Spacecraft System

David Y. Kusnierkiewicz

Applied Physics Laboratory/Johns Hopkins University
11100 Johns Hopkins Road M1-114
Laurel, MD 20723
(301) 953-5092
Fax (301) 953-6556
david_kusnierkiewicz@jhuapl.edu

Spacecraft System

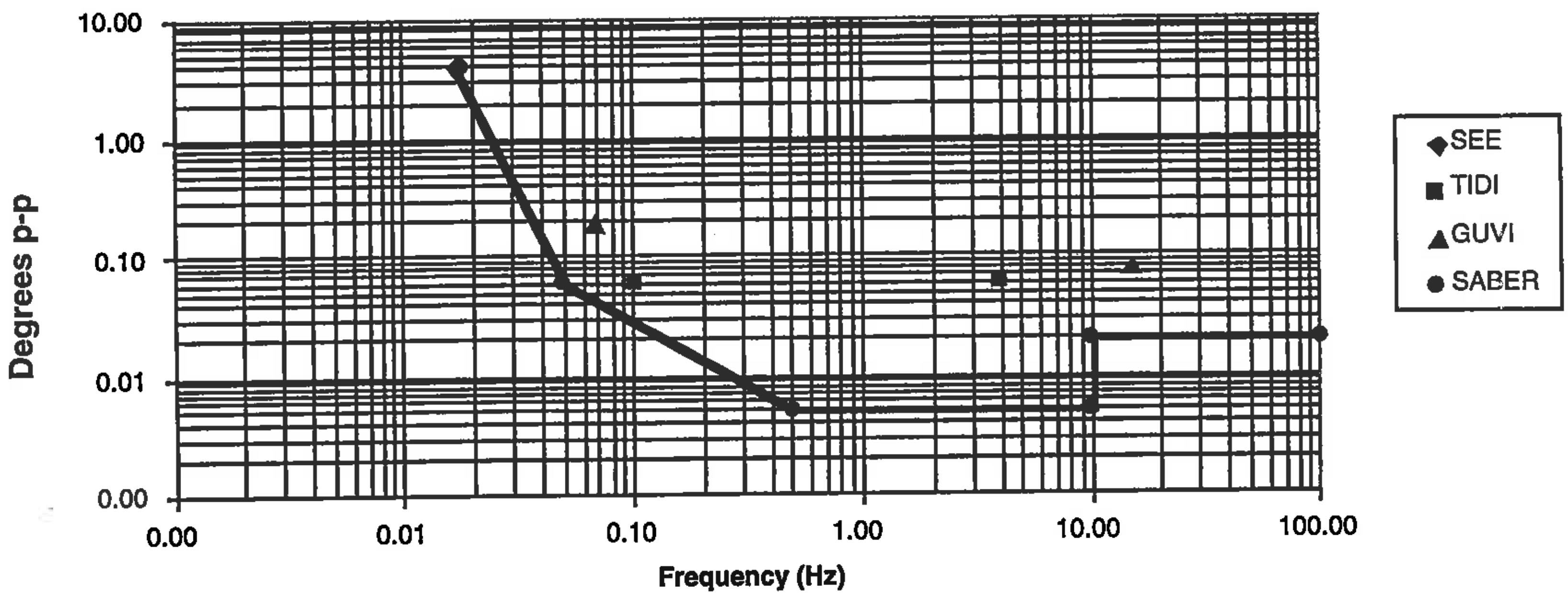
- Presentation Outline
  - Spacecraft Requirements Changes
  - Spacecraft Requirements
  - Spacecraft Design Changes From PDR
  - Spacecraft Description
  - Redundancy and Cross Strapping
  - IEM Overview
  - Spacecraft Flight Configuration
  - Mass/Power Summaries and Histories
  - Margin Management
  - Reliability Assessment
  - Spacecraft Risk Management

Spacecraft Requirements Changes

- Attitude Control specification changed from 1 degree to 0.5 degrees (3-sigma, each axis).
  - Allows raising of nominal orbit to 625 km
    - Altitude increase desired by Science
      - SABER would require baffle redesign without tighter control spec
- Jitter specification modified (see following slides)
  - Driven by SABER

- These requirements changes did not require changes to spacecraft design

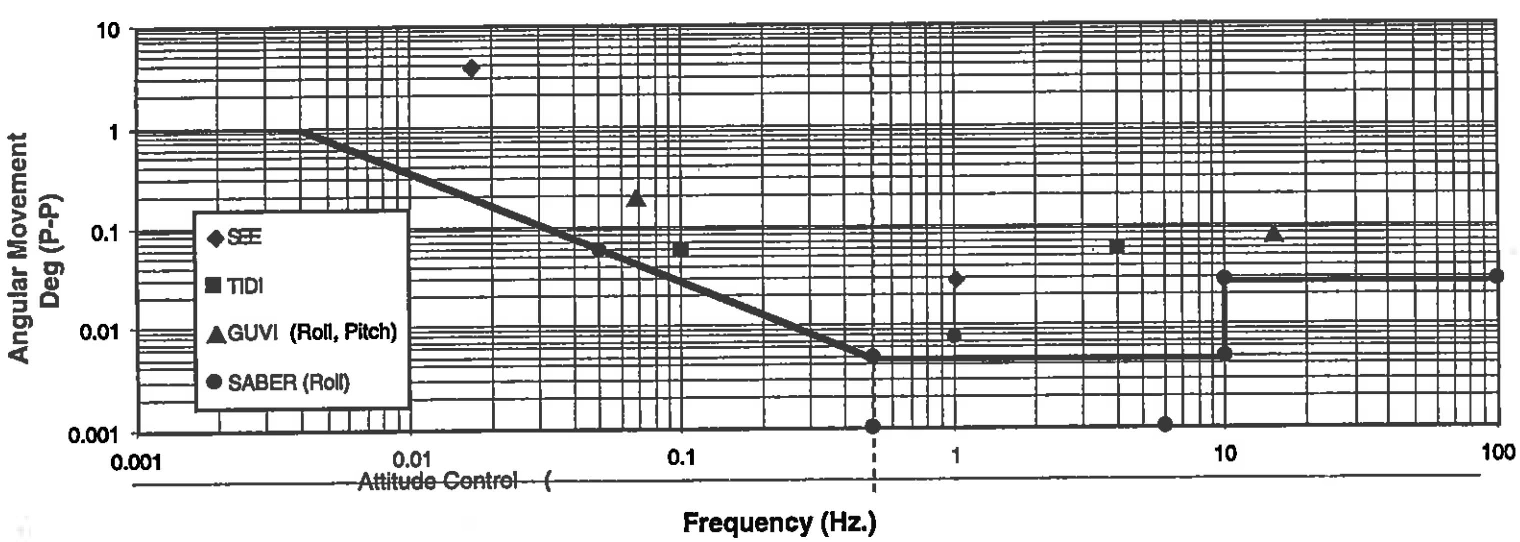
Requirements - Attitude
Old Jitter and Stability
(Each Axis)



TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Requirements - Attitude
New Jitter and Stability
(Each Axis)



Allowable Angular Movement

Requirements-Instrument Interfaces

- The Interface Control Document (ICD), which consists of three parts (the Component Environmental Specification, or CES, the General Instrument Interface Specification, or GIIS, and the Specific Instrument Interface Specification, or SIIS) shall provide a comprehensive agreement for all Spacecraft to Instrument interfaces, including:
  - Mechanical Interfaces (bolt patterns, size and type of bolts, etc.)
  - Electrical Interface (number and type of connectors, pinouts, etc.)
  - Thermal Interface (environments, radiator sizes and finishes, dissipations, etc.)

