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Spacecraft to Science Instrument Data Interface Control Document

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Preface

This document is controlled by the MIT Center for Space Research. Formal changes can only be ratified through an ECO process which includes a signature from Astrium.

Revision 01 of this document is being circulated for in preliminary spacecraft design for proposal purposes.

1 Introduction

The flight hardware for the Coral Reef Mission, which is referred to herein as the Observatory, may be logically divided into two parts: the Science Payload and the Spacecraft Bus. The Science Payload is composed 14 separate instruments which, by design, have a high degree of commonality. At the highest level each instrument consists of an optical camera, cooled CCD focal plane, and supporting electronics. We note that the instruments have ***no*** interfaces with each other, only with the Spacecraft Bus.

1.1 Scope

This document describes the data interface between the several instruments and the spacecraft bus. The meanings of individual bits and data words are defined, their composition into data and telemetry packets, and the timing relationships among those packets. The purely electrical circuit details of the data interface are contained in a separate Electrical ICD, 43-03002.

1.2 Instrument Nomenclature

There are three different kinds of instrument whose names which reflect their scientific function:

Quantity	Descriptive Name
12	**Picture** – a monochromatic n x 1024 pixel image; 10 m resolution
1	**Pan** – a panchromatic n x 1024 pixel image; 5 m resolution
1	**Palette** – a 1024 element spectral dispersion of a central pixel

The 12 **Picture** instruments are distinguished by a reference number which relates to the center of their respective spectral bands.

Nomenclature	Center Wavelength	Full Bandwidth
Picture/aaa	aaa nm	20 nm
Picture/bbb	bbb nm	20 nm
Picture/ccc	ccc nm	10 nm
Picture/ddd	ddd nm	10 nm
Picture/eee	eee nm	10 nm
Picture/fff	fff nm	10 nm
Picture/ggg	ggg nm	10 nm
Picture/hhh	hhh nm	10 nm
Picture/iii	iii nm	10 nm
Picture/jjj	jjj nm	10 nm
Picture/kkk	kkk nm	20 nm
Picture/mmm	mmm nm	20 nm

This document describes the command and data interface between the individual instruments and the spacecraft Command and Data Handling (C&DH) system. In all cases, unique application IDs allow us to distinguish the different instruments in the command (see section 2.1.2) and telemetry (see section 3.1.2) streams.

1.3 Bit Numbering Convention

The following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (*i.e.* the most left justified when drawing a figure) is defined to be “Bit 0”; the following bit is defined to be “Bit 1” and so on up to “Bit N-1”. When the field is used to express a numeric value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field. Unless otherwise noted, such values will be expressed in decimal notation within this document.

Note that the 1553 serial bus uses a Least Significant Bit (LSB) first protocol. Since both instrument and spacecraft, however, deal with the 1553 bus through parallel word transfers to a protocol chip, we will ignore this complication here.

1.4 Pixel Mapping Conventions

The **Picture** and **Palette** instrument hardware process data from one row of a Time Delay and Integration (TDI) Charge Coupled Device (CCD) detector every 1.3 millisecond (nominally), corresponding to the time that the Observatory advances 10 meters along its 98 degree inclination ground track. The **Pan** instrument hardware processes row data every 0.65 milliseconds (nominally). At the interface, the lowest numbered pixel corresponds to the east-most edge of the field of view. In the cast of the **Palette** instrument, the lowest numbered pixel corresponds to the shortest measured wavelength.

1.5 Constants Calculated and Derived

The “Instrument ID” is a 4 bit code set by jumpers in the spacecraft cable which plugs into the instrument (see the Electrical ICD for implementation details). This code is used to uniquely address each instrument on the 1553 command and telemetry bus.

The “Instrument Serial Number” is a 5 bit code set by jumpers within the instrument at the time of manufacture.

