XRT TELEMETRY DATA FORMATS

XRT-PSU-028

Author: David Burrows

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Approved by:	Signature	Date
David Burrows, PSU XRT Lead		
Robert Klar, SwRI SwRI XRT Software Lead		
John Nousek, PSU Narrow Field Instruments Lead		
Margaret Chester MOC Lead		
Richard Fink SDC Software Support		
Frank Marshall Ground Systems Lead		

REVISION SUMMARY

REV	RELEASE DATE	BRIEF DESCRIPTION/REASON FOR CHANGE	AFFECTED PAGES
1.0	02 November 2000	Initial release.	All
1.3	15 December 2000	Updated to include MSSL comments	
1.4		Small changes	
1.5	1 March 2001	Changed definition of Postage Stamp message, added content, including Mode Change message, new RT messages requested by SwRI, and science data formats	All
1.6	15 March 2001	Changes suggested by Rob Klar, SwRI.	All
1.7	21 March 2001	Updated entire document, added T/M I/F Test Message, added CCD Frame Headers	All
2.0	23 March 2001	Revisions based on SwRI meeting: added XRT State, Changed XRT Mode flag values, deleted some CUBIC status HK that are no longer relevant, etc.	
2.1	3 April 2001	Changed definition of tertiary headers to match proposal from Louise Bashar.	All
2.2	10 April 2001	Changed definition of Science Observation Header structure, deleted several telemetry formats. Major update	All
3.0	21 April 2001	Revised to match new ACS Telecommand format and to permit Science Data to be sent to S/C as it is collected instead of as	8-13,15,21, 25,27,29,35, 37,46,48,49, 51-52,55,58
3.1	15 May 2001	Added support for TRDRSS HK messages	
3.2	7 August 2001	Corrected errors identified by Rich Fink; updated for CDR; updated for new Target ID definition; revised science data formats to simplify flight software	Too many to list
3.3	10 August 2001	Revised data formats to simplify flight software	All
3.4	2 October 2001	Cleaned up, release version	All

3.5	11 October 2001	Added statement that multi-byte words are big-endian. Also changed Tables 16 and 17 per Robert Klar's request	15, 33, 34, 36, 45, 48
3.6	17 October 2001	Changed nomenclature of "Observation Segment" to "Snapshot" to agree with Project useage.	Throughout section 5.
3.7	2 November 2001	Corrected errors found by Dave Koller in V3.5. Also fixed more nomenclature errors, and changed Snapshot Header ID value, and added EOT.	15, 44, 48, 52,56,59,62, 65,68,71,72, 77-83
3.8	28 November 2001	Corrected errors found by Robert Klar	16, 18, 26, 43, 48
3.9	8 February 2002	Corrected errors in all science data formats. Major changes: 1) CCSDS ID changed from 0x0B40 to 0x0D40 2) Product number definition changed 3) Raw Image Frame Header length corrected 4) HK value format corrected in Snapshot trailer 5) Length of last trailer corrected 6) Data added to HK realtime and TDRSS packets 7) Command statistics packet errors corrected 8) Definition of readout times and exposure times changed	28, 52-82
3.10	18 February 2002	Added 2 AP_IDs for Segmented TDRSS messages following Level 0 processing. Added 2 baseline HK voltages to CCD Frame Headers, added details of data formats, added Amp # to CCD Frame Headers; added NCOL, NROWS to Image Mode Frame Header; added Appendices on Readout Times and CCD Pixel Layout.	36, 38, 40, 54, 55,57, 60, 63, 67, 70, 84-89
3.11	2 March 2002	Corrected coordinate axes on Figure 8	84
3.12	28 March 2002	Changed AP_ID for XRT Position RT-to-RT telecommand, changed Bias Map exposure time to Bias Map # Frames, added amplifier number to XRT Position messages	37, 45, 46, 47, 74
3.13	28 March 2002	Added waveform number to XRT Position message and telecommand, changed frame formats for timing modes	37, 46,57, 61, 65
4.0	11 May 2002	Added telemetry packets for TEC and BHC; added description of SSR Memory Dump packets; added details to Science Data section.	18, 39-41, 50, 54, 62-101
4.1	18 May 2002	Changed description of Ap_ID 0x48A to match the data actually being written into the HK Test Message	32,33
4.2	6 June 2002	Added Roll Angle to XRT Postage-Stamp Image Message	46
4.3	20 June 2002	Added Baseline Offset to Windowed Timing and Photon Counting Frame Headers; added offset column to header tables	60-95
4.4	4 July 2002	Added pixel overflow and underflow to photon-counting frame header, added number of events to low-rate photodiode frame header and windowed timing frame header, added checksum to photon-counting frame header, added HK to bias frame hdr.	69-70, 73-76, 78-79, 87-88
4.5	?	?	