Requirements-Instrument Interfaces (Cont'd)

- Test Environments and Testing Requirements
  - Electromagnetic Compatibility (Grounding Plans, Test requirements, etc.)
  - Status Mode Word Definitions
  - GSE - I&T Interfaces
  - Clear Fields of View
  - Disturbance Torques
  - Attitude Determination and Control Capabilities
  - Purge Implementation and Capabilities
  - Payload Operations Center (POC) to Mission Operations Center (MOC) Interfaces

Requirements - Mechanical/Structural

- The spacecraft shall fit in the volume defined by a right cylinder 80.9 inches in diameter and 108 inches in height
- Spacecraft (Bus and instruments) Mass limit shall be defined by the capability of a "Med-Lite" Launch Vehicle to our target orbit: (Currently 660 kg)
- Vibration, Shock, Acoustic, Accelerations shall be defined by enveloping environments of candidate LV's. This information shall be included in the Component Environmental Specification (APL No. 7363-9010) for all spacecraft subsystems and instruments
- Alignments of all sensitive components of instruments and S/C sensors shall be specified consistent with an overall pointing error budget

Requirements - Thermal

- Allowable temperature ranges and gradients shall be included in the ICDs for all instruments; for all Spacecraft Subsystems these requirements shall be incorporated in the TIMED Component Environmental Specification (APL No. 7363-9010)

Requirements - Subsystems

- Design Reviews:
  - Each subsystem will have two design reviews conducted by an independent review panel. A Preliminary Design Review (PDR), concentrating on requirements and interfaces, is to be held around the time of Mission PDR. An Engineering Design Review (EDR) of the detailed electrical design, breadboard performance data (if applicable), and packaging concept will be conducted prior to Mission CDR. A Fabrication Feasibility Review (FFR) is required prior to drawing package sign-off.
  - All Action Items must be answered in writing to the Project Office at APL
  - Lead Engineers shall provide support as required to all system-level reviews

Requirements - Subsystems (Cont'd)

- GSE
  - Subsystem lead engineers shall be responsible for their GSE
  - All GSE shall be designed to be consistent with the overall Ground System
  - Level 1 drawings shall be considered adequate, except for GSE which connects to the spacecraft bus; this requires level 2a
- Testing Requirements
  - All spacecraft subsystems shall be environmentally tested per the TIMED Component Environmental Specification (APL No. 7363-9010)

Requirements - Subsystems (Cont'd)

- Spacecraft Integration:
  - All subsystem lead engineers shall support spacecraft I&T

- Spacecraft Interfaces
  - All instruments shall incorporate a MIL-STD-1553B data bus interface

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Requirements - Communications

- Uplink Data Rate: 2000 b/s
- Downlink Data Modes and Minimum Required Information Rates:
  - 1. All Real Time TM plus Recorder Playback ("High Rate"): 3.955×10^6 b/s
  - 2. Real Time Spacecraft (Housekeeping Only) TM ("Low Rate"): 9018 b/s
- Link Margin:
  - Uplink: 6 dB
  - Downlink: 3 dB

Requirements - Communications (Cont'd)

- Error Probability:
  - Packets delivered with detected and flagged errors: 1×10^{-3}
  - Packets delivered with undetected errors: 1×10^{-10}
- Availability:
  - **95**% of all source packets produced by the payload instruments must be collected by the spacecraft bus and delivered to the Payload Operations Centers

(Changes from PDR in **bold**)

Requirements - Spacecraft Antenna Coverage

- Command Receive:
  - sufficient link margin over 95% of sphere
- Mode 1 Transmit:
  - sufficient link margin over a ±66° cone centered on nadir
- Mode 2 Transmit:
  - sufficient link margin over 95% of sphere
- GPS Receive:
  - sufficient link margin over a ±80° cone centered on zenith

Requirements - Command & Data Handling

- Daily Average Housekeeping Data Rate: 5,500 b/s
- Daily Average Instrument Data Rate: 16,954 b/s
- Total Daily Storage Capacity (Housekeeping and Instruments): 2.5 Gbits
- Timing uncertainty: **10** msec relative to Universal Time Coordinated (UTC)

(Changes from PDR in **bold**)

Requirements - Command & Data Handling (Cont'd)
"Broadcast" Messages

- These data shall be transmitted once per second via MIL-STD-1553 to all instruments:
  - Time
  - Position (Latitude, Longitude, Altitude)
  - Velocity
  - Night-to-Day Terminator crossings (subsatellite point)
  - Day-to-Night Terminator crossings (subsatellite point)
  - Spacecraft Attitude (Roll, Pitch, and Yaw)
  - Sun Vector

Requirements - Command & Data Handling (Cont'd)
"Broadcast" Warnings

- Warnings of the following events shall be transmitted in advance to all instruments:
  - Solar Panel Rotations
  - Spacecraft Yaw Maneuvers
  - Emergency Instrument Shutdowns
  - Loss of Attitude Control

Requirements - Attitude

- Spacecraft Orientation:
  - Earth pointing, 1 RPO Pitch, 0 Roll and Yaw rates
  - one 180° turn about the yaw axis per 180° of Sun/Orbit plane rotation (to keep the cold side of the spacecraft in shadow at all times)
  - Attitude Control: **0.5**° control, each axis, 3σ
  - Attitude Knowledge: 0.03° each axis, inertial, 3σ

- Attitude constraint:
  - Sun vector shall be greater than 90° from the +Y radiator panel during normal operations

(Changes from PDR in **bold**)

Requirements - Navigation

- Position Knowledge: 300 m, each axis, 3σ
- Velocity Knowledge: 0.25 m/s, each axis, 3σ

Requirements - Power System

- Maximum Orbit Average Load Power: 410 W
- Maximum Cycle Life: 12,000 eclipses
- Main Bus Voltage and Regulation: 22-35 VDC
- All redundant or non-critical subsystems shall be both switched and fused
- Low Voltage Battery Protection System is required

Requirements - EMC

- Subsystem and Component EMC testing requirements shall be defined in the Component Environmental Specification (APL Document No. 7363-9010)
- Harnessing shall be developed in accordance with an approved Spacecraft EMC Plan
- Grounding shall be provided in accordance with an approved Spacecraft EMC Plan
- Self-Compatibility shall be verified by a system level test
- Electro-Static Discharge (ESD): subsystems shall be insensitive to ESD experienced during normal integration and test handling; typical ESD control practices will be employed during all normal integration and test operations

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Subsystem Engineering Design Reviews

• Solar Array	July 15, 1997
• Uplink Card	October 15
– CCD	October 15
• Structure	October 15
• Power	November 21
• Harness	November 19
• ***Downlink Card***	***January 15, 1998***
– Downlink Modulator	October 17, 1997
– Downlink Framer	November 20

Subsystem Engineering Design Reviews (Cont'd)

• IEM	
– C&DH	November 20
– SSR	November 20
– PCI	November 20
– RIUs	November 20
– ***GNS***	***January 14, 1998***
– CMD&TLM I/F	November 20, 1997
– DC/DC Converter Cards	November 25
• G&C	
– AIU	November 21
– FC	November 20
– ***ST***	***December 11***
– ***Gyro***	***December 18***
– Rods	November 4
– Wheels	November 4
– Solar Array Drive	November 13

Spacecraft Design Changes From PDR

- High Speed Serial Link (& GNS 1 pps signal) between IEMs **eliminated**
  - Greatly simplifies software design, testing
    - Solid State Recorder size is **2.5 Gbits**
    - **No "Ping-pong"** mode between SSRs
      - Affects contingency planning
- RF Antenna Switch changed to **provide optional "omni- coverage"**
  - Simplifies safing design
- Solar Array substrates changed from aluminum core w/ composite face sheets to **aluminum face sheet**
  - Mass reduction
  - Thermal twang evaluated, acceptable

Spacecraft Design Changes (Cont'd)

