPV 15 A-hr NiH_2 battery
- Unregulated 28 +6/-4 V
- Regulated ±15V, and ±5V

SPACECRAFT BUS DIMENSIONED PLAN VIEW

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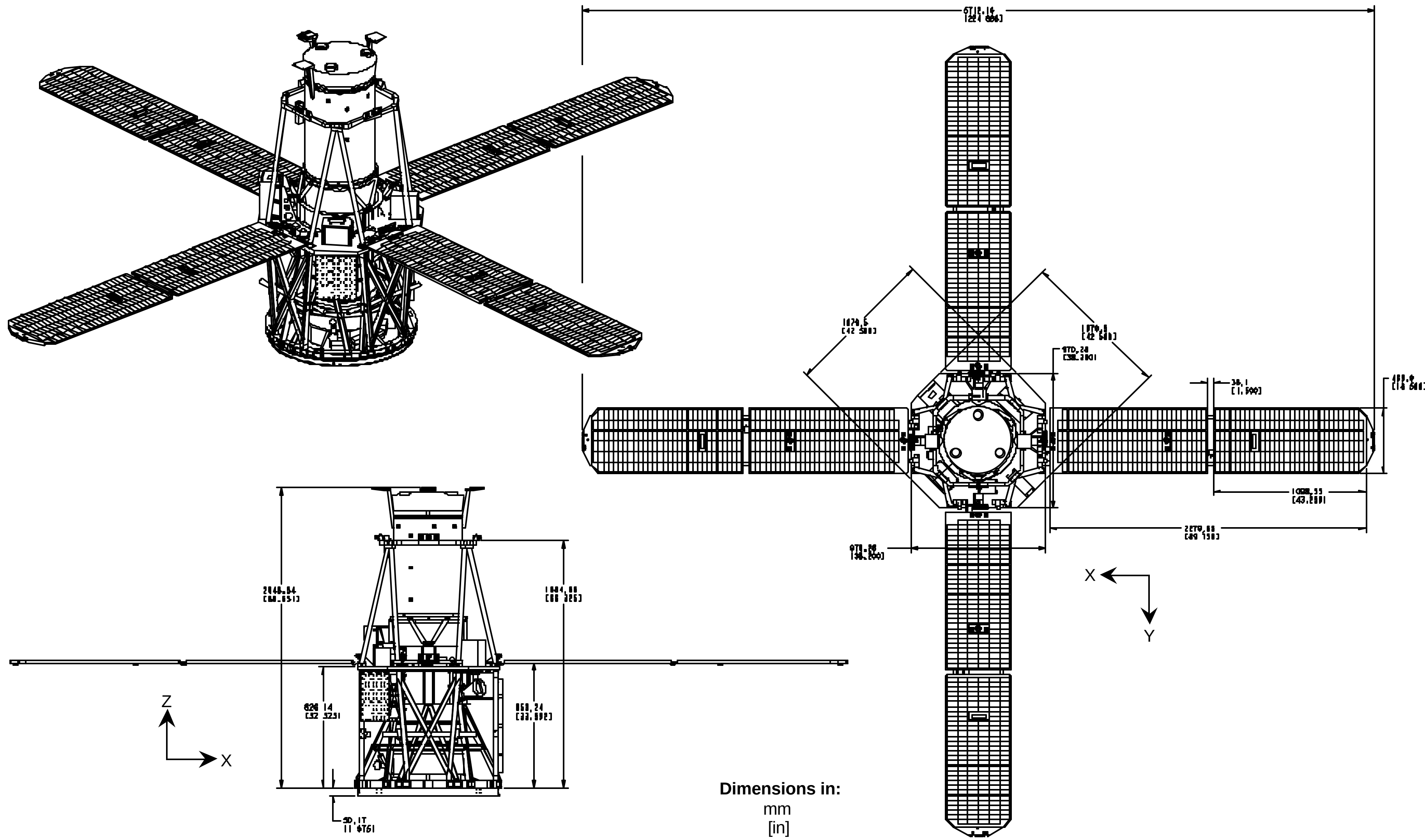
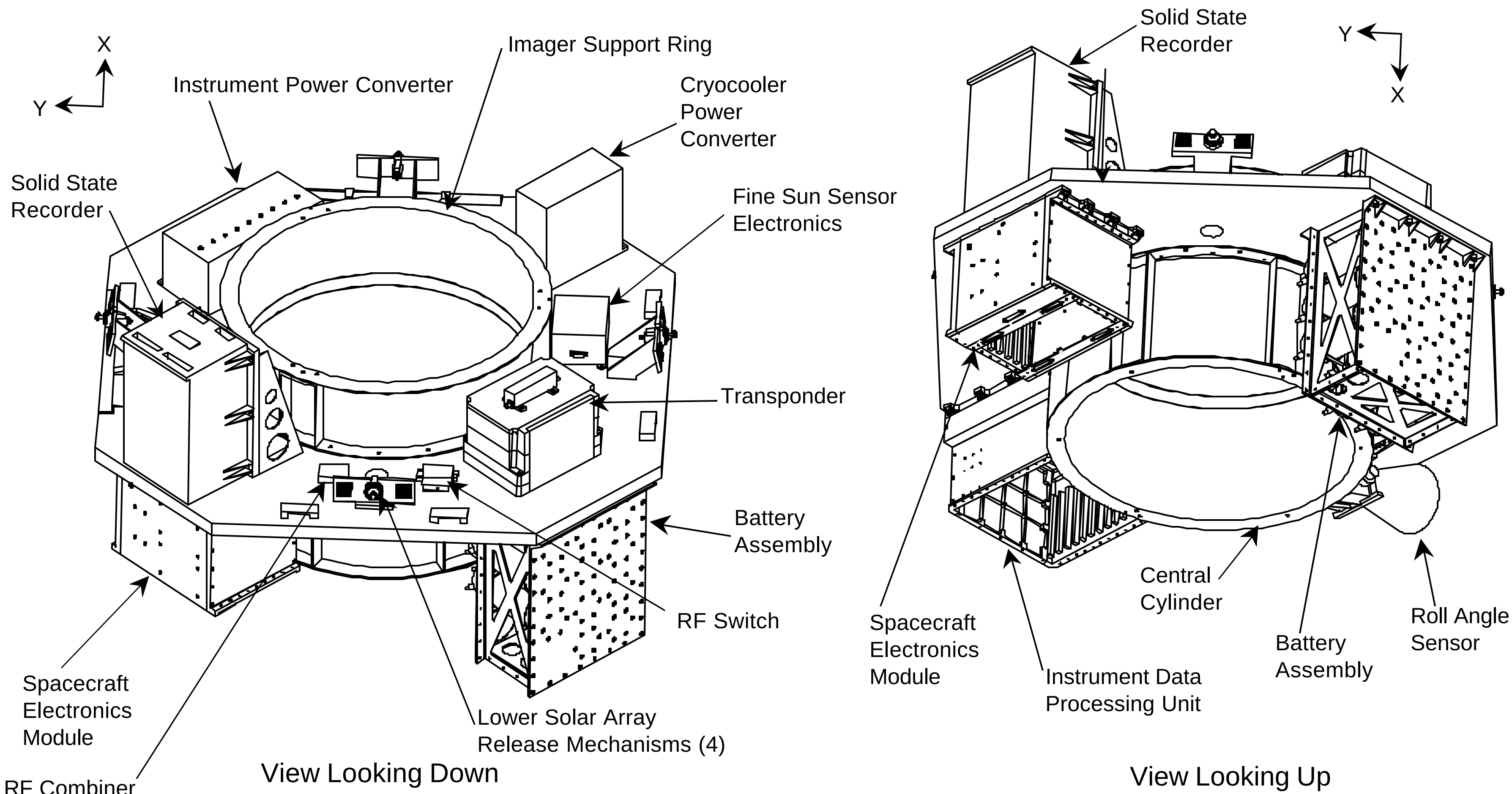


Dimensions in:
mm
[in]

EQUIPMENT DECK LAYOUT



View Looking Down
(Sun-Side of Equipment Deck)

View Looking Up
(Shade-Side of Equipment Deck)

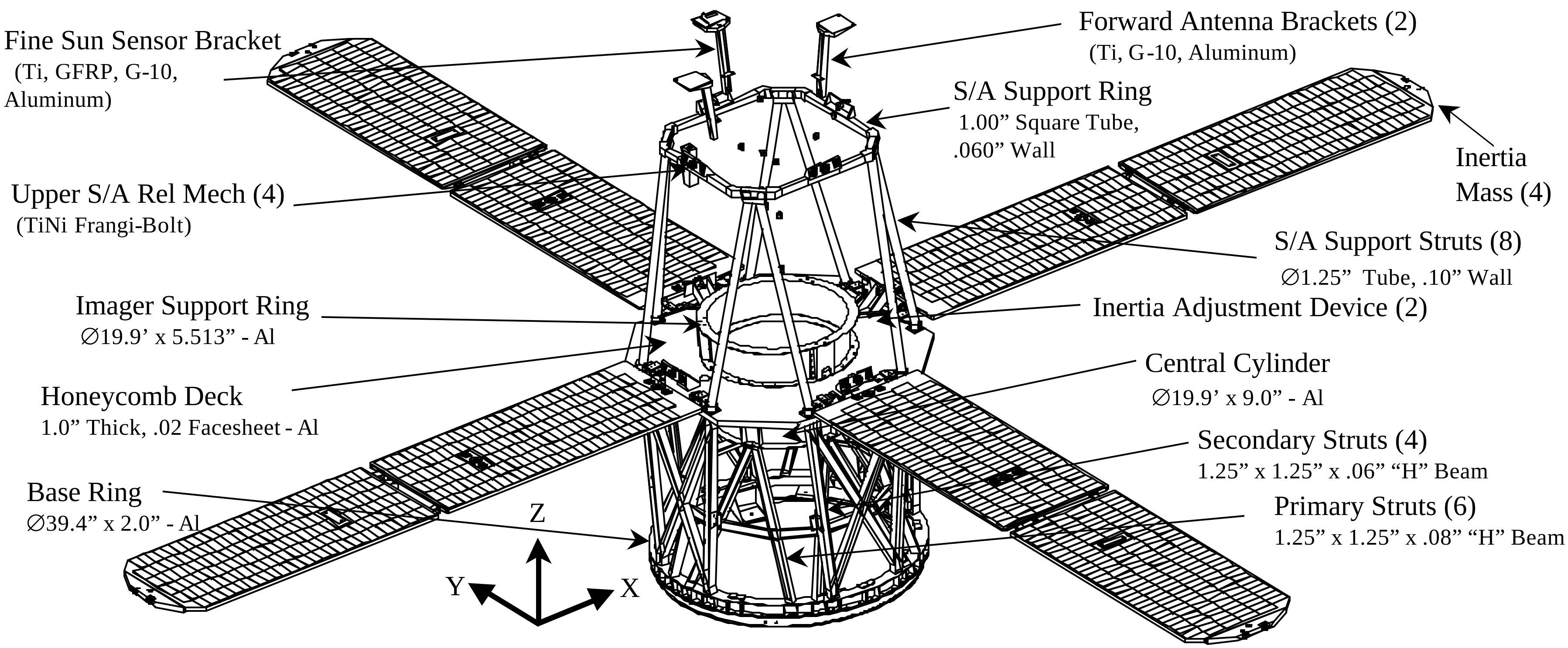
BUS STRUCTURE & MECHANISMS

Design:

- ∅39.4" Base Ring Provides L/V & Spectrometer I/F
- 1.25" x 1.25" "H" Beam Cross-Section Struts
- 1.0" AL-Honeycomb Deck Supports Electronic Boxes
- ∅19.9" x 0.10" Thick Ring Provides Imager Interface
- ∅1.25" x 0.06" Thick Tube Supports Solar Arrays
- Standard 38.81" L/V Interface with 1.0" to L/V Envelope
- Supports 160 kg of Payload
- Supports All Payload & S/C Field-of-View Requirement
- Spin-Stabilized with Is/It> 1.1
- On-Orbit Spin Axis Adjust-ment up to 12° with .002° Resolution

Features:

- Open Design Provides Access During I&T and Clear View for Secondary Science Objective
- Solar Array Substrates Insensitive to Thermal Gradient



ATTITUDE CONTROL SUBSYSTEM ON-ORBIT CONFIGURATION

Control System Objective

Initialization:

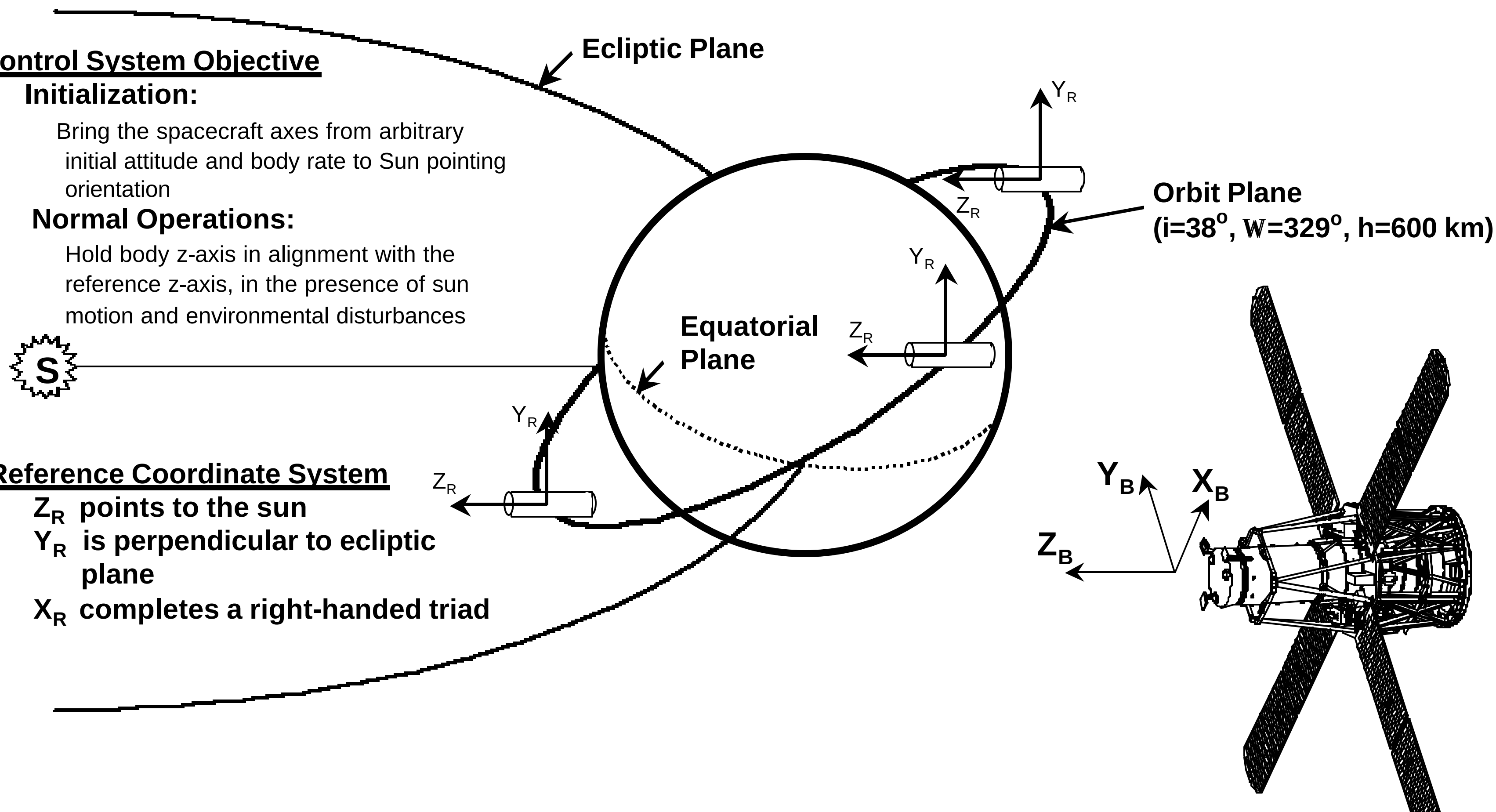
Bring the spacecraft axes from arbitrary initial attitude and body rate to Sun pointing orientation

Normal Operations:

Hold body z-axis in alignment with the reference z-axis, in the presence of sun motion and environmental disturbances

Reference Coordinate System

- Z_R **points to the sun**
- Y_R **is perpendicular to ecliptic plane**
- X_R **completes a right-handed triad**



Spacecraft Body Coordinate System

HESSI Electrical Power Subsystem

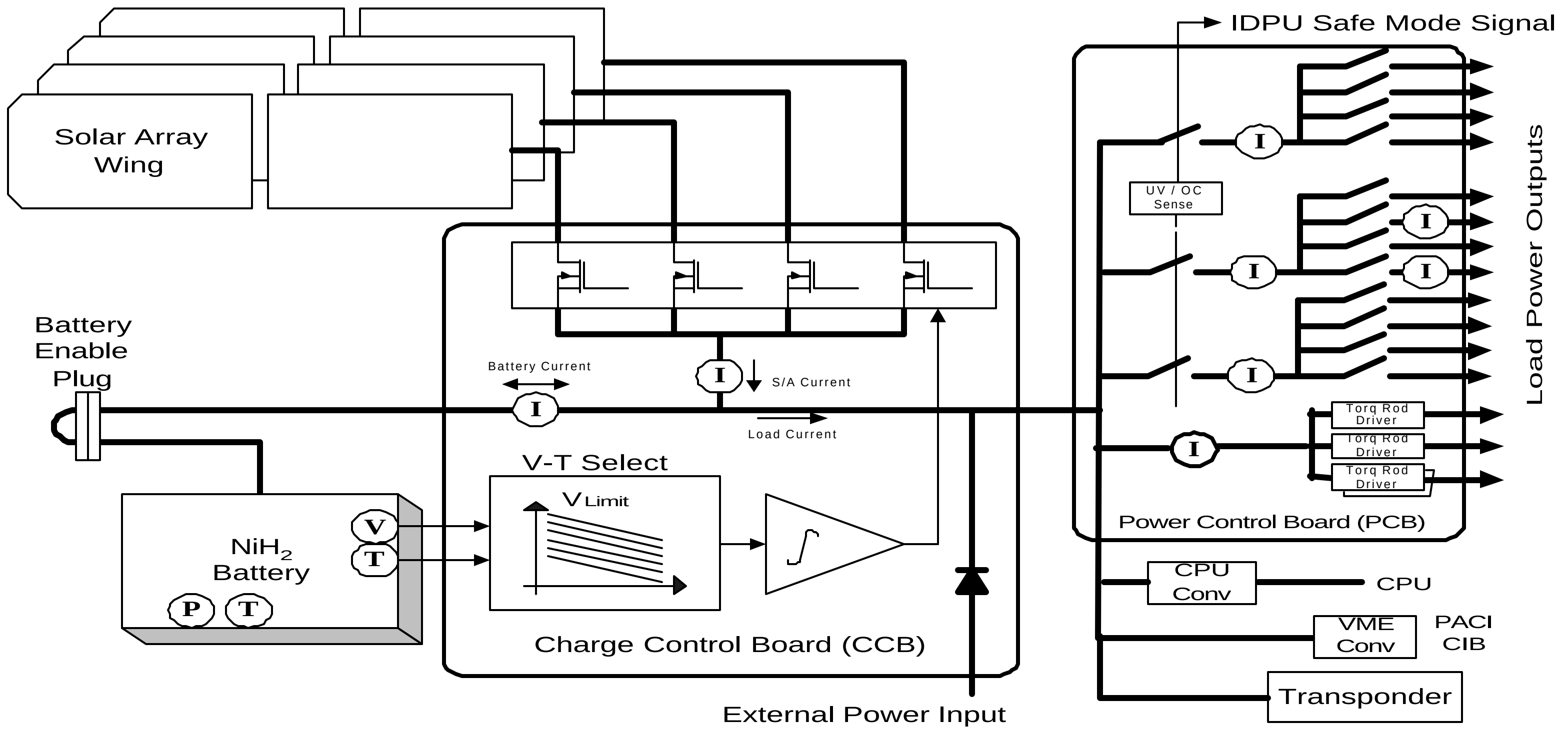
ELECTRICAL POWER SUBSYSTEM

Design:

- 24 - 34 Vdc Power Bus
- 505W EOL Silicon Solar Array
- Four deployable, non-articulating solar array wings
- 15 Ahr Battery, 11 CPVs, Temperature & Pressure Telemetry
- 16 Selectable V/T Charge Control with default setting
- Bus Impedance < 200 mOhm

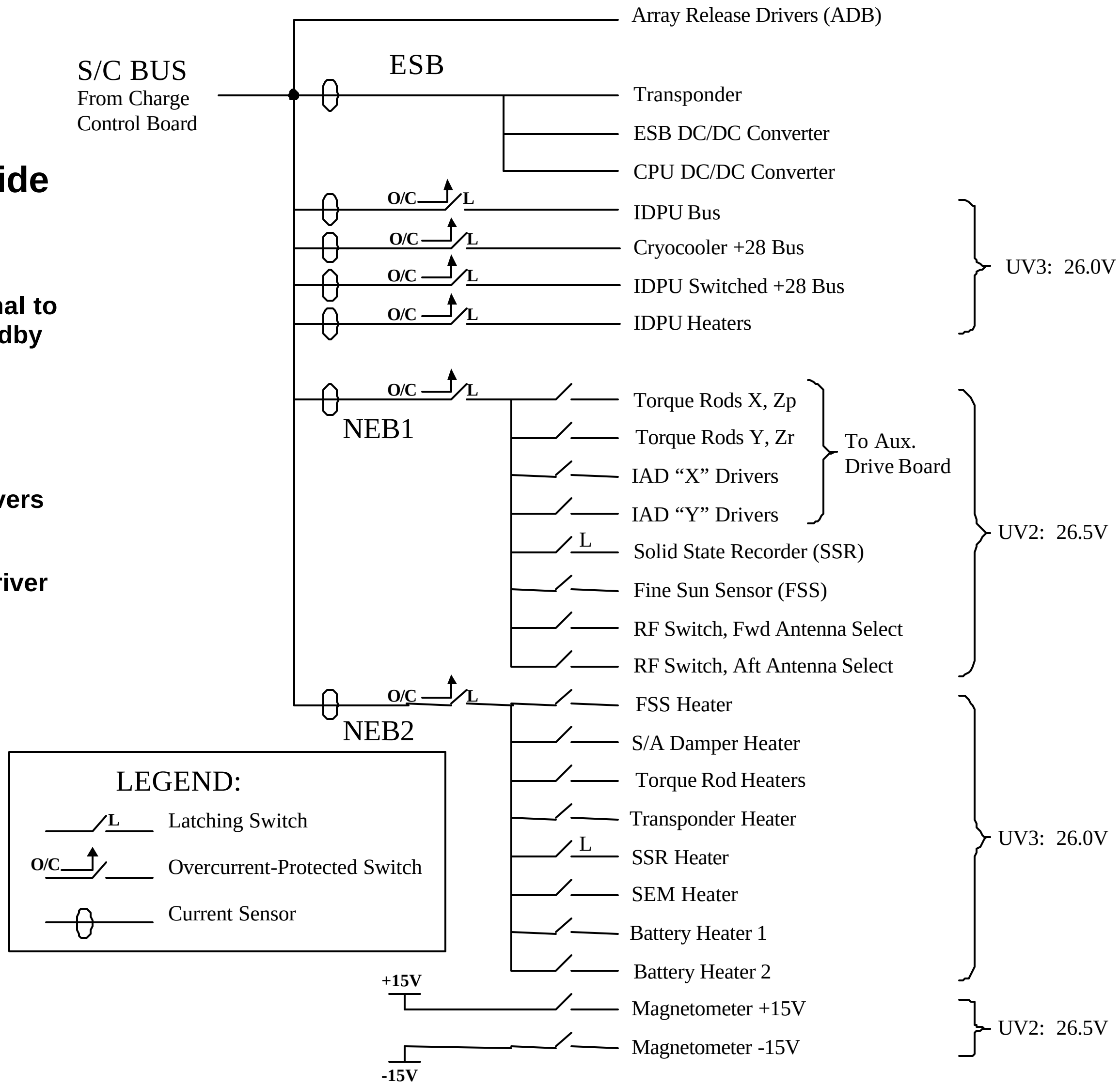
Features:

- 98% EPS Efficiency, DET Battery Dominated Bus
- 65% EOL Solar Array Margin, nominal operating loads
- 21% EOL Solar Array Margin, NTE operating loads
- 89% EOL Battery Energy Storage Margin, nominal operating loads
- 47% EOL Battery Energy Storage Margin, NTE operating loads
- CCB / PCB Integrated Within Spacecraft Electronics Module
- Undervoltage and Overcurrent load shedding on Non Essential Bus
- Primary / Secondary ground isolation
- Single Point Ground



PCB Load Switching

- Power Control Board Provides Power to All S/C Loads
- Three Undervoltage Trips Provide Tiered Load Shedding:
  - UV1: 26.7V
    - Activate IDPU "Safemode" Signal to Put Payload in Low Power Standby Mode
  - UV2: 26.5V
    - Turn Off NEB1 Loads:
      Torque Rod Drivers
      Inertia Adjust Device Motor Drivers
      Solid State Recorder
      Fine Sun Sensor
      Transmit Antenna RF Switch Driver
    - Turn Off Magnetometer
    - Turn Off CPU
  - UV3: 26.0V
    - Turn Off Payload
    - Turn Off NEB2 S/C Heaters
- NEB Bus Switches and Payload Power Switches Have Overcurrent Shutdown
  - Bus Switches Open if Current >150% Max Expected Values



HESSI Telemetry & Command

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HESSI Telecommunications Subsystem

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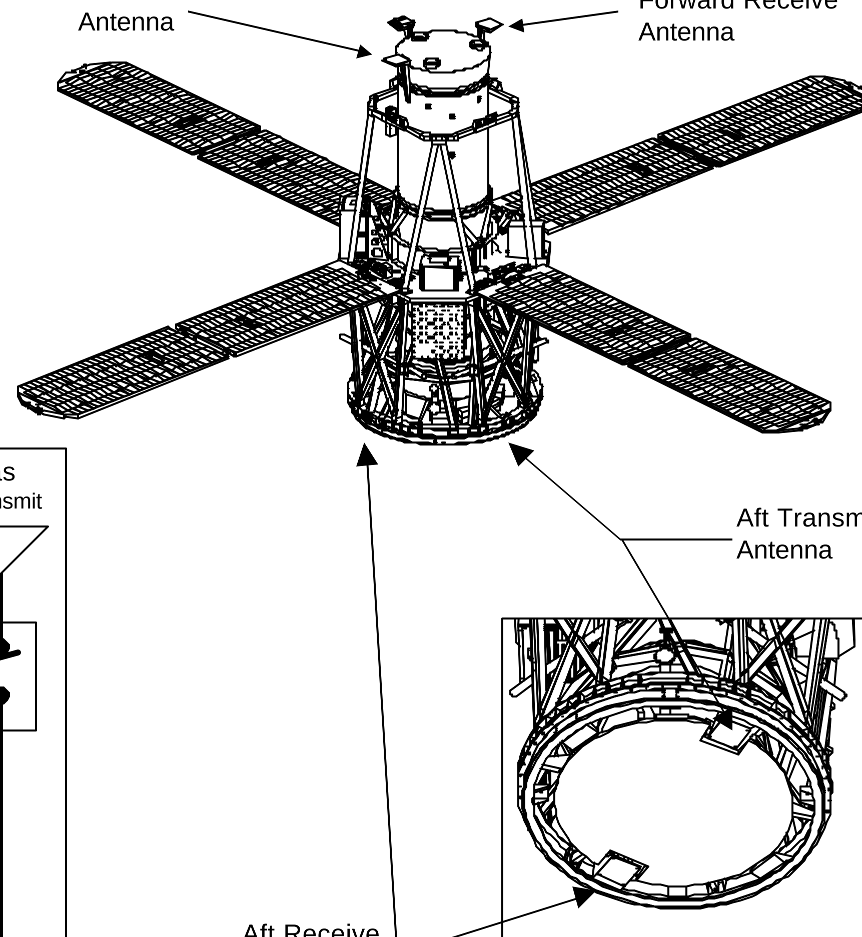
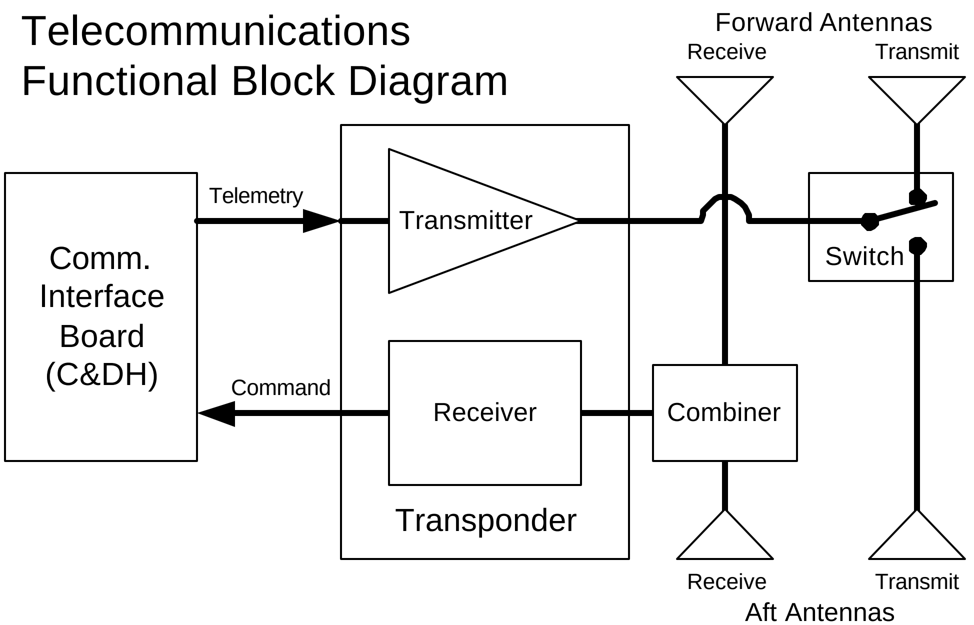
Key Features :

