<table>
<tr><td colspan="2">University of Michigan
Space Physics Research Laboratory</td></tr>
<tr><td>TIDI Flight Software
Requirements Specification</td><td>CAGE No. 0TK63
Drawing No. 055-3320H
Project TIDI
Contract No. NASW-5-5049
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</table>

Approval Record

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REVISION RECORD

Rev	Description	Date
A	Released for PDR distribution. This revision has not been formally reviewed.	1/15/97
B	Post PDR revision. Major overhaul with many changes.	3/17/97
C	General update. 1. Now using a Control Program Holding Buffer and a Control Program Buffer instead of Control Program Buffers 1 and 2. 2. Changed TIDI CCSDS Application ID from 00AH to 500H. 3. Added CCD gain control to the Scan Table. 4. Added an Exposure Repeat Count to the Scan Table Interval Definition to allow multiple CCD exposures at the same telescope elevations. 5. Added instrument parameters for Filter Wheel 2 position and error flags. 6. Numerous small changes to control the second filter wheel. 7. Added filter wheel position status to all science TM packets. 8. Changed all instrument memory addresses used in telemetry and commands to a standard 24-bit format. 9. Reserved TIDI TM Packet Types 248 through 255 for GSE use. TIDI will not produce these packet types. 10. Reduced the maximum size of CCSDS Telecommand Packets from 2048 to 1024 bytes. 11. Reduced the maximum size of TIDI Command Packets from 2040 to 1016 bytes. 12. Updated temperature control heater and sensor names. 13. Updated Boot Code temperature setpoints. 14. Removed special "ratio" temperature control requirements for the profiler. The three heater/sensor pairs are now controlled independently. 15. Replaced the term "Real Time Telemetry" with "Instrument Status Word". 16. Moved the definition of the Instrument Status Word to a separate document (055-3512). 17. Move the definition of the Instrument Parameters to a separate document (055-3519). 18. Eliminated programmable status TM packet formats. Defined one status packet type that contains all the Instrument Parameters except for the Control Program Global Variables. 19. Added the Dump Control Program Variables command. 20. Changed TM packet IDs to contiguous numbers starting with 0. 21. Replaced the 8-bit Scan Table Step with the 16-bit Exposure Count in the status information contained in the science TM packets.	9/22/97

REVISION RECORD - Continued

Rev	Description	Date
D	Minor revision. 1. Added byte-order information to Conventions section. 2. Made it clear that the Boot Code does temperature control. 3. Changed Instrument Time epoch to Jan 6, 1980 to match the spacecraft time epoch. 4. Any command received by the Boot Code disables autobooting. Previously just the Disable Autoboot command disabled autobooting. 5. The Error Report TM packet is now fixed length containing an error ID and four error parameters. Previously the Error Report TM packet was variable length. 6. Changed the Wait Command wait period units from milliseconds to centiseconds. 7. Changed all commands that specify source and/or destination IPs to allow specifying local parameters. 8. Added Allocate Local Variables command. 9. Added Deallocate Local Variables command.	10/28/97

REVISION RECORD - Continued

Rev	Description	Date
E	Minor Revision 1. Added shutter control to the scan table. 2. Removed automatic bearing lube overscan. Will be handled by the Control Program since it only has to be done once or twice per orbit. 3. Removed the Reference Listing of Instrument Parameters to reduce confusion. For a complete listing of the Instrument Parameters, see Doc #055-3519, TIDI Instrument Parameter Definition. 4. Fixed the size of the CCD Image Science Data TM packet at 256 bytes. Added Pixel Number field to allow the CCD image to be broken up into multiple TM packets. 5. Changed temp control algorithm from Proportional Integral Derivative (PID) to Proportional Integral (PI). The results of Jon Harvey's thermal analysis indicate that temp overshoot will not be a problem and that PI temp control will be adaquate. 6. Removed the "Optimize Telescope Movement" and "Optimize Filter Wheel Movement" commands. Current hardware design and analysis indicates that these commands are not required. 7. Add an explanation that Error TM packets may be transmitted out of correct time sequence because they have transmission priority over all other TM packets. 8. Limited the size of all TIDI commands to 248 bytes to ease the processing burden on the flight software. This change affected the following commands: Write Memory, Append to CCD Binning Table, Append to Control Program Holding Buffer, Append to Scan Table. 9. Added Telescope Shutter Status bits to all the Science Data TM packets. This changed the size of all the Science Data TM packets. 10. Expanded the descriptions of the Science Data TM packet fields to make it clear that the reported mechanism states are the commanded states, not the actual states determined from readbacks. 11. Changed the CCSDS Telecommand Confirmation procedure. Command Confirmation TM Packets are now sent only for valid CCSDS Telecommand Packets. Invalid CCSDS Telecommand packets are now reported with Error Report TM packets. 12. Reduced the size of the Command Confirmation TM packet by removing error information. 13. Made it clear that multiple Memory Dump TM Packets can be sent in response to a single Dump Memory command. 14. Limited the size of Memory Dump TM packets to 256 bytes. 15. Fixed format errors in the Error Report TM Packet Field definition. 16. Fixed several minor typos. 17. Added the currently defined error codes and error parameters.	3/10/98

REVISION RECORD - Continued

F	Minor revision 1. Added CCD Binning Table format. 2. Added binning table number argument to the Clear CCD Binning Table and Append to Binning Table commands. 3. Added current Binning Table ID to the Science Data TM packets and Instrument Parameters. 4. Now using actual LVDT positions in the Science Data TM packets instead of commanded LVDT positions. 5. Added Autonomous Safety Actions section. 6. Changed PROM address range from 0 - 3FFFH to 0 - 5FFFH. 7. Changed description of Error Code 6. 8. Added latest error codes. 9. Updated Figure 2 - TIDI CPU View of the World to reflect latest hardware design. 10. Changed the description of the TM Packet Checksum field in Table 3 - TIDI TM Packet Fields. Changed the checksum coverage to include the TIDI TM Packet Sync Code. This change documents how all existing software is calculating the packet checksum. 11. Change the TCMD confirmation description to add the following: If a CCSDS Telecommand packet is valid, except for the Sequence Source Count, an Error Report TM packet shall be transmitted AND the contents of the packet shall be executed. 12. Revised the Scan Control section to remove programmable Erase Time. The Erase Time is now calculated by the Instrument Software. 13. Change Spectral Science Data TM Packet to variable size based on the Binning Table. 14. Eliminated the Calibration Science Data TM Packet and Photometer Science Data TM Packet types. 15. Increased the size of the CCD image conveyed in the CCD Image Data TM Packet from 50 x 600 pixels to 60 x 600 pixels. 16. Changed the Scan Table Format to meet science requirements.	7/21/98

REVISION RECORD - Continued

G	Minor changes that accumulated during coding. 1. Numerous minor clarifications. 2. Major changes to the status fields of the Spectral Science Data TM Packet and CCD Image Data TM Packet. 3. Changed the size of the CCD image from 60 x 600 pixels to 50 x 600 pixels because the CCD Image RAM is not large enough to contain 60 x 600 16-bit values. 4. Changed the number of CCD Binning Tables from eight to two to conserve memory and because more than two tables are not necessary. 5. Made it clear that 0 CCD integration time is OK. 6. Prohibited science data mode changes within a scan table. 7. Changed telescope step size to 0.004884° (20°/4095). 8. Added appendices for opcode tables and opcodes that are legal while scanning. 9. Change binning table format to reverse the order of the bins.	12/10/98
H	1. Added note that memory writes to and dumps from Data RAM cannot cross over the 1C000h boundary. 2. Changed all references to telescope elevation to use a 4096 count span instead of 4095 count span. Changed nominal telescope elevation from 23° to 20.3°. 3. Added Copy CPHB to Primary EEPROM command. Used the previously spare command ID 38. 4. Added Copy CPHB to Secondary EEPROM command. Used the previously spare command ID 39. 5. Updated error code and error parameter descriptions. 6. Fixed several typos and minor errors. 7. Added CCD Integration Time to Science Data TM Packets. 8. Added Erase-Expose-Convert minimum cycle time of one second. 9. Added Erase-Expose-Convert cycle mechanism stability minimum time of 750 milliseconds. 10. Added a definition of Safe Mode and the conditions that cause it. 11. Added a full explanation of all status information that appears in Science Data TM packets.	10/6/99

Table of Contents

1. Acronyms and Abbreviations

1553	Same as Mil-Std-1553B
8051	Generic term for a microcontroller that is compliant with the Intel 8051 microcontroller core architecture.
ADC	Analog to Digital Converter
B	Binary
Byte	An 8 bit data word
Cal.	Calibration
CCD	Charge Coupled Device
CCSDS	Consultative Committee for Space Data Systems
Clear	Clear a variable to a value of zero.
CMD	Command
CP	Control Program (Buffer)
CPH	Control Program Holding (Buffer)
CPU	Central Processing Unit. In this document the term CPU refers to the UT69RH051 microcontroller
CRC	Cyclic Redundancy Check (using the CRC-16 method)
DDC	Device Data Corporation
EEPROM	Electrically Erasable Programmable Read-Only Memory
False	zero
Flight Software	TIDI Flight Software (includes Boot Code and Instrument Software)
FPA	Focal Plane Assembly
FPGA	Field Programmable Gate Array
FW	Filter Wheel
GSE	Ground Support Equipment
H	Hexadecimal
Hz.	Hertz
I/O	Input/Output
ID	Identifier
IP	Instrument Parameter
ISW	Instrument Status Word
JHUAPL	Johns Hopkins University Applied Physics Laboratory
KB	Kilobyte = 1024 bytes
Kb	Kilobit = 1000 bits
Kbyte	Kilobyte = 1024 bytes
LS	Least Significant
LVDT	Linear Variable Differential Transformer
MH	Motor Heater (Deck)
MHz	megahertz

Mil-Std-1553B	A dual-redundant serial data communications bus defined by Aircraft Internal Time Division Command/Response Multiplex Data Bus, with Notice II, 9/8/86
MS	Most Significant
msec	Millisecond
PI	Proportional Integral
PID	Proportional Integral Derivative
PROM	Programmable Read-Only Memory
PWM	Pulse Width Modulation
R&QA	Reliability and Quality Assurance
R/W	Read/Write
RAM	(Read/Write) Random Access Memory
Reset	Clear a variable to a value of zero
S/C	Spacecraft
SAA	South Atlantic Anomaly
Set	Set a variable to a value of one
SPRL	Space Physics Research Laboratory
TBD	To be determined
TBS	To be specified
TIDI	TIMED Doppler Interferometer
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics spacecraft
TM	Telemetry
True	one
usec	microsecond
UTMC	United Technologies Microelectronics Center

2. Conventions

2.1. Requirements & Descriptive Text

This document contains requirements and descriptive text. The descriptive text is used to explain and elaborate on the requirements. So that the two types of text are clearly distinguishable, testable requirements appear in bold italics. Background and descriptive text appears in plain text.

2.2. Bit Order

For any N-bit wide register or variable, Bit N-1 is defined as the MS bit and Bit 0 is the LS bit. For 16-bit, 24-bit or 32-bit values formed by the concatenation of 8-bit bytes, the MS byte is in the lowest memory address and the LS byte is in highest address.

In telemetry and command packets, there are different types of data values consisting of different number of bits. As shown in Figure 1 below, the CCSDS recommendations define Bit 0 of an N-bit data field as the most significant (MS) bit. This is contrary to the near universal bit numbering convention where Bit N-1 is defined as the MS bit of an N-bit data field. In both conventions the MS bit is transmitted first.

To remain compatible with the CCSDS recommendations and to allow usage of the more common bit numbering convention, any bit fields defined in the CCSDS recommendations use the Bit 0 = MS bit convention and all other bit fields used in this document use the Bit N-1 = MS bit convention.

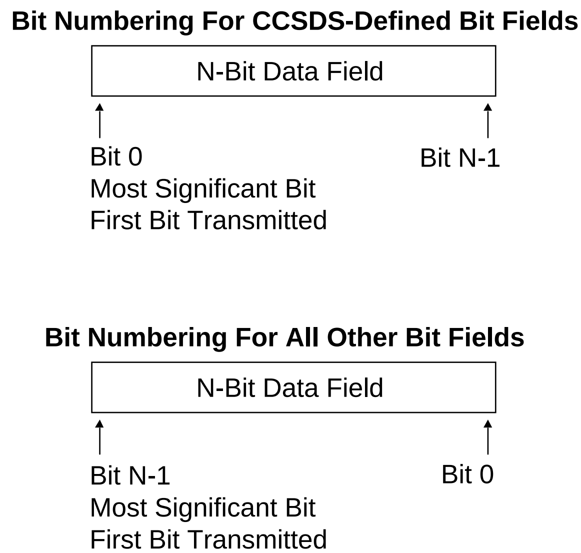

Figure 1 - Data Field Bit Numbering Conventions

2.3. Number Base

All numbers are base 10 unless otherwise indicated. Hexadecimal numbers are indicated by the “H” suffix. Binary numbers are indicated by the “B” suffix.

2.4. 24-Bit Addresses

Due to bank switching, a 16 bit address is not sufficient to fully specify the address all the instrument memory and devices. So, within this specification, all memory and memory-mapped devices are given 24 bit addresses. The MS 8 bits of the address select the memory segment and the LS 16 bits are the offset within that memory segment.

Table 1 - 24-Bit Address of All Memory Areas

24-Bit Address	Memory Area Addressed
00xxxxH	PROM from 0000H to 5FFFH (R)
01xxxxH	Data RAM from 0000H to FFFFH, including on-board I/O registers (R/W)
02xxxxH	Program RAM from 0000H to FFFFH (R/W)
03xxxxH	EEPROM from 0000H to 0FFFFH (R/W)
04xxxxH	EEPROM from 10000H to 1FFFFH (R/W)
05xxxxH	1553 RAM from 0000H to 7FFFH (R/W)
06xxxxH	CCD Controller Deck from 0000H to 3FFFH
07xxxxH	Motor/Heater Deck from 0000H to 3FFFH
08xxxxH	Data Acquisition Deck from 0000H to 3FFFH
09xxxxH	Telescope Servo Deck from 0000H to 3FFFH

3. Related Documents

1. TIDI Flight Software Development Plan, SPRL Document #055-3319

2. TIDI Flight Software Test Plan, SPRL Document #055-3322
3. TIDI Flight Software Design Specification, SPRL Document #055-3321
4. TIDI Flight Software Test Procedure, SPRL Document #055-3434
5. TIDI Instrument Status Word Definition, SPRL Document #055-3512
6. TIDI Instrument Parameter Definition, SPRL Document #055-3519
7. TIMED General Instrument Interface Specification (GIIS), JHUAPL Drawing #7363-9050
8. MIL-STD-1553B, Aircraft Internal Time Division Command/Response Multiplex Data Bus, Revision B

4. Background

The Background section contains no specifications and intended only to give the reader enough background information to understand and evaluate the Flight Software requirements contained in this document.