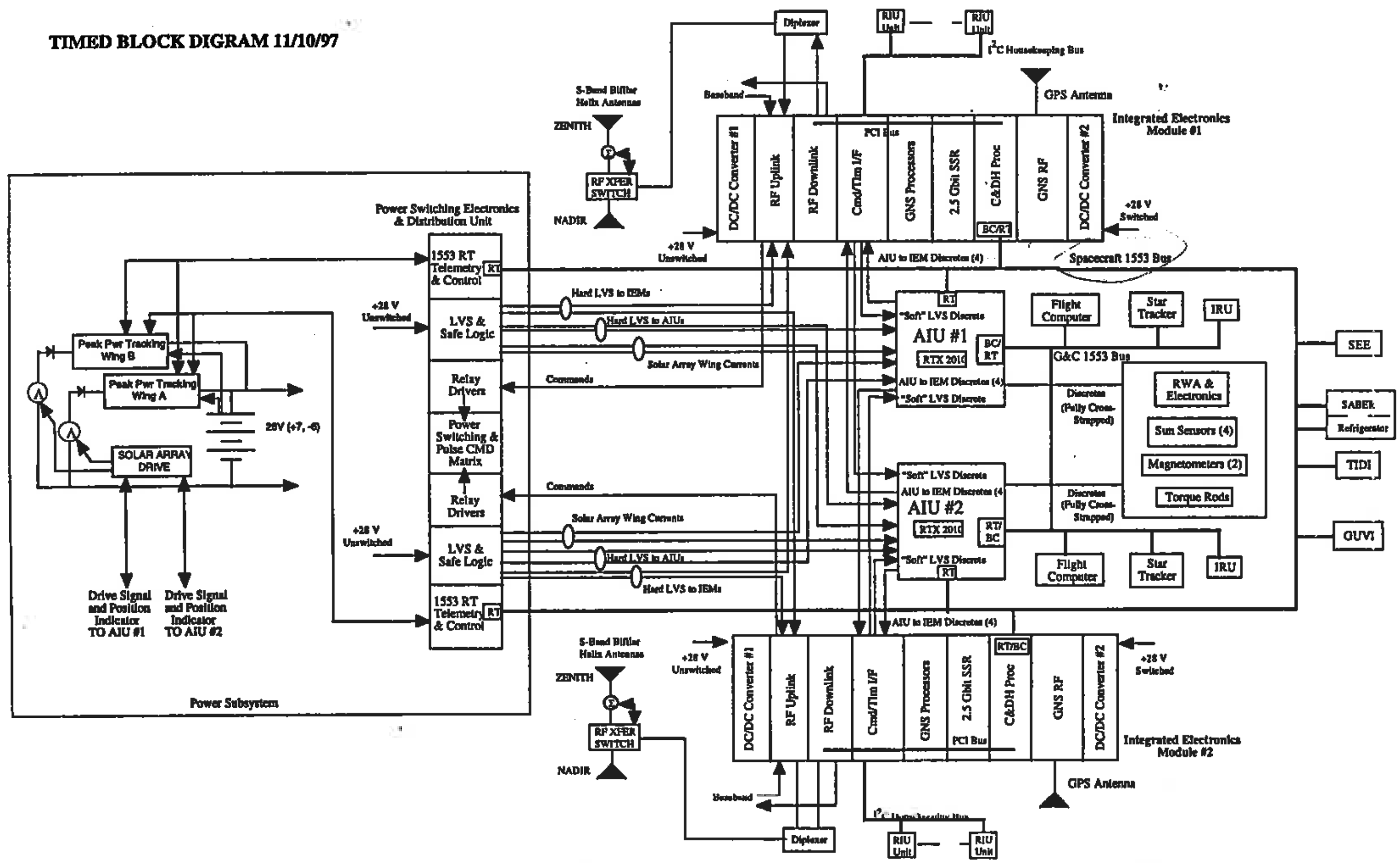
- Solar Array tilt angle changed to **20 degrees** from horizontal (from 30 degrees)
  - Less aerodynamic torquing of spacecraft
- **Two 3-axis Ring Laser Gyro Units** instead of a single (4-axis) Hemispherical Resonant Gyro Unit
  - Increased Mass, Power; significantly lower cost
- **Fourth Sun Sensor** added
  - Magnetometers and Sun Sensors **fully cross-strapped** to both AIUs
- **Mongoose V** processor is baseline
  - Second processor added to GNS subsystem
    - Single processor performance inadequate at 12 MHz
- **Second 1553 RT** provided for SABER Refrigerator
- Low Voltage load shedding **executed serially** through Critical Command Decoder (CCD) instead of by tripping a single switch in power system

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Spacecraft Block Diagram

TIMED BLOCK DIGRAM 11/10/97



TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Spacecraft Description

- Aluminum Structure, Al Honeycomb Panels
  - Composite Optical Bench for TIDI, Star Cameras
  - **Aluminum** Face Sheets on Solar Panels
- Three Axis stabilized; no propulsion
  - One side of spacecraft always cold
- On-board Autonomous GPS Navigation
- S-Band Communications
- Two solar panel wings (GaAs Cells) with single axis drive
- 22 cell Individual Pressure Vessel Nickel Hydrogen battery
- **Most** Spacecraft relay commands executable without software through Critical Command Decoder (CCD, located on Uplink Card in IEM; always powered)

Spacecraft Description (Cont'd)

- Fully redundant spacecraft bus (Both Star Trackers Needed to meet Attitude Knowledge Requirement)
- Two 1553 Bus Architecture (Similar to NEAR)
  - C&DH/Spacecraft 1553 Bus
  - G&C 1553 Bus
    - AIUs are RTs on C&DH 1553, BC/RT for G&C 1553
- Instruments are on C&DH 1553 Bus
  - Instrument Discretes Only for S/C Monitored Temperatures
    - Interface through RIUs

- Each IEM is a single-string C&DH processor, 2.5 Gbit SSR, GPS Navigation System (GNS), and RF Communications "Subsystem" (Similar to ACE)

- No Discrete (non-1553) Cross-Strapping Between IEMs
  - High Speed Serial Interface from PDR eliminated

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Spacecraft Redundancy

Subsystem	Brute Force	Internal	Tolerant	Partial
Instruments				X
IEM (C&DH, SSR, RF, GNS)	X			
Power System Electronics	X			
Battery			X	
Solar Arrays			X	
Attitude Interface Units	X			
Star Trackers*	X			
IRU	X			
Reaction Wheels		X		
Magnetometer	X			
Sun Sensors	X			
Torque Rods		X		
Flight Computer	X			

*Both Star Trackers Needed to Meet Knowledge Requirement

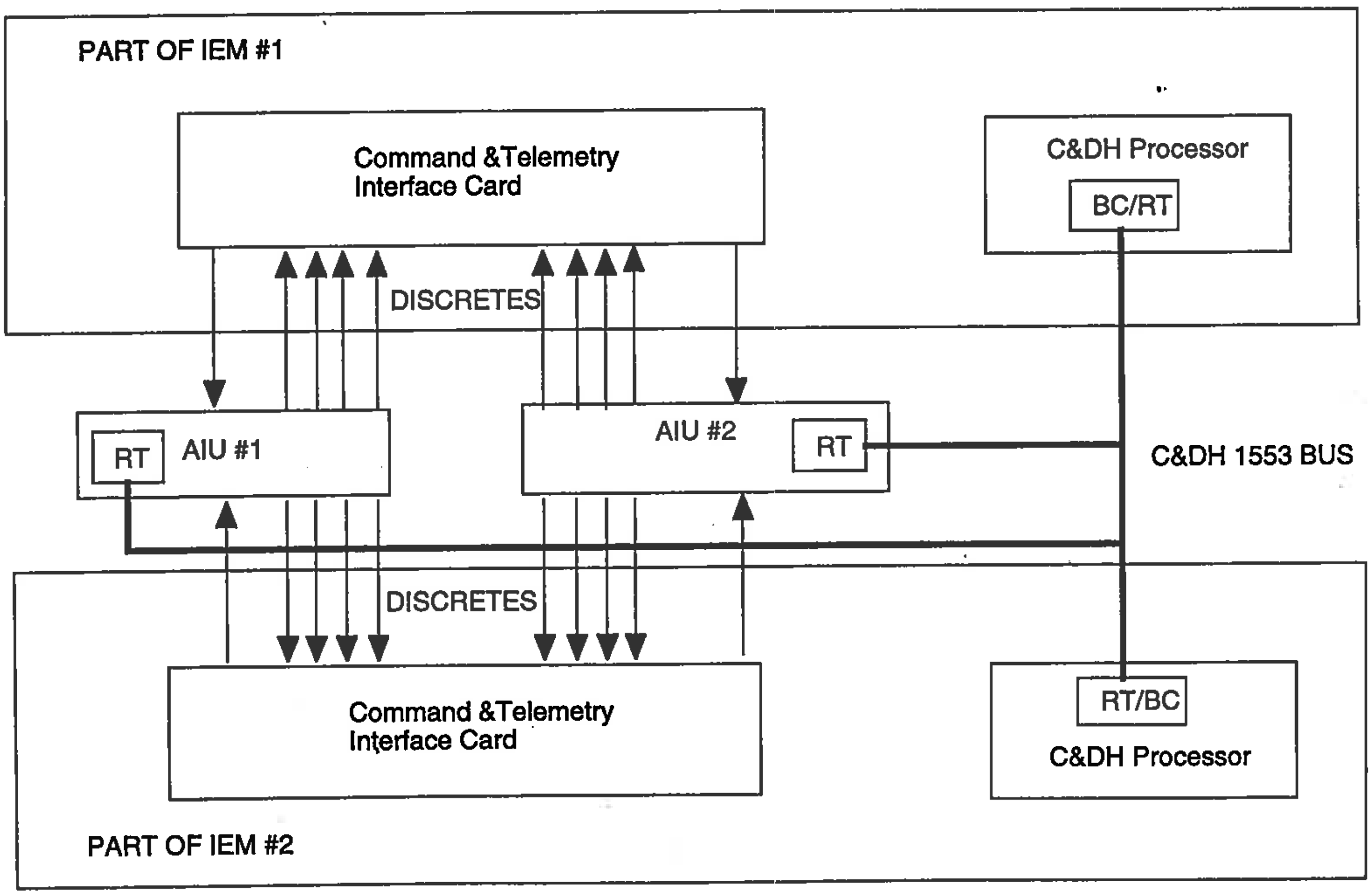
Spacecraft Redundancy (Cont'd)