4.6	1 September 2002	Added figure showing location of neighborhood pixels for photon-counting mode. Made substantial corrections to message formats to agree with actual data formats. Specifically: Ap_ID 0x4E2: added floating point centroid position (used 8 spare bytes) Section 5.6: changed "frame" size for photodiode mode to 631 x 602. Changed definition of N_pixels in frame header. Added discussion of first pixels of first frame. Section 5.7: Low-rate Photodiode Mode Frame Header: item 55 now contains the number of pixels following the header. Section 5.8: Windowed Timing Mode Frame Header: deleted baseline offset from field 54 – not necessary, since only pixels above LLD are telemetered. Section 5.11: Changed Bias Frame data to 16 bit two's complement signed integers. Section 5.13: Changed HK sums and squared sums to floating point. Changed use of words assigned to Bias Row – now stores 2 bias rows and some status words Added section on XRT coordinate system definitions in Appendix A Updated Appendix B	All 47 65-68 69-72 73-76 87-89 92-95 99 102-103

TABLE OF CONTENTS

TABLES

1 OVERVIEW

This document defines the data formats for the Swift X-ray Telescope (XRT). All XRT data are transferred as CCSDS packets across the MIL-STD-1553 data bus. All XRT telemetry data are formatted as Swift Telemetry Protocol Data Units (ST_PDUs), which are defined in section 4.8 of the Swift 1553 ICD (document 1143-EI-S19121). The format of an ST_PDU is shown in Figure 1 (taken from Figure 4-6 of the 1553 ICD). An ST_PDU begins with a 2 byte Transfer Request Counter, which is incremented whenever new data are presented on the 1553 data bus. This is followed by exactly 958 bytes of data, formatted as one or more CCSDS packets (also referred to as CCSDS Path Protocol Units, or CP_PDUs). CP_PDUs may not be split across ST_PDUs. As shown in Figure 1, ST-PDUs are zero-filled following the end of the last CP_PDU (shown as a packet header and telemetry data pair in Figure 1).