4.1. Hardware Overview

From the UT69RH051 (CPU) point of view, TIDI consists of several types of memory and I/O devices configured as shown in

Figure **2** below.

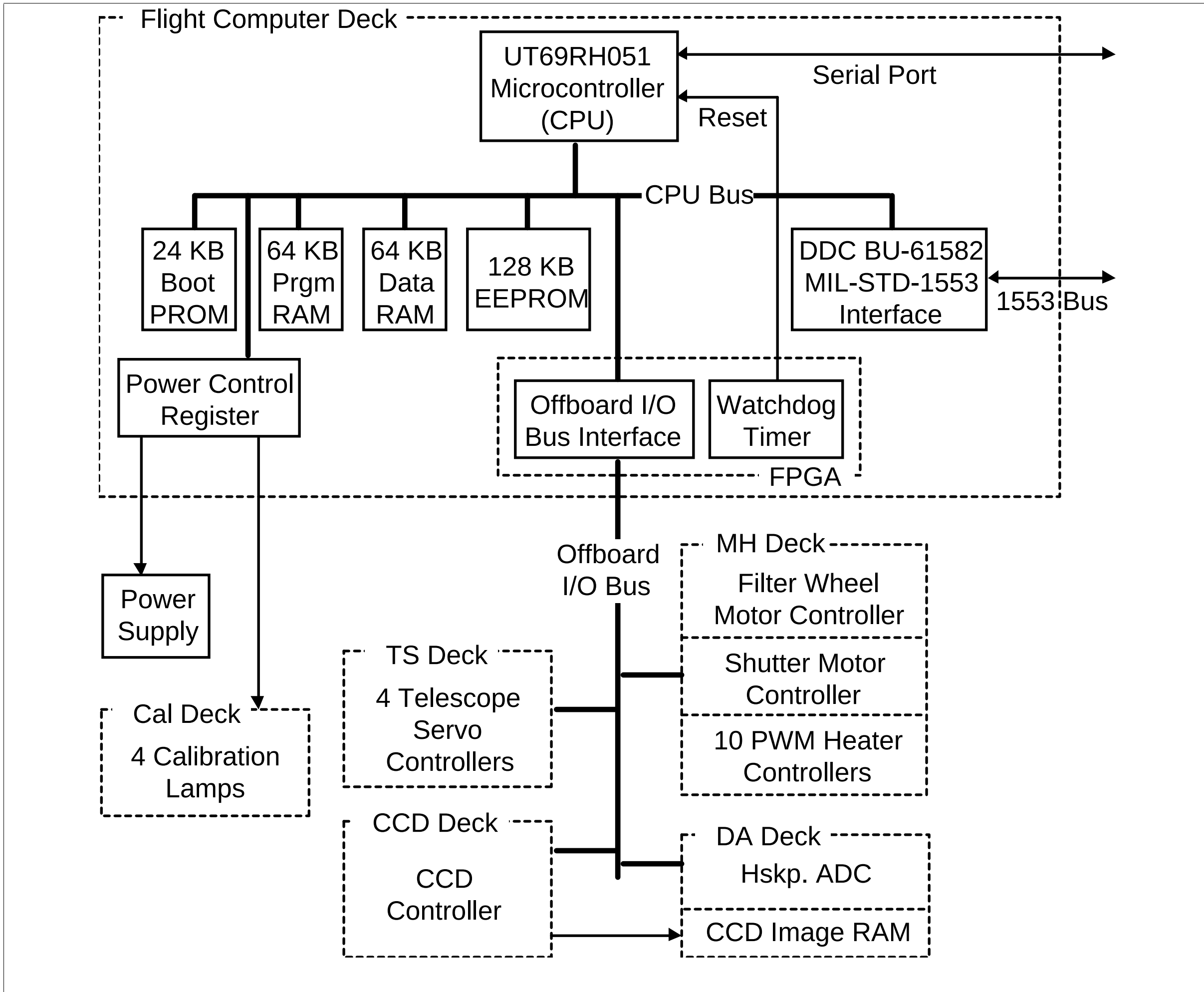

Figure 2 - TIDI CPU View of the World

4.2. Hardware Subsystems

4.2.1. Microcontroller (CPU)

The Central Processing Unit (CPU) is a UTMC UT69RH051 microcontroller that contains:

1. An Intel 8051 instruction set compatible processing unit
2. Three 16 bit counter/timers
3. 256 bytes of on-chip data RAM
4. 32 programmable I/O lines (16 dedicated to external memory address and data)
5. An asynchronous serial communication port

4.2.2. Memory

There are four types of memory external to the CPU:

1. Boot PROM - 24 Kbytes of fuse-link PROM used for storage and execution of the Boot Code.
2. Program RAM - 64 Kbytes of static RAM used as execution space for the Instrument Software.
3. Data RAM - 64 Kbytes of static RAM used for data storage.

4. EEPROM - 128 Kbytes of EEPROM used as non-volatile storage the Instrument Software and the Default Control Program.

Since the CPU can directly access only 128 Kbytes of external memory, bank switching is used to access the external memory and the Offboard I/O Bus.

4.2.3. Power Control Register

The Power Control Register is an 8 bit latch that is used by the CPU to turn selected power supply voltages on and off. The Power Control Register output bits are assigned as follows:

Bit 0	Telescope servo motor power control
Bit 1	Calibration Lamp power control
Bit 2	Cal Lamp #1 (HAK) control
Bit 3	Cal Lamp #2 (Neon) control
Bit 4	Cal Lamp #3 (Incandescent #1) control
Bit 5	Cal Lamp #4 (Incandescent #2) control
Bits 6-7	Spare

4.2.4. 1553 Interface

The entire 1553 interface, except for two coupling transformers is contained on a single Device Data Corporation (DDC) BU-61582 hybrid circuit. The BU-61582 also contains 32 Kbytes of RAM that is used for control structures and to buffer incoming and outgoing messages.

4.2.5. Field Programmable Gate Array

The Field Programmable Gate Array (FPGA) is a monolithic programmable logic device that contains the Offboard I/O Bus Interface, the Watchdog Timer and other logic functions required for the Flight Computer.

4.2.6. Offboard I/O Bus Interface

The Offboard I/O Bus Interface maps the 64 Kbyte Offboard I/O Bus address space into the CPU address space which allows the CPU to read from and write to the other electronics decks. The Offboard I/O Bus Interface also contains a latch for each of the deck interrupt request lines.

4.2.7. Watchdog Timer

The Watchdog Timer is used to reset the CPU if a software lockup or hardware upset occurs. The Watchdog Timer must be cleared by the CPU at least every 2 seconds or it will expire and reset the CPU. To ease software debugging, the Watchdog Timer may be disabled by installing a hardware jumper block.

4.2.8. CCD Controller

The CCD controller is a custom design implemented in an FPGA. The Offboard I/O Bus interface to the CCD controller consists of a group of 8-bit control and status registers and an array of RAM values used to store the CCD Binning Tables. After the CPU initializes the controller by writing configuration information to the control registers and CCD Binning Table, the controller can run in a continuous or single-cycle mode converting CCD data into 12 bit values, putting them into the CCD Image RAM (located on the DA Deck) and interrupting the CPU when CCD data is available.

4.2.9. Heater Controllers

Each of the 10 Heater Controllers consists of a Pulse Width Modulator (PWM) and a driver that powers a heater. The heater pulse widths are set by the CPU and can be set to a resolution of 8 bits. The heater pulse frequency is set in hardware and is not programmable.

4.2.10. Housekeeping Analog to Digital Converter

The Housekeeping Analog to Digital Converter (ADC) used to convert analog sensor voltages into 12 bit digital values. The housekeeping ADC is controlled directly by the CPU.

4.2.11. Filter Wheel Controller

The Filter Wheel (FW) Controller controls the movement of the two filter wheels. When a FW movement is required, the CPU writes the desired position and acceleration profile to control registers and the controller moves the FW using the programmed acceleration profile. The FW Controller interrupts the CPU when the movement is completed. The FW Controller also provides FW position and error status to the CPU.

4.2.12. Shutter Motor Controller

There are four stepper motors that each drive a telescope shutter. The CPU writes the desired motor position to a controller register and then commands the motor controller to move the motor to the desired position. There is no position feedback from the shutters, so the shutters are driven into mechanical stops whenever they are opened or closed.

4.2.13. Telescope Servo Controllers

There are four Telescope Servo Controllers that control telescope motion. Each controller consists of a hardware PID loop that is controlled with high level commands by the CPU.

5. Flight Software Overview

The Flight Software Overview section contains no specifications and is intended to give the reader a general understanding of the flight software high level functions and partitioning.

The TIDI Flight Software consists of two separate software components:

1. Boot Code
2. Instrument Software

The Instrument Software executes an uploadable Control Program which is the primary means of programming instrument operations on orbit.

5.1. Boot Code Overview

The Boot Code is stored in PROM and executed from PROM upon CPU reset or power up. The Boot Code performs the following functions:

1. Initializes the TIDI hardware, including the 1553 bus interface, and does the minimum required to put all CPU controlled hardware into a safe state.
2. Waits for the Autoboot Time-out Period and then automatically executes the Boot Procedure. The Boot Procedure copies the Instrument Software from EEPROM to Program RAM and then executes the Instrument Software in Program RAM.
3. Responds to the following commands received from the 1553 bus:

a. Disable Autoboot. Prevent the Boot Code from automatically executing the Boot Procedure.

b. Boot Immediately. Execute the Boot Procedure immediately.

c. Write Memory. Write to any memory or I/O location.

d. Dump Memory. Transmit the contents of any memory or I/O location.

e. Calculate Cyclic Redundancy Check (CRC). Calculate the CRC for any section of memory.

f. Execute code in RAM. Begin program execution at any Program RAM location.

g. No Operation

3. Transmits Status TM packets periodically.
4. Controls instrument temperatures.

5.2. Instrument Software Overview

The Instrument Software is stored in EEPROM and executed in RAM after the Boot Procedure is complete. The Instrument Software performs the following functions:

1. Executes commands received from the 1553 bus
2. Executes the Control Program.
3. Controls scanning (coordinated telescope movement, filter wheel movement, calibration lamp control and CCD data collection).
4. Controls instrument temperatures
5. Limit checks critical instrument parameters
6. Controls telescope shutters and telescope elevations for sun avoidance
7. Periodically reads instrument housekeeping sensors
8. Formats science and engineering telemetry (TM)
9. Transmits telemetry to the spacecraft over the 1553 bus

5.3. Control Program

The Control Program is executed by the Instrument Software and gives TIDI the ability to execute commands in response to changing conditions such as: Instrument Time; spacecraft position; spacecraft attitude; terminator crossings and yaw maneuvers.

The Control Program consists of a block of TIDI Commands. Any valid TIDI command may be included in the Control Program.

When the Instrument Software is initialized, the Default Control Program is copied from EEPROM into RAM and executed. The Control Program and the Default Control Program are independently loadable via command.

6. General Requirements

6.1. Telemetry Packet Formatting

6.1.1. CCSDS Source Packet Format

TIDI shall transmit telemetry to the spacecraft in the form of fixed length CCSDS Source Packets that conform to the format given in Figure 3 below.

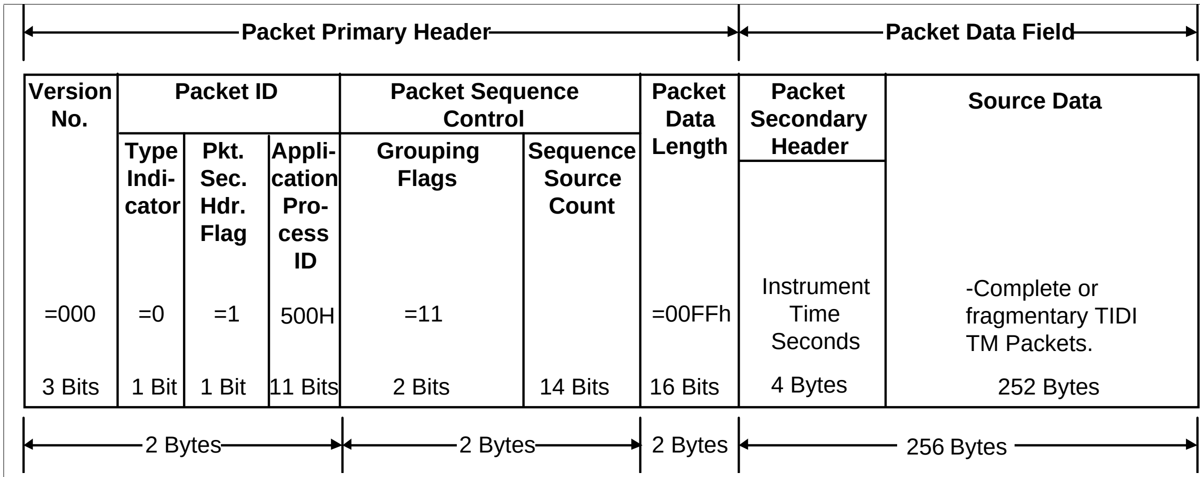

Figure 3 - CCSDS Source Packet as Used for TIDI TM

An explanation of each CCSDS Source Packet bit field as used for TIDI telemetry is explained in Table 2 below.

Table 2 - CCSDS Source Packet Fields as Used for TIDI Telemetry

Field	Usage
Version Number (3 bits)	Identifies the version of the packet structure. Always set to 000B.
Type Indicator (1 bit)	Identifies this packet as telemetry (as opposed to telecommand). Always set to 0.
Packet Secondary Header Flag (1 bit)	Indicates the presence or absence of a Packet Secondary Header in the Packet Data Field. Always set to 1 to indicate that there is always a Packet Secondary Header present.
Application Process ID (11 bits)	Identifies the packet as a TIDI telemetry packet. Always set 101 0000 0000B.
Grouping Flags (2 bits)	Used for segmenting large Source Packets. TIDI does not use segmented Source Packets therefore these flags are always set to 11B.
Sequence Source Count (14 bits)	A modulo 16,384 sequence number that is used to maintain the sequential order of packets. The Sequence Source Count of the first packet after initialization is 0 and is increased by one for each subsequent packet.
Packet Data Length (16 bits)	Equal to the number of bytes in the Packet Data Field minus one. Always set to 00FFH.
Packet Secondary Header (4 bytes)	Contains the value of the Instrument Time Seconds IP when the Source Packet was created.
Source Data (252 bytes)	Contains one or more complete or partial TIDI TM Packets.

6.1.2. TIDI Telemetry Packet Format

The CCSDS Source Data packet Source Data field shall be packed with variable-length TIDI Telemetry Packets.

The basic unit of TIDI telemetry is the TIDI TM Packet which contains science or engineering telemetry. TIDI TM Packets are packed into CCSDS Source Packets and transmitted over the Mil-Std-1553B bus to the spacecraft. Figure 4 below shows how TIDI TM Packet are encapsulated and transmitted on the 1553 bus.

