Flight Software

Stephen Musko
Space Physics Research Laboratory
(734) 936-3105
musko@umich.edu

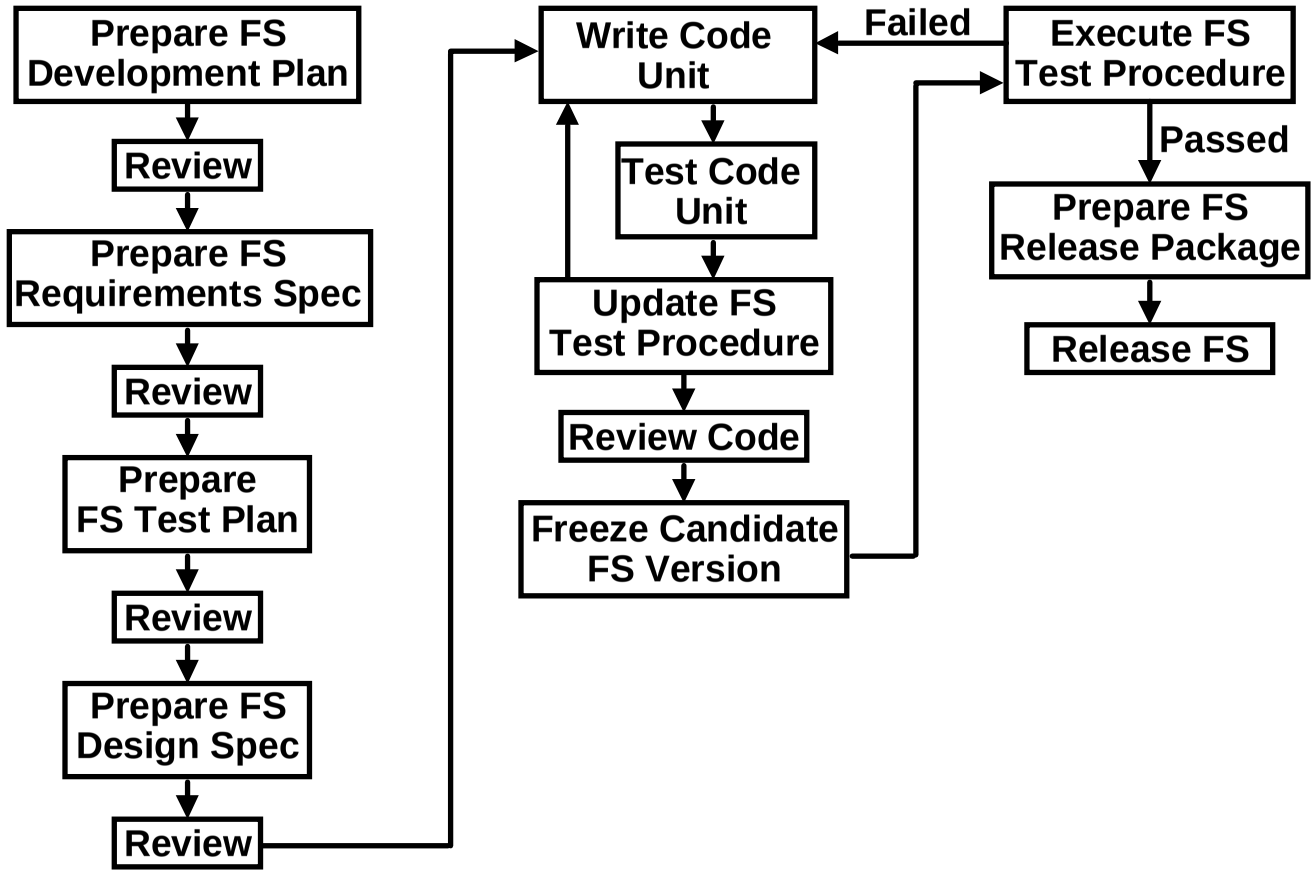
SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software Topics

- Development Process & Documents
- Status
- Software Development and Test System
- Requirements
- Design
- Memory Usage and Performance
- Test Plan
- Changes from PDR