Subsystem	Brute Force	Internal	Tolerant	Partial
Solar Array Drive		X		
GPS Antennas	X			
RF Comm Antennas	X			
RIUs	X			

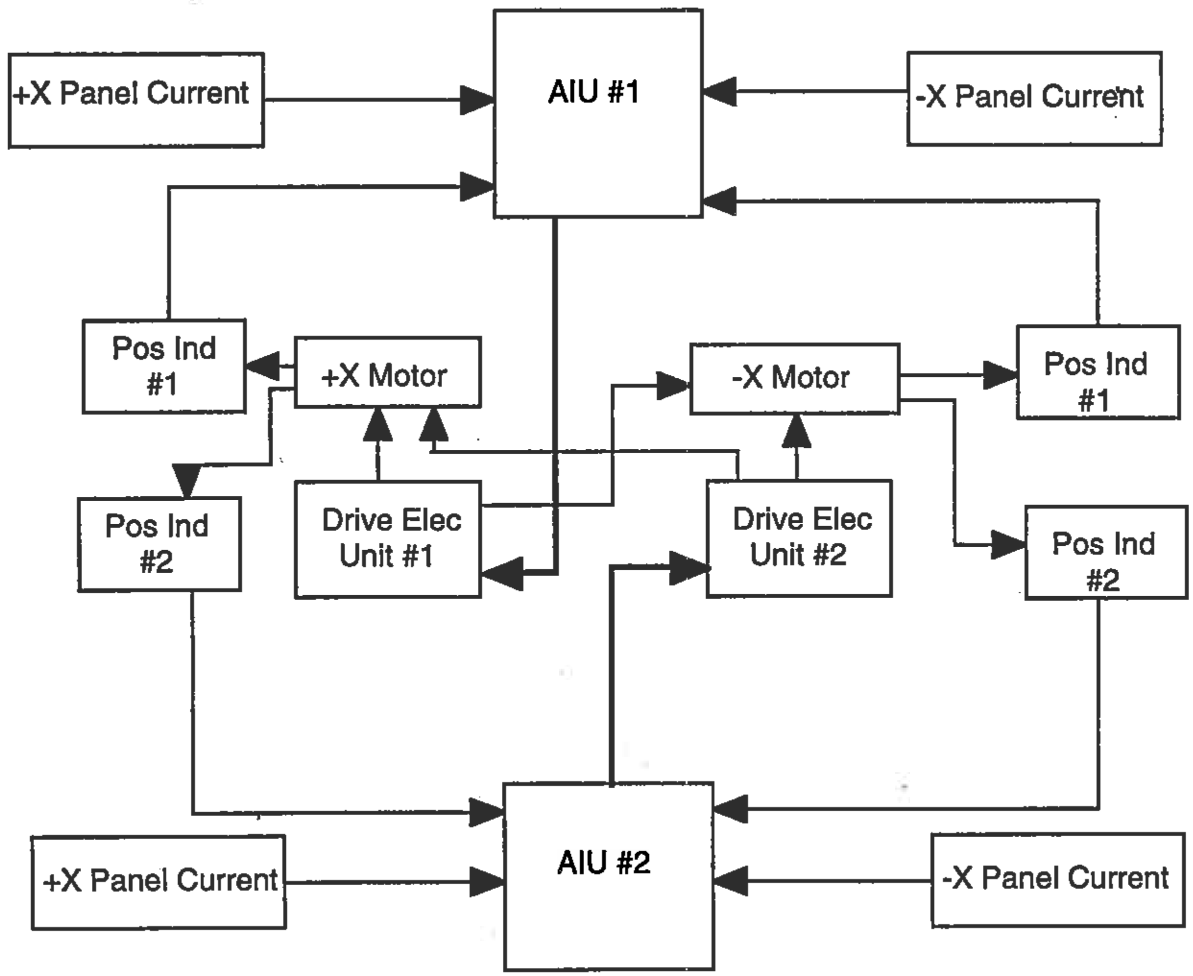
Cross-Strapping

- Each IEM is a single string Combination of C&DH, SSR, GNS, and RF Communications Subsystems
  - One IEM is the Spacecraft (or C&DH 1553) Bus Controller
    - The other IEM (when powered) is a 1553 Remote Terminal
  - Each IEM has a dedicated I^2C Housekeeping Bus (Remote Interface Units, RIUs)
- Each IEM Has a dedicated 1553 interface to each half of the PSE/DU, and cross-strapped discretes
  - Each half of the PSE/DU has full stand-alone functionality
- Each AIU has fully cross strapped interfaces to G&C Components, either through discretes or the G&C 1553 bus
  - Each AIU is a remote terminal on the Spacecraft 1553 Bus
- Each AIU has fully cross strapped discrete interfaces to each IEM
- Each AIU has a dedicated interface to each half of the Solar Array Drive (and position indicators), with cross-strapped solar array currents