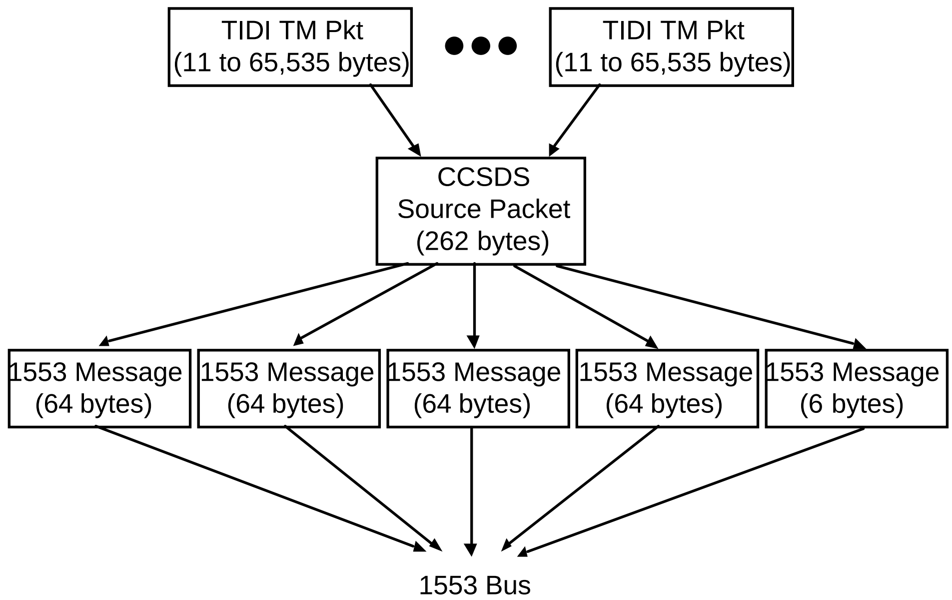

Figure 4 - TM Packet Encapsulation

All TIDI TM Packets have a common format which is shown in Figure 5 below:

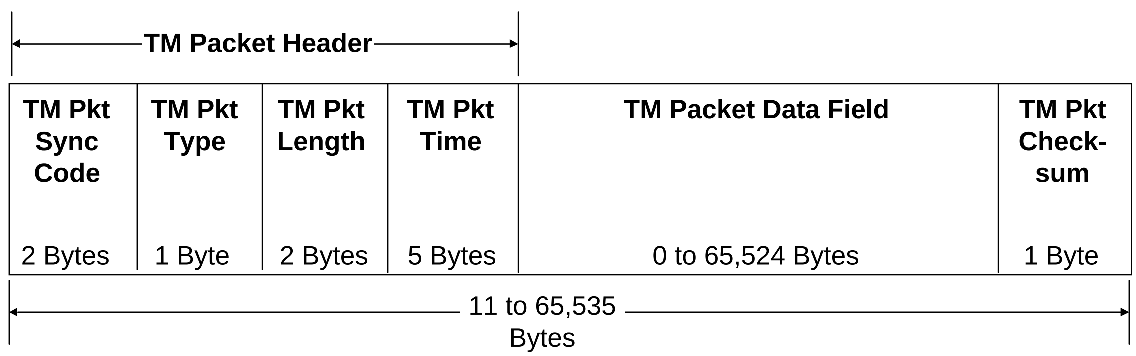

Figure 5 - TIDI TM Packet Format

An explanation of each of the TIDI TM Packet fields appears below in Table 3 below.

Table 3 - TIDI TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	A fixed bit pattern of 8AD8H. All TM Packets begin with this sync code.
TM Packet Type (1 byte)	Indicates the type of telemetry contained in the TM Packet Data Field.
TM Packet Length (2 bytes)	The total number of bytes in the TM Packet (11 to 65,535).
TM Packet Time (5 bytes)	The Instrument Time when the packet was created or the time of some other significance event such as the start of the CCD integration period. The most significant 4 bytes are the number of seconds since Jan 6, 1980. The least significant byte is the number of centiseconds and ranges from 0 to 99.
TM Packet Data (0 to 65,524 bytes)	Dependent on the TM Packet Type.
TM Packet Checksum (1 byte)	The modulo 256 arithmetic sum of the all the bytes in the TM Packet beginning with the TM Packet Sync Code and ending with the last byte in the TM Packet Data Field.

6.2. Telemetry Packet Sequencing

TIDI TM Packets are are not strictly required to be transmitted in correct time sequence. All TM packets, except Error Report TM packets, are required to be transmitted in correct time sequence. Error TM packets may be transmitted out of correct time sequence because Error TM packets have transmission priority over all other TM packets.

6.3. Command Packet Formatting

TIDI shall receive all commands in the form of variable length CCSDS Telecommand Packets that conform to the format given in Figure 6 below.

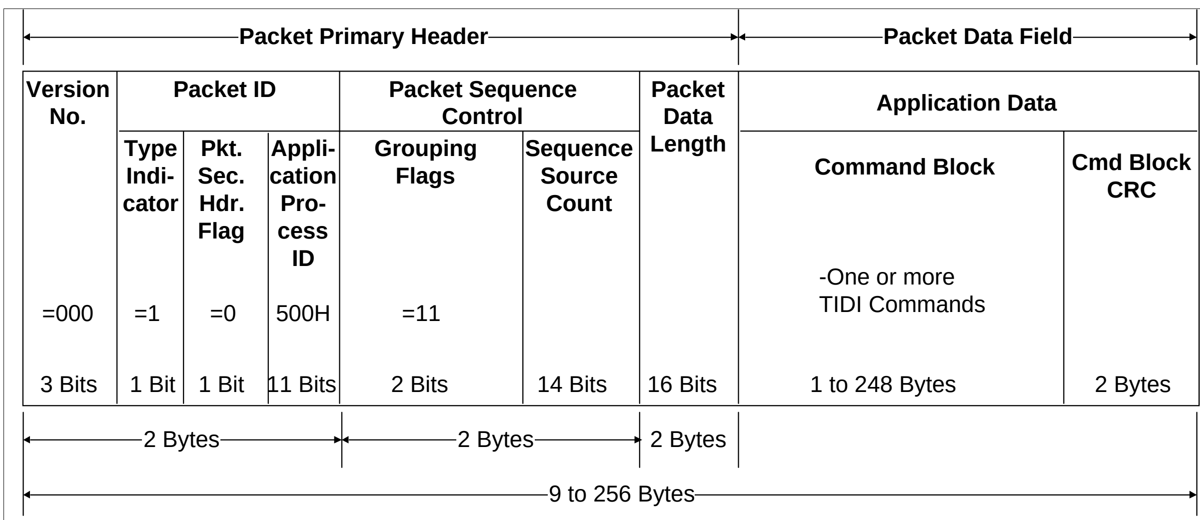

Figure 6 - CCSDS Telecommand Packet Format as Used for TIDI Commands

The usage of each CCSDS Source Packet bit field as used for TIDI telemetry is explained in Table 4 below.

Table 4 - CCSDS Telecommand Packet Fields as Used for TIDI Commands	
Field	Usage
Version Number (3 bits)	Identifies the version of the packet structure. Always set to 000B.
Type Indicator (1 bit)	Identifies this packet as telecommand (as opposed to telemetry). Always set to 1.
Packet Secondary Header Flag (1 bit)	Indicates the presence or absence of a Packet Secondary Header in the Packet Data Field. Always set to 0 to indicate that there is no Packet Secondary Header present.
Application Process ID (11 bits)	Identifies the packet as a TIDI telecommand packet. Always set 101 0000 0000B.
Grouping Flags (2 bits)	Used for segmenting large Telecommand Packets. TIDI does not use segmented Telecommand Packets therefore these flags are always set to 11B.
Sequence Source Count (14 bits)	A modulo 16,384 sequence number that is used to maintain the sequential order of packets. The Sequence Source Count of the first packet of the mission is 0 and is increased by one for each subsequent packet.
Packet Data Length (16 bits)	Equal to the number of bytes in the Command Block and the Command Block CRC minus one. Can range from 2 through 249.
Command Block (1 to 248 bytes)	Contains one or more TIDI commands. All TIDI commands have a common format which is shown in Figure 7 below.
Command Block CRC	A 16-bit CRC that covers the Command Block.

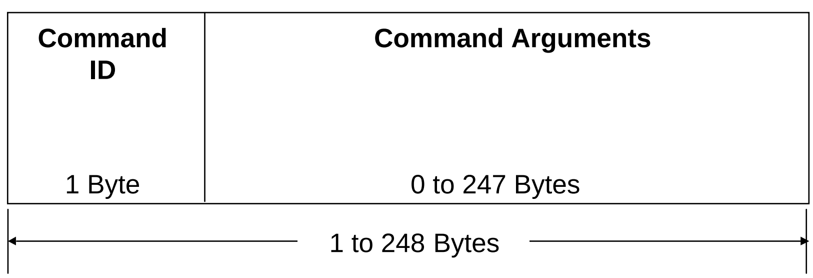

Figure 7 - TIDI Command Format

6.4. Synchronous Command Execution

All TIDI commands are executed synchronously. The currently executing command is fully completed before execution of the next command is begun.

6.5. Time Handling

6.5.1. Instrument Time

The Boot Code and the Instrument Software shall maintain an Instrument Time which consists of a 32 bit second counter and an 8 bit centisecond counter. The second counter contains the number of seconds since January 6, 1980. The centisecond counter shall be clocked at 100Hz. The value of the centisecond counter shall range from 0 through 99. When the centisecond counter wraps from 99 to 0, the second counter shall be increased by one.

6.5.2. Instrument Time Initialization

The Instrument Time shall be cleared to all zeros during Boot Code initialization and during Instrument Software initialization.

6.5.3. Instrument Time Synchronization

The Flight Software shall synchronize Instrument Time with Spacecraft Time ± 2 msec.

7. Boot Code Requirements

7.1. Valid Commands

The Boot Code shall execute the following commands received from the 1553 bus:

Table 5 - Valid Boot Code Commands

Command	Explained in Section
Disable Autoboot	10.1, Page 41
Boot Now	10.3, Page 42
Write Memory	10.4, Page 42
Dump Memory	10.5, Page 42
Calculate Cyclic Redundancy Check (CRC)	10.7, Page 42
Execute RAM Code	10.8, Page 43
No Operation	10.1, Page 41

7.2. Telemetry

7.2.1. Science Telemetry

The Boot Code shall not transmit Science Data TM packets.

7.2.2. Engineering Telemetry

7.2.2.1. Required TM Packet Types

The Boot Code shall transmit the Engineering Telemetry packet types in Table 6 below:

Table 6 - Boot Code Telemetry Packet Types

Packet Type	Transmitted When
Status TM Packet	Once every 5 seconds.
Command Confirmation TM Packet	In response to every valid CCSDS Telecommand Packet received.
Memory Dump TM Packet	In response to a Dump Memory command
CRC TM Packet	In response to a Calculate CRC command.
Error Report TM Packet	To report errors and events such as start of execution.

7.2.2.2. Boot Status TM Packet Transmission Frequency

The Boot Code shall transmit one Status TM Packet every 5 seconds.

The format and contents of the Status TM Packet is defined in Section 0.

7.2.2.3. Instrument Status Word

The Boot Code shall write an Instrument Status Word (ISW) to the first 4 data words (64 bits) of 1553 transmit subaddress T12. The ISW format and contents shall be identical to the ISW transmitted by the Instrument Software. The ISW shall be updated at 1Hz.

See the TIDI Instrument Status Word Definition, Doc. #055-3512 for the format and contents of the Instrument Status Word.

7.3. Initialization

The Boot Code shall execute the following initialization procedure immediately after release from CPU reset.

1. Close all telescope shutters.
2. Turn off all calibration lamps.
3. Initialize the 1553 interface.
4. Execute the Boot Procedure if:
   a. A Boot Now Command is received or
   b. The Autoboot Time-out Period has passed since release from CPU reset. The Disable Autoboot command and all other commands disable autobooting until the next CPU reset.

7.4. Autoboot Time-out Period

The Boot Code shall execute the Boot Procedure 300 seconds after initialization if a Disable Autoboot command has not been received.

7.5. Boot Procedure

The Boot Code shall execute the following procedure to transfer control from Boot Code to the Instrument Software.

1. Copy the primary copy of the Instrument Software from EEPROM to RAM.
2. Calculate the Instrument Software CRC in RAM.
3. Verify the validity of the Instrument Software in RAM by comparing the calculated CRC with the CRC stored at the end of the Instrument Software in RAM.
4. If the Instrument Software in RAM is not valid, execute Steps 1, 2 and 3 using the backup copy of the Instrument Software in EEPROM.
5. If the Instrument Software in RAM is still not valid, send an Error Report TM Packet reporting a boot error, abandon the boot procedure and return to Boot Code execution.
6. Write any required memory bank switching instructions and a JMP 0 instruction to FFF0H in Program RAM.
7. Begin Instrument Software execution by jumping to address FFF0H in Program RAM.

7.6. CCD Control

The CCD Controller shall not be initialized by the Boot Code. The Boot Code shall not read data from the CCD.

The CCD Controller comes up from an Offboard I/O Bus reset in a known, idle state and no other initialization is required to leave it in a safe, idle state.

7.7. Telescope Position Control

The Boot Code shall not initialize the telescope servo controllers. The Boot Code shall not move the telescopes.

The Telescope Servo Controllers come up from an Offboard I/O Bus reset in known, idle states and no other initialization is required to leave them in safe, idle states.

7.8. Filter Wheel Control

The Boot Code shall not initialize the Filter Wheel Controller. The Boot Code shall not move the filter wheel motor.

The Filter Wheel Controller comes up from an Offboard I/O Bus reset in a known, idle state and no other initialization is required to leave it in a safe, idle state.

7.9. Shutter Motor Control

The Boot Code shall not move the shutters, except to close them at initialization.

7.10. Calibration Lamp Control

The Boot Code shall not turn any calibration lamps on.

7.11. Temperature Control

The Boot Code shall control instrument temperatures using fixed non-programmable setpoints, on/off control of the heaters and no hysteresis. The heater controllers shall be updated by the Boot Code at a frequency of one Hertz.

If a temperature is below the setpoint, the corresponding heater is set to 100% duty cycle. If a temperature is at or above the setpoint, the corresponding heater is set to 0% duty cycle. The Boot Code setpoint temperatures are specified in Document #055-3519, TIDI Instrument Parameter Definition.

8. Instrument Software Requirements

8.1. Commanding

8.1.1. 1553 Commands

The Instrument Software shall execute commands received from the 1553 Bus.

8.1.2. Control Program

The Instrument Software shall have the ability to execute a Control Program stored in memory.

The Control Program is loaded into the instrument by using the Append to Control Program command. The Control Program consists of a variable size block of commands. Any valid TIDI command may be contained in the Control Program.