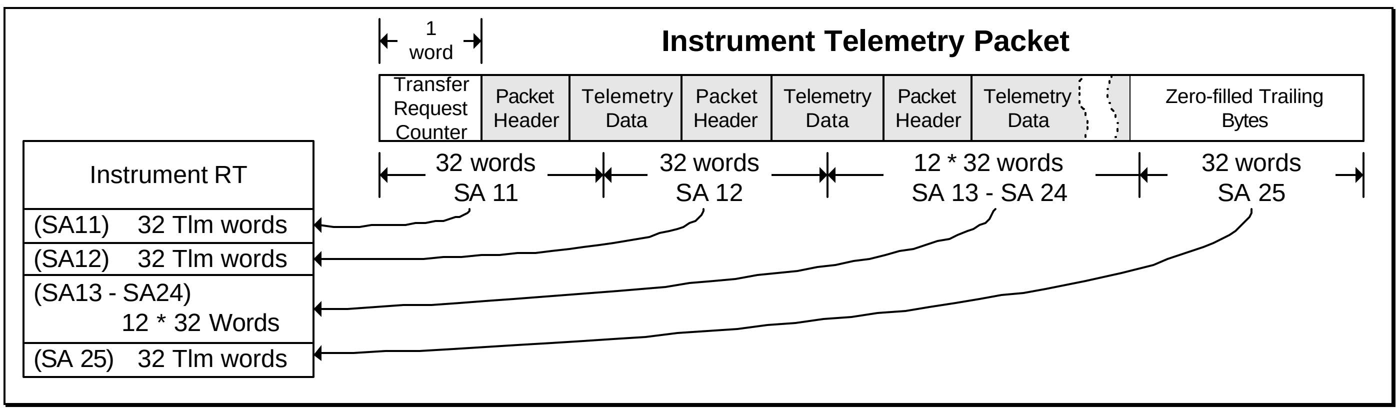

Figure 1: Swift Telemetry Protocol Data Unit structure

1.1 CCSDS Path Protocol Data Unit

Figure 2 illustrates the structure of the Swift CCSDS telemetry packet, which is described in detail in the following paragraphs (quoted verbatim from the Swift 1553 ICD).

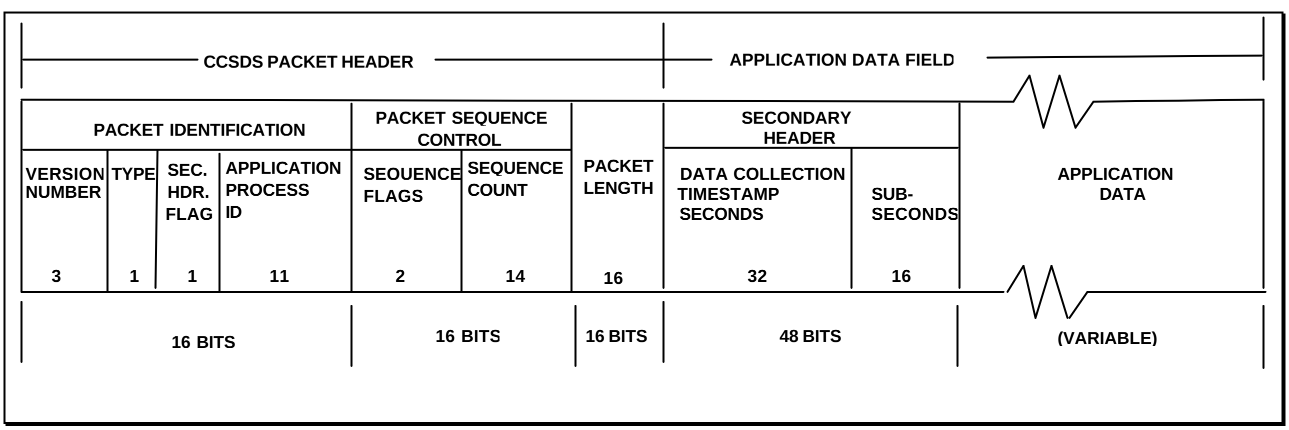

Figure 2: CCSDS Telemetry Packet Structure

1.1.1 Primary Header Format

The CCSDS Primary Header shall consist of 6 bytes subdivided into the following fields shown in Table 1. [CCSDS 701.0-B-2 (Blue Book), Section 3.3.3, page 3-12].

Table 1: CCSDS Primary Header Format

Field Name	Sub-Field Name	#Bits	#Bytes
Packet Identification	Version Number	3	
	Type	1	
	Secondary Header Flag	1	
	Application Process ID	11	2
Packet Sequence Control	Sequence Flags	2	
	Packet Name or Sequence Count	14	2
Packet Length		16	2
TOTAL		48	6

1.1.2 Packet Identification Field

The packet identification shall be two bytes in length and shall consist of 4 fields.