AIU to IEM Cross-Strapping



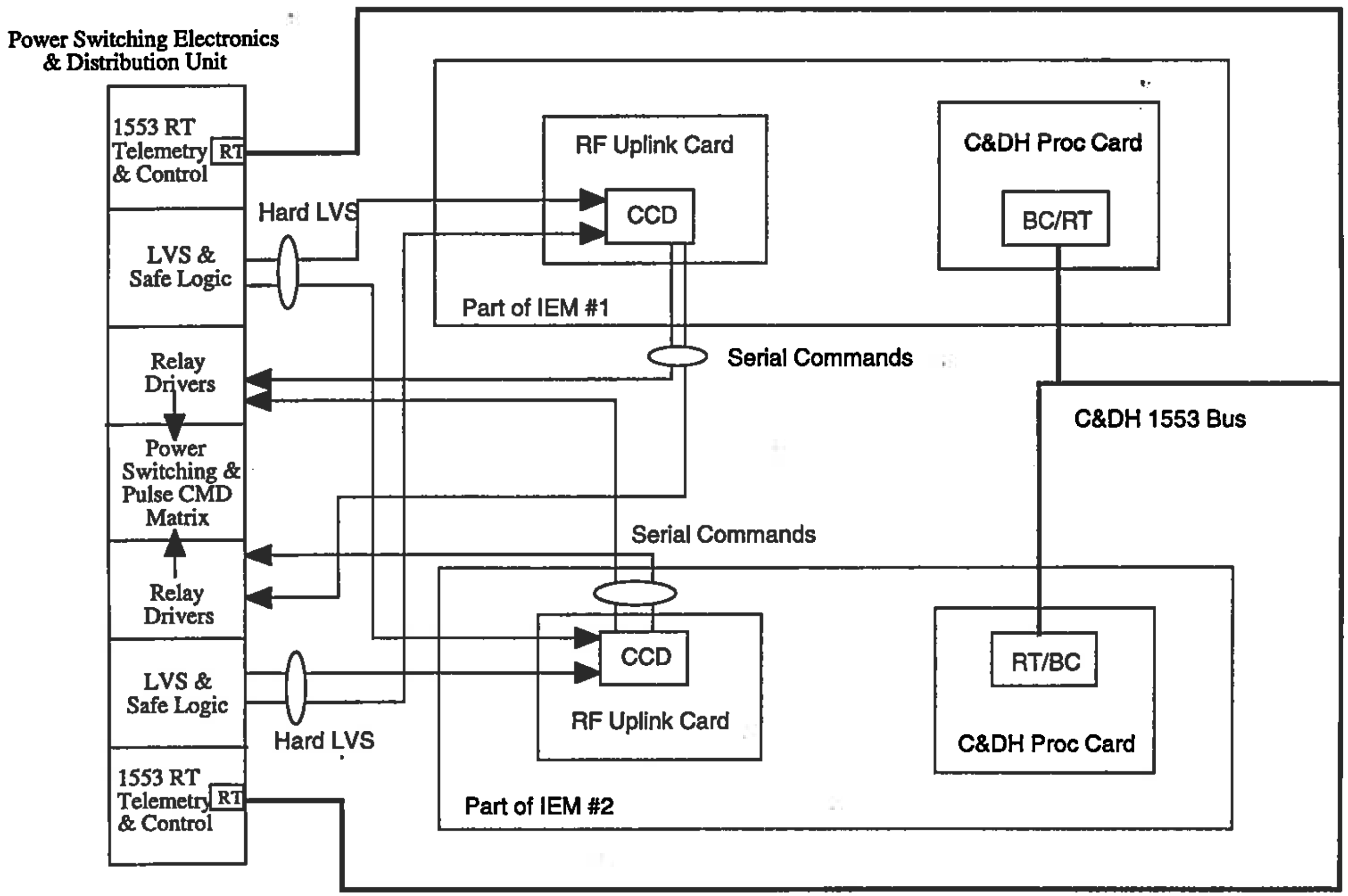
AIU to SAD Cross Strapping



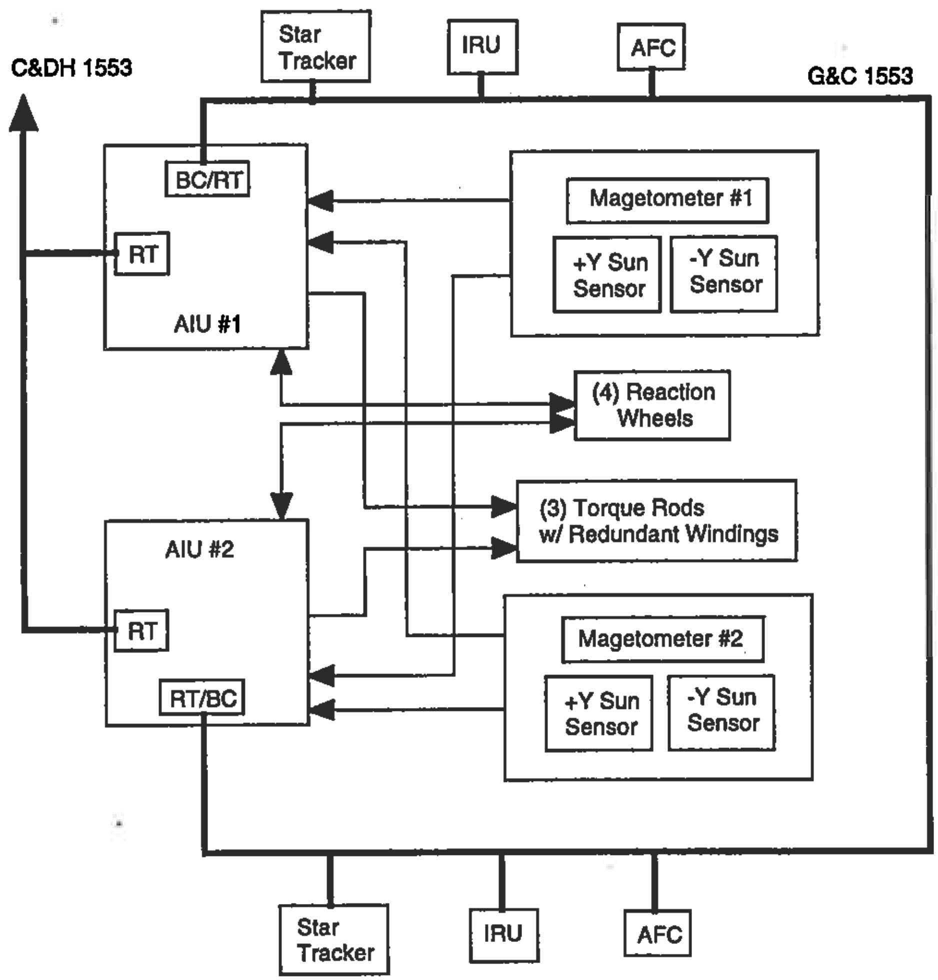
TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

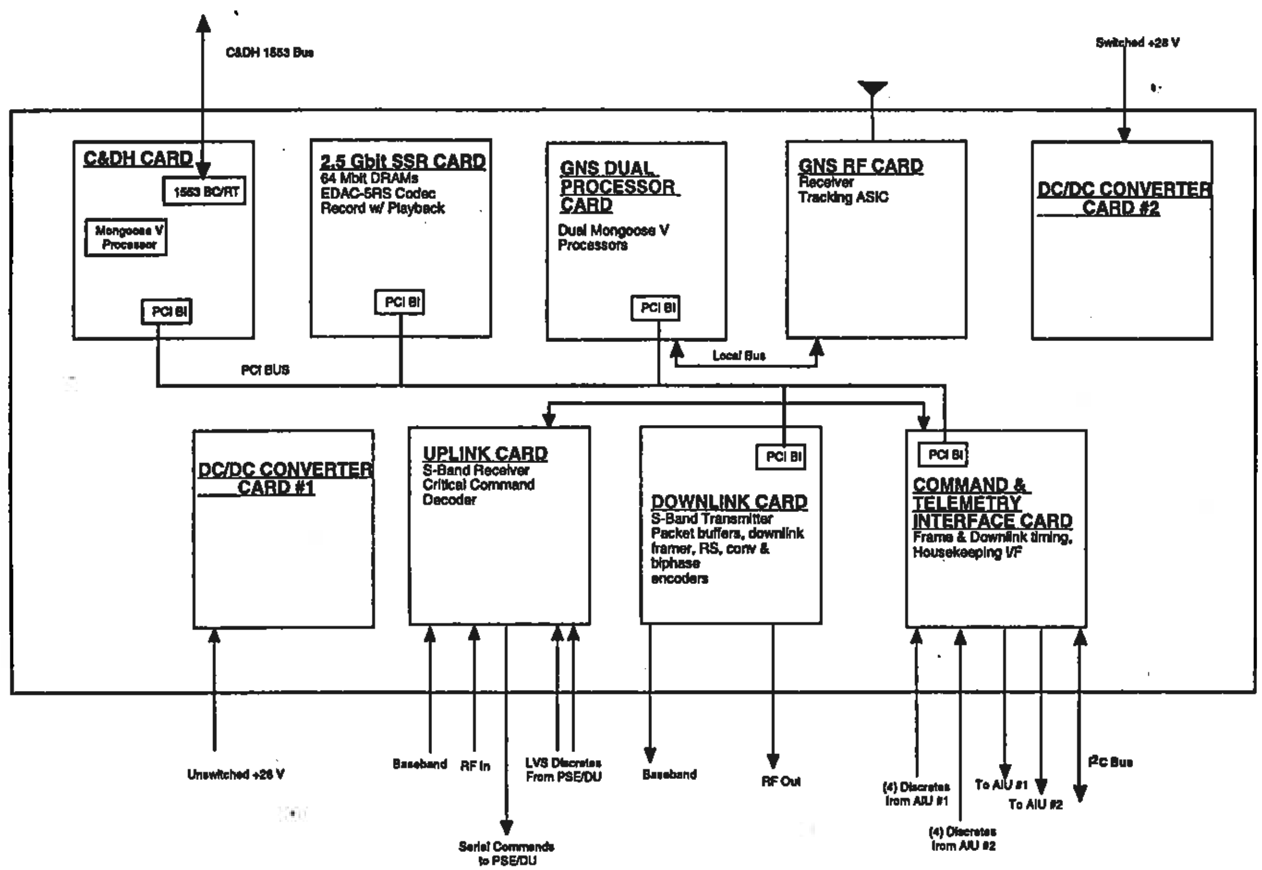
IEM to PSE/DU Cross-Strapping



G&C Component Cross Strapping



IEM BLOCK DIAGRAM



TIMED IEM BLOCK DIAGRAM

INTEGRATED ELECTRONICS MODULE OVERVIEW

- Card Cage Construction Housing C&DH, Solid State Recorder, GNS, and RF Communications Subsystems (Reduction in S/C Integration Time)
  - Industry Standard Parallel Bus (PCI Version 2.10) Backplane
    - 16 bit data transfers, 12 bit addressing, 5 MHz
  - Extended SEM-E cards (8.5 x 6.0 inches)
  - Interfaces to External Buses
    - I2C (Twisted wire, 100 kHz, 8-bit byte transfer) Bus
      - Spacecraft Housekeeping Telemetry
    - 1553 Bus
      - Communicate with Instruments, G&C, and Power
  - <u>NO</u> High Speed Serial Links between IEMs
    - Eliminated after PDR

TIMED IEM CARDS

- 9 Cards, 5 on PCI Bus
  - PCI Bus Cards (Powered together):
    - RF Downlink
      - Transmitter portion of card switched separately
    - Cmd/Tlm I/F (RIU I/F)
    - C&DH Processor
      - Rule Based Autonomy
    - SSR
    - GNS Dual Processors (2 processors on 1 card)
  - GNS RF
  - 2) DC/DC Converter Cards (1 switched, 1 unswitched)
  - 1) RF Uplink Card (Unswitched)