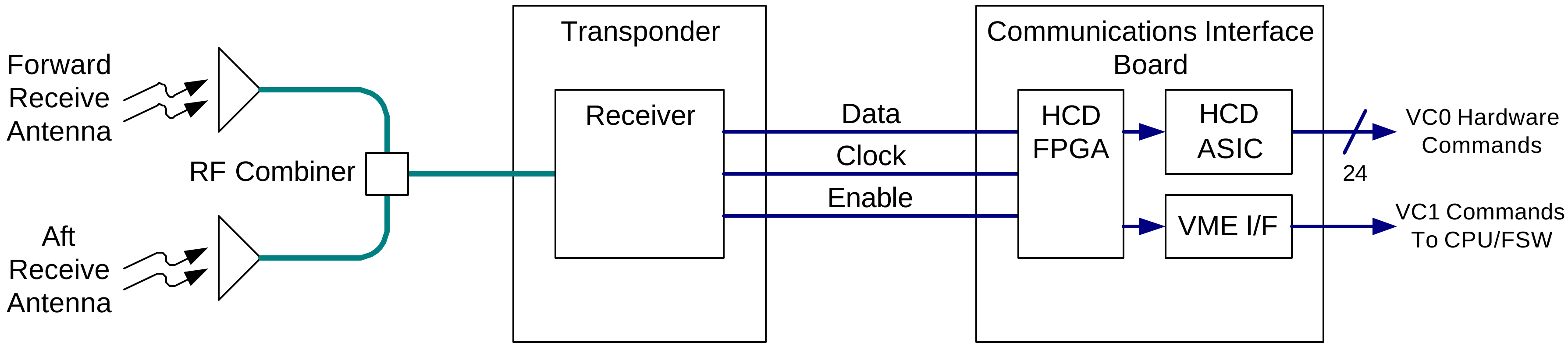
• Transmitter Output Power	5 Watts
• Downlink Datarates	4 Mbps, 1Mbps, 125 kbps
• Uplink Frequency	2039.6458 MHz
• Downlink Frequency	2215 MHz
• Receive Acquisition Range	+/- 120 kHz
• Receive Tracking Range	+/- 150 kHz
• Uplink Datarate	2 kbps
• Receive Sensitivity	-113 dBm



Telecommunications Functional Block Diagram



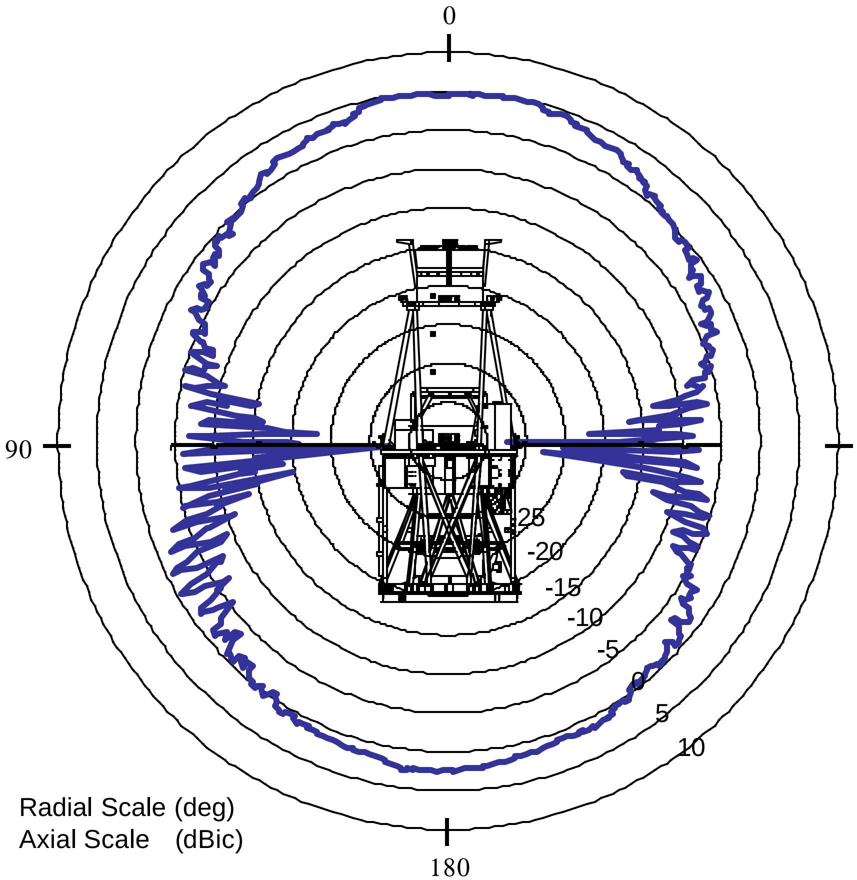
Hardware Command Path



- **Hardware Commands from Ground Can Always Be Executed by C&DH**
  - **Receiver Portion of Transponder and CIB Always On**
  - **Hardware Command Decoding Does Not Depend on CPU or Flight Software**
- **RF Commands from Ground Can Be Received by Either Antenna**
- **Receiver Portion of Transponder Provides Command Data to Communications Interface Board (CIB)**
- **CIB Decodes Hardware Commands (Virtual Channel 0) and Sets State of 24 Hardware Command Outputs**
  - **Hardware Command Outputs Control CPU On/Off Status, Telemetry Transmitter, Transmit Antenna Selection, Downlink Data Rate, SOH Telemetry Frame Rate, Battery Charge V/T Curve Selection, and Solar Wing Release Actuators**
- **All Other Commands (Virtual Channel 1) Forwarded to CPU and Flight Software for Processing Via VME Interface**

Uplink Antenna Coverage

- **Positive Link Margin at 5° Ground Station Elevation Angle to -31.48 dB Antenna Gain**
- **4p Steradian Command Uplink Coverage At Higher Elevation Angles (Additional 12dB at 90° Elevation)**

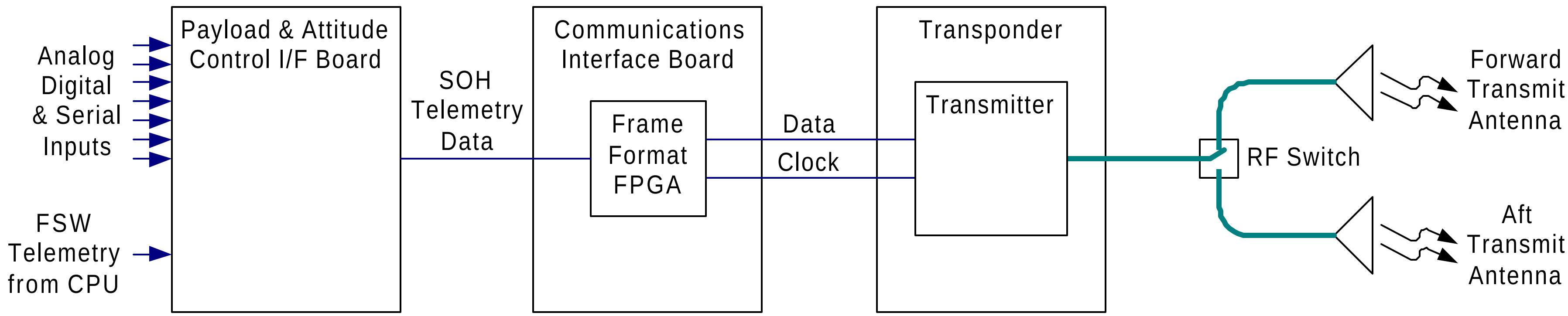


Radial Scale (deg)
Axial Scale (dBic)

Uplink Budget

Groundstation Parameters	
Uplink Frequency	2039.65
HPA Output Power (Watts)	50.00
HPA Output Power (dBW)	16.99
Antenna Gain (dBi)	44.83
Cable Loss (dB)	1.00
Pointing Loss	0.50
Transmitted EIRP (dBW)	60.32
Link Parameters	
Elevation Angle (deg)	5.0
Range Loss (dB)	166.24
Rain + Atmospheric (dB)	1.00
Polarization Loss (dB)	0.10
Sum of Uplink Losses (dB)	**167.34**
Spacecraft Losses (dB)	4.50
Receiver Input Power (with antenna gain=0dB, dBm)	**-81.52**
Sensitivity for 10-7 BER @ 1 rad modulation index (dBm)	-113.00
Carrier Acquisition Sensitivity (un-modulated)	-116.00
Minimum Antenna Gain for Carrier Acquisition	**-34.48**
Minimum Antenna Gain for 10-7 BER	**-31.48**