The Control Program gives the Instrument the ability to modify its operation based on changing conditions.

8.1.2.1. Two Control Program Buffers

The Instrument shall be capable of accepting and loading a new control program while executing a control program.

This requirement is met by using two control program buffers: the Control Program (CP) Execution Buffer and the Control Program Holding (CPH) Buffer. The procedure for loading and executing a control program is:

1. Clear the CPH Buffer by executing the Clear Control Program Holding Buffer command.
2. Load the control program into the CPH Buffer by executing one or more Append to Control Program commands.
3. Validate the CPH Buffer load by executing the Validate Control Program Holding Buffer command. This step is not mandatory, but strongly recommended.
4. Begin control program execution by executing the Execute Control Program command.

When the Execute Control Program command is executed, the contents of the CPH Buffer are copied into the Control Program Execution Buffer and validated automatically. If the contents are valid, control program execution begins.

8.1.2.2. Control Program Validation

To facilitate Control Program validation, the first 2 bytes of a Control Program shall contain the Control Program Size and the last 2 bytes shall contain the Control Program CRC. Before executing a Control Program, the Instrument Software shall calculate the CRC of the Control Program and compare it against the stored Control Program CRC.

The Control Program Size equals the number of executable bytes in the Control Program plus two. The Control Program CRC covers only the Control Program (not the Control Program Size).

8.1.3. Command Priority

Commands received from the 1553 bus shall have execution priority over commands resulting from Control Program execution.

This is required so that Control Program execution can be stopped at any time by ground command.

8.2. Valid Commands

The Instrument Software shall execute the commands contained in Table 7 below.

Table 7 - Valid Instrument Software Commands

Command	Explained in Section
Add	10.20, Page 47
Allocate Local Variables	10.42, Page 53
Append to a CCD Binning Table	10.27, Page 49
Append to Control Program Holding Buffer	10.28, Page 49
Append to Scan Table	10.29, Page 49
Calculate CRC	10.7, Page 42
Call Subroutine	10.15, Page 45
Clear a CCD Binning Table	10.26, Page 48
Clear Control Program Holding Buffer	10.25, Page 48
Clear Scan Table	10.30, Page 49
Compare	10.24, Page 48
Copy CPHB to Primary EEPROM	10.39, Page 52
Copy CPHB to Secondary EEPROM	10.40, Page 52
Deallocate Local Variables	10.43, Page 53
Decrement	10.23, Page 48
Dump Control Program Global Variables	10.6, Page 43
Dump Memory	10.5, Page 42
Execute RAM Code	10.8, Page 43
Increment	10.22, Page 47
Jump	10.9, Page 43
Jump if Equal	10.10, Page 44
Jump if Greater Than	10.12, Page 44
Jump if Less Than	10.13, Page 44
Jump if Not Equal	10.11, Page 44
Let Watchdog Timer Expire	10.41, Page 52
Load Parameter	10.19, Page 46
No Operation	10.1, Page 41

Return from Subroutine	10.16, Page 45
Set Cal Lamp States	10.36, Page 51
Set Filter Wheel Position	10.35, Page 51
Set Shutter Position	10.38, Page 52
Set Telescope Elevation	10.37, Page 51
Start Scanning	10.32, Page 50
Start Control Program Execution	10.17, Page 45
Stop Control Program Execution	10.18, Page 46
Stop Scanning at End of Scan	10.33, Page 50
Stop Scanning Immediately	10.34, Page 50
Subtract	10.21, Page 47
Validate Control Program Holding Buffer	10.29, Page 49
Wait	10.14, Page 45
Write Memory	10.4, Page 42

8.3. Instrument Parameters (IP)

The Instrument Software shall maintain a table of variables known as the Instrument Parameters.

The functions of the Instrument Parameters are to:

1. Make status information available for telemetry.
2. Provide a means of controlling certain instrument operating parameters such as CCD binning and temperature control.
3. Make status information available to the Control Program.

The IPs are defined in a separate document, 055-3519, TIDI Instrument Parameter Definition.

At initialization the Instrument Software shall set the Instrument Parameters to the default values contained in TIDI Instrument Parameter Definition, Doc. #055-3519.

8.4. Telemetry

8.4.1. Science Telemetry

The Instrument Software shall transmit one Science Data TM Packet at the end of each CCD erase-expose-convert cycle.

A Science Data TM packet contains the CCD data for one exposure and enough status information to identify the data. See Section 9.1 for a description of the contents of the Science Data TM packets.

8.4.2. Engineering Telemetry

The Instrument Software shall transmit Status TM Packets at a rate controlled by the Status TM Packet Rate IP. The Status TM Packet shall contain all the values in the IP table, except for the Control Program Global Variables.

See Section 0 for the format of the Status TM Packet.

8.4.3. Command Confirmation

The Instrument Software shall transmit one Command Confirmation TM packet for every valid CCSDS Telecommand Packet received from the 1553 bus.

The Command Confirmation TM packet contains the Sequence Source Count of the telecommand packet and the Instrument Time that the packet was validated. (See Section 9.5, Command Confirmation TM Packet.)

The Instrument Software shall transmit one Error Report TM packet for every invalid CCSDS Telecommand Packet received from the 1553 bus.

The Error Report TM packet contains the Sequence Source Count of the telecommand packet and other information to help operators determined the cause of the error.

If a CCSDS Telecommand packet is valid, except for the Sequence Source Count, an Error Report TM packet shall be transmitted AND the contents of the packet shall be executed.

8.4.4. Instrument Status Word

The Instrument Software shall write an Instrument Status Word (ISW) to the first 4 data words (64 bits) of 1553 transmit subaddress T12. The ISW shall be updated at 1Hz. The ISW shall contain the status information defined in document 055-3512, TIDI Instrument Status Word.

8.5. Scan Control

When the Start Scanning command is executed the Instrument shall start controlling and coordinating telescope positions, filter wheel positions, calibration lamp states and CCD data collection as described below. Scanning shall continue until a Stop Scanning command is executed.

All aspects of scanning are controlled by the contents of the Scan Table. See Section 11, Page 53 for a description of the Scan Table.

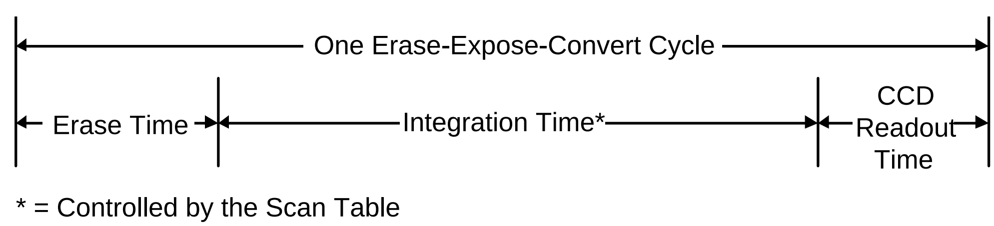

Figure 8 - TIDI Scan Timing

8.5.1. Erase-Expose-Convert Cycle

An Erase-Expose-Convert cycle is subdivided into the Erase Time, Integration Time and the CCD Readout Time.

8.5.1.1. Minimum Cycle Time

The total Erase-Expose-Convert cycle time shall not be less than one second. The instrument software shall extend the Erase Time as required to ensure that that this requirement is met.

8.5.1.2. Minimum Mechanism Stability Time

The mechanisms (filter wheels, shutters and telescopes) must be stable (not moving) at least 750 milliseconds before the end of the CCD Readout Time. The instrument software shall extend the Erase Time as required to ensure that that this requirement is met. The Minimimum Mechanism Stability Time ensures that the instrument software will have enough processing time to prepare for the next Erase-Expose-Convert cycle.

8.5.2. Erase Time

The Erase Time begins when the CCD Readout Time ends. The Erase Time is calculated by the Instrument Software. The greater of the following two times is used to program the CCD controller for the next Erase Time.

1. The time it will take to change the mechanism states (filter wheel positions, telescope positions, cal lamp states etc.) for the next exposure including settling time. This is calculated by the Instrument Software based on the current mechanism states and the states required for the next exposure.
2. The value of the Minimum Erase Time Instrument Parameter.

At the beginning of the Erase Time the Instrument Software begins changing the state of the mechanisms. It is considered an error if the mechanisms are not in the correct state by the end of the Erase Time.

8.5.3. Integration Time

The Integration Time begins when the Erase Time ends. The Integration Time is directly programmable via the Scan Table. The CCD pixels are allowed to accumulating charge during the Integration Time.

8.5.4. CCD Readout Time

The CCD Readout Time begins when the Integration Time ends. During the CCD Readout Time, the CCD Controller clocks data off the CCD and converts it to digital form. All of the CCD data becomes available to the CPU at the end of the CCD Readout Time. The CCD Readout Time is dependent on the CCD Binning Table which is commandable.

8.6. Temperature Control

Temperatures shall be controlled through:

1. Software Proportional Integral (PI) control loops or
2. Direct control of the heater duty cycles.

The operation of the PI control loops is controlled by the value of the Temperature Control IPs. The PI control loops can be individually disabled to allow direct control of the heater duty cycles via the Load Parameter command.

8.6.1. Heater Controller Update Frequency

The heater power levels (duty cycles) shall be updated by the Instrument Software at a frequency of at least 1 Hz.

8.7. Telescope Position Control

The Instrument Software shall control the operation of the Telescope Servo Controllers so that movement and settling time is minimized.

8.7.1. Default Telescope Control Parameters

The default telescope control parameters shall be determined by ground testing.

It is expected that the default telescope control parameters will be sufficient to operate the instrument throughout its design lifetime.

8.8. Filter Wheel Position Control

The Instrument Software shall control the operation of the Filter Wheel Controller so that movement and settling time between any two FW positions is minimized.

8.8.1. Default Filter Wheel Control Parameters

The default Filter Wheel control parameters shall be determined by ground testing.

It is expected that the default filter wheel control parameters will be sufficient to operate the instrument throughout its design lifetime.

8.9. Sun Avoidance

For all four telescopes: The Instrument Software shall close the telescope shutter and hold the telescope at the minimum elevation when the angular separation between the Sun and the telescope boresight is less than a commandable angle. The Instrument Software shall open the telescope shutter and allow normal telescope movement when the angular separation between the Sun and the telescope boresight is greater than a commandable angle.

The Sun Avoidance Shutter Open Angle and the Sun Avoidance Shutter Close Angle are commandable Instrument Parameters.

8.10. Spacecraft Warnings

8.10.1. Spacecraft Warning Names

Table 8 below assigns names to the spacecraft warning indicators that appear in the Spacecraft Status Message. These names are assigned only for convenience and are used only in this document.

Table 8 - Spacecraft Warning Names

S/C Warning Name	Description
SC_WARN_VAL_FLAG_1	Warning Flag Validity Bit 1
SC_IN_SAA_FLAG	South Atlantic Anomaly Indicator
SC_TIDI_PWR_FLAG	TIDI Powerdown Indicator
SC_WARN_VAL_FLAG_2	Warning Flag Validity Bit 2
SC_YAW_FLAG	Yaw Maneuver Indicator
SC_PANEL_ROTATE_FLAG	Solar Panel Rotation Indicator
SC_SUN_SAFE_FLAG	Spacecraft Attitude Sun Safe Indicator
SC_LOW_VOLT_FLAG	Software LVS Indicator
SC_POSITION_VAL_FLAG	Time Offset, Position and Velocity Validity Indicator
SC_ATTITUDE_VAL_FLAG	G&C Time and Attitude Validity Indicator
SC_SUN_VEC_VAL_FLAG	G&C Time and Sun Vector Validity Indicator

8.10.2. Spacecraft Warning Responses

The instrument shall respond to spacecraft warnings as follows in **Table 9** below.

Table 9 - Spacecraft Warning Responses

S/C Warning	Set S/C Warning Bit in Science TM Pkts	Enter Safe Mode if Safe Mode is Enabled	Set Data Invalid bit in Science TM Pkts if not in Safe Mode	Other Responses
SC_WARN_VAL_FLAG_1 = 0	Yes	Yes	Yes	

SC_IN_SAA_FLAG = 1	No	No	Yes	Set SAA Bit in Science TM Pkts
SC_TIDI_PWR_FLAG = 1	Yes	Yes	Yes	
SC_WARN_VAL_FLAG_2 = 0	Yes	Yes	Yes	
SC_YAW_FLAG = 1	Yes	Yes	Yes	
SC_PANEL_ROTATE_FLAG = 1	Yes	No	Yes	
SC_SUN_SAFE_FLAG = 1	Yes	Yes	Yes	
SC_LOW_VOLT_FLAG = 1	Yes	Yes	Yes	
SC_POSITION_VAL_FLAG = 0	No	Yes	Yes	
SC_ATTITUDE_VAL_FLAG = 0	No	Yes	Yes	
SC_SUN_VEC_VAL_FLAG = 0	No	Yes	Yes	
Spacecraft Status Message not received for more than 3 seconds	No	Yes	Yes	

8.11. Instrument Safe Mode

Instrument Safe Mode is defined as:

1. Telescopes parked pointed toward the Earth and
2. Filter wheel motion stopped and
3. All shutters closed and
4. All calibration lamps off and
5. Scanning continues (Erase-Expose-Convert cycles are executed), but the mechanisms remain in their Safe Mode positions.

The instrument shall enter Safe Mode if any of the following conditions exist. The instrument shall exit Safe Mode if none of the following conditions exist.

1. SC_WARN_VAL_FLAG_1 = 0
2. SC_TIDI_PWR_FLAG = 1
3. SC_WARN_VAL_FLAG_2 = 0
4. SC_YAW_FLAG = 1
5. SC_SUN_SAFE_FLAG = 1
6. SC_LOW_VOLT_FLAG = 1
7. SC_POSITION_VAL_FLAG = 0
8. SC_ATTITUDE_VAL_FLAG = 0
9. SC_SUN_VEC_VAL_FLAG = 0
10. Spacecraft Status Message not received for more than 3 seconds

8.12. Instrument Input Overcurrent

If the instrument input current exceeds the value of the SC_In_Red_Limit IP, the Instrument Software shall set the TC_AUT_BIT (instrument autonomy) and the TD_CUR_LIM_EXED_in the Instrument Status Word.

8.13. Autonomous Safety Actions

8.13.1. Telescope Servo Overcurrent Condition

When the Telescope Servo Deck reports an overcurrent condition for any of the telescope servo drives, the Instrument Software shall disable (turn off) the failed servo drive and set the appropriate Telescope Overcurrent bits in the IP Table.

8.13.2. Heater Group Overcurrent Condition

When the Motor Heater deck reports an overcurrent condition for either of the heater groups (5 heaters per group), the Instrument Software shall disable (turn off) the failed heater group and set the appropriate overcurrent bit in the IP Table.