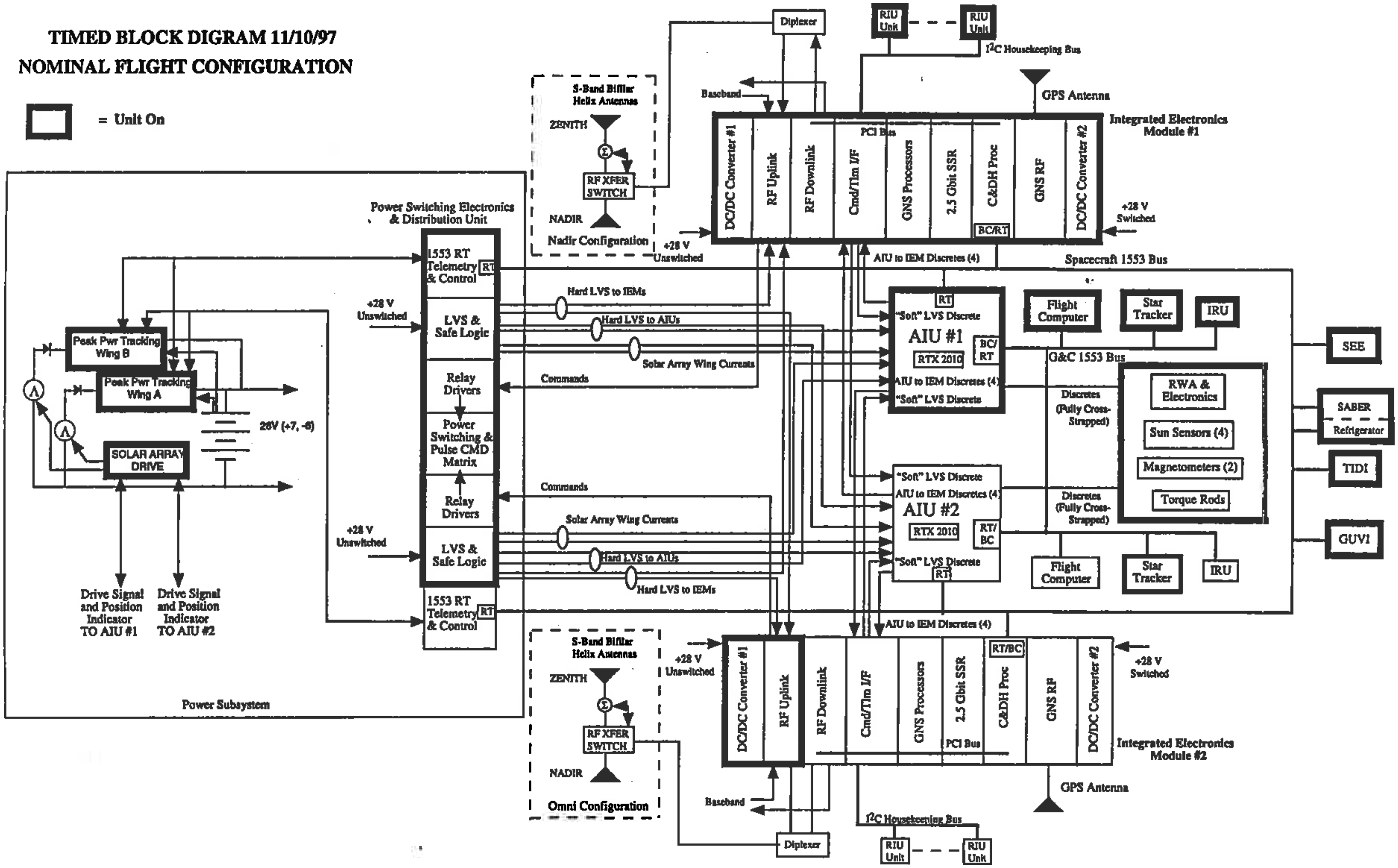
Flight Processors

- Each IEM has:
  - One C&DH Mongoose-V
  - Two GNS Mongoose-Vs (on a single card)
- G&C has:
  - Two Mongoose-V Attitude Flight Computers
  - Two RTX 2010 AIU Processors

Spacecraft Flight Configuration

- Both RF Uplink Cards (Command receivers, Critical Command Decoders) are on.
  - Antenna associated with active IEM is configured for Nadir
  - Antenna associated with inactive IEM configured for Omni
- Only ONE IEM is usually powered (Both are ON for launch), and the associated RIUs
- One AIU, One Attitude Flight Computer, One IRU ON
- Reaction Wheels, Magnetometers ON (Magnetometers not cross-strapped between AIUs)
- BOTH Star Trackers are ON (To meet Attitude Determination spec)
- All Power System Components Except 1 Telemetry/Control Unit
- All Instruments ON
- Transmitter Switched ON Autonomously Over Ground Station

TIMED BLOCK DIGRAM 11/10/97
NOMINAL FLIGHT CONFIGURATION



Spacecraft Operational Consideration

- Use of PCI Bus, and having C&DH Processors on that bus, means that entire IEM must be powered for C&DH Processor to be ON (PCI Bus not compatible with unpowered cards on bus)
  - Normally, only ONE C&DH Processor is ON (Only one IEM is on; Power, Reliability Consideration)
    - Only ONE Processor executing C&DH Rule Based Autonomy
  - When Hard LVS is hit, both IEMs are turned OFF
    - <u>No</u> C&DH Processor in this state
      - AIU most critical Unit on S/C

"Critical" Command Decoder

- All PSE/DU relay commands can be executed without software interpretation through the "Critical" Command Decoder on the RF Uplink Card.
  - Both RF Uplink Cards and CCDs always powered
  - Commands executed through serial interface to PSE/DU
  - "Omni coverage" on Command Receiver in unpowered IEM; Nadir coverage on Command Receiver in powered IEM
- CCD executes load shedding in response to a Hard LVS (discrete) notification from PSE/DU
  - Command sequence hard wired into Actel

Hard LVS Command Sequence

	Command Function	CMD #
1	SABER OFF	19
2	SABER Op.Htr OFF	32
3	GUVI OFF	3
4	SEE OFF	50
5	TIDI OFF	34
6	Star Camera #1 OFF	41
7	Star Camera #2 OFF	57
8	Flight Computer #1 OFF	45
9	Flight Computer #2 OFF	61
10	RF Sw #1 Sel Omni	5
11	RF Sw #2 Sel Omni	21
12	XMTR #1 Amp OFF	33
13	XMTR #2 Amp OFF	49
14	PSE 1553 I/F A OFF	97

Hard LVS Command Sequence (Cont'd)

Command Function	CMD #
15 PSE 1553 I/F B OFF	113
16 RIU #1 OFF	2
17 RIU #2 OFF	18
18 IEM #1 OFF	15
19 IEM #2 OFF	31
20 AIU #1 ON	8
21 AIU #2 ON	24
22 RW #1 ON	4
23 RW #2 ON	20
24 RW #3 ON	36
25 RW #4 ON	52
26 Mag #1 ON	6
27 Mag #2 ON	22

Hard LVS Command Sequence (Cont'd)

Command Function	CMD #
28 Batt Pri Diff Temp Cntrl Dis	104
29 Batt Sec Diff Temp Cntrl Dis	120
30 PPT/AHI Cntrl Dis	90
31 GUVI Surv Htr ON	7
32 SABER Surv Htr ON	23
33 TIDI Surv Htr ON	35
34 SEE Surv Htr ON	51
35 Ord Pri Safe	103
36 Ord Sec Safe	119

Relays

- PSE/DU has the spacecraft power relays (128), with the exception of the relays for the following units, which are in the AIUs:
  - IRU
  - Torque Rods
  - Solar Array Drive relays
    - AIU needs to control these units for safing the spacecraft
    - These relays are not controlled by CCD
- NOP Relay included in PSE/DU

Spacecraft Discretes

- Four (4) Discretes from each AIU to each IEM (Fully Cross Strapped)
  - Heartbeat
  - Boot/Flight Code Status Indicator
  - AIU Selected/Not Selected Status Indicator
  - Attitude OK/Not OK
    - Provides warning of serious loss of attitude

- One (1) discrete (cross strapped) from each IEM to each AIU
  - "Soft" LVS
  - S/C assumes Sun pointing (Safe) attitude when activated

Spacecraft Discretes (Cont'd)

- One (1) discrete from PSE/DU to AIU (Cross strapped between AIUs)
  - Hard LVS, set below "Soft" LVS
    - S/C assumes sun pointing (safe) attitude

- Hard LVS Discrete also between each PSE/DU and CCD in IEM
  - Initiates load shedding Command Sequence
  - Fully Cross Strapped