1.1.2.1 Version Number Sub-field

The Version Number sub-field shall be set to 000B, signifying the Version 1 CCSDS Packet.

1.1.2.2 Type Sub-field

The Type Sub-field bit shall be set to the value 0B for telemetry packets, and 1B for telecommand packets.

1.1.2.3 Secondary Header Flag Sub-field

The Secondary Header Flag sub-field shall be set to 1B indicating that a secondary header exists.

1.1.2.4 Application Processor Identifier Sub-field

The Application Processor Identifier sub-field shall be used to address commands to different subsystems of the spacecraft and identifies different telemetry packets. Assignments of Application Process Identifier (APIDs) for the Swift XRT are shown in Table 4.

1.1.3 Packet Sequence Control Field.

The Packet Sequence Control field shall be two bytes in length and shall contain a Sequence Flag subfield and a Sequence Count subfield.

1.1.3.1 Sequence Flags Sub-field.

For telemetry, the Sequence Flags sub-field shall be set according to the type of data contained in the telemetry Packet Data field. These flags may be set to indicate that the telemetry Packet Data field is a segment of a larger set of application data.

The encoding of the Sequence Flags is as follows:

00 = Packet Data field contains a continuation segment of application data.

01 = Packet Data field contains the first segment of application data.

10 = Packet Data field contains the last segment of application data.

11 = Packet Data field contains unsegmented application data.

For telemetry packets, the S/C will ignore the Sequence Flags sub-field and route the telemetry packet unaltered to the appropriate destination, based on the telemetry packet's APID. The ground shall have the responsibility of reconstructing the larger, unsegmented telemetry packet from multiple segmented telemetry packets. The maximum length of a reconstructed telemetry packet is 64K, which is the maximum allowable by CCSDS standards. The instrument sets the packet header Packet Sequence Flags sub-field to control the reconstruction of the larger telemetry packet. To transfer a large telemetry packet, an instrument shall:

a) appropriately set the Sequence Flags sub-field in the header of each segmented packet;
b) transmit all segmented packets using the same APID;
c) increment the Packet Sequence Count sub-field in the header of each segmented packet

Although any telemetry packet may be segmented, the ground system may not be able to correctly decomutate segmented telemetry data for real-time display. Therefore, for all real-time telemetry, the Sequence Flags sub-field shall be set to 11B to indicate that the data field is unsegmented.

1.1.3.2 Packet Sequence Count Sub-field

For telemetry packets, the Packet Sequence Count sub-field shall contain a straight sequential count (modulo 16384) which numbers each CP_PDU generated on a particular APID. This field must be used for segmented telecommands. This field can be ignored for unsegmented telecommands.

1.1.4 Packet Length Field

The Packet Length field shall contain the length (in bytes) of the remainder of the data structure that is enclosed between the first bit of the Application Data field and the last bit of the Packet (i.e., the last bit of the Application Data field).

The field is expressed as follows:

Packet Length = {(Number of Bytes in Application Data Field) – 1}.

1.2 Standardized Swift Telemetry Secondary Header

Every telemetry packet shall contain a secondary header consisting of the time at which the telemetry packet is transferred to the C&DH system via the 1553 bus. This secondary header consists of a 32-bit big-endian seconds field, and a 16-bit big-endian sub-seconds field. Each incremental count in the sub-seconds field represents 20 microseconds, and after one second the count rolls over from 49999 to 0. Figure 2 illustrates the structure of the telemetry packet.

1.3 Standardized Swift Telemetry Tertiary Header

Every XRT standard telemetry packet shall contain a tertiary header consisting of the Observation Number, data collection time and UTC updates (all unsigned integers). The Observation Number consists of a 24 bit Target ID and an 8 bit Observation Segment, as defined by Frank Marshall's TargetID document and the Swift Instrument Telemetry Format Standards. The format of the Tertiary Header is shown in Table 2.