Flight Software Development Process & Documents



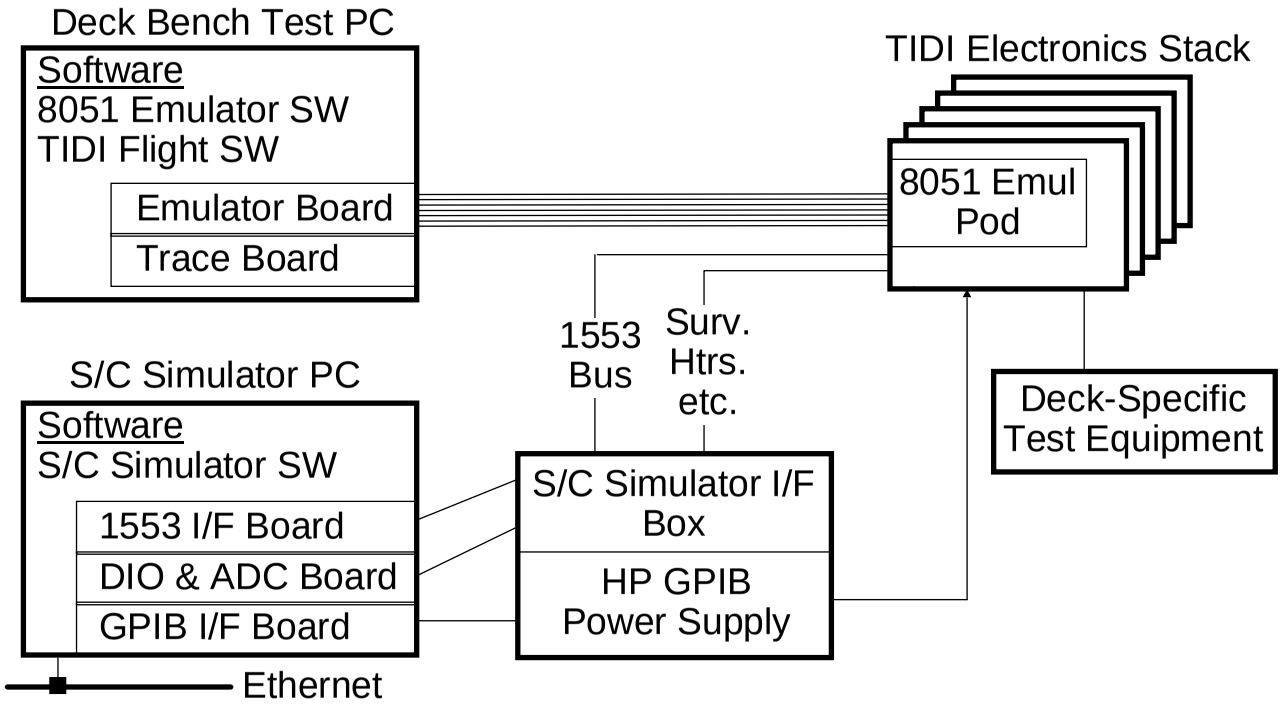
SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software Status

- Requirement Spec completed
- Design Spec completed
- Coding and Unit Test 50% completed - will be completed 9/1/98
- Test Plan completed
- Test Procedure will be completed 12/1/98

Flight Software
Bench Test System



Flight Software
Software Development Tools

- Keil 8051 C Compiler
- Keil 8051 Simulator
- MKS Source Integrity Version Control System
- Opus Make
- Codewright Editor