- Analog Solar Wing Currents (2) provided from Power system to each AIU
  - Solar Wing Currents not used for determining sun position (except as backup to sun sensors)
    - Four coarse sun sensors (two hot side, two cold side, cross-strapped between AIUs) used for finding the sun

- Discrete (redundant) interfaces from AIU to SAD for motor drive and position indicator

REMOTE INTERFACE UNITS (RIU)

- TIMED Implementation with ACTEL Gate Array
  - Future Implementation with ASIC **(Not likely for TIMED)**
- Interface to Temperatures (16), Current and Voltage Monitors for Spacecraft Housekeeping Telemetry
- I^2C Bus; Daisy Chained Twisted Pair, 100 kHz, 8-bit byte transfers
  - Reduction in harnessing

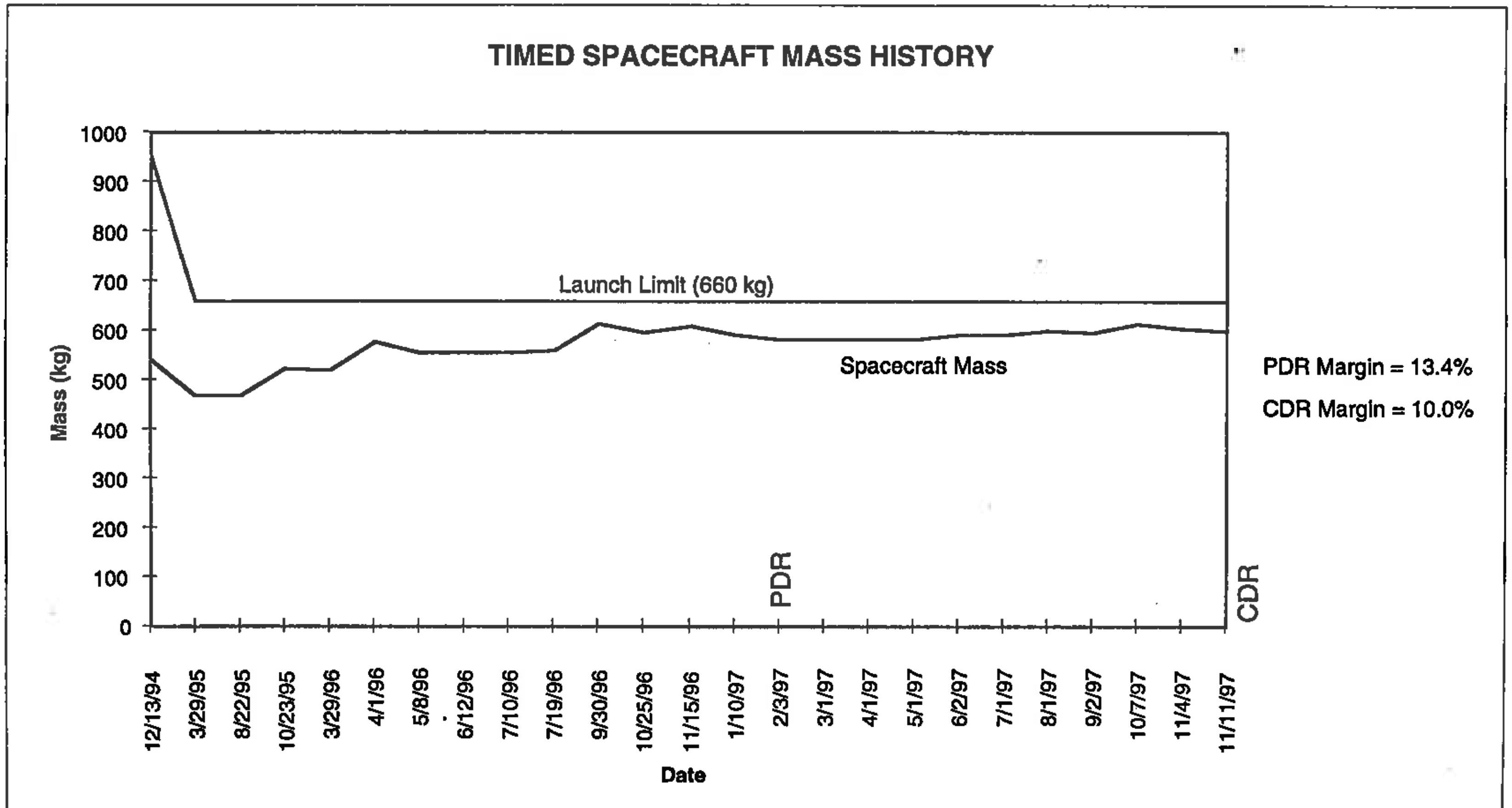
MASS AND POWER BUDGETS

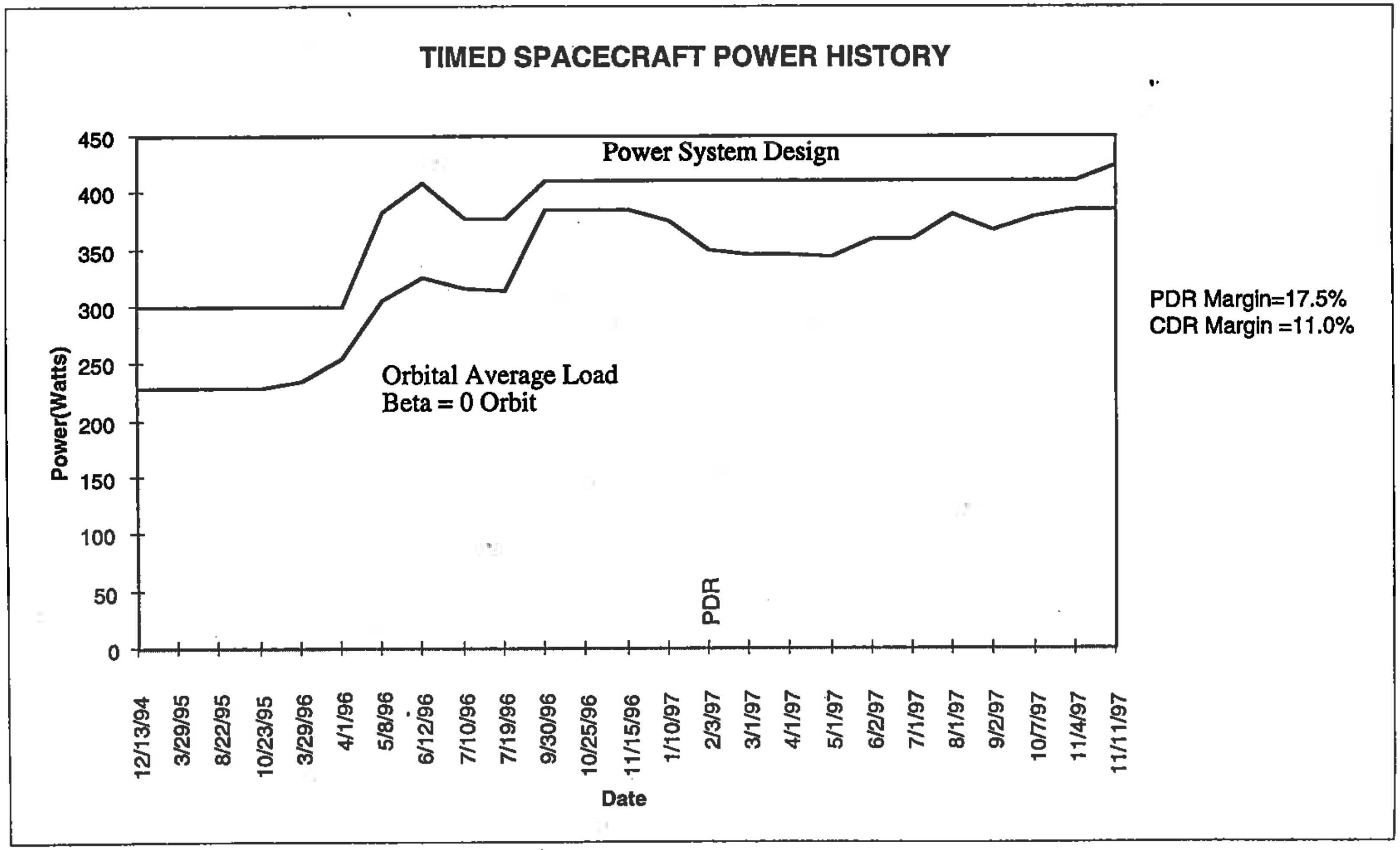
Instruments	151 kg	(22.8%)	151 Watts	(35%)
Power	186	(28)	31.5	(7.4)
RF Antennas, Switches	4.2	(0.64)	0	(0)
Navigation Antennas	2.1	(0.3)	0	(0)
G&C	60.4	(9.2)	106	(25)
IEM	27.7	(4.2)	49.6*	(11.6)
Thermal	16.9	(2.6)	40	(9.4)
Harness	36.3	(5.5)	5.7	(1.3)
Structure	115.6	(17.5)	0	(0)
Margin	60	(10%)	42.2	(11%)
Total	660 kg		426 Watts	