Table 2: XRT Telemetry Tertiary Header Format

ITEM	Size (bytes)	Comments
Observation Segment	1	Observation Segment ID assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
SC_Time_Sec	4	Spacecraft Time of Data Collection
SC_Time_Subsec	2	XRT Time in subsec (units of 20 µs)
UTC_Delta_Sec	4	UTC Correction of packet creation time
UTC_Delta_Subsec	2	UTC Correction of packet creation time

Graphically, this structure is shown in Figure 3.

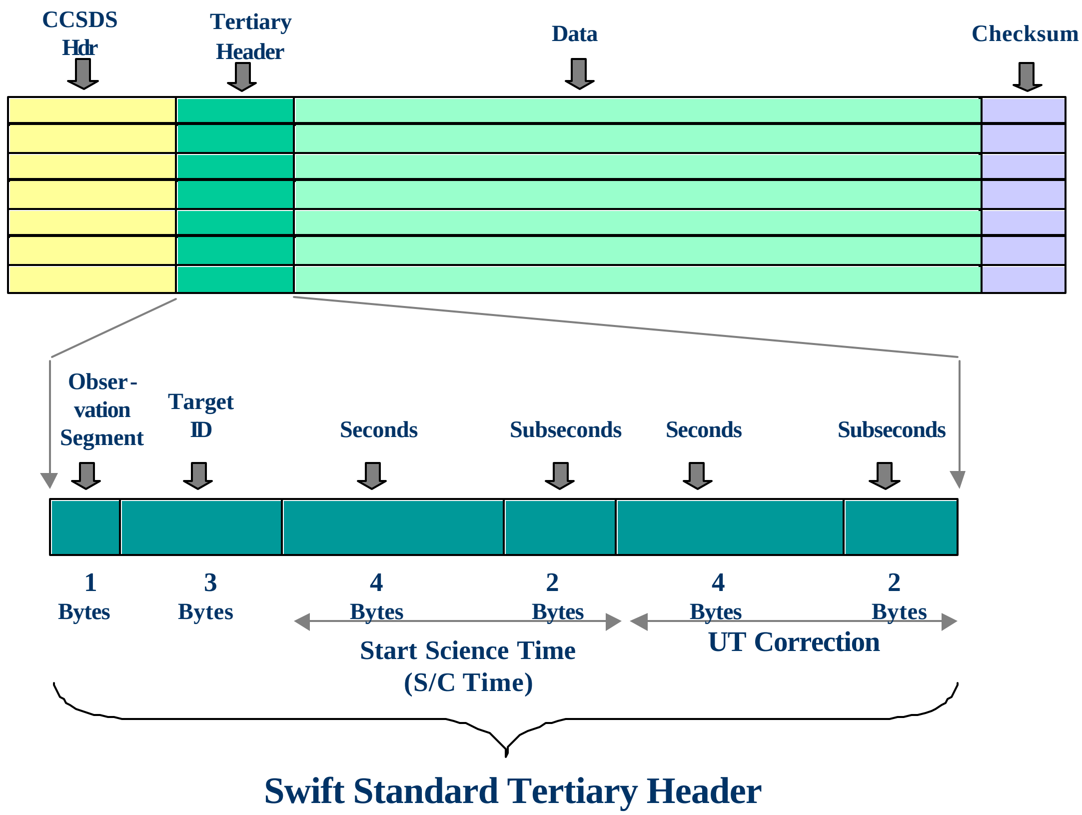

Figure 3: Standard Telemetry Products Format

1.4 Large Data Products

Standard telemetry products can accommodate up to 64 Kbytes of data, using segmented CCSDS packets. Larger data products require the use of the Swift Large Data Products protocol.