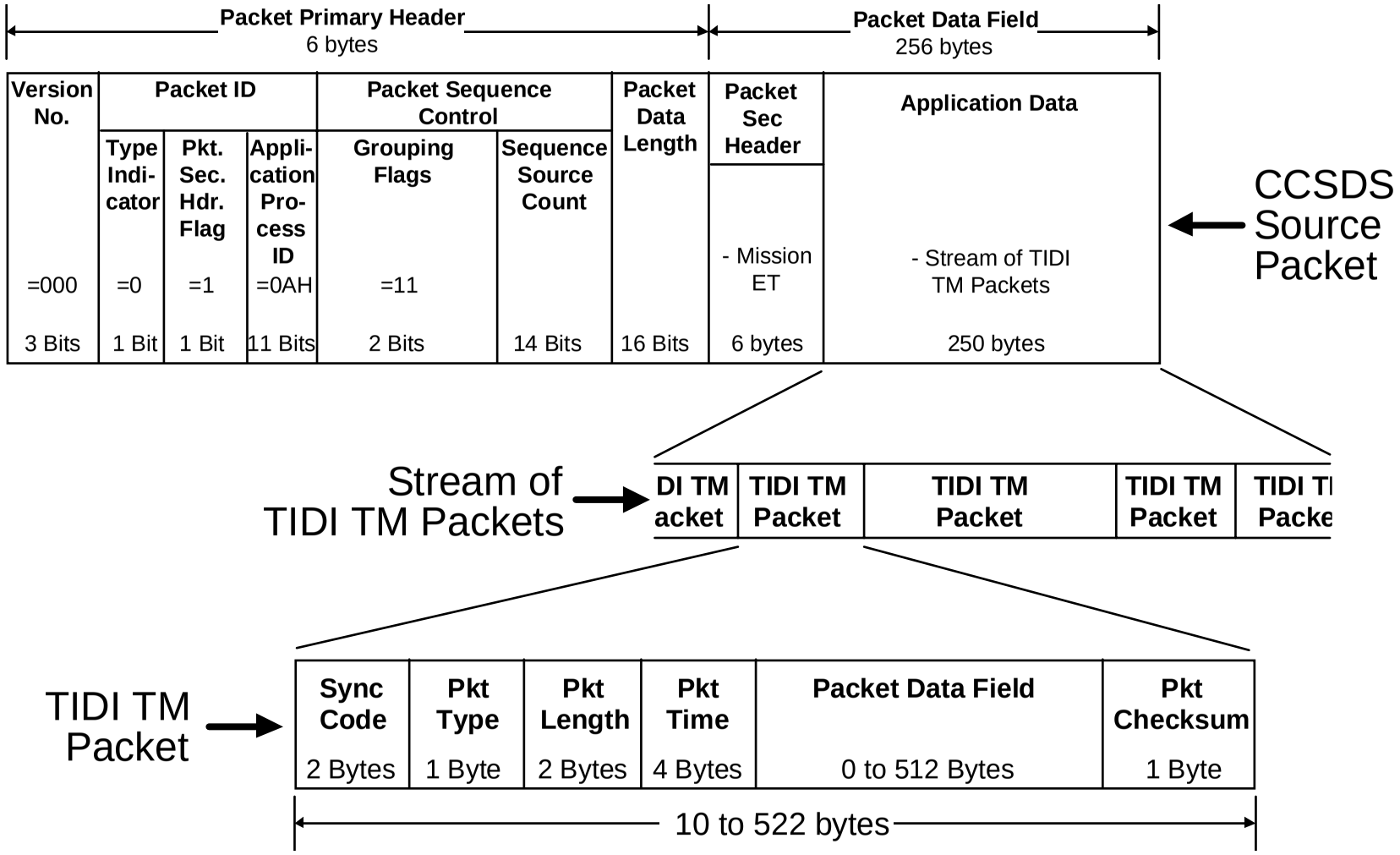
SPACE PHYSICS RESEARCH LABORATORY

TIDI

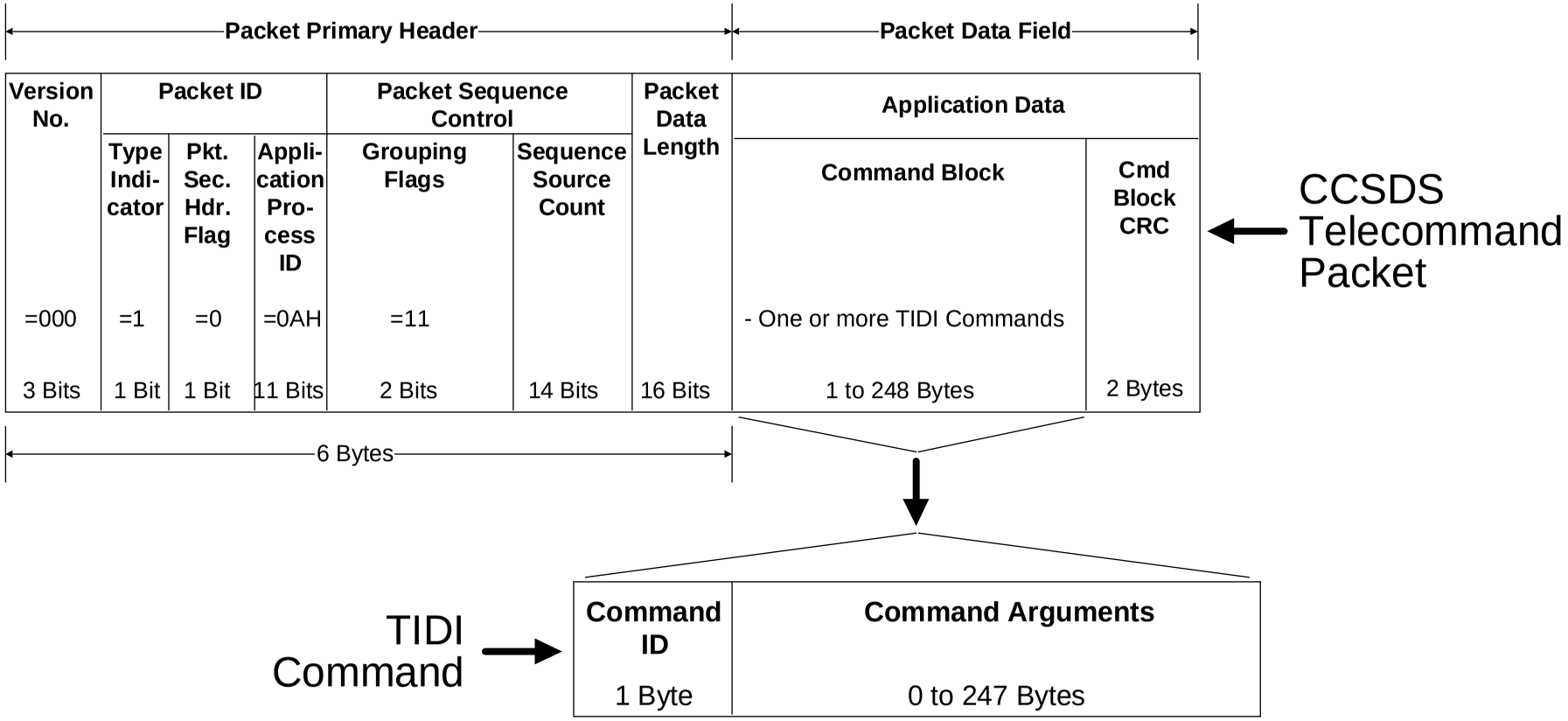
Flight Software Requirements

- Execute commands from 1553 bus
- Execute Control Program
- Control Scanning
- Control Temperatures
- Control shutters and telescope positions for Sun avoidance
- Read housekeeping sensors
- Sync instrument time with S/C time
- Format and transmit science and engineering TM
- Respond to spacecraft warnings
  - Solar panel rotation
  - Loss of attitude control
  - Power down
- Limit check critical houskeeping values

Flight Software Telemetry Packetization



Flight Software Command Packetization



Flight Software
Instrument Status Word

- 64 bits of instrument status that is inserted in S/C real time telemetry
- Not packetized
- Transmitted to S/C via dedicated 1553 subaddress
- Updated by the instrument at 1 Hz.

- Status Word Values
  - Aliveness Toggle 1 bit
  - Inst. Autonomy Bit 1 bit
  - CMD Packet Count 3 bits
  - Cmd Reject Count 3 bits
  - Error Count 4 bits
  - Error Pkt. Sent 1 bit
  - Reboot Flag 1 bit
  - Limit Flags 10 bits
  - Position Error Flags 6 bits
  - Filter & Shutter Pos. 10 bits
  - Boot Code Flag 1 bit
  - Mechanism Moved 1 bit
  - Cal. Lamp States 4 bits
  - Spare 18 bits

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software