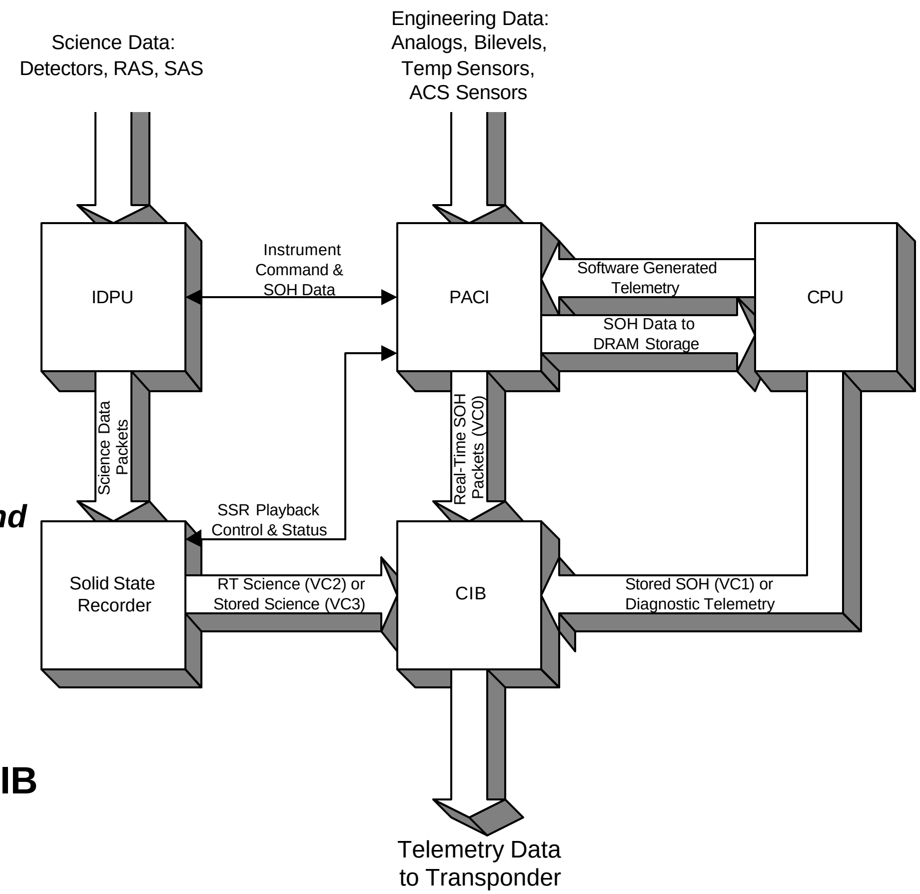
Hardware Telemetry Path



- **PACI Collects State of Health (SOH) Data Via Analog, Digital and Serial Inputs and Generates SOH Telemetry Packet**
  - **If CPU is On, CPU Writes Flight Software SOH Telemetry to PACI SOH Telemetry Packet**
  - **FSW Changes AP ID in SOH Telemetry to Indicate That FSW Data is Included in Packet**
  - **PACI Generates SOH Packets 1Hz or 8Hz Rate (Ground Commandable)**
- **CIB Frame Formatter Adds Header and Reed-Solomon Code to SOH Data**
  - **CIB Interleaves PACI SOH Telemetry Packets With Stored Telemetry Packets and Diagnostic Telemetry Packets From CPU and Science Data Packets From Instrument if These Components Are On**
- **CIB and PACI Always Produce SOH Telemetry and Send it to Transponder**
  - **SOH Telemetry Data Available to Ground Whenever Transmitter is On**
- **Receipt of Telemetry on Ground Does Not Depend on CPU or Flight Software**
  - **Transmitter On/Off and Transmit Antenna Select RF Switch Controlled by Hardware Decoded Commands**

TELEMETRY DATA FLOW

- **Telemetry Data Virtual Channel Definitions:**
  - **VC0: Real-Time SOH**
    - ***Data Collected and Assembled by PACI***
    - ***Includes FSW Generated Data from CPU and Instrument SOH from IDPU***
    - ***Generated at 1 Hz or 8 Hz Rate (Ground Commandable)***
  - **VC1: Stored SOH and Diagnostic Data**
    - ***VC1 Data Generated by Flight Software***
    - ***RT SOH Data Stored in CPU DRAM***
    - ***SOH Data Packets Stored at 0.1 Hz Rate***
  - **VC2: Real-Time Science**
  - **VC3: Stored Science**
    - ***All Science Data Packets Generated by IDPU and Stored in SSR***
    - ***Control of SSR Read-Out Pointer Determines Whether Data is Real-Time or Stored***
  - **VC7: Fill**

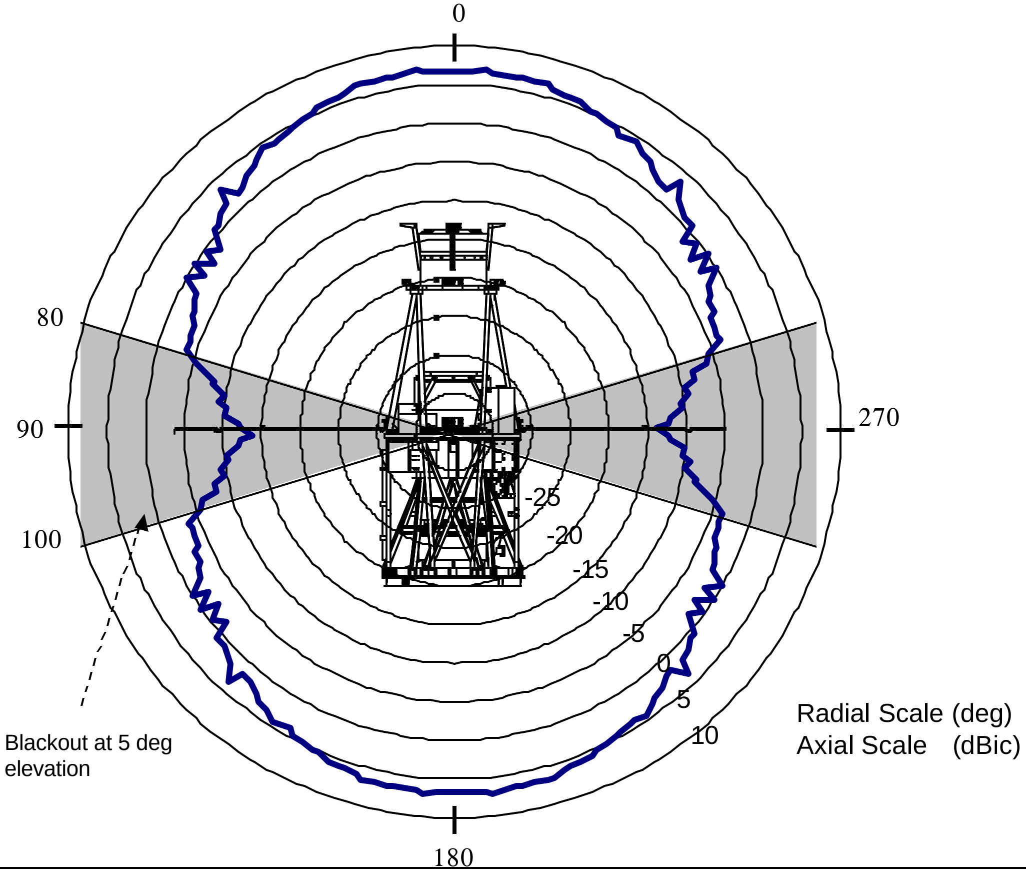


- **All Telemetry Data Routed to Transponder Via CIB**
  - **CIB Determines Priority for Each Telemetry Type**

- **VC0 Hardware Encoded Telemetry Data Available Even if CPU is OFF**

RF DOWNLINK BUDGET AND ANTENNA COVERAGE

- **Negative Link Margin at 4 Mbps Data Rate With 5° Ground Station Elevation Angle for S/C Aspect Angles 90°±10°**
- **Positive Margin at All S/C Aspect Angles When Ground Station Elevation Angles >18° at 4 Mbps or at 5° Elevation with 125 kbps rate**



Downlink Budget

Spacecraft Parameters	
Downlink Frequency (MHz)	2.215E+09
Transmitter Power Out (Watts)	5.0
Transmitter Power Out (dBW)	6.99
Spacecraft Component Losses (dB)	**2.50**
Power into Transmit Antenna (dBW)	4.49
Antenna Gain (for 80° look angle, dB)	-8.00
Transmitted EIRP (dBW)	**-3.51**
Link Parameters	
Elevation Angle (deg)	5.0
Range Loss (dB)	166.96
Pointing Loss (Ground Station)	0.50
Rain + Atmospheric (dB)	1.00
Polarization Loss (dB)	0.10
Sum of Downlink Losses (dB)	**168.56**
Groundstation Parameters	
Received Power (dBW)	-172.07
Receive G/T (dB)	21.00
Boltzmans Constant (dBW/K-Hz)	-228.60
Receiver Implementation Loss (dB)	1.50
Datarate (bps)	4.00E+06
Datarate (dB-bps)	6.60E+01
Downlink bit error rate	1.00E-06
Required Eb/No	8.00
Downlink Margin (dB)	**2.01**

LAUNCH AND EARLY OPERATIONS

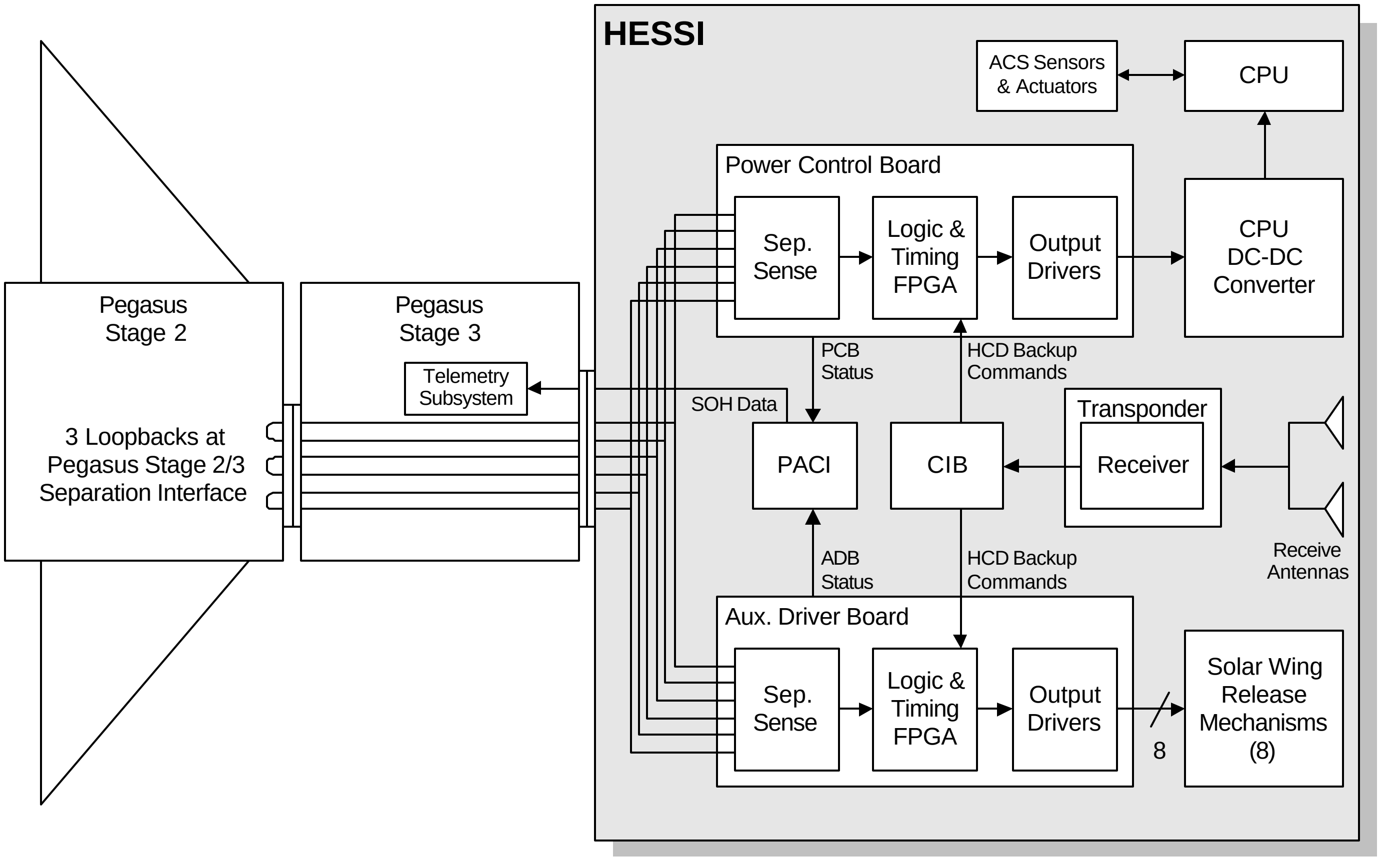
Launch Vehicle Separation Detection and Monitoring