8.13.3. Instrument Input Overcurrent Condition

When the instrument input current exceeds the value of the SC_In_Red_Limit instrument parameter, the Instrument Software shall set the TC_AUT_BIT (instrument autonomy bit) in the Instrument Status Word (in addition to setting the appropriate red limit exceeded bits in the Instrument Status Word and the IP Table). The instrument autonomy bit is interpreted by the spacecraft as a request to turn TIDI power off.

9. Telemetry Packet Types and Formats

9.1. Reserved TM Packet Types

TIDI TM Packet Types 248 through 255 shall be reserved and not produced by the Boot Code or the Instrument Software.

The reserved packet types are produced by various GSE and calibration equipment.

9.2. Spectral Science Data TM Packet

The Spectral Science Data TM Packet is used to transmit up to 255 channels of 14-bit CCD bin values. The number of bins is determined by the Binning Table.

Table 10 - Spectral Science Data TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	Always set to 0.
TM Packet Length (2 bytes)	Variable from 30 to 475 bytes.
TM Packet Time (5 bytes)	The Instrument Time when the CCD Integration Time began.
TM Packet Data (variable)	**Byte 0:** **Bit 0**: Data Invalid (1 = data invalid). See description below. **Bit 1**: Telescope Elevation Error (1 = error). See description below. **Bit 2**: Filter Wheel Position Error (1 = error). See description below. **Bit 3**: In South Atlantic Anomaly (1 = in SAA).

	See description below. **Bit 4**: S/C Warning (1 = warning). See description below. **Bits 5-7**: Actual Cal Lamp states. (0 = all off, 1 = lamp one on, 2 = lamp two on, 3 = lamp three on, 4 = lamp 4 on). See description below. **Byte 1:** **Bits 0-2:** Actual Filter Wheel 1 Filter Number (0 to 7). See description below. **Bits 3-5:** Actual Filter Wheel 2 Filter Number (0 to 7). See description below. **Bit 6:** Filter Wheel 1 Filter Number Invalid (1 = invalid = not filter centered). See description below. **Bit 7:** Filter Wheel 2 Filter Number Invalid (1 = invalid = not filter centered). See description below. **Byte 2:** **Bit 0**: Actual Shutter 1 State (1 = open, 0 = closed). See description below. **Bit 1:** Actual Shutter 2 State **Bit 2:** Actual Shutter 3 State **Bit 3:** Actual Shutter 4 State **Bit 4:** Shutter Timing Error (1 = error). See description below. **Bit 5:** Filter Wheel Timing Error (1 = error). See description below. **Bit 6:** Telescope Timing Error (1 = error). See description below. **Bit 7**: Sun Avoidance in Effect. See description below. **Bytes 3-4:** Scan table ID. See description below. **Byte 5 -6:** Exposure Count. See description below. **Bytes 7 - 12:** **Bits 11-0:** Actual Telescope 1 elevation. See description below. **Bits 23-12**: Actual Telescope 2 elevation **Bits 35-24:** Actual Telescope 3 elevation **Bits 47-36:** Actual Telescope 4 elevation Note that Telescope 1 elevation is in Bytes 11 and 12 and Telescope 4 elevation is in Bytes 7 and 8. **Bytes 13 - 14:** CCD Binning Table ID. See description below.

	Bytes 15 - 16: CCD Integration Time (centiseconds). **Bytes 17 - N:** From 1 to 255 bit-packed 14-bit CCD bin values.
TM Packet Checksum (1 byte)	Variable

9.2.1. Data Invalid Status Bit

The Data Invalid status bit in the Science Data TM packet is set if any condition that might have invalidated the science data existed during the scan cycle Integration Time.

The Data Invalid bit is set if the instrument is NOT in Safe Mode AND any of the following conditions existed:

1. S/C Status Message SC_IN_SAA_FLAG = 1
2. S/C Status Message SC_POSITION_VAL_FLAG = 0
3. S/C Status Message SC_ATTITUDE_VAL_FLAG = 0
4. S/C Status Message SC_SUN_VEC_VAL_FLAG = 0
5. S/C Warning Status bit in the Science Data TM packet (see Section 9.2.3) is set
6. S/C Status Message has not been received in more than 3 seconds

The Data Invalid bit is also set if any of the following conditions existed:

1. Telescope Elevation Error bit in the Science Data TM packet is set
2. The Telescope Timing Error bit in the Science Data TM packet is set
3. The Filter Wheel Position Error bit in the Science Data TM packet is set
4. The Filter Wheel Timing Error bit in the Science Data TM packet is set
5. The Shutter Timing Error bit in the Science Data TM packet is set

9.2.2. Telescope Elevation Error Status Bit

The Telescope Elevation Error status is set if either of the following conditions existed at the beginning or end of the scan cycle Integration Time.

1. Any telescope was in motion
2. Any telescope latched position error flag (positive or negative) was set

9.2.3. Filter Wheel Position Error Status Bit

The Filter Wheel Position Error status bit is set if either of the following conditions existed at the beginning or end of the scan cycle Integration Time.

1. Either filter wheel was in motion
2. Either filter wheel was out of position

9.2.4. Telescope Timing Error Status Bit

The Telescope Timing Error status bit is set if any telescope did not complete a required elevation change before the beginning of the scan cycle Integration Time.

9.2.5. In South Atlantic Anomaly Status Bit

The South Atlantic Anomaly status bit is set if the S/C Status Message SC_IN_SAA_FLAG was equal to 1 at the beginning or end of the scan cycle Integration Time.

9.2.6. S/C Warning Status Bit

The S/C Warning bit is set if any of the following conditions existed at the beginning or end of the scan cycle Integration Time:

1. S/C Status Message SC_YAW_FLAG = 1
2. S/C Status Message SC_PANEL_ROTATE_FLAG = 1
3. S/C Status Message SC_TIDI_PWR_FLAG = 1
4. S/C Status Message SC_SUN_SAFE_FLAG = 1
5. S/C Status Message SC_LOW_VOLT_FLAG = 1
6. S/C Status Message SC_WARN_VAL_FLAG_1 = 0
7. S/C Status Message SC_WARN_VAL_FLAG_2 = 0

9.2.7. Actual Calibration Lamp States

The Actual Calibration Lamp States field contains the actual state of the calibration lamps during the scan cycle Integration Time. The actual lamp states can be different from the lamp states contained in the scan table only when the instrument is in Safe Mode. In Safe Mode, all calibration lamps are turned off.

9.2.8. Actual Filter Wheel Filter Number

The Actual Filter Wheel Number field contains the filter number (0 - 7) of the filter center that was closest to the optical axis of the instrument at the end of scan cycle Integration Time. The actual filter wheel filter numbers could be different from the filter wheel numbers contained in the scan table due to the instrument being in Safe Mode or a filter wheel mechanism failure.

9.2.9. Filter Wheel Filter Number Invalid Status Bit

The Filter Wheel Number Invalid status bit is set if the filter reported in the Actual Filter Wheel Filter Number field was not centered in the instrument optical path at the end of the scan cycle Integration Time.

9.2.10. Actual Shutter States

The Actual Shutter States field contains the actual states of the shutters at the end of the scan cycle Integration Time. The actual shutter states can be different from the shutter states contained in the scan table due to the instrument being in Safe Mode or Sun avoidance. In Safe Mode, all the shutters are closed. When a particular telescope is avoiding the Sun, only its shutter is closed.

9.2.11. Shutter Timing Error Status Bit

The Shutter Timing Error status bit is set if any shutter did not complete a required change of state before the beginning of the scan cycle Integration Time.

9.2.12. Filter Wheel Timing Error Status Bit

The Filter Wheel Timing Error status bit is set if either filter wheel did not complete a required movement before the beginning of the scan cycle Integration Time.

9.2.13. Telescope Timing Error Status Bit

The Telescope Timing Error status bit is set if any telescope did not complete a required movement before the beginning of the scan cycle Integration Time.

9.2.14. Sun Avoidance in Effect Status Bit

The Sun Avoidance in Effect Status Bit is set if any telescope was in sun avoidance mode at the beginning of the scan cycle Erase Time. When in sun avoidance mode a telescope is moved to position 256 and its shutter is closed.

9.2.15. Scan Table ID

The Scan Table ID field contains the first two bytes of the Scan Table (the Scan Table ID).

9.2.16. Exposure Count

The Exposure Count field contains the number of CCD integrations that have occurred since the first integration of the scan table. The Exposure Count is reset to zero every time the first integration of the first interval in the scan table occurs. The exposure count ranges from zero to the number of integrations in the scan table minus one.

9.2.17. Actual Telescope Elevation

The Actual Telescope Elevation field contains the elevation of the telescopes at the end of the scan cycle Integration Time. The contents of the Actual Telescope Elevation field can (and probably will) be different from the telescope elevations contained in the scan table due to Earth eccentricity, Earth oblateness, S/C attitude and thermal-mechanical distortion compensation performed by the instrument software.

9.2.18. CCD Binning Table ID

The CCD Binning Table ID field contains the ID (not the Binning Table Number) of the binning table that was used to convert the CCD data into digital form.

9.2.19. CCD Integration Time

The CCD Integration Time field contains the scan cycle Integration Time in centiseconds. The contents of the CCD Integration Time field always equal the CCD Integration time contained in the scan table.

9.3. CCD Image Data TM Packet

The CCD Image Science Data TM Packet is used to transmit an array of 50 x 600 CCD pixel values. Since, for practical reasons, the size of the The CCD Image Science Data TM Packet is limited to 256 bytes, multiple CCD Image Science Data TM Packets are required to telemeter all pixel values in the 50 x 600 array.

Each pixel value is transmitted as a 12 bit value (with no ADC gain information). When using CCD image mode (as opposed to CCD spectral mode) the ADC gain is set by the value of the CCD_Cntl_Reg_2 instrument parameter, not by the contents of the binning table. All pixels in the CCD image are converted with the same ADC gain.

Table 11 - CCD Image Science Data TM Packet Fields	
Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	Always set to 2.
TM Packet Length (2 bytes)	Variable (32 to 256 bytes)
TM Packet Time (5 bytes)	The Instrument Time when the CCD exposure period began.
TM Packet Data (17 to 245 bytes)	Bytes 0 - 16: Same as Spectral Science Data TM Packet. Bytes 17-18: Pixel Number: The number of the first pixel contained in this TM Packet. The pixels are numbered 0 through 29999. The lowermost rightmost pixel of the CCD image is pixel #0. The uppermost leftmost pixel of the CCD image is pixel #29999. Pixel #0 is in the first TM packet of the image. Pixel #29999 is in the last TM packet of the image. Bytes 19 - 244 150 - 12 bit pixel values
TM Packet Checksum (1 byte)	Variable

9.4. Status TM Packet

The Status TM Packet contains the bit-packed values of all the Instrument Parameters, except for the Control Program Global Variables.

Table 12 - Status TM Packet Fields	
Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	4
TM Packet Length (2 bytes)	Depends on the length of the IP table defined in Doc. #055-3519. As of 10/7/99 (IP Def Rev. AC) it was 302.
TM Packet Time (5 bytes)	The Instrument Time when the packet was created.
TM Packet Data (291 bytes)	Bytes 0 - 290: Bit-packed field of all instrument parameter values except for the Control Program Global Variables. Only the significant bits of each parameter are included.
TM Packet Checksum (1 byte)	Variable

9.5. Command Confirmation TM Packet

One Command Confirmation TM Packet is transmitted after the reception and validation of each CCSDS Telecommand Packet received from the 1553 bus. A Command Confirmation TM Packet is sent only if the

CCSDS Telecommand Packet is valid. Error Report TM Packets are sent in response to invalid CCSDS Telecommand Packets.

Table 13 - Command Confirmation TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	5
TM Packet Length (2 bytes)	13
TM Packet Time (5 bytes)	Instrument Time when the packet was validated.
TM Packet Data (2 bytes)	Bytes 0 - 1: The Sequence Source Count of the validated CCSDS telecommand.
TM Packet Checksum (1 byte)	Variable

9.6. Memory Dump TM Packet

One or more Memory Dump TM Packets are sent in response to each Dump Memory Command.

Table 14 - Memory Dump TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	6
TM Packet Length (2 bytes)	Variable (maximum of 256 bytes)
TM Packet Time (5 bytes)	The Instrument Time when the Memory Dump TM packet was created.
TM Packet Data (variable, maximum of 245 bytes)	Bytes 0 - 2: First memory address contained in this packet in 24 bit address format. (See Section 2.4.) Bytes 3 - N: Memory Contents
TM Packet Checksum (1 byte)	Variable

9.7. CRC TM Packet

One CRC TM Packet is transmitted in response to each Calculate Memory CRC Command.

Table 15 - CRC TM Packet Fields	
Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	7
TM Packet Length (2 bytes)	18
TM Packet Time (5 bytes)	The Instrument Time when the CRC TM packet was created.
TM Packet Data (7 bytes)	Bytes 0 - 2: First memory address included in the CRC calculation in 24 bit address format. (See Section 2.4.) Bytes 3 - 4: Number of bytes included in the CRC calculation. Bytes 5 - 6: CRC (CRC-16 method)
TM Packet Checksum (1 byte)	Variable

9.8. Error Report TM Packet

One Error Report TM Packet is transmitted for each detected error condition.

Table 16 - Error Report TM Packet Fields	
Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	8
TM Packet Length (2 bytes)	21
TM Packet Time (5 bytes)	The Instrument Time when the Error Report TM packet was created.
TM Packet Data (10 bytes)	Bytes 0 - 1: Error Code. See Section 12, Error Codes. Bytes 2 - 3: Error parameter 1 Bytes 4 - 5: Error parameter 2 Bytes 6 - 7: Error parameter 3 Bytes 8 - 9: Error parameter 4
TM Packet Checksum (1 byte)	Variable

9.9. Null TM Packet

Used as filler under certain circumstances to pad CCSDS Source Packets. The Instrument Software pads and sends the current CCSDS Source Packet if the the the current CCSDS Source Packet has been under construction for more than Comm_Null_Fill_Delay (an IP) seconds.

Table 17 - Null TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	9
TM Packet Length (2 bytes)	Variable (maximum of 256 bytes)
TM Packet Time (5 bytes)	The Instrument Time when the Null TM packet was created.
TM Packet Data (variable size, maximum of 245 bytes)	Filled with zeros, variable length.
TM Packet Checksum (1 byte)	Variable

9.10. Control Program Variable Dump TM Packet

One Control Program Variable Dump TM Packet is transmitted in response to each Dump Control Program Variables Command. Contains the current values of the Control Program Global Variable Instrument Parameters.

Table 18 - Control Program Variable Dump TM Packet Fields

Field	Usage
TM Packet Sync Code (2 bytes)	Always set to 8AD8H.
TM Packet Type (1 byte)	10
TM Packet Length (2 bytes)	139
TM Packet Time (5 bytes)	The Instrument Time when the TM packet was created.
TM Packet Data (128 bytes)	Bytes 0 - 127: Current values of the Control Program Global Variable Instrument Parameters
TM Packet Checksum (1 byte)	Variable

10. Commands

10.1. No Operation Command

The No Operation command has no effect on instrument operation and is provided as a means of testing the command and telemetry links.