* Note: IEM Mass and Power includes C&DH, Navigation, and RF Communications

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics





TIMED SPACECRAFT POWER HISTORY
Power System Design
Orbital Average Load
Beta = 0 Orbit
PDR
Power(Watts)
450
400
350
300
250
200
150
100
50
0
12/13/94
3/29/95
8/22/95
10/23/95
3/29/96
4/1/96
5/8/96
6/12/96
7/10/96
7/19/96
9/30/96
10/25/96
11/15/96
1/10/97
2/3/97
3/1/97
4/1/97
5/1/97
6/2/97
7/1/97
8/1/97
9/2/97
10/7/97
11/4/97
11/11/97
Date
PDR Margin=17.5%
CDR Margin =11.0%

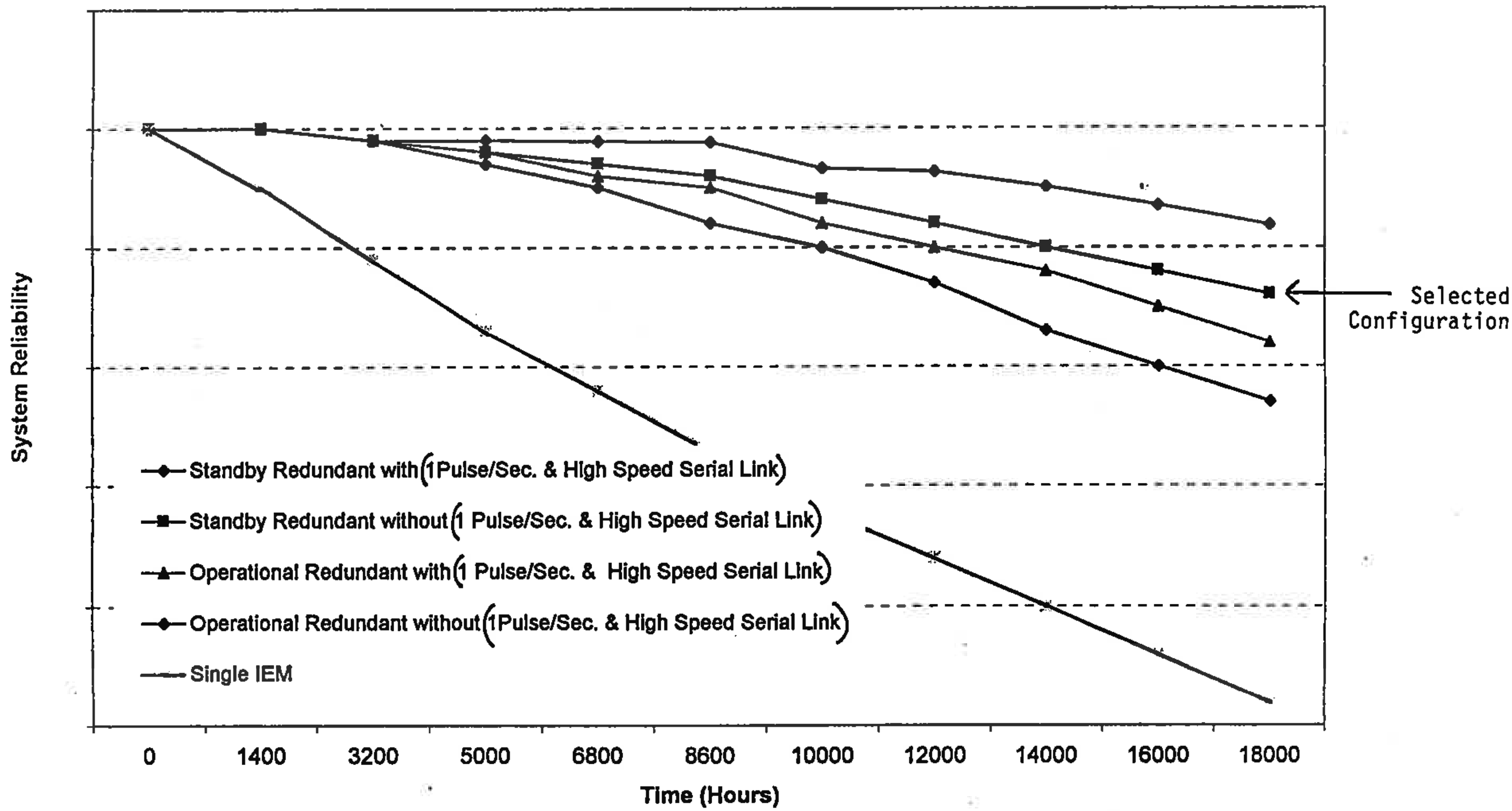
Margin Management

- Instrument mass and power growth controlled by ICDs
  - Not to Exceed values in General Instrument Interface Specifications (Signed Off)
- Additional 8% Mass (52.8 kg) Available from Launch Vehicle
  - See Launch Vehicle Status Presentation
- Solar Panels are being populated as densely as possible with solar cells to maximize available power on-orbit
- Internal subsystem growth must be approved by Spacecraft System, Lead Structural, and Lead Power System engineers

Relative Reliability Assessment

- Relative Reliability Assessment performed on IEM Configurations with and without High Speed Serial Link (HSSL) and GNS 1PPS signal
  - HSSL between IEMs was part of PDR design
    - Intent was to enhance robustness of spacecraft design
      - Cross Strapped SSRs between the two IEMs
- In order to make use of HSSL (e.g., ping-pong recorder operation), both IEMs must be powered
- Relative Reliability Assessment showed that eliminating HSSL, and leaving the redundant IEM unpowered until needed was a **more reliable** configuration than having the HSSL, and keeping the redundant IEM powered throughout the mission

Relative Reliability Assessment of Alternative IEM Configurations



Risk Management

- Fabrication of Engineering Model IEM
  - Early verification of design
  - I&T workaround
- Multiple "Brassboard" copies of (reduced) IEMs for subsystem hardware and software development
- Solar Cell Qual Panel tests of Cells on Aluminum Face Sheets
- Solar Panel Deployment Tests
- Alternative Implementations for Moderate-Risk Designs
  - Actel Implementation of RIU is baseline; ASIC is fall forward option
  - ASIC Implementation of GNS Tracking Correlator; Actel is fall back option
- Mongoose V is baseline design (EM in house); no alternative without programmatic impact

Flight Spares

IEM	Make/Buy	Qty for Flight	Spares
Uplink Card	Make	2	1
Cmd & Tlm I/F	Make	2	1
Downlink	Make	2	1
GPS	Make	2	1
C&DH Proc	Make	2	1
DC/DC Conv #1	Make	2	1
DC/DC Conv #2	Make	2	1
Solid State Recorder	Make	2	1
Backplane	Make	2	1
Card Cage	Make	2	0
RIUs	Make	14	1

Flight Spares (Cont'd)

RF/GPS	**Make/Buy**	**Qty for Flight**	**Spares**
GPS Patch Antenna	Buy	2	1
S-Band Helix	Make	4	1
RF Switch	Buy	2	1
Diplexer	Buy	2	1
GPS LNA	Buy	2	1
POWER			
Battery	Buy Cells	1 Battery	1
Peak Power Tracker	Make	20 Modules	2
Solar Array	Buy	2 Wings	Cells
Power Switching, Fuses	Buy Parts	1	Parts

TIMED

Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics

Flight Spares (Cont'd)

G&C	Make/Buy	Qty for Flight	Spares
AIU	Make	2	Electronics
Star Cameras	Buy	2	0
IRU	Buy	1	0
RWA	Buy	4/+Electronics	0
Flight Computer	Make	2	Electronics
Solar Array Drive	Buy	2	0
Torque Rods	Buy	3	0
Magnetometer	Buy	2	0
Sun Sensors	Make	3	1
Thermal			
Heaters	Buy	?	Yes
Thermostats	Buy	?	Yes
Thermistors	Buy	?	Yes

Conclusion

The Current TIMED Spacecraft Design Meets Requirements with Appropriate Margins and is Ready to Procede to Fabrication