The XRT utilizes the Swift Large Data Products Format to telemeter its science data. We implement the Large Data Products (LDP) as described in the Swift Instrument Telemetry Format Standards (410.4-SPEC-0030). The format of the LDP is shown in Figure 4. For the XRT, each Observation Buffer, which contains all of the science data for a single Observation of a given Target, is telemetered as a single LDP of up to several Megabytes in size. Within each ST_PDU, the LDP structure consists of a four byte LDP Header followed by TBD bytes of data. The LDP Header format, shown in Table 3, uniquely identifies the location of each ST_PDU within this data stream.

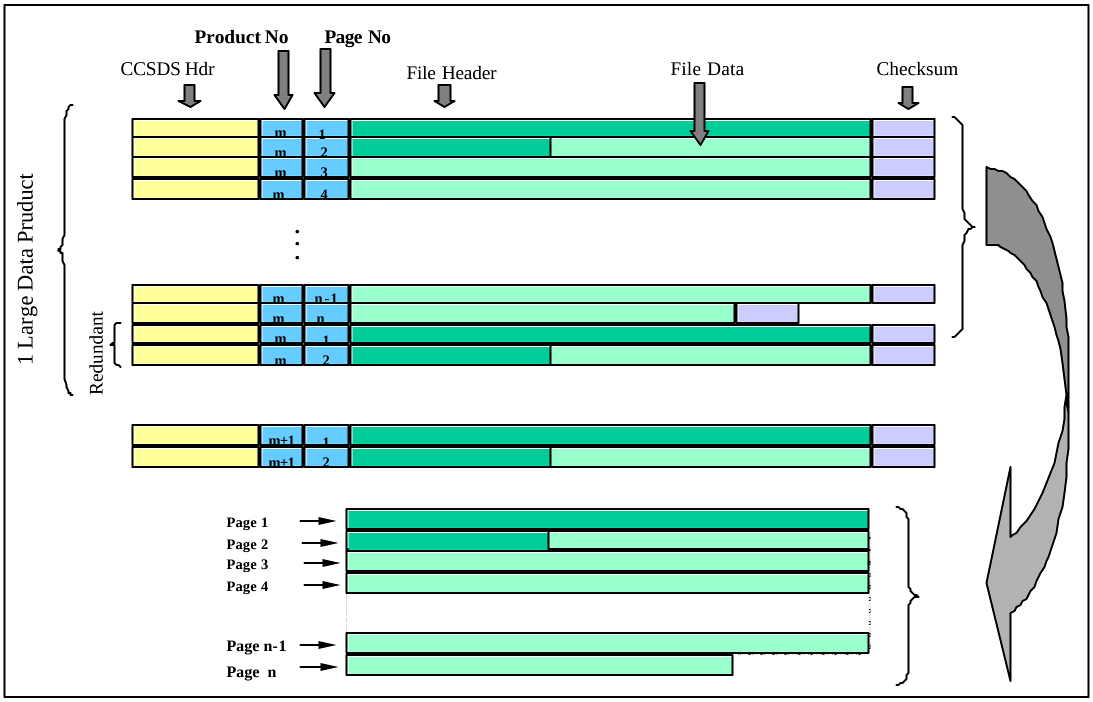

Figure 4: Large Data Product structure (overview)

Table 3: XRT Large Data Structure Header Format

ITEM	Size (bits)	Comments
Product Number	16	Unique ID # for this LDP
Page Number	16	Sequential Page # within this LDP

Each large data product can be referred to as a file, which begins and ends with a header (the second copy is for redundancy). The header begins with a standard header format consisting of the number of pages in the file followed by the Swift Tertiary Header. This standard header may be followed by a nonstandard, instrument-specific header. The XRT telemetry formats use the nonstandard header for all LDPs. The File Header format is shown in Figure 5.

