Rev.	ECO	Description	Checked	Approval	Date
01	32-002	Initial Release for comment		RFGoeke	1/7/05
02	32-003	Convert to 6 detectors and add Priority Packets		RFGoeke	2/25/05
03	32-008	Delete Priority Packets; add 6 video enables		RFGoeke	4/19/05

Spacecraft to CRaTER Data Interface Control Document

Dwg. No. 32-02001

Revision 03
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Preface

Revision 01 of this document is being circulated for comment. It contains a general proposal for the implementation of the experiment command and data interface. (It is derived from the SPIDR ICD.)

Revision 02 responds to the change in overall detector architecture from 1 thin and 5 thick detectors, to 3 thin/thick pairs of detectors. It adds both high and low rate calibration signals for testing telemetry performance, and further adds the ability to guarantee a telemetry allocation for particular sets of grade-coded events.

Revision 03 incorporated many comments. For the instrument team we

- Add the "Good Event" counter in secondary science. We will get this information in real time during flight, whereas the primary science delivery might well be delayed;
- Clarify what the System Reset command does;
- Separate the detector bias on/off commands for thick and thin detectors;
- Add commands to individually switch detector video chains on/off;
- Remove the packet priority scheme – s/c C&DH monitoring of secondary science can handle the functionality required to switch discriminator accept masks;
- Redo the Secondary Science and Housekeeping definitions to keep up with command changes;
- The analog housekeeping awaits detailed hardware design before we determine the final entries for the telemetry table.

Per Goddard request, the following changes are implemented:

- The command function codes have been moved from the Application ID to the Secondary Header;
- The 1 Hz clock drifts relative to GMT, so we add a few sub-second bits to guarantee that each science interval will be uniquely tagged;
- Maximum data packets per second command removed;
- The command sub-address range has been compressed;
- We increase the time-of-next-sync-pulse command to 64 bits (to include the sub-seconds) and change the secondary header of the telemetry packets to be consistent with spacecraft usage;
- The telemetry Application ID assignments will be made later by the spacecraft folks;
- The description of primary telemetry packet flow control has been expanded and now explicitly references the use of the 1553 RT status word.

1 Introduction

The flight hardware for the Cosmic Ray Telescope for Effects of Radiation (CRaTER) instrument on the Lunar Reconnaissance Orbiter (LRO) is composed of a single assembly incorporating both radiation detector and all associated power, command, data processing, and telemetry electronics. Other ICDs control electrical (32-02002), mechanical (32-02003), and thermal (32-02004) interfaces.

1.1 Scope

This document describes the data interface between the CRaTER science instrument and the space craft 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. All information necessary to define both command and telemetry dictionaries are contained herein.

1.2 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.

1.3 Detector Numbering Convention

The six silicon particle detectors are numbered sequentially {1 .. 6}from zenith to nadir when the instrument is on the spacecraft bus in orbit around the moon. Under the current instrument accommodation design, the instrument baseplate faces the zenith. Within the instrument the silicon detectors are mounted in pairs {1,2}, {3,4} and {5,6}; each pair consisting of a thin (300µm) and a thick (1000µm) detector. The thin detectors are located at positions {1,3,6} and the thick detectors are located at positions {2,4,5}.

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 and Secondary Header value 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 command and telemetry packets.
5-15	Application Process ID	Value TBD for the CRaTER instrument
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 Secondary Header Format

The Secondary Header is used by the C&DH to route the packet data to the appropriate 1553 RT Sub-Address. Note that the primary and secondary headers are 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
0-10	Reserved		Fixed value = 0
11-15	Command ID		Individual command decoding shown in Section 2.4

2.2 1 Hz Reference

A time synchronization pulse will be delivered to the instruments once each second. The leading edge will be correlated to spacecraft time to within 10 ms. These pulses delimit one second data intervals in which telemetry data is accumulated. NB: the 1Hz clock is not synchronized to GMT, and will slowly drift relative to GMT. For this reason alone we monitor the sub-seconds field of the time-of-next-sync command so that we are guaranteed a unique, incrementing time tag.