Table 19 - No Operation Command Fields	
Field	Usage
Command ID (1 byte)	0
Command Arguments (none)	none

10.2. Disable Autoboot Command

The Disable Autoboot command prevents the Boot Code from executing the Boot Procedure automatically when the Autoboot Time-out Period has expired. The Disable Autoboot command is valid only when the Boot Code is executing.

Table 20 - Disable Autoboot Command Fields	
Field	Usage
Command ID (1 byte)	1
Command Arguments (0 bytes)	none

10.3. Boot Now Command

The Boot Now command causes the Boot Code to execute the Boot Procedure immediately. The Boot Now command is valid only when the Boot Code is executing.

Table 21 - Boot Now Command Fields	
Field	Usage
Command ID (1 byte)	2
Command Arguments (0 bytes)	none

10.4. Write Memory Command

The Write Memory command allows uploading of data to memory and I/O registers.

Table 22 - Write Memory Command Fields	
Field	Usage
Command ID (1 byte)	3
Command Arguments (Variable Length)	Bytes 0 - 2: First address to write to in 24-bit address format. (See Section 2.4.) Byte 3: Number of bytes to write. Ranges from 1 to 243. Bytes 4 - N: Data to be written

Note that, when writing to Data RAM, the address range of a single write command cannot straddle the 1C000H memory address. This is due to limitations of the instrument software.

10.5. Dump Memory Command

The Dump Memory command allows downloading of data from memory and I/O registers. The Instrument responds by transmitting one or more Memory Dump TM Packets containing the requested dump data.

Table 23 - Dump Memory Command Fields	
Field	Usage
Command ID (1 byte)	4
Command Arguments (5 bytes)	Bytes 0 - 2: First address to dump in 24-bit address format. (See Section 2.4.) Bytes 3 - 4: Number of bytes to dump

10.6. Dump Control Program Variables Command

The Dump Control Program Variables command allows downloading of the Control Program Global Variable Instrument Parameters. The Instrument responds by transmitting a single Control Program Variable Dump TM Packet.

Table 24 - Dump Control Program Variables Command Fields	
Field	Usage
Command ID (1 byte)	5
Command Arguments (0 bytes)	none

10.7. Calculate CRC Command

The Calculate CRC command causes the Instrument to calculate the CRC of a block of memory using the CRC-16 method. The Instrument then transmits a CRC TM Packet containing the calculated CRC.

Table 25 - Calculate CRC Command Fields	
Field	Usage
Command ID (1 byte)	6
Command Arguments (5 bytes)	Bytes 0 - 2: First address to include in the CRC calculation in 24-bit address format. (See Section 2.4.) Bytes 3 - 4: Number of bytes to include in the CRC calculation.

10.8. Execute RAM Code Command

The Execute RAM Code Command causes the CPU to begin executing program code at a specified Program RAM address

Table 26 - Execute RAM Code Command Fields	
Field	Usage
Command ID (1 byte)	7
Command Arguments (3 bytes)	Bytes 0 - 2: Program RAM address in 24-bit address format. (See Section 2.4.)

10.9. Jump Command

The Jump Command loads the Next Command Offset IP with the specified value.

Table 27 - Jump Command Fields	
Field	Usage
Command ID (1 byte)	8
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP

10.10. Jump if Equal Command

The Jump if Equal Command loads the Next Command Offset IP with the specified value if the Equal Flag IP is True.

Table 28 - Jump If Equal Command Fields	
Field	Usage
Command ID (1 byte)	9
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP if the Equal Flag IP is True.

10.11. Jump if Not Equal Command

The Jump if Not Equal Command loads the Next Command Offset IP with the specified value if the Equal Flag IP is False.

Table 29 - Jump If Not Equal Command Fields	
Field	Usage
Command ID (1 byte)	10
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP if the Equal Flag is False.

10.12. Jump if Greater Than Command

The Jump if Greater Than Command loads the Next Command Offset IP with the specified value if the Equal Flag IP is False and the Greater Than Flag IP is True.

Table 30 - Jump if Greater Than Command Fields	
Field	Usage
Command ID (1 byte)	11
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP if the Equal Flag IP is False and the Greater Than Flag IP is True.

10.13. Jump if Less Than Command

The Jump if Less Than Command loads the Next Command Offset IP with the specified value if the Equal Flag IP is False and the Greater Than Flag IP is False.

Table 31 - Jump if Less Than Command Fields	
Field	Usage
Command ID (1 byte)	12
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP if the Equal Flag IP is False and the Greater Than Flag IP is False.

10.14. Wait Command

The Wait command causes the suspension of Control Program execution for the specified wait period. Any commands received from the 1553 bus during the wait period are executed.

Table 32 - Wait Command Fields	
Field	Usage
Command ID (1 byte)	13
Command Arguments (2 bytes)	Bytes 0 - 1: Wait period in centiseconds.

10.15. Call Subroutine Command

The Call Command pushes the current value of the Next Command Offset IP on the Return Address Stack and then loads the Next Command Offset IP with the specified value.

Table 33 - Call Subroutine Command Fields	
Field	Usage
Command ID (1 byte)	14
Command Arguments (2 bytes)	Bytes 0 - 1: Value to be loaded into the Next Command Offset IP. This a byte offset from the first executable byte of the Control Program (the byte following the Control Program Length).

10.16. Return from Subroutine Command

The Return from Subroutine command pops a value off the Return Address Stack and loads it into the Next Command Offset IP.

Table 34 - Return from Subroutine Command Fields	
Field	Usage
Command ID (1 byte)	15
Command Arguments (0 bytes)	none

10.17. Start Control Program Execution Command

The Start Control Program Execution Command causes the Instrument to copy the contents of the Control Program Holding (CPH) Buffer into the Control Program (CP) Buffer and validate the contents of the CP Buffer. If the CP Buffer contains a valid control program, CP execution is begun, otherwise an Error Report TM packet is sent.

Table 35 - Start Control Program Execution Command Fields	
Field	Usage
Command ID (1 byte)	16
Command Arguments (0 bytes)	none

10.18. Stop Control Program Execution Command

The Stop Control Program Execution Command causes the Instrument to stop executing the Control Program.

Table 36 - Stop Control Program Execution Command Fields	
Field	Usage
Command ID (1 byte)	17
Command Arguments (0 bytes)	none

10.19. Load Parameter Command

The Load Parameter Command loads the Destination with the Source.

Table 37 - Load Parameter Command Fields	
Field	Usage
Command ID (1 byte)	18
Command Arguments (variable length)	Bytes 0 - N: Source and Destination Selectors (See Section 10.19.1, Source IP and Destination IP Selectors.)

If the size (bit width) of the Source is smaller than the Destination IP, the Source is converted to the size of the Destination IP (by left zero padding) before loading the Destination IP. If the Source is larger than a Destination IP, the Source value is truncated to the size of the Destination.

10.19.1. Source IP and Destination IP Selectors

Several commands (Load Parameter, Add, Subtract, Compare, Increment, Decrement) contain Source and Destination selectors. These selectors are a compact way of specifying the type and ID of the source and destination.

A destination may be a local variable or an Instrument Parameter. A source may be a local variable, an Instrument Parameter or a constant.

Local variables must be explicitly allocated by the Control Program after entering a subroutine and explicitly deallocated by the Control Program before returning from a subroutine. The Allocate Local Variables and Deallocate Local Variables commands are used for this purpose.

Local variables are numbered 1 through N where N is the number of local variables allocated by the subroutine. All local variables are 32 bits wide.

The selector length varies from 2 bytes to 7 bytes.

The first byte (Byte 0) of the selector contains two 4-bit fields that specify the source and destination type. The following one or two bytes contain the destination IP ID or local variable number. The following zero to four bytes contain the source IP ID, local variable number or constant.

Table 38 - Destination and Source Selector Fields

Field	Usage
Destination Type and Source Type (1 byte)	Bits 0 - 3: Destination Type 1 = 8 bit Instrument Parameter ID 2 = 16 bit Instrument Parameter ID 3 = 8 bit local variable number Bits 4 - 7: Source Type 0 = none 1 = 8 bit Instrument Parameter ID 2 = 16 bit Instrument Parameter ID 3 = 8 bit local variable number 4 = 8 bit constant 5 = 16 bit constant 6 = 32 bit constant
Destination (1 or 2 bytes)	Destination IP ID or local variable number.
Source (0,1, 2 or 4 bytes)	Source IP ID, local variable number or constant.

10.20. Add Command

The Add Command adds the Source to the Destination and then loads the sum into the Destination.

Table 39 - Add Command Fields

Field	Usage
Command ID (1 byte)	19
Command Arguments (variable length)	Bytes 0 - N: Source and Destination Selectors (See Section 10.19.1, Source IP and Destination IP Selectors.)

The Source and Destination are converted to 32-bit size (by left zero padding) before being added. The result is truncated to the size of the Destination.

10.21. Subtract Command

The Subtract Command subtracts the Source from the Destination and then loads the difference into the Destination.

Table 40 - Subtract Command Fields

Field	Usage
Command ID (1 byte)	20
Command Arguments (variable length)	Bytes 0 - N: Source and Destination Selectors (See Section 10.19.1, Source IP and Destination IP Selectors.)

The Source and Destination are converted to 32-bit size (by left zero padding) before being subtracted. The result is truncated to the size of the Destination.

10.22. Increment Command

The Increment Command adds one to the Destination.

Table 41 - Increment Command Fields	
Field	Usage
Command ID (1 byte)	21
Command Arguments (2 bytes)	Bytes 0 - N: Destination Selector (See Section 10.19.1, Source IP and Destination IP Selectors.)

10.23. Decrement Command

The Decrement Command subtracts one the Destination.

Table 42 - Decrement Command Fields	
Field	Usage
Command ID (1 byte)	22
Command Arguments (2 bytes)	Bytes 0 - N: Destination Selector (See Section 10.19.1, Source IP and Destination IP Selectors.)

10.24. Compare Command

The Compare Parameter Command performs an unsigned comparison of the Source and the Destination and sets the states of the Control_Prgm_Equal_Flag and the Control_Prgm_GT_Flag IPs as follows:

Condition	Control_Prgm_Equal_Flag IP	Control_Prgm_GT_Flag IP
Source = Destination	True	undefined
Source > Destination	False	True
Source < Destination	False	False

Table 43 - Compare Parameter Command Fields	
Field	Usage
Command ID (1 byte)	23
Command Arguments (variable length)	Bytes 0 - N: Source and Destination Selectors (See Section 10.19.1, Source IP and Destination IP Selectors.)

The Source and Destination are converted to 32-bit size (by left zero padding) before being compared.

10.25. Clear Control Program Holding Buffer Command

Clears the contents of the Control Program Holding buffer. Actually sets the first two bytes in the buffer to zero to indicate that the control program size is zero.

Table 44 - Clear Control Program Holding Buffer Command Fields	
Field	Usage
Command ID (1 byte)	24
Command Arguments (0 bytes)	none

10.26. Clear CCD Binning Table Command

Clears the contents of one of two CCD Binning Tables. This command is valid only when not scanning.

Table 45 - Clear CCD Binning Table Command Fields	
Field	Usage
Command ID (1 byte)	25
Command Arguments (1 byte)	Byte 0 : The CCD Binning Table to be cleared. Ranges from 0 to 1.

10.27. Append to CCD Binning Table Command

Appends bytes to one of two CCD Binning Tables. This command is valid only when not scanning. See Section 14, Page 62 for the Binning Table format.

Table 46 - Append to CCD Binning Table Command Fields	
Field	Usage
Command ID (1 byte)	26
Command Arguments (variable)	Byte 0: The CCD Binning Table to be appended to. Ranges from 0 to 1. Byte 1 : Number of bytes to be appended to the CCD Binning Table. Ranges from 1 to 245. Bytes 2 - N: Bytes to be appended.

10.28. Append to Control Program Holding Buffer Command

Appends one or more bytes to the Control Program Holding Buffer.

Table 47 - Append to Control Program Holding Buffer Command Fields	
Field	Usage
Command ID (1 byte)	27
Command Arguments (Variable Length)	Byte 0: Number of bytes to be appended to the Control Program Holding Buffer. Ranges from 1 to 246. Bytes 1 - N: Bytes to be appended.

10.29. Validate Control Program Holding Buffer

Validates the contents of the Control Program Holding (CPH) Buffer by calculating the Control Program CRC and comparing it to the CRC stored in the last two bytes of the Control Program. The result of the validation is stored in the CPH Buffer Valid IP. If the validation fails, an Error Report TM Packet is transmitted.

Table 48 - Validate Control Program Holding Buffer Command Fields	
Field	Usage
Command ID (1 byte)	28
Command Arguments (0 bytes)	none

10.30. Clear Scan Table Command

Clears the contents of the Scan Table. This command is valid only when not scanning.

Table 49 - Clear Scan Table Command Fields	
Field	Usage
Command ID (1 byte)	29
Command Arguments (0 bytes)	none

10.31. Append to Scan Table Command

The Append to Scan Table command is used to load the Scan Table. This command is valid only when not scanning.

Table 50 - Append to Scan Table Command Fields	
Field	Usage
Command ID (1 byte)	30
Command Arguments (Variable Length)	Byte 0: Number of bytes to be appended to the Scan Table. Ranges from 1 to 246. Bytes 1 - N: Bytes to be appended.

10.32. Start Scanning Command

The Start Scanning command causes the instrument to begin scanning immediately. If a Scan Table has not been loaded, this command is not valid.

Table 51 - Start Scanning Command Fields	
Field	Usage
Command ID (1 byte)	31
Command Arguments (0 bytes)	none

10.33. Stop Scanning at End of Scan Command

The Stop Scanning at End of Scan command causes the instrument to stop scanning after the last exposure of the current scan table. If the Instrument is not scanning, this command has no effect.

Table 52 - Stop Scanning at End of Scan Command Fields	
Field	Usage
Command ID (1 byte)	32
Command Arguments (0 bytes)	none

10.34. Stop Scanning Immediately Command

The Stop Scanning Immediately command causes the instrument to stop scanning at the end of the current CCD exposure. All mechanisms are left in the state they were in when scanning was stopped. If the Instrument is not scanning, this command has no effect.

Table 53 - Stop Scanning Immediately Command Fields

Field	Usage
Command ID (1 byte)	33
Command Arguments (0 bytes)	none

10.35. Set Filter Wheel Position Command

The Set Filter Wheel Position command immediately moves a Filter Wheel to the specified position.

Table 54 - Set Filter Wheel Position Command Fields

Field	Usage
Command ID (1 byte)	34
Command Arguments (2 bytes)	Byte 0: Filter Wheel (1 or 2). Byte 1: Filter wheel position in motor steps clockwise from the encoder index mark (0 - 199). The index mark motor position is 0.