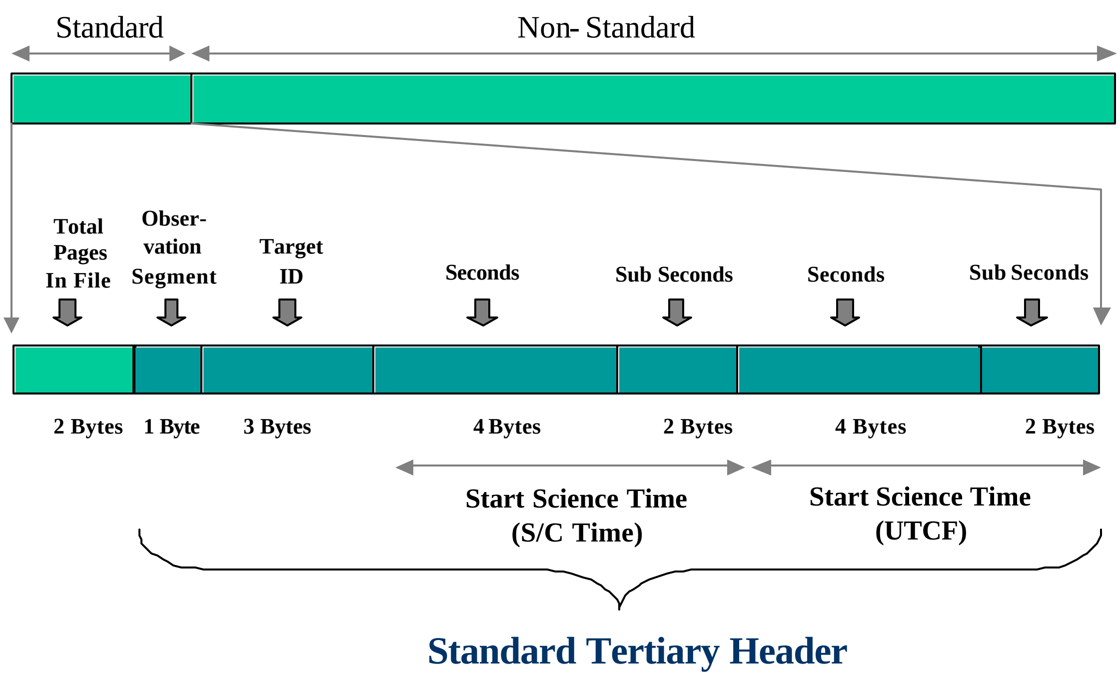

Figure 5: Large Data Product File Header Format

1.5 XRT AP_ID assignments

XRT data packets are identified by AP_IDs in the range 0x480 - 0x59F (from 1143-EI-S19121, Swift 1553 ICD, Table 4-2). There are three fundamental data types produced by the XRT: TDRSS packets, Real-time Telemetry packets, and Solid-State Recorder (SSR) packets. These are identified by their AP_Ids, as shown in Table 4. We describe each in turn.

Table 4: XRT Ap_ID Assignments

Data Type	APID Range	# APIDs
Real-time telemetry	0x480 – 0x4DF	96
TDRSS telemetry	0x4E0 – 0x53F	96
SSR telemetry	0x540 – 0x59F	96

2 REAL-TIME TELEMETRY PACKETS

XRT Real-Time Telemetry data packets are identified by AP_IDs in the range 0x480 - 0x4DF (from 1143-EI-S19121, Swift 1553 ICD, Table 4-2). There are several distinct types of XRT Real-Time Telemetry Data Packets, each with a different AP_ID, as shown in Table 5.

Table 5: XRT Real-Time Telemetry Packets

AP ID	Message Type	Message Size (bytes)	# Packets
0x480	XRT Startup	230	1
0x481	XRT Memory Status	108	1
0x482	XRT Task Status	230	1
0x483	XRT Errors/Events	230	1
0x484	XRT Analog HK	230	1
0x485	XRT Periodic Processing	108	1
0x486	XRT Mode Change	60	1
0x487	XRT Memory Dump	Variable	1
0x488	XRT Command Statistics	230	1
0x489	XRT Command Echo	94	1
0x48A	XRT Telemetry Test	230	1
0x48B	XRT Tube Heater Control	230	1
0x48C	XRT CCD Interface	90	1
0x48D	XRT TEC PS Status	120	1
0x48E	XRT Baffle Heater Control	80	1

These messages are routed to the S/C C&DH system for inclusion in the S/C Real-Time Telemetry. During ground contacts, these data are available in real time. These messages are also placed in the Solid-State Recorder by the Swift C&DH subsystem as part of its housekeeping data. Each of these messages is described further in the following sections.