2.3 Command Timing

Instrument commands (with the exception of Time of Next Sync Pulse, see section 2.5) shall occur no more often than once per (1 second) data interval. There is no minimum time requirement between commands (including the Time of Next Sync Pulse).

The time of command execution is not currently defined. Commands may take effect either on receipt or at the next 1 Hz Reference Pulse (the later is preferred).

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 -- distinguished by the least significant 5 bits of the Secondary Header. The RT Sub-Addresses are identical to the specified bits of the Secondary Header..

Sub-Add	No. of Data Bits	Description	Default	Reference
1	64	Time of next sync pulse Bits 0-31 = seconds Bits 32-63 = sub-seconds	(none)	2.5.1
2	16	Command Echo	(none)	2.5.2
3	16	Global Discrete Commands Bit 0 = Thin Detector Bias Off Bit 1 = Thin Detector Bias On Bit 2 = Thick Detector Bias Off Bit 3 = Thick Detector Bias On Bit 4 = Electrical Cal Off Bit 5 = Electrical Cal On Bit 6 = Electrical Cal Low Rate Bit 7 = Electrical Cal High Rate Bit 11 = Data Test Mode Bit 14 = Clear all Commands Bit 15 = System Reset	 Off Off Off Low No action (none)	2.5.3
4	16	Video Processing Commands Bit 0 = Detector D1 Processing Off Bit 1 = Detector D1 Processing On Bit 2 = Detector D2 Processing Off Bit 3 = Detector D2 Processing On Bit 4 = Detector D3 Processing Off Bit 5 = Detector D3 Processing On Bit 6 = Detector D4 Processing Off Bit 7 = Detector D4 Processing On Bit 8 = Detector D5 Processing Off Bit 9 = Detector D5 Processing On Bit 10 = Detector D6 Processing Off Bit 11 = Detector D6 Processing On	 On On On On On On	2.5.4
5	64	Discriminator Accept mask	All "1"s	2.5.5
6	16	Event Amplitude Discriminator, Thin Detectors {1,3,6}	255,0	2.5.6
7	16	Event Amplitude Discriminator, Thick Detectors {2,4,5}	255,0	2.5.6
8-30	16	Reserved		

2.5 Command Descriptions

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 Mission Epoch. The value is valid on the next received 1Hz 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.

2.5.2 Command Echo

This command has 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 Global Discrete Commands

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

- Thin Detector Bias on/off controls the application of (fixed) bias voltage to the thin silicon detectors
- Thick Detector Bias on/off controls the application of (fixed) bias voltage to the thick silicon detectors
- Electrical Cal on/off controls a fixed energy calibration signal injected into the event chains
- Electrical Cal Rate selects between a low (1 Hz) rate and a high (2KHz) rate cal signal.
- The test mode is intended to verify internal data logic during instrument verification and is not intended for use at the obiter level.
- 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. If the implementation includes an FPGA which reads a PROM on power up, that PROM will be read again (to clear accumulated SEU hits in the FPGA).

2.5.4 Video Processing Commands

The discrete commands are used to gate on/off the individual video processing chains for each detector. When "off" the chains are electrically active, but the data is ignored; a noisy chain can thus be logically removed from processing and not adversely affect system dead time.

2.5.5 Discriminator Accept Mask

The six silicon detectors are numbered {1 .. 6} starting with the detector closest to the zenith window. Treating the output of the low level threshold detectors as a 6 bit number, there are 63 possible states by which a single event may be categorized. We set the corresponding bit to a one for each threshold state we wish to accept. For example:

- mask := `0x0000 0000 8000 808B` selects events which trigger one and only one detector threshold.
- mask := `0x7FFF FFFF FFFF FFFF` accepts all events;
- mask := `0x0000 0000 0000 0000` rejects all events.

2.5.6 Event Amplitude Discriminators

Amplitude discrimination is applied to the energy content of the events detected by an individual detector. The Most Significant 8 bits of the command are a High Level Discriminator, defining a limit beyond which events are considered invalid. The Least Significant 8 bits of the command are a Low Level Discriminator, defining a limit below which events are considered invalid. The settings are applied separately to Detectors {1,3,6} and Detectors {2,4,5}.