2 Commands

2.1 Packet Description

The following describes command packets which conform to the Consultative Committee for Space Data Systems (CCSDS) Recommendations for Packet Telecommands (CCSDS 201.0-B-3 and CCSDS 202.0-B-2) except as noted below. These telecommand (referred to hereafter simply as "command") packets are generated by ground software and uplinked to the spacecraft for delivery. The spacecraft C&DH maps the Application Process ID to a particular MIL-STD-1553 Remote Terminal (RT) address and sub-address and forwards only the data content of the packet to the individual instrument.

2.1.1 Primary Header Format

The format of the primary CCSDS header is as follows:

Bit Position(s)	Description	Usage Notes
0-2	Version Number	Static value of 0
3	Type	Value of 1 for Telecommand Packets
4	Secondary Header Flag	Value of 1 when a secondary header is present, as it is for telemetry packets; value of 0 for these command packets.
5-15	Application Process ID	Determines command routing; see the separate table below
16-17	Segmentation Flags	Static value of 3; no segmentation will be used
18-31	Sources Sequence Count	This counter is meant to be incremented separately for each Application ID.
32-47	Packet Length	The number of data bytes following the primary header

2.1.2 Application ID Assignments

The Application Process ID is used by the C&DH to route the packet data to the appropriate 1553 Remote Terminal and RT Sub-Address. Note that the primary header is not forwarded to the instrument, only the 16 or 32 bit application data. The table below shows the bit assignments:

Bit Positions	Description	RT Address	Usage Notes
5	Science ID		Static value of 1 for science instruments; a value of 0 is used for spacecraft functions
6-9	Instrument ID	16 17 18 19 20 21 22 23 24 25 26 27 28 29	Value = 1 for Picture/aaa Value = 2 for Picture/bbb Value = 3 for Picture/ccc Value = 4 for Picture/ddd Value = 5 for Picture/eee Value = 6 for Picture/fff Value = 7 for Picture/ggg Value = 8 for Picture/hhh Value = 9 for Picture/iii Value = 10 for Picture/jjj Value = 11 for Picture/kkk Value = 12 for Picture/mmm Value = 13 for Pan Value = 14 for Palette
10	Reserved		Fixed value = 0
11-15	Command ID		Individual command decoding shown in Section 2.4

2.1.3 Secondary Header Format

There is no secondary header used in the command packets.

2.2 1 Hz Reference

A time synchronization pulse will be delivered to the instruments once each second; their occurrence shall define a "data reference interval." The leading edge will be synchronized to spacecraft time to within 0.7 millisecond.

2.3 Command Timing

There is no minimum time requirement between commands (including the Time of Next Sync Pulse).

Commands will take effect on receipt except for those at subaddress 9 and 30; these take effect at the next 1 Hz Reference Pulse.

2.4 Command Application Data Format

There are three types of commands sent to the instrument -- spacecraft time updates, magnitude commands, and discrete bit commands -- which are distinguished by the least significant 5 bits of the Application ID. The RT Sub-Addresses are identical to the specified bits of the Application ID.

App ID/ Sub-Add	No. of Data Bits	Description	Default	Reference
1	32	Time of next sync pulse	(none)	2.5.1
2-7	16	Command Echo	(none)	2.5.2
8	16	Discrete Commands -- Immediate Bit 0 = Start CCD clocking Bit 1 = Stop CCD clocking Bit 2 = Start Data transmission Bit 3 = Stop Data transmission	0	2.5.3
9	16	Discrete Commands – Synchronized Bit 0 = Analog power On Bit 1 = Analog power Off Bit 2 = Data Test Mode On Bit 3 = Data Test Mode Off Bit 14 = Clear all commands Bit 15 = System Reset	0	2.5.4
10-16	16	Reserved	0	
17	16	Ground Velocity Trim	0	2.5.5
18	8	Set Bias Voltage A	0	2.5.6
19	8	Set Bias Voltage B	0	
20	8	Set Bias Voltage C	0	
21	8	Set Bias Voltage D	0	
22	16	Load PRAM -- Header	(none)	2.5.7
23	64	Load PRAM -- Data	(none)	
24	8	Integration Row Count	48	2.5.8
25-30	16	Reserved		
30	8	Set Focal Plane Temperature	0	2.5.9

2.5 Command Description

Note that the event processing commands (*e.g.:* Amplitude Discriminators, X Reject, Y Reject) are applied simultaneously to each event to determine its validity and subsequent disposition in the data stream.