10.36. Set Calibration Lamp States Command

The Set Cal Lamp States command immediately changes the on/off states of all calibration lamps to the specified state. Only one lamp may be on at a time.

Table 55 - Set Calibration Lamp States Command Fields

Field	Usage
Command ID (1 byte)	35
Command Arguments (1 byte)	Byte 0: Cal Lamps State 0 = All lamps off 1 = Lamp 1 (HAK) on 2 = Lamp 2 (Neon) on 3 = Lamp 3 (Incandescent 1) on 4 = Lamp 4 (Incandescent 2) on

10.37. Set Telescope Elevation Command

The Set Telescope Elevation command immediately changes the position of the specified telescope to the specified elevation.

Table 56 - Set Telescope Elevation Command Fields	
Field	Usage
Command ID (1 byte)	36
Command Arguments (2 bytes)	Bytes 0 - 1: Bits 0 -11: Telescope Elevation. Valid values: 0 through 4095. One step equals 0.004883° (20°/4096). 0 = 30.3° elevation. 4095 = 10.30488° elevation. Bits 12 - 13: unused, set to zero Bits 14 - 15: Telescope (0 - 3)

10.38. Set Shutter Position Command

The Set Shutter Position command immediately changes the position of the specified telescope shutter to the specified position.

Table 57 - Set Shutter Position Command Fields	
Field	Usage
Command ID (1 byte)	37
Command Arguments (1 byte)	Byte 0: Bits 0 - 1: Telescope (0 - 3) Bit 2: Shutter Position (0 = closed, 1 = open) Bits 3 - 7: unused, set to zero

10.39. Copy CPHB to Primary EEPROM

The Copy CPHB to Primary EEPROM command copies the contents of the Control Program Holding Buffer to the Primary Default Control Program area of EEPROM (address 3C000H through 3FFFFH). The CPHB is copied only if the Control_Prgm_HB_Valid IP is TRUE. The Control_Prgm_HB_Valid IP is set to TRUE when there the contents of the CPHB is valid and the Validate CPHB command is executed. The Control_Prgm_HB_Valid IP is also set to TRUE when there the contents of the CPHB is valid and the Execute Control Program command is executed.

Table 58 - Copy CPHB to Primary EEPROM	
Field	Usage
Command ID (1 byte)	38
Command Arguments (none)	none

10.40. Copy CPHB to Secondary EEPROM

The Copy CPHB to Secondary EEPROM command copies the contents of the Control Program Holding Buffer to the Secondary Default Control Program area of EEPROM (address 4C000H through 4FFFFH). The CPHB is copied only if the Control_Prgm_HB_Valid IP is TRUE. The Control_Prgm_HB_Valid IP is set to TRUE when there the contents of the CPHB is valid and the Validate CPHB command is executed. The Control_Prgm_HB_Valid IP is also set to TRUE when there the contents of the CPHB is valid and the Execute Control Program command is executed.

Table 59 - Copy CPHB to Secondary EEPROM	
Field	Usage
Command ID (1 byte)	39
Command Arguments (none)	none

10.41. Let Watchdog Timer Expire Command

The Let Watchdog Timer Expire command lets the Watchdog Timer expire causing a CPU reset. This permits Watchdog Timer testing and a way to execute Boot Code by command.

Table 60 - Let Watchdog Timer Expire Command Fields	
Field	Usage
Command ID (1 byte)	40
Command Arguments (none)	none

10.42. Allocate Local Variables Command

The Allocate Local Variables command is used by control programs to allocate a specified number of local variables. Local variables are valid only within the subroutine in which they were allocated and must be deallocated before returning from the subroutine in which they were allocated.

Table 61 - Allocate Local Variables Command Fields	
Field	Usage
Command ID (1 byte)	41
Command Arguments (1 byte)	Number of local variables to allocate. All local variables are 32-bits wide.

10.43. Deallocate Local Variables Command

The Deallocate Local Variables command is used to deallocate local variables that were allocated with the Allocate Local Variables command.

Table 62 - Deallocate Local Variables Command Fields	
Field	Usage
Command ID (1 byte)	42
Command Arguments (1 byte)	Number of local variables to deallocate.

11. Scan Table Format

The Scan Table is a variable size data structure that contains all the information required to control scanning. Figure 9 below shows the structure of the Scan Table.

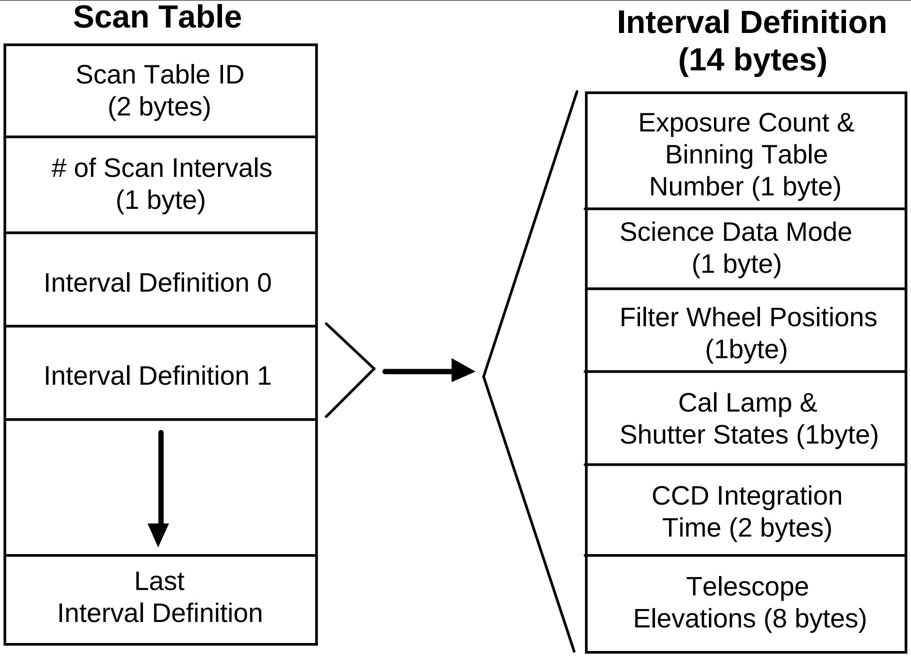

Figure 9 - Scan Table Structure

Table 63 below contains a description of each field of the Scan Table and the Interval Definition.

Table 63 - Scan Table Field Descriptions

Field Name	Description
Scan Table ID	2 Bytes - Can be any value. This value is reported in Science Data TM Packets and in the Scan Table ID IP.
# of Scan Intervals	1 Byte - The number of Interval Definitions contained in the Scan Table.
Exposure Count & Binning Table Number	1 Byte <u>Bits 0 - 4: Exposure Count</u>: The number of CCD erase-expose-convert cycles to perform in this interval. Allows the instrument to make multiple CCD exposures at the same telescope elevations and mechanism states. <u>Bits 5 - 7: Binning Table Number</u>: Sets the CCD Binning Table used to control horizontal pixel binning. Ranges from 0 to 1.
Science Data Mode	1 Byte - Controls the way data is read from the CCD and formatted into Science Data TM Packets. NOTE: Only one type of Science Data Mode may appear in each scan table. (You cannot change Science Data Modes within a scan table.) <u>00H = Spectral Data Mode</u>. CCD data is formatted into Spectral Science Data TM packets of variable length. The binning table determines the number of CCD bin values contained in the each TM packet. <u>01H = CCD Image Mode</u>. The binning table is ignored and the CCD data is read as an array of 60 x 600 CCD pixels. The data is transmitted in a series of CCD Image Science TM packets.

Table 63 - Scan Table Field Descriptions

Field Name	Description
Filter Wheel Positions	1 Byte - Bits 0 - 2: Filter Wheel 1 Position (0 - 7) Bits 3 - 5: Filter Wheel 2 Position (0 - 7) Bits 6 - 7: Spare
Cal Lamp & Shutter States	1Byte Bits 0 - 2: 0 = All lamps off 1 = Lamp 1 (HAK) on 2 = Lamp 2 (Neon) on 3 = Lamp 3 (Incandescent 1) on 4 = Lamp 4 (Incandescent 2) on Bit 3: Telescope 1 Shutter Position (0 = closed, 1 = open) Bit 4: Telescope 2 Shutter Position (0 = closed, 1 = open) Bit 5: Telescope 3 Shutter Position (0 = closed, 1 = open) Bit 6: Telescope 4 Shutter Position (0 = closed, 1 = open) Bit 7: Spare
CCD Integration Time	2 Bytes - The CCD Integration Time in centiseconds. Ranges from 0 to 4095.
Telescope Elevations	8 Bytes: Byte 0 - 1: Telescope 1 Initial Elevation. Valid values: 0 through 4095. One step equals 0.004883° (20°/4096). 0 = 30.3° elevation. 4095 = 10.30488° elevation. Bytes 2 - 3 : Telescope 2 Initial Elevation. Byte 4 - 5 : Telescope 3 Initial Elevation. Byte 6 - 7 : Telescope 4 Initial Elevation.

12. Error Codes

The following error codes and error parameters are returned in the Error Report TM packet.

Table 64 - Error Codes

Error Code	Description	Error Parameters
1	Partial header in TM packet queue. Internal flight software error. Contact flight software engineer.	none
2	(unused error code)	
3	TM packet buffer overflow. No remaining buffer space to store outgoing TM packets. One or more contiguous TM packets were discarded.	none
4	Invalid header in TM packet queue. Internal flight software error. Contact flight software engineer.	none
5	Partial packet in TM packet queue. Internal flight software error. Contact flight software engineer.	none
6	Source packet buffer alignment error. The spacecraft did not read the correct number of bytes from subaddress T1 at the beginning or end of a CCSDS source packet. CCSDS Source packets were probably lost.	none
7	1553 format error. A type of low level 1553 bus	none

	error detected by the 1553 bus interface controller.	
8	1553 status error. A type of low level 1553 bus error detected by the 1553 bus interface controller.	none
9	Partial header in error packet queue. Internal flight software error. Contact flight software engineer.	none
10	Invalid header in error packet queue. Internal flight software error. Contact flight software engineer.	none
11	Partial packet in error packet queue. Internal flight software error. Contact flight software engineer.	none
12	1553 subaddress R1 data buffer overflow error. Ran out of buffer space for incoming CCSDS TCMD packets. One TCMD packet was lost.	none
13	1553 subaddress R1 message size error. R1 received a 1553 message of size other than 64 bytes.	none
14	Telecommand Version Number or Packet ID error. Received a CCSDS TCMD packet with an invalid Version Number or Packet ID in the packet header. The TCMD packet was discarded.	Param 1: Received sequence source count. Param 2: Expected sequence count source.
15	Telecommand grouping flags error. Received a CCSDS TCMD packet with invalid Grouping Flags in the packet header. The TCMD packet was discarded.	Param 1: Received sequence source count. Param 2: Expected sequence count source.
16	Telecommand size error. Received a CCSDS TCMD packet with an invalid Packet Size in the packet header. The TCMD packet was discarded.	Param 1: Received sequence source count. Param 2: Expected sequence count source.
17	Telecommand sequence source count error. Received a CCSDS TCMD packet with an invalid Sequence Source Count in the packet header. The TCMD packet WAS NOT discarded.	Param 1: Received sequence source count. Param 2: Expected sequence count source.
18	Telecommand CRC error. Received a CCSDS TCMD packet with a CRC error in the Command Block (Application Data field). The TCMD packet was discarded.	Param 1: Received sequence source count. Param 2: Expected sequence count source.
19	Address wrap error. Received a command containing an address range that wraps from FFFFH to 0000H.	Params 1 - 4: The first 8 bytes of the command.
20	Bad memory segment error. Received a command that contained a 24-bit address that specified an unknown memory segment.	Params 1 - 4: The first 8 bytes of the command.
21	PROM write error. Received a command that attempted to write to PROM.	Params 1 - 4: The first 8 bytes of the command.
22	Segment range error. Received a command that contained a 24-bit address that wrapped past the end of the memory segment.	Params 1 - 4: The first 8 bytes of the command.

23	Deck CRC error. Received a Calculate CRC command attempting to calculate a CRC in deck interface memory.	Params 1 - 4: The first 8 bytes of the command.
24	Execute non-program RAM error. Received an Execute RAM Code command containing an execution address outside of Program RAM.	Params 1 - 4: The first 8 bytes of the command.
25	Illegal command ID error. Received a command containing an illegal command ID.	Params 1 - 4: The first 8 bytes of the command.
26	Partial command error. Received an incomplete command.	Params 1 - 4: The first 8 bytes of the command.
27	EEPROM write timeout error. The EEPROM did not complete a write cycle within 20 msecs.	Param 1: Write destination segment. Param 2: Write destination address of the start of the block that timed out. Param 3: Number of bytes in the block that timed out. Param 4: Elapsed time since the EEPROM write operation was started (in msec).
28	EEPROM verify error. The EEPROM did not retain the data written to it.	Param 1: EEPROM segment. Param 2: EEPROM address of the start of the block that did not verify. Param 3: Size of the block that did not verify.
29	Data RAM verify error. The Data RAM did not retain data written to it.	Param 1: Data RAM segment Param 2: Data RAM address of the start of the block that did not verify. Param 3: Size of the block that did not verify.
30	Page window verify error. A write command with a destination address in the XC000H to XFFFFH range failed to verify.	Param 1: Page window segment Param 2: Page window address of the start of the block that did not verify. Param 3: Number of bytes in the block that did not verify.
31	Data segment page error. The address range specified in a command crossed the boundary between data RAM and the page window (1C000H).	Params 1 - 4: The first 8 bytes of the command.
32	Dump memory command timeout error. There was insufficient TM bandwidth to complete a Dump Memory command. The command was aborted to avoid waiting indefinitely for TM bandwidth.	none
33	The primary copy of the Instrument Software in EEPROM has an invalid size.	Param 1: The primary Instrument Software size in EEPROM.
34	The secondary copy of the Instrument Software in EEPROM has an invalid size.	Param 1: The secondary Instrument Software size in EEPROM.
35	When calculated in Program RAM, the primary copy of EEPROM has an invalid (non-zero) CRC.	Param 1: The calculated CRC
36	When calculated in Program RAM, the	Param 1: The calculated CRC

	secondary copy of EEPROM has an invalid (non-zero) CRC.	
37	Boot code startup event. Not a true error. Sent when the boot code starts running.	none
38	Instrument Software startup event. Not a true error. Sent when the Instrument Code starts running.	none
39	Sequencer too slow error. The sequencer task did not complete within one second. Contact the flight software engineer.	none
40	Tried to write to Program RAM while executing from Program RAM. This is not allowed due to hardware constraints.	Params 1 - 4: The first 8 bytes of the command.
41	Bad command argument: illegal destination type.	Params 1 - 4: The first 8 bytes of the command
42	Bad command argument: illegal source type.	Params 1 - 4: The first 8 bytes of the command
43	Bad command argument: illegal destination IP ID.	Params 1 - 4: The first 8 bytes of the command
44	Bad command argument: illegal dest local var number.	Params 1 - 4: The first 8 bytes of the command
45	Bad command argument: illegal source IP ID.	Params 1 - 4: The first 8 bytes of the command
46	Bad command argument: illegal source local var number.	Params 1 - 4: The first 8 bytes of the command
47	Unimplemented command	Params 1 - 4: The first 8 bytes of the command
48	Write command too big. Too many data bytes in the command packet.	Params 1 - 4: The first 8 bytes of the command
49	Bad command argument: A source argument required but missing.	Params 1 - 4: The first 8 bytes of the command
50	Bad command argument: The destination IP is not commandable.	Params 1 - 4: The first 8 bytes of the command
51	Bad command argument: The command contains a unused source argument.	Params 1 - 4: The first 8 bytes of the command
52	Too many local variable allocated. The total number of allocated local vars is limited to 128.	none
53	Deallocated more local variable s than allocated.	none
54	Tried to access unallocated local variable.	none
55	Bad command argument: Bad local variable count. Tried to allocate more 128 local variables.	Params 1 - 4: The first 8 bytes of the command
56	Bad command argument: excessive telescope elevation.	Params 1 - 4: The first 8 bytes of the command
57	Timed out executing Set Telescope Elevation command.	Param 1: Telescope number (1 - 4)
58	Latched positive position error after Set	Param 1: Telescope number (1 - 4)