Boot Code vs. Instrument Software

- **Boot Code**
  - Executes after CPU reset
  - Stored in PROM
  - Executes out of PROM
  - Automatically boots the Instrument Software
  - Limited command set
  - Special version for thorough memory testing
- **Instrument Software**
  - Stored in EEPROM (uploadable)
  - Executes out of RAM
  - Full command set

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software
Boot Code Commands

- Disable Autoboot
- Boot Now
- Write Memory
  - RAM
  - EEPROM
  - I/O Registers
- Dump Memory
  - PROM
  - RAM
  - EEPROM
  - I/O Registers
- Calculate Cyclic Redundancy Check (CRC)
- Execute RAM Code
- No Operation

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software
Instrument Software Commands

- **Control Program Execution**
  - Start Control Program
  - Stop Control Program
  - Clear Control Program Buffer
  - Append to Control Program Buffer
  - Jump
  - Jump if Equal
  - Jump if Not Equal
  - Jump if Greater Than
  - Jump if Less Than
  - Wait
  - Call Subroutine
  - Return from Subroutine
- **Parameter Manipulation**
  - Load Parameter
  - Add Parameter
  - Subtract Parameter
  - Increment Parameter
  - Decrement Parameter
  - Compare Parameter

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software
Instrument Software Commands (cont)