2.5.1 Time of Next Sync Pulse

This is the value of a counter maintained by the C&DH which represents, nominally, the number of seconds which have elapsed since the Epoch of 1 January 1970. The value is valid on the next received 1 Hz Reference Pulse (Section 2.2). This command shall be sent during each (1 second) data interval, at least 100 milliseconds before the Reference Pulse to which its value applies, and at least 100 milliseconds following the previous Reference Pulse. This command shall be sent whenever 28VDC is supplied to the instrument. If the instrument fails to receive the time update, a value of zero shall be set.

2.5.2 Command Echo

These commands have no effect within the instrument. The echo may be used for command/telemetry integrity tests on the ground and to tag science observations while on orbit (since the command is echoed into the data stream).

2.5.3 Discrete Commands – Immediate

These discrete commands are used to control data flow

- CCD clocking on/off controls the switching of the row and column drivers.
- Data transmission on/off gates the transmission of video data to the mass memory interface.

Note that the CCD clocking is normally turned on several seconds before data transmission is enabled.

2.5.4 Discrete Commands -- Synchronized

These discrete commands are used to control specific state changes within the instrument.

- Analog power on/off does what one would expect.
- A test data mode is provided for easy-to-interpret end-to-end data flow testing.
- Clearing all commands will result in all values or functions reverting to their default (also initial power up) state.
- A System Reset command will have exactly the same effect as a power-up reset except that the Source Sequence Count in the Primary 1553 Header is not reset.

2.5.5 Ground Velocity Trim

The CCD rows are advanced in synchrony with the observatory proceeding along its ground track, nominally every 1.35 millisecond. The Most Significant 2 bits are zero. The 14 bit value represents the number of 16MHz clock ticks which are added to a fixed 1.000 millisecond base value to specify the (dwell) time between row advances. It is possible to change this number while clocking is in progress.

2.5.6 Set Bias Voltage

The CCD clock driver and bias voltages can be adjusted to optimize performance, especially as radiation damage accumulates. The ranges will be selected after the particular CCD chip is selected.

2.5.7 Load PRAM

The CCD is clocked according to microinstructions contained in a programmable random access memory. The value of the Header command specifies the starting address and number of data packets to follow in a TBD format. The Data command values must follow in sequence, but could be interrupted by non-PRAM commands – in particular the Time-of-next-Sync-Pulse.

2.5.8 Integration Row Count

Depending upon the CCD chip chosen, it may not be necessary to integrate across the whole chip, using instead, as an example, only 48 rows out of the available 96.

2.5.9 Set Focal Plane Temperature

The Focal Plane temperature may be commanded to any value between –70 C and +60 C; the setpoint is equal to (-70 + 0.5*Count). Physical limitations – *e.g.*: radiator area – will restrict the achievable temperature range to be less than this command range. Nominal operating temperature is expected to be –30 C.

3 Telemetry

The following describes telemetry packets which conform to the Consultative Committee for Space Data Systems (CCSDS) Recommendations for Packet Telemetry (CCSDS 102.0-B-4) except as noted below. Telemetry packets are generated independently by each instrument on both RS-422 and MIL-STD-1553 interfaces.

3.1 RS422 Packet Description

The RS422 telemetry packets have a fixed length of 1566 bytes and contained data time-tagged to the nearest second by the value recorded in the secondary packet header.

Bit Position	Data Description
0-47	Primary Header
48-95	Secondary Header
96-12527	Science Data

3.1.1 Primary Header Format

The Primary Header format for telemetry packets is identical to that described for use in telecommands described in section 2.1.1 .