	Telescope Elevation command.	
59	Latched negative position error after Set Telescope Elevation command.	Param 1: Telescope number (1 - 4)
60	Bad command argument: illegal filter wheel number.	Params 1 - 4: The first 8 bytes of the command
61	Bad command argument: illegal filter wheel position.	Params 1 - 4: The first 8 bytes of the command
62	Filter wheel 1 initization indexing time out.	none
63	Filter wheel 2 initization indexing time out.	none
64	Filter wheel 1 initialization indexing failure.	none
65	Filter wheel 2 initialization indexing failure.	none
66	Shutter initialization time out error.	none
67	Filter wheel 1 initialization positioning failure.	none
68	Filter wheel 2 initialization positioning failure.	none
69	Instrument input current red limit exceeded.	none
70	A filter wheel movement timed out.	<u>If the time out occurs while scanning</u>: A single error packet with no parameters is sent. Then watchdog is allowed to expire. <u>If the time out occurs while executing a Set FW Position command</u>: Two error packets are sent and then the watchdog is allowed to expire. The first error packet contains the following params. The second error packet contains no error params. Param 1: FW Number Param 2: Desired position Param 3: Current position
71	Telescope in wrong position after executing a Set Telescope Elevation command.	Param 1: Telescope number Param 2: Desired elevation Param 3: Actual elevation
72	Filter wheel in wrong position after executing a Set Filter Wheel Position command.	Param 1: FW number (1 or 2) Param 2: Desired position Param 3: Actual position
73	Bad command argument: The unused argument bits in a Set Shutter Position command are not zero.	Params 1 - 4: The first 8 bytes of the command
74	Timed out executing Set Shutter Position command.	Param 1: Shutter number (1 - 4) Param 2: Desired position
75	Bad command argument: Invalid calibration lamp number.	Params 1 - 4: The first 8 bytes of the command
76	Bad command argument: Invalid binning table	Params 1 - 4: The first 8 bytes of the

	number.	command
77	Bad command argument: too many bin table append bytes.	Params 1 - 4: The first 8 bytes of the command
78	Binning table overflow. The command was not executed because the binning table would have overflowed.	none
79	Binning table append verify error. An Append to Binning Table command failed because the data read back from the binning table did not match the written data.	Param 1: CCD deck memory seg Param2: CCD deck memory address Param3: Number of bytes in the block that did not verify.
80	Binning table translation verify error. An Append to Binning Table command failed because the translated gain byte did not verify when read back from the binning table on the CCD deck.	Param 1: CCD deck segment Param 2: CCD deck address of the byte that did not verify
81	Extraneous bits set in binning table.	Param 1: CCD deck segment Param 2: Address of byte with extraneous bits
82	Scan table overflow. The command was not executed because the Scan Table would have overflowed.	none
83	Bad command argument: Too many scan table append bytes.	Params 1 - 4: The first 8 bytes of the command
84	Start scan error: No scan table loaded.	none
85	Command invalid while scanning.	Param 1: Command ID of the command that is invalid while scanning.
86	Unexpected interrupt error, watchdog will expire.	none
87	Start scan error: Invalid scan table size.	none
88	Scan error: Incomplete scan cycle. The Scan Control Block was not updated by the time the Convert Done interrupt occurred. Scanning was stopped automatically. This indicates that there was not enough CPU time available in the scan cycle to prepare for the next scan cycle.	none
89	Scan error: CCD image RAM overwritten. CCD Image RAM was overwritten before the spectral science TM packet for the previous exposure was completed. The partially completed science TM packet was discarded.	none
90	Control Program Holding Buffer overflow. Could not execute an Append to Program Holding Buffer command because there was not enough space left in the CPH Buffer.	none
91	Append to Control Program Holding Buffer command too big.	Params 1 - 4: The first 8 bytes of the command

92	Control Program Holding Buffer validation error: Invalid CP length.	none
93	Control Program Holding Buffer validation error: Invalid CP CRC.	none
94	Control Program Holding Buffer validation error: CPHB empty.	none
95	Control program execution error: Executed past the end of the control program.	none
96	Control program execution halted due to Control program execution error.	none
97	Control program error: Invalid CRC in execution buffer.	none
98	Invalid Primary Default Control Program. The Primary Default Control Program could not be executed because it was invalid after being loaded into the Control Program execution buffer.	none
99	Invalid Secondary Default Control Program. The Secondary Default Control Program could not be executed because it was invalid after being loaded into the Control Program execution buffer.	none
100	Bad command argument: invalid jump offset.	none
101	Control program execution error: Subroutines nested too deeply. Ran out of subroutine return address stack space.	none
102	Control program execution error: Return address stack underflow. Executed one to many Return commands.	none
103	Entering Safe Mode event. Not a true error. Sent when the instrument enters Safe Mode.	none
104	Exiting Safe Mode event. Not a true error. Sent when the instrument exits Safe Mode.	none
105	Invalid state machine state. A software state machine entered an unknown state. This is a nasty internal error from which there is no recovery. This error causes the watchdog timer to expire.	Param 1: Address of the function in which the error occurred.
106	A mechanism movement was not completed by the time the corresponding CCD conversion was completed. Scanning was stopped.	none
107	A Start Scanning command failed because the CCD controller failed to produce a Conversion Done interrupt.	none
108	Could not start scanning because the scan table contains both image and spectral science modes.	none

13. Instrument Parameters

The Instrument Parameters (IPs) are fully defined in the document, TIDI Instrument Parameter Definition, document #055-3519. For the latest and most complete IP definitions, refer to the latest revision of document #055-3519.

14. Binning Table Format

The Binning Table is a variable size data structure that contains information required to control CCD horizontal pixel binning. Figure 10 below shows the structure of the Scan Table. The binning table is limited to 255 bins (total length of 512 bytes).

Binning Table Format

Byte Offset	
0	Binning Table ID MSB
1	Binning Table ID LSB
2	Bin N Width
3	Bin N Gain and Discard Control Bits
4	Bin N-1 Width
5	Bin N-1 Gain and Discard Control Bits
	First Bin Width
	First Bin Gain and Discard Control Bits

Figure 10 - Binning Table Format

Table 65 - Binning Table Field Descriptions below contains a description of each field of the Binning Table.

Table 65 - Binning Table Field Descriptions

Field Name	Description
Binning Table ID	An arbitrary number that is reported in science TM packets.
Bin Width	The width, in pixels of the horizontal bin. Ranges from 1 to 255.
Bin Gain and Discard Control Bits	Bits 0 - 1: ADC gain for the bin. Ranges from 0 to 3. 0 is the lowest gain, 3 is the highest gain. Bit 2: Discard Control Bit. If this bit is 1, the bin value is discarded (not stored in image RAM on the DA deck).

15. Appendix A - TIDI Commands Sorted by Opcode

Command	**Opcode (dec)**	**Opcode (hex)**	**Command Arguments**
No Operation	0	00H	<none>
Disable Autoboot	1	01H	<none>
Boot Now	2	02H	<none>
Write Memory	3	03H	address[3], length[1], data[length]
Dump Memory	4	04H	address[3], length[2]
Dump Control Program Global Variables	5	05H	<none>
Calculate CRC	6	06H	address[3], length[2]
Execute RAM Code	7	07H	address[3]
Jump	8	08H	byte_offset[2]
Jump if Equal	9	09H	byte_offset[2]
Jump if Not Equal	10	0AH	byte_offset[2]
Jump if Greater Than	11	0BH	byte_offset[2]
Jump if Less Than	12	0CH	byte_offset[2]
Wait	13	0DH	centiseconds[2]
Call Subroutine	14	0EH	byte_offset[2]
Return from Subroutine	15	0FH	<none>
Start Control Program Execution	16	10H	<none>
Stop Control Program Execution	17	11H	<none>
Load Parameter	18	12H	src_and_dest_selectors[2-7]
Add	19	13H	src_and_dest_selectors[2-7]
Subtract	20	14H	src_and_dest_selectors[2-7]
Increment	21	15H	src_and_dest_selectors[2-7]
Decrement	22	16H	src_and_dest_selectors[2-7]
Compare	23	17H	src_and_dest_selectors[2-7]
Clear Control Program Holding Buffer	24	18H	<none>
Clear a CCD Binning Table	25	19H	binning_table_number[1]
Append to a CCD Binning Table	26	1AH	table_number[1], length[1], data[length]
Append to Control Program Holding Buffer	27	1BH	length[1], data[length]
Validate Control Program Holding Buffer	28	1CH	<none>
Clear Scan Table	29	1DH	<none>
Append to Scan Table	30	1EH	length[1], data[length]
Start Scanning	31	1FH	<none>
Stop Scanning at End of Scan	32	20H	<none>
Stop Scanning Immediately	33	21H	<none>
Set Filter Wheel Position	34	22H	fw_wheel[1], position[1]
Set Cal Lamp States	35	23H	lamp_states[1]
Set Telescope Elevation	36	24H	elevation_and_tel_number[2]
Set Shutter Position	37	25H	position_and_tel_number[1]
Copy CPHB to Primary EEPROM	38	26H	<none>
Copy CPHB to Secondary EEPROM	39	27H	<none>
Let Watchdog Timer Expire	40	28H	byte_offset[2]
Allocate Local Variables	41	29H	number_of_vars[1]

Deallocate Local Variables	42	2AH	number_of_vars[1]

16. Appendix B - TIDI Commands Sorted Alphabetically

Command	Opcode (dec)	Opcode (hex)	Command Arguments
Add	19	13H	src_and_dest_selectors[2-7]
Allocate Local Variables	41	29H	number_of_vars[1]
Append to a CCD Binning Table	26	1AH	table_number[1], length[1], data[length]
Append to Control Program Holding Buffer	27	1BH	length[1], data[length]
Append to Scan Table	30	1EH	length[1], data[length]
Boot Now	2	02H	<none>
Calculate CRC	6	06H	address[3], length[2]
Call Subroutine	14	0EH	byte_offset[2]
Clear a CCD Binning Table	25	19H	binning_table_number[1]
Clear Control Program Holding Buffer	24	18H	<none>
Clear Scan Table	29	1DH	<none>
Compare	23	17H	src_and_dest_selectors[2-7]
Copy CPHB to Primary EEPROM	38	26H	<none>
Copy CPHB to Secondary EEPROM	39	27H	<none>
Deallocate Local Variables	42	2AH	number_of_vars[1]
Decrement	22	16H	src_and_dest_selectors[2-7]
Disable Autoboot	1	01H	<none>
Dump Control Program Global Variables	5	05H	<none>
Dump Memory	4	04H	address[3], length[2]
Execute RAM Code	7	07H	address[3]
Increment	21	15H	src_and_dest_selectors[2-7]
Jump	8	08H	byte_offset[2]
Jump if Equal	9	09H	byte_offset[2]
Jump if Greater Than	11	0BH	byte_offset[2]
Jump if Less Than	12	0CH	byte_offset[2]
Jump if Not Equal	10	0AH	byte_offset[2]
Let Watchdog Timer Expire	40	28H	byte_offset[2]
Load Parameter	18	12H	src_and_dest_selectors[2-7]
No Operation	0	00H	<none>
Return from Subroutine	15	0FH	<none>
Set Cal Lamp States	35	23H	lamp_states[1]
Set Filter Wheel Position	34	22H	fw_wheel[1], position[1]
Set Shutter Position	37	25H	position_and_tel_number[1]
Set Telescope Elevation	36	24H	elevation_and_tel_number[2]
Start Control Program Execution	16	10H	<none>
Start Scanning	31	1FH	<none>
Stop Control Program Execution	17	11H	<none>
Stop Scanning at End of Scan	32	20H	<none>
Stop Scanning Immediately	33	21H	<none>
Subtract	20	14H	src_and_dest_selectors[2-7]
Validate Control Program Holding Buffer	28	1CH	<none>
Wait	13	0DH	centiseconds[2]

Write Memory	3	03H	address[3], length[1], data[length]

17. Appendix C - TIDI Commands Legal While Scanning

Command	**Legal while Scanning**
Add	Yes
Allocate Local Variables	Yes
Append to a CCD Binning Table	**No**
Append to Control Program Holding Buffer	Yes
Append to Scan Table	**No**
Boot Now	N.A
Calculate CRC	Yes
Call Subroutine	Yes
Clear a CCD Binning Table	**No**
Clear Control Program Holding Buffer	Yes
Clear Scan Table	**No**
Compare	Yes
Copy CPHB to Primary EEPROM	Yes
Copy CPHB to Secondary EEPROM	Yes
Deallocate Local Variables	Yes
Decrement	Yes
Disable Autoboot	N.A.
Dump Control Program Global Variables	Yes
Dump Memory	Yes
Execute RAM Code	Yes
Increment	Yes
Jump	Yes
Jump if Equal	Yes
Jump if Greater Than	Yes
Jump if Less Than	Yes
Jump if Not Equal	Yes
Let Watchdog Timer Expire	Yes
Load Parameter	Yes
No Operation	Yes
Return from Subroutine	Yes
Set Cal Lamp States	**No**
Set Filter Wheel Position	**No**
Set Shutter Position	**No**
Set Telescope Elevation	**No**
Start Control Program Execution	Yes
Start Scanning	**No**
Stop Control Program Execution	Yes
Stop Scanning at End of Scan	Yes
Stop Scanning Immediately	Yes
Subtract	Yes
Validate Control Program Holding Buffer	Yes
Wait	Yes
Write Memory	Yes