- **Hardware Control**
  - Load Scan Table
  - Start Scanning
  - Stop Scanning
  - Set Filter Wheel Position
  - Set Calibration Lamp States
  - Set Telescope Elevation
  - Set Shutter Position
  - Clear CCD Binning Table
  - Append to CCD Binning Table
- **Miscellaneous**
  - Write Memory
  - Dump Memory
  - Calculate CRC
  - Execute RAM Code
  - No Operation
  - Let Watchdog Timeout

Flight Software
Instrument Control Program

- **Control Program**
  - Comprises a block of commands
  - Loaded with Append to Control Program command
  - Executed continuously by the Instrument Software
  - Has access to the Instrument Parameter Table
- **1553 commands have priority over the Control Program**
- **Default Control Program is stored in EEPROM**
  - Loaded and executed at initialization
  - Used for parameter set up, default scan control etc.

Flight Software
Commandable Instrument Parameters

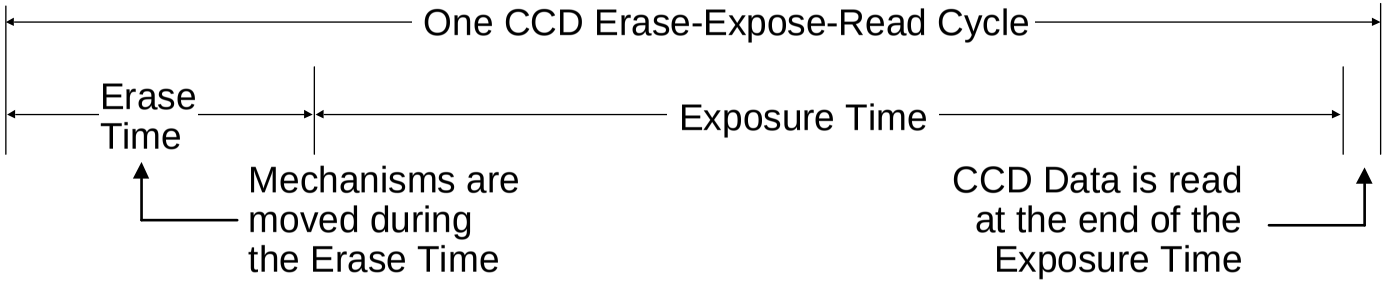
- **Commandable Parameters**
  - PI Temp Controller Parameters
  - Heater Duty Cycles (when PI temp control is disabled)
  - Sun Avoidance Mode Entry Sun Angle
  - Sun Avoidance Mode Exit Sun Angle
  - CCD Control Parameters
  - Telescope Control Parameters
  - Earth Oblateness Comp. On/Off
  - Control Program Global Variables
  - Status TM Packet Rate
  - Control Program Execution Time
  - Red and Yellow Limits

Flight Software
Non-commandable Instrument Params

- **Instrument Status**
  - Analog Sensor Readings
  - Filter Wheel Positions
  - Telescope Positions
  - Current Scan Table ID
  - Commanded Shutter Positions
  - Filter Wheel Position Error Flags
  - Telescope Position Error Flags
  - Latched Reboot Flag
  - Scanning Flag
  - Executing Control Program Flag
  - Other miscellaneous status
- **Spacecraft Status**
  - Most Recent Terminator Crossing
  - Most Recent Node Crossing
  - Universal Time
  - Latitude, Longitude, Altitude
  - Velocity
  - Yaw, Pitch, Roll
  - Sun Vector
  - Latched Warning Flags
    - Solar Panel Rotation
    - Yaw Manuever
    - Loss of Attitude Control
    - Power Down

Flight Software Scanning Control

- **Scanning is the coordinated control of:**
  - **Telescope, Filter Wheel and Shutter Positions**
  - **Calibration Lamp states**
  - **CCD Erase and Exposure Times**
  - **CCD ADC Gain**
  - **Science Data Mode**
- **Scan timing is controlled by the Scan Table**
- **Scanning is started and stopped via command**



Flight Software
Science Data TM Packets

- 4 Science Data TM Packet Types
  - Spectral Science Data TM Packets contain 120 14-bit channel values
  - Calibration Science Data TM Packets contain 150 14-bit channel values
  - CCD Image Science Data TM Packets contain 50 x 300 14-bit pixel values
  - Photometric Science Data TM Packets contain 5 14-bit photometric values
- All Science Data TM Packets contain:
  - Data Validity Flags
  - Mechanism Positions and Position Error Flags
  - Calibration Lamp States
  - Instrument Time at start of CCD exposure
  - Scan Table ID
  - Exposure Count