3.1.2 Application ID Assignments

The Application ID assignments for telemetry are similar to those used for commands (see section 2.1.2.

Bit Positions	Description	Usage Notes
5	Science ID	Static value of 1 for science instruments; a value of 0 is used for spacecraft functions
6-9	Instrument ID	Value = 1 for Picture/aaa Value = 2 for Picture/bbb Value = 3 for Picture/ccc Value = 4 for Picture/ddd Value = 5 for Picture/eee Value = 6 for Picture/fff Value = 7 for Picture/ggg Value = 8 for Picture/hhh Value = 9 for Picture/iii Value = 10 for Picture/jjj Value = 11 for Picture/kkk Value = 12 for Picture/mmm Value = 13 for Pan Value = 14 for Palette
10-15	Reserved	Value = 0

3.1.3 Secondary Header Format

The secondary header is composed of three parts (note that bit 48 must be 0 to be CCSDS compliant):

Bit Position	Data Description
48	Reserved; value = 0
49-53	Instrument Serial Number
54-63	Milliseconds elapsed since 1 Hz
64-95	Spacecraft time in seconds

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The instrument serial number is a unique five bit number set at time of manufacture.

The spacecraft time value is valid for the beginning of the current 1 second data interval, hence it is a constant for all packets put out during this data interval. Spacecraft time is augmented by the instrument counting the number of milliseconds elapsed since the last 1 Hz pulse.

3.1.4 Telemetry Flow Control

Generation of RS422 telemetry packets is inhibited if either of CCD Clocking or Data Transmission discrete command states are OFF. There is no bit level or byte level flow control.

The rate of telemetry packet generation is determined by the observatory velocity along the ground track, with one packet being generated for each 10 meters of advance; at 550 Km altitude this is approximately one packet per 1.35 ms. The Pan instrument delivers two packets in each such interval.

The sum of the science instruments will deliver a maximum of 160 Mbits/sec, or 20 Mbytes/sec, to the spacecraft mass storage unit.

3.1.5 Telemetry Application Data Format

Bit positions 96 to 12527 are filled with a sequence of 12 bit values, each representing the signal from a single CCD pixel. There are 1024 active pixels plus 12 overclocks being reported in each packet.

3.2 MIL-STD-1553 Packet Description

The MIL-STD-1553 telemetry packets are of two separate types: a secondary science packet and a general housekeeping packet.

3.2.1 Primary Header Format

The Primary Header format for telemetry packets is identical to that described for use in telecommands (see section 2.1.1).

3.2.2 Application ID Assignments

The Application ID assignments for telemetry are similar to those used for commands (see section 2.1.2.).

Bit Positions	Description	RT Sub-Addr.	Usage Notes
5	Science ID		Static value of 1 for science instruments; a value of 0 is used for spacecraft functions
6-8	Instrument ID		Value = 1 for Picture/aaa Value = 2 for Picture/bbb Value = 3 for Picture/ccc Value = 4 for Picture/ddd Value = 5 for Picture/eee Value = 6 for Picture/fff Value = 7 for Picture/ggg Value = 8 for Picture/hhh Value = 9 for Picture/iii Value = 10 for Picture/jjj Value = 11 for Picture/kkk Value = 12 for Picture/mmm Value = 13 for Pan Value = 14 for Palette
9-13	Reserved		Value = 0
14-15	Data ID	1 2	Value = 1 for secondary science Value = 2 for housekeeping

3.2.3 Secondary Header Format

The secondary header contains the spacecraft time valid for the data interval during which the telemetry request was made (note that bit 48 must be 0 to be CCSDS compliant). If the 1 Hz Pulse (paragraph 2.2) is not received and the instrument is using its own free running reference, bit 63 is set.