SPECTRUMASTRO

HESSI
HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER

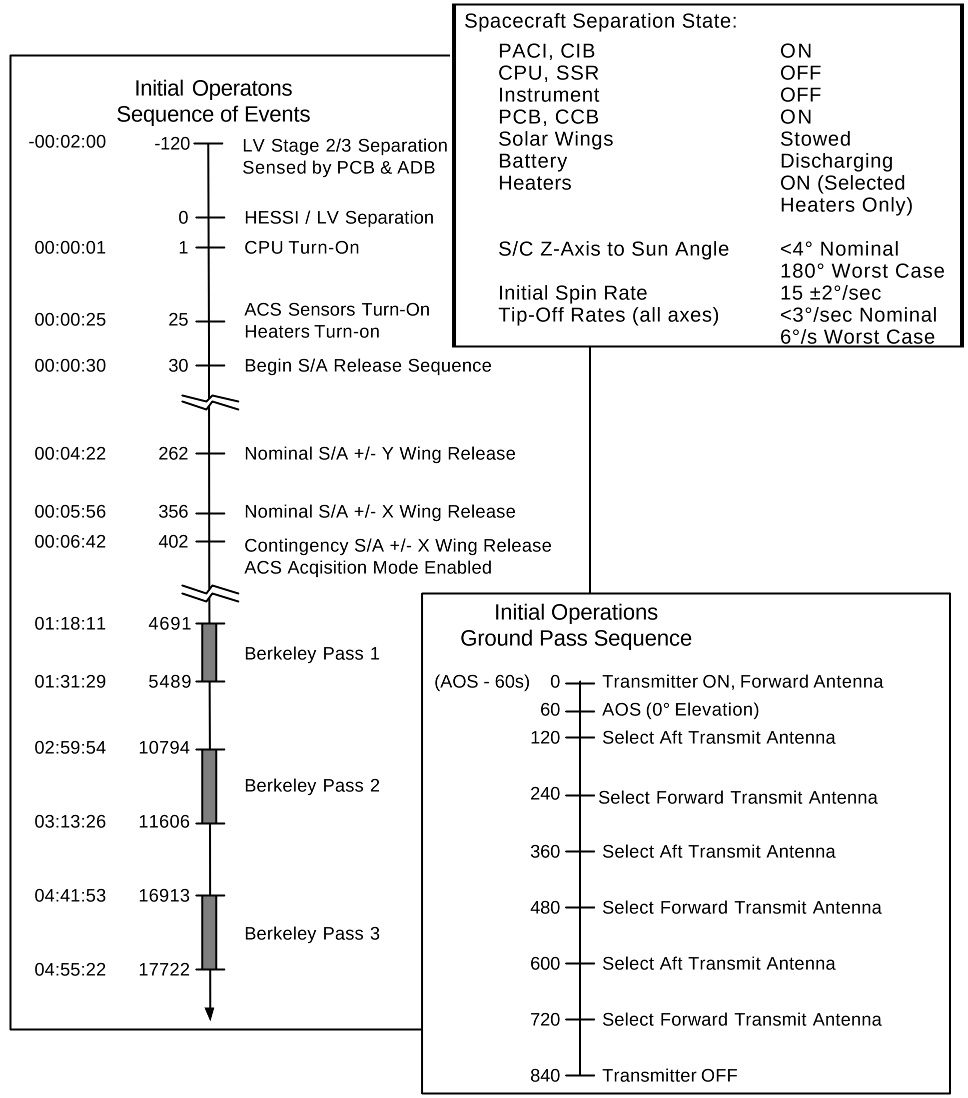
HESSI Senses Separation Via Loopbacks in the Launch Vehicle Harness at the Stage 2 to Stage 3 Separation Interface Which Initiates the Post-separation Initialization Sequence

- **Stage 2/3 Separation Was Selected to Initiate Initialization Sequence (Instead of Stage 3/Spacecraft Separation) to Provide Ground Visibility of HESSI Wake up Via Pegasus Telemetry Stream**
- **Three (3) Redundant Separation Sense Loopbacks: Any Two of Three Separation Loops Open Initiate Sequence**
- **Sequence Timing Controlled by FPGAs in Power Control Board (PCB) and Auxiliary Driver Board (ADB) and by Flight Software**



LAUNCH AND EARLY OPERATIONS TIMELINE

- **Spacecraft Dormant Until Separation From Launch Vehicle**
  - **Only Essential Bus Components Powered ON**
- **PCB Senses Separation and Turns On CPU**
- **ADB Senses Separation and Initiates Solar Wing Deployment After 2 Minute Delay**
  - **Separation Indicated at LV Stage 2/3 Separation by 2 of 3 Umbilical Loopbacks Open**
  - **Ground Sees CPU Turn-On and ADB Separation Sense via Pegasus Telemetry**
  - **Ground Can Override Separation Indicators by Command**
- **Flight Software Running on CPU Turns On Heaters and ACS Components and Begins Attitude Control Operations**
  - **Instrument Heaters Powered ON When Positive Power Balance Achieved**
- **FSW Sequence Turns on Transmitter and Toggles Between Forward and Aft Antennas During Initial Passes**
- **Ground Control Initiates Spin Up to 15 RPM Once Sun Pointing is Achieved**
- **Ground Control May Begin Adjustment of Spacecraft Balance After Spin Up to 15 RPM**

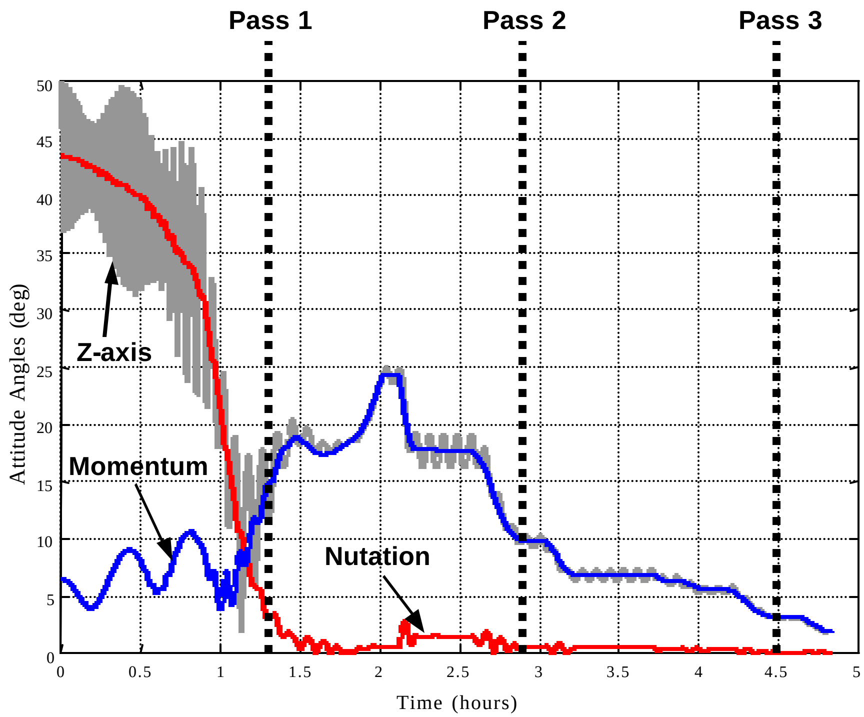


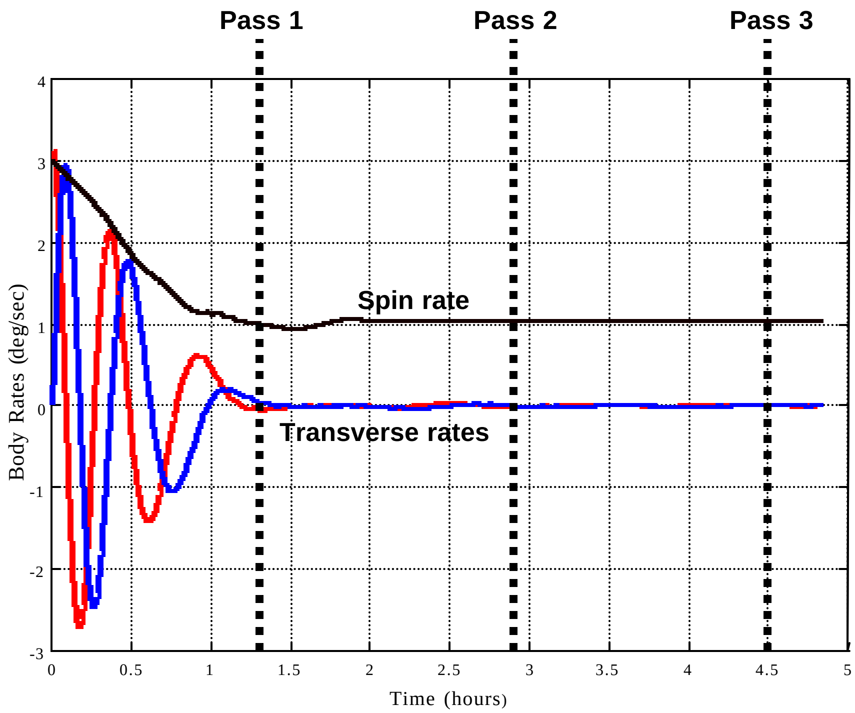
ATTITUDE CONTROL SUBSYSTEM
NOMINAL SUN ACQUISITION

SPECTRUMASTRO

HESSI
HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER

- **LV Tip-Off Conditions: Momentum vector within 10 deg of Sun**
  4 deg/sec transverse rate
  15 deg/sec spin rate
- **30-second array deployment with 2-second delay between arrays adds 2° of additional nutation**
- **Initial 2 hour Acquisition Mode ("B-dot" law) establishes spin rate and damps transverse rates**
- **FSS utilized when Sun cone angle is within 32 degrees**
- **30-minute eclipse once per orbit with precession control disabled**