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.

3.1 MIL-STD-1553 Packet Description

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

3.1.1 Primary Header Format

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

3.1.2 Application ID Assignments

The Application ID assignments for telemetry as follows:

Bit Positions	Description	RT Address	Usage Notes
5-15	Data ID		Value = TBD for primary science Value = TBD+1 for secondary science Value = TBD+2 for housekeeping

3.1.3 Secondary Header Format

The secondary header contains the spacecraft time valid at the leading edge of the 1 Hz pulse preceding this telemetry request (note that bit 48 must be 0 to be CCSDS compliant): Although bits 80-95 would normally contain a 16-bit sub-seconds value, we truncate that information and jam an Instrument Serial Number into this field.

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Bit Position	Data Description
48	Reserved; value = 0
49-79	Spacecraft time in seconds
80-83	Spacecraft time in sub-seconds
84-90	Reserved; value = 0
91-95	Instrument Serial Number

3.1.4 Telemetry Flow Control

Primary science telemetry packets are filled without loss in a 9 byte repeating format as events arrive until 50 events have been collected. The resulting 462 byte packet (6 bytes of primary header, 6 bytes of secondary header, and 450 bytes of data) is then queued for collection by the spacecraft C&DH system and the next event will start filling the subsequent packet. If the preceding packet has not been retrieved by the time this packet is filled, data collection will stall. (Statistics continue to be collected and reported in the secondary science packet.)

On the 1553 data bus, queries to the instrument Remote Terminal periodically retrieve the Status Word. Only when a primary science telemetry packet is available will the Service Request Bit (bit time 11) be set.

When the 1 second sync pulse arrives, the current packet fill will be terminated, the packet placed in the output queue, and a new packet started. This packet will, in general, not be the full 462 bytes in length. (In fact, it is a valid to have a zero data length packet – when, for example, the detector bias is off.) The length field in the primary header will indicate the extent of valid data.

3.1.5 Telemetry Timing

Primary science telemetry packets queries would optimally occur every 40 ms, resulting in a maximum primary science throughput of 1250 events, or 92 400 data bits per second. There are no hardware restrictions on when or how often such 1553 bus queries occur, however.

Secondary science and housekeeping 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.

3.1.6 Telemetry Application Data Format

3.1.6.1 Primary Science

The event data for a single event in the primary science packet consists of a 9 byte block:

Relative Bit Position	Data Description
0-11	Event Amplitude, Detector 1
12-23	Event Amplitude, Detector 2
24-35	Event Amplitude, Detector 3
36-47	Event Amplitude, Detector 4
48-59	Event Amplitude, Detector 5
60-71	Event Amplitude, Detector 6

3.1.6.2 Secondary Science

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

Relative Bit Position	Data Description	Reference
0	Electrical Cal On = 1	3.2.6
1	Electrical Cal Rate High = 1	
2	Thin Detector Bias Voltage On = 1	
3	Thick Detector Bias Voltage On = 1	
4	Detector D1 Processing Enabled = 1	
5	Detector D2 Processing Enabled = 1	
6	Detector D3 Processing Enabled = 1	
7	Detector D4 Processing Enabled = 1	
8	Detector D5 Processing Enabled = 1	
9	Detector D6 Processing Enabled = 1	
10	Fixed value = 0	
11-15	RT SubAddr of Last Command	
16-31	Contents of Last Command	3.2.5
32-47	Telemetry Stall Counter	3.2.2
48-63	Event Reject Counter	3.2.3
64-79	Good Event Counter	3.2.4

The data in this packet was latched by the immediately preceding 1 Hz Reference Pulse.