Flight Software
Miscellaneous TM Packet Types

- **Status TM Packet**
  - Contains all Instrument Parameter Values except Control Program Global Variables
  - Programmable packet transmission rate (1 pkt/sec or slower)
- **Command Confirmation Packet**
- **Memory Dump Packet**
- **Control Program Global Variable Dump Packet**
- **CRC TM Packet**
- **Error Report Packet**
- **Null Packet**

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software TM Production

	TIDI TM Pkt Size (bits)	TIDI TM Pkt Rate (pkts/sec)	TIDI TM Pkt Bit Rate (bits/sec)	CCSDS Source Pkt Overhead (bits/sec)	Total TM Rate (bits/sec)
Science Data TM Packet	1872	1	1872	74	1956
Status TM Packet	2704	0.1	270	11	281
Margin					257
					2494

SPACE PHYSICS RESEARCH LABORATORY TIDI

Flight Software Top Level Design

- **Code is divided into**
  - **Interrupt code (High Priority)**
    - **Interrupt Service Routines**
    - **Event Service Routines**
  - **Non-interrupt code (Low Priority)**
    - **Main Loop**
    - **Tasks**
    - **Utility Routines**
- **Tasks are state machines called from a main loop**
  - **Each task limits its own execution time**
- **Tasks share the CPU through cooperative multitasking**
- **Same architecture used for TOMS/Earth Probe flight SW**

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software ISRs and ESRs

- **Interrupt Service Routines**
  - Millisecond ISR
  - 1553 ISR
  - I/O Bus ISR
  - ADC Timer ISR
- **Event Service Routines**
  - Centisecond ESR
  - Command Message ESR
  - TM Message ESR
  - S/C Status Message ESR
  - Start of Second ESR
  - Time Code ESR
  - Motor Heater Deck ESR
  - CCD Data Available ESR
  - Filter Wheel Position ESR
  - Shutter Position ESR
  - Telescope Position ESR

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software Tasks

- Prepare Commands
- Execute Commands
- Control Motors
- Send Source Packets
- Load Scan Control Block
- Build Science Data Packet
- Sync Instrument Time
- Send Status Packet
- Read S/C Status
- Do Housekeeping

Flight Software
Projected Total Memory Usage

- **The following memory estimates are based on the design specification and the code already written**
  - **PROM**

    16K total available, 13K will be required for Boot PROM code
  - **Data RAM**

    64K total available, 48K will be required for program variables
  - **Program RAM**

    64K total available, 22K will be required for Instrument Software
  - **EEPROM**

    128K total available, 76K will be required for Instrument Software and Default Control Program

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software Performance

- **Critical Tasks and ISRs are coded and tested.**
  - **Instrument timekeeping**
  - **CMD reception**
  - **TM production and transmission**
  - **Instrument parameter access**
- **No performance concerns to date although tight coding has been required**
- **Almost all deadlines are handled by ISR code allowing the tasks to use up to 75 msec per invocation**
- **The most demanding task code deadline is 975 msec (Spacecraft Start of Second message)**
- **Design Spec CPU Load Estimate has held up so far at approximately 30% CPU utilization**

SPACE PHYSICS RESEARCH LABORATORY TIDI

Flight Software Test Plan

- Visually inspect code
- Unit Test with 8051 simulator on PC
- Unit Test with 8051 emulator on the engineering model electronics stack (100% coverage)
- System Testing
- Stress Testing
  - Try to crash the flight software with high command rates
  - Try to crash the flight software with invalid commands
- Code Review
- Formal Test Procedure - Test all requirements. Executed on the flight model before instrument calibration begins.

SPACE PHYSICS RESEARCH LABORATORY

TIDI

Flight Software
Significant Changes from PDR

- Sun avoidance now requires moving telescopes to lowest elevation
- Modified commands and status for 2nd filter wheel
- Eliminated programmable format for Status TM packets. Status TM packet size now fixed.
- Added “Allocate Local Vars” and “Deallocate Local Vars” commands
- Removed autonomous bearing lube overscanning.
- Changed temp control from PID to PI
- Removed “Optimize Telescope Movement” and “Optimize Filter Wheel Movement” commands

Flight Software
CCD Binning

- **Multiple binning tables are stored in RAM**
- **CCD Binning is controlled by the current Binning Table**
- **Current Binning Table is selected in the Scan Table**
  - **Can be changed many times during a scan**
- **Binning Table contains one entry for each horiz. bin (up to 256 bins)**
- **Each Binning Table entry contains a bin width (1 to 255 pixels), a bin gain (4 ranges) and a "discard bin" bit**