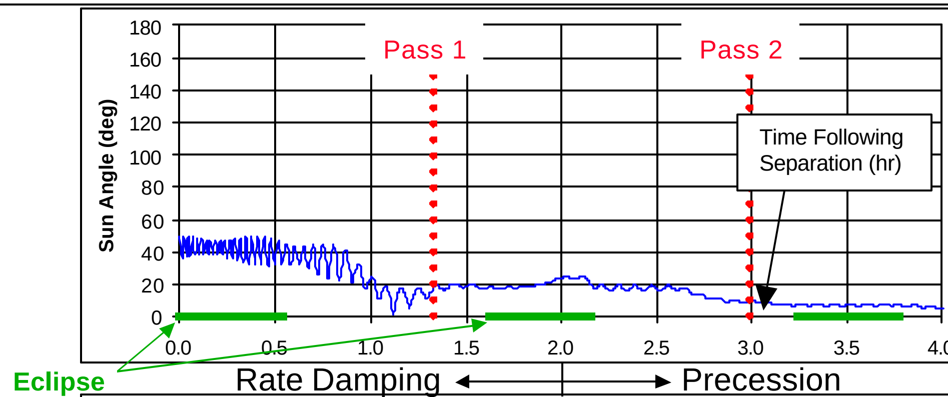


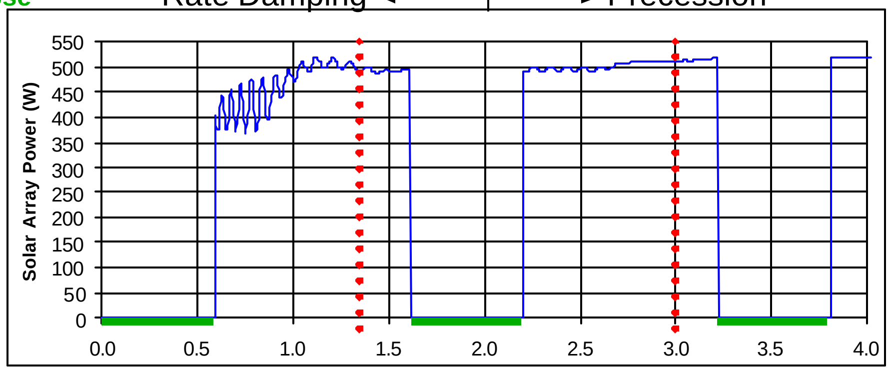
LAUNCH AND EARLY ORBIT POWER NOMINAL ACQUISITION CONDITIONS

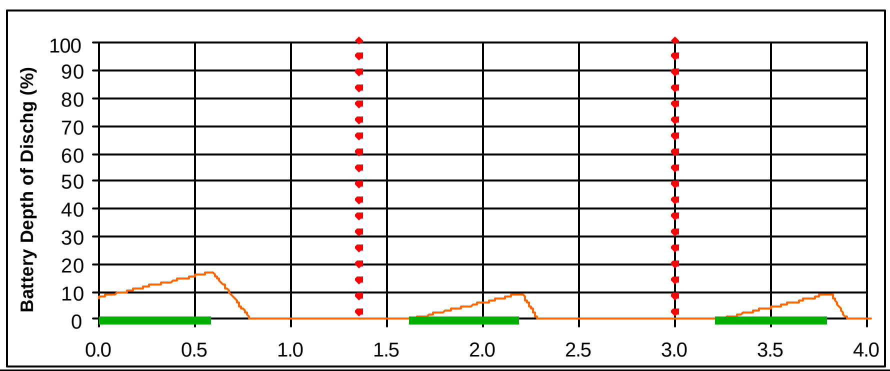
- **Initial Conditions at Separation**
  - **Time on internal power = 30 minutes**
  - **Attitude from Sun line = 4 degrees**
  - **Spin Rate at LV Separation = 15 deg/sec**
  - **Tip-off Transverse Axes Rates = 3 deg/sec**
  - **Eclipse Timing: Enter Eclipse immediately following separation**
- **Power Load (Watts)**

	Launch	SA Deploy	Rate Damp	Precession
C&DH	13.7	26.2	26.2	26.2
EPS	10.5	109.4	15.0	15.0
Telecom	4.8	4.8	9.6	9.6
ACS	0.0	3.8	13.2	13.2
TCS	0.0	0.0	5.4	5.4
Total:	29.0	144.2	69.4	69.4

- **Telecommunications**
  - **Transmitting telemetry 14 minutes/orbit**
- **Attitude Control**
  - **Simulation results show attitude profile from separation through sun acquisition**
  - **Vertical dotted lines indicate ground station passes**
- **Power/Energy Profile**
  - **Spacecraft is power-positive at eclipse exit**
  - **Battery DOD does not exceed 20% during acquisition**

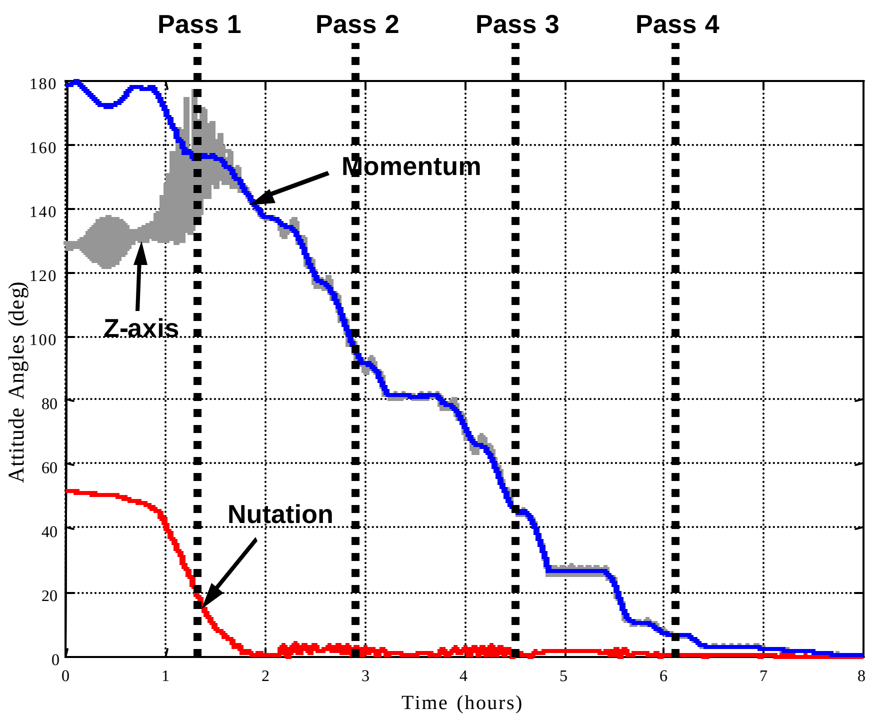


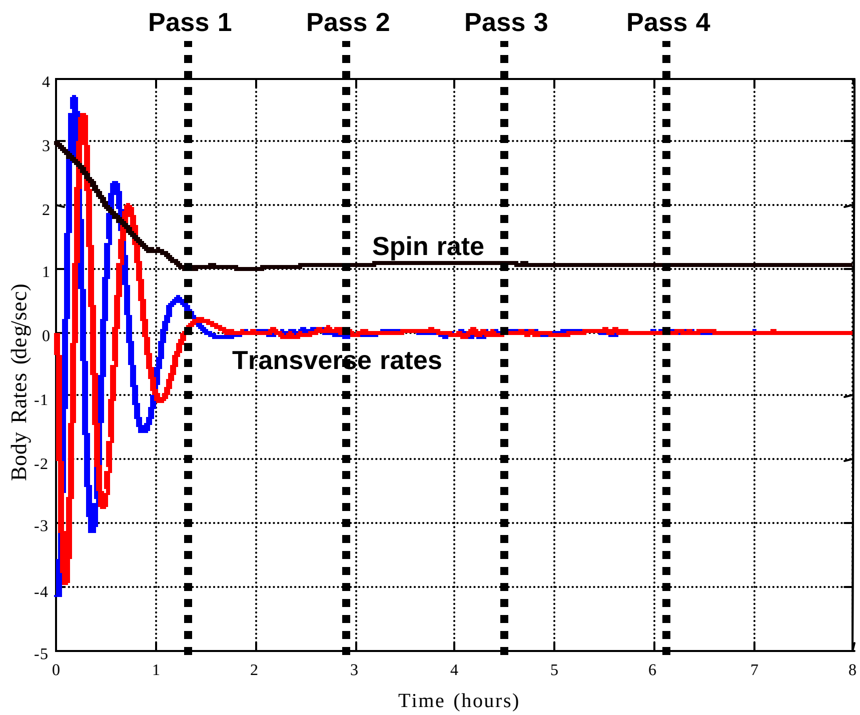




ATTITUDE CONTROL SUBSYSTEM SUN ACQUISITION WITH WORST-CASE LV ATTITUDE ERROR

- **LV Tip-Off Conditions: Momentum vector 180 deg away from Sun**
  6 deg/sec transverse rate
  15 deg/sec spin rate
- **30-second array deployment with 2-second delay between arrays adds 2° of additional nutation**
- **Initial 2 hour Acquisition Mode ("B-dot" law) establishes spin rate and damps transverse rates**
- **FSS utilized when Sun cone angle is within 32 degrees**
- **30 minute eclipse once per orbit with precession control disabled**