3.1.6.3 Housekeeping

The application data contents of the housekeeping packet are as follows:

Relative Word Position	Data Description	Reference
0	Event Amplitude Discriminator Setting, D1,3,6	3.2.7
1	Event Amplitude Discriminator Setting, D2,4,5	
2-5	Discriminator Accept Mask	
6	Packet Priority Setting	
7	28VDC Monitor	3.2.8
8	+5VDC Monitor	3.2.9
9	+15VDC Monitor	3.2.10
10	-15VDC Monitor	3.2.11
11	Detector Bias Current Monitor	3.2.12
12	Detector Bias Voltage Monitor	3.2.13
13	Forward Bulkhead Temperature	3.2.14
14	Aft Bulkhead Temperature	
15	Analog Electronics Temperature	
16	Power Supply Temperature	
17	TBD Temperature	
18	Detector Assembly Temperature	

The data in this packet is accumulated once per second and available to telemetry in the following interval. It is only a matter telemetry utilization that we read out the housekeeping packets at a slower rate than the data is actually being made available.

3.2 Telemetry Description

3.2.1 Event Records

Each detected photon event is recorded once and only once in the data stream. Events which are considered valid – those satisfying both amplitude and discriminator mask criteria – are either packed into a primary science packet or counted by the stall counter and reported in the secondary science packet. All other events – by definition invalid – increment the Event Reject counter.

3.2.2 Telemetry Stall Counter

While processing science telemetry packets the instrument must occasionally go "off line" to provide inter-packet timing gaps, generate headers, and wait for the Orbiter C&DH to retrieve a packet from the queue. In these cases, otherwise valid events are lost. The Stall Counter records a count of all events lost under these conditions. Upon receipt of the 1 Hz Reference Pulse the counter is read out into Secondary Science and reset to zero.

3.2.3 Event Reject Counter

This counter keeps track of every incident event ***not*** put into the data stream as a valid event because it has failed either amplitude or discriminator mask criteria. Note that these events, because they are never queued for telemetry, are never counted by the Stall counter. Upon receipt of the 1 Hz Reference Pulse the counter is read out into Secondary Science and reset to zero.

3.2.4 Good Event Counter

This counter keeps track of every incident event put into the data stream as a valid event. (The information is, therefore, redundant, but having it in the secondary science packet is convenient for in-flight monitoring.)

The Stall, Event Reject, and Good Event counters are implemented as 16 bit counters. The analog circuitry is only capable of processing 2^{15} events per second, however, so the counters should never roll over. Because all event processing – whether valid, invalid, or lost – takes the same length of time (30 μs TBR), the sum of these three counters provides an accurate dead-time correction for each 1 second data interval.

3.2.5 Contents of Last Command

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 a value of zero. If the last command received was a "Discriminator Accept Mask", which has 64 bits of data content, only the least 16 significant bits are echoed.

3.2.6 Discrete State Indicators

There are ten one bit state indicators:

- Electrical Calibration On/Off – indicates whether the 10Hz event injection circuitry is currently enabled.
- Electrical Calibration Rate High/Low – indicates whether the calibration signal is injected at 2KHz or 1 Hz.
- Thin/Thick Detector Bias On/Off Command – indicates the state of the last detector bias command.
- Detector Processing Enable Command – indicates the state of the detector processing matrix.

3.2.7 Command Settings

The telemetry words for

- Event Amplitude Discriminator Levels, Detector 1
- Event Amplitude Discriminator Levels, Detector 2-5
- Discriminator Mask

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

3.2.8 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 * count, where K is TBR

The value of 1 LSB is TBR.

3.2.9 +5VDC Monitor

A value indicating the voltage of the instrument regulated +5VDC. The nominal engineering value in volts is

V = K * count, where K is TBR

The value of 1 LSB is TBR.

3.2.10 +15VDC Monitor

A value indicating the voltage of the instrument regulated +15VDC. The nominal engineering value in volts is

V = K * count, where K is TBR

The value of 1 LSB is TBR.

3.2.11 -15VDC Monitor

A value indicating the voltage of the instrument regulated -15VDC. The nominal engineering value in volts is

V = K * count, where K is TBR

The value of 1 LSB is TBR.

3.2.12 Detector Bias Current Monitor

A value indicating the current being drawn by the high voltage power supply. The nominal engineering value in amperes is

I = K * count, where K is TBR

The value of 1 LSB is TBR.

3.2.13 Detector Bias Voltage Monitor

A value indicating the voltage of the instrument high voltage. The nominal engineering value in volts is

V = K * count, where K is TBR

The value of 1 LSB is TBR.

3.2.14 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