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Bit Position	Data Description
48-51	Reserved; value = 0
52-55	Instrument Serial Number
56-62	Reserved; value = 0
63	1 Hz Pulse not received
64-95	Spacecraft time in seconds

3.2.4 Telemetry Timing

Telemetry packets must be retrieved from the 1553 Remote Terminal in the interval between 100 and 900 milliseconds following a 1 Hz Reference Pulse.

Secondary science packets shall be read during every 1 second data interval during which primary science data is being collected.

Housekeeping packets shall be read every 16 seconds while 28VDC power is supplied to the instrument.

3.2.5 Telemetry Application Data Format

3.2.5.1 Secondary Science

The application data contents of the secondary science packet are as follows:

Relative Bit Position	Data Description	Reference
0	CCD Clocking Enabled	3.3.1
1	Data Transmission Enabled	
2	Data Test Mode Enabled	
3-5	Reserved, Value = 0	
6-15	Ground Velocity Trim	3.3.2
11-15	RT SubAddr of Last Command	
16-31	Contents of Last Command	

This data in this packet was latched by the immediately preceding 1 Hz Reference Pulse. In this context "Last Command" means the command received during that preceding data interval; if no command was received during that interval, these bits have zero value.

3.2.5.2 Housekeeping

The application data contents of the housekeeping packet are as follows. Unused bits are set to zero. A single A/D converter and 16 channel analog multiplexer are used to collect the analog data.

Relative Word Position	MUX Address	Bit Position	Data Description	Reference
0		0-16	PRAM Version Number	3.3.3
1		0-8	Integration Row Count	3.3.2
2	0	0-12	Bias Voltage A	3.3.5
3	1	0-12	Bias Voltage B	
4	2	0-12	Bias Voltage C	
5	3	0-12	Bias Voltage D	
6	4	0-12	28VDC Monitor	3.3.4
7	5	0-12	+5VDC Monitor	3.3.5
8	6	0-12	+15VDC Monitor	
9	7	0-12	-15VDC Monitor	
10	8	0-12	Signal Ground reference	
11	9	0-12	Forward Optics Temperature	3.3.6
12	10	0-12	Aft Optics Temperature	
13	11	0-12	Focal Plane Temperature	
14	12	0-12	Grat Temperature	
15	13	0-12	Electronics Assembly Temperature	

3.3 Telemetry Description

3.3.1 Discrete State Indicators

There are three one bit state indicators:

- CCD Clocking On/Off – indicates whether the CCD is currently enabled for clocking.
- Data Transmission – indicates whether science data transmission is enabled.
- Data Test Mode – indicates whether test data is being generated.

3.3.2 Command Settings

The telemetry words for

- Ground Velocity Trim
- Integration Row Count

are readouts of the respective registers. The values should be identical to the last command which set these registers.

3.3.3 PRAM Version Number

Each new version of the PRAM code will include a unique ID code which is read into telemetry.

3.3.4 28VDC Monitor

A value indicating the voltage of the spacecraft 28VDC bus as seen by the instrument. The nominal engineering value in volts is

V = K * (signed)count, where K is 0.010 (TBR)

3.3.5 Regulated Voltage Monitor

A value indicating the voltage of an instrument regulated quantity. The nominal engineering value in volts is

V = K * (signed)count, where K is 0.005 (TBR)

3.3.6 Temperatures

Instrument temperature is measure by applying a 1.0 ma current to a parallel combination of a 2.25K@25C thermistor and a 5.23K resistor and reading the resulting voltage. The transfer function is as follows; it has an accuracy of approximately 0.3C over a range of –40 to +40C (TBR).

aa = (count * 20 * 5.23e3) / (5.23e3 – 20 * count)

qq = log(aa)

T = 1 / (1.074e-7 * qq * qq * qq + 2.372e-4 * qq + 1.4733e-3) - 273.16

4 RS422 Serial Line Protocol

The CCSDS packets described above are packed into a mission unique format given below solely for transport between the instrument and the spacecraft on the RS422 science data lines.

4.1 Synchronization

Each CCSDS Primary Header is preceded by the fixed sync pattern 0x1ACFFC1D.