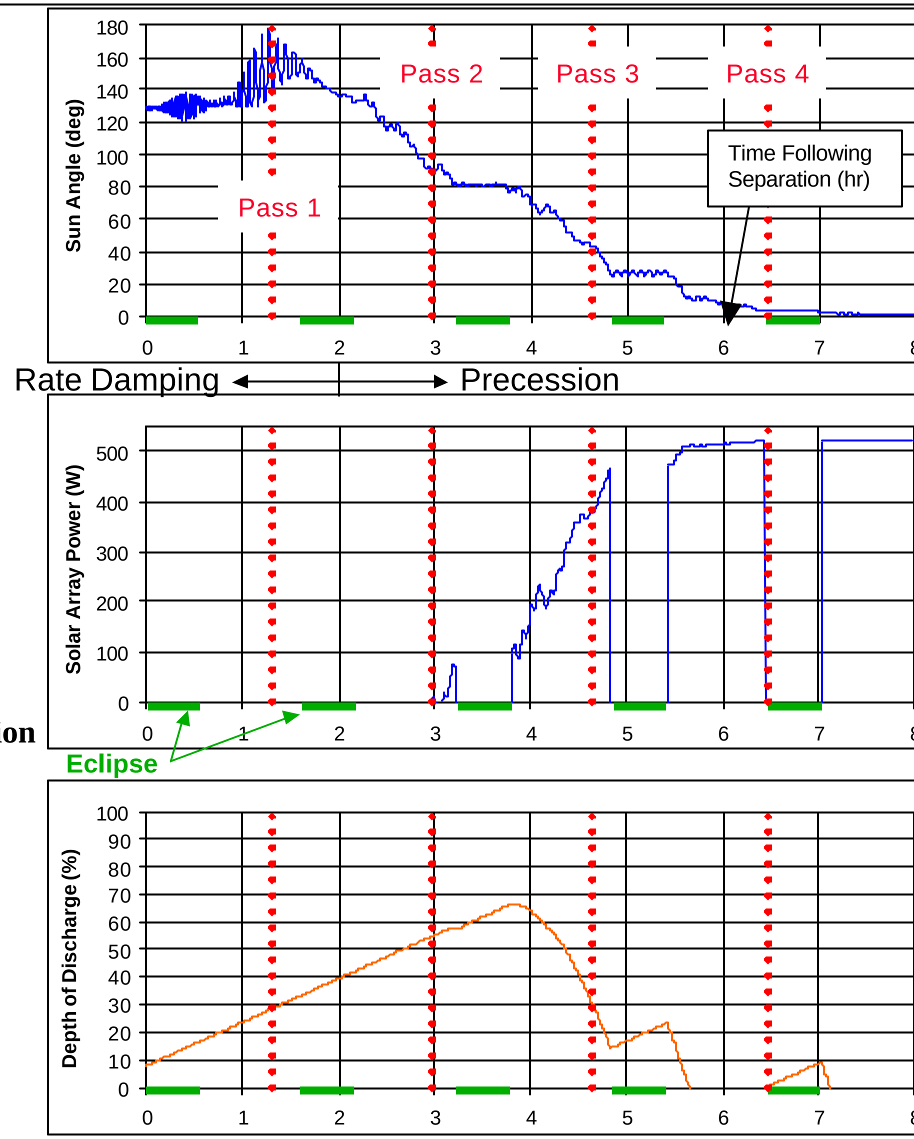


LAUNCH AND EARLY ORBIT POWER WORST CASE CONDITIONS

- **Initial Conditions at Launch Vehicle Separation**
  - **Time on internal power = 30 minutes**
  - **Z-Axis Angle to Sun line = 180 degrees**
  - **LV Separation Spin Rate = 15 deg/sec**
  - **Tip-off Rate = 6 deg/sec**
  - **Eclipse Timing: Enter eclipse at separation**
- **Telecommunications**
  - **Transmitting telemetry 14 minutes/orbit**
- **Power Load (Watts)**

	Launch	SA Deploy	Rate Damp	Precession
C&DH	13.7	26.2	26.2	26.2
EPS	10.5	109.4	15.0	15.0
Telecom	4.8	4.8	9.6	9.6
ACS	0.0	3.8	13.2	13.2
TCS	0.0	0.0	5.4	5.4
Total:	29.0	144.2	69.4	69.4

- **Attitude Control**
  - **Simulation results show attitude profile from separation through sun acquisition**
  - **Bars on time axis indicate eclipse times**
  - **Vertical dotted lines indicate ground station passes**
- **Power/Energy Profile**
  - **Spacecraft accomodates these conditions**
  - **Battery DOD reaches ~67% during sun acquisition**
  - **Power positive in less than 4 hours**



ON-BOARD FAULT RESPONSES

FAULT PROTECTION

Fault Protection Design Philosophy

- Minimize On-board Autonomy
- Safe Spacecraft and Allow Ground to Diagnose and Recover Spacecraft
- Bus Failure Modes Effects and Criticality Analysis Used to Identify High Risk Failure Modes Which Require Fault Protection Responses

HESSI Bus Architecture Provides Ample Time for Ground to Respond to Many Faults

- Spin-Stabilization Allows Spacecraft to Generate Power For Significant Time Duration Even if Active Attitude Control is Disabled
  - Solar Array Produces >50% of Nominal Power For >60 Days Without Attitude Control (Sufficient for Continuous Safe Mode Operations)
- Command & Data Handling Architecture Generates Telemetry and Processes Ground Commands Even With Flight Processor Off
  - Science Data Generation and Storage Independent of Flight Processor Operation and is Unaffected by Flight Processor Resets and Short Outages

On-Board Fault Protection Includes Hardware and Software Fault Responses

- Hardware Fault Responses
  - For Failure Modes Which Require Immediate Response (Prior to Next Scheduled Ground Contact)
  - Do Not Depend On Flight Software Operation -- They Work Even if CPU OFF
  - Typically Have “Hard-Coded” Thresholds
- Software Fault Responses
  - Place Spacecraft in Safe State for Ground Diagnosis and Recovery
  - Require CPU and Flight Software to Operate
  - Have Thresholds Adjustable by Ground Operations

SAFE MODE

Safe Mode Objective

- Operational Mode Which Depends on Minimal Set of Hardware and Software Functionality to Maintain Positive Energy Balance, Ensure Commandability and Recoverability
- Allows Spacecraft to Survive Without Ground Intervention
- Provide Telemetry to Ground for Diagnosing Spacecraft Health

Safe Mode Configuration & Power Summary:

Subsystem	Component	Power	Comments
Command & Data Handling	CIB	5.0	Low Data Rate Telemetry
	PACI	5.9	On
	CPU	0.0	Off
	SSR	0.0	Off
	OCXO	0.6	On
Telecommunications	Transponder	4.8	Receive only mode
Attitude Control	Torque Rods	0.0	Drivers Off
	Fine Sun Sensor	0.0	Off
	Magnetometer	0.0	Off
Thermal Control	Battery Htr	14.8	
	Xponder Htr	8.4	
	SSR Heater	5.8	
	FSE Heater	5.8	
	Trq Rod Htrs	2.7	
Electrical Power	PCB	2.7	
	CCB	4.0	
	DC-DC Conv.	3.1	
	Bus Subtotal	63.6	
Instrument	Instrument Total	37.6	Instrument Safe Mode
	IDPU Heater	12.8	
	Total	113.9	
	Eclipse Battery DOD	16%	

AUTONOMOUS FAULT RESPONSES (1 OF 2)

Flight Processor / Flight Software

- **Bit Flips in Processor RAM**
  - FSW Performs EDAC Memory Scrubbing
- **Processor Watchdog Timer (WDT) Time-out**
  - External WDT in CIB Not Reset for 1 Second: Reset CPU and Reboot FSW, Loss of Stored SOH Telemetry
- **Loss of 1 Hz Clock Tick**
  - No Loss of FSW Functionality; FSW Uses 64 Hz CPU Internal Timer
- **Loss of 64 Hz O/S Tick**
  - FSW Still Commandable via CIB Interrupt; Lose ACS, SOH Telemetry Storage Tasks; No Onboard Response
- **Unresponsive FSW Task**
  - Allow WDT to Reset CPU if Any Tasks Hang
- **FSW Maintains Fault Log in PACI RAM**
  - Provides Record of Processor Resets, SOH Telemetry, Event Messages

Attitude Control

- **Large Sun Pointing Angle Error or Large Spin Rate Error**
  - FP FSW Removes Power from Torque Rod Drivers, Commands ACS to Idle Mode
  - This FP Response Disabled for Launch and Initial Sun Acquisition
- **ACS FSW Sensor Processing Determines Sensor Data Validity, Ignores Single Bad Data Points**
  - ACS FSW Goes into Idle Mode if Sun Sensor or Magnetometer Data Unavailable
- **Torque Rod Driver or Torque Rod Coil Failure**
  - Redundant Z-Torque Rod Drivers in ADB (1 Driver for Each Coil)
  - X- and Y-Torque Rods Have Redundant Coils, Drivers Automatically Compensate for Open Circuit Coil
  - X-Torque Rod and Driver Redundant with Y-Torque Rod and Driver (Need 1 of 2)
- **Torque Rod Commanded to High Current**
  - ADB Torque Rod Driver Commands Time Out After 2 Seconds (Normally Refreshed at 10Hz)

AUTONOMOUS FAULT RESPONSES (2 OF 2)

Electrical Power

- Excessive Current Draw on PCB Current Sensors
  - FP FSW Removes Power from Loads Associated with Current Sensor
- Low Battery State of Charge (From Battery Pressure Telemetry)
  - FP FSW Reduces Loads to Conserve Battery Energy and Commands Instrument to Safe Mode
- Bus Undervoltage Detection in PCB Senses Hard Shorts/Low Battery State of Charge
  - PCB Hardware Sheds Loads to Remove Fault/Conserve Battery Energy -- Safe Mode

Telecommunications

- Transmitter Not Commanded OFF
  - PCB Timer Automatically Commands Transmitter Off 15 minutes After Last ON Command
- RF Switch Actuated with Transmitter ON
  - PCB Inhibits Transmitter Power While Switching Antenna RF Switch to Preclude Hot Switching

Command and Data Handling

- No Uplink Commands Received in 144 hrs
  - FP FSW Executes Predefined Sequence to Reset CIB and PACI Boards
- Loss of CIB Codeblock Received Interrupt
  - No Loss of Telecommands, Uplink is Both Interrupt Driven and Polled
- Loss of CIB D/L Buffer Empty Interrupt
  - Sporadic Stored SOH Transmissions, Continue to Transmit RT SOH; No Onboard Response
- Loss of PACI Interrupt
  - Lose ACS, IDPU Telemetry and SSR Telemetry, Continue to Transmit RT SOH
- Spurious CIB or PACI Interrupts
  - FP FSW Disables Interrupt, Same Effect as Loss of Interrupt, FSW Continues to Operate