All RT Telemetry Packets can also be transmitted through TDRSS. See Section 3.6 for more information.

All multi-byte fields in XRT telemetry records are in big-endian order: MSB,LSB for two byte fields; MSB(3), Byte2, Byte 1, LSB(0) for four-byte fields.

2.1 XRT Startup Message

The XRT initiates a Built-In Test (self-test) on startup and produces a diagnostic message to report the results. The structure of this message is shown in Table 6.

Table 6: Contents of XRT Startup Message

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0C80** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x480)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x00DF**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Observation Segment	1	Observation Segment assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
S/C Clock Time at Last Boot	6	S/C Clock Time at Last Boot
UTC_Delta	6	UTC Correction
Boot Configuration Index	4	Boot Configuration Index
Boot Count	4	Boot Count
LE Task ID	4	Last Exception Task ID
LE Vector Number	4	Last Exception Vector Number
LE Stack Pointer	4	Last Exception Stack Pointer
LE Vector Offset	4	Last Exception Vector Offset
LE Errno	4	Last Exception Errno
LE Data Access Register	4	Last Exception Data Access Register
LE DS Interrupt Status Registe	4	Last Exception Data Storage Interrupt Status Reg.
LE FP S&C Register	4	Last Exception Floating Pt. Status and Control Reg.
LE External Interrupt Mask 0	4	Last Exception External Interrupt Mask Register 0
LE External Interrupt Mask 1	4	Last Exception External Interrupt Mask Register 1
Skip BIT Flag	4	Skip BIT Flag
Cleared Memory Size	4	Cleared Memory Size
CPU Bus Speed	4	CPU Bus Speed

Table 6: Contents of XRT Startup Message (cont.)

ITEM	Size (bytes)	Comments
BC0 start address	4	Beginning Address of BC0 in EEPROM
BC0 end address	4	Ending Address of BC0 in EEPROM
BC0 copy address	4	Address in DRAM to copy BC0 on boot
BC0 entry address	4	Address in DRAM to begin execution of BC0
Checksum of BC0 (Stored)	4	Checksum of BC0 (Stored)
Checksum of BC0 (Calculated)	4	Checksum of BC0 (Calculated)
BC1 start address	4	Beginning Address of BC1 in EEPROM
BC1 end address	4	Ending Address of BC1 in EEPROM
BC1 copy address	4	Address in DRAM to copy BC1 on boot
BC1 entry address	4	Address in DRAM to begin execution of BC1
Checksum of BC1 (Stored)	4	Checksum of BC1 (Stored)
Checksum of BC1 (Calculated)	4	Checksum of BC1 (Calculated)
SCA Checksum (Stored)	4	System Config. Area Checksum (Stored)
SCA Checksum (Calculated)	4	System Config. Area Checksum (Calculated)
ACA Checksum (Stored)	4	Application Config. Area Checksum (Stored)
ACA Checksum (Calculated)	4	Application Config. Area Checksum (Calculated)
EEFS Checksum (Stored)	4	EEPROM File System Checksum (Stored)
EEFS Checksum (Calculated)	4	EEPROM File System Checksum (Calculated)
Summary of BIT results	4	Summary of BIT results
DRAM BIT results	64	1 bit per 256KB block, 0-128MB
Checksum	2	
Total	**230**	

2.2 XRT Memory Status Message

The XRT continuously scrubs DRAM to correct bit-errors caused by SEUs. Scrubber statistics are reported at a low rate (nominal period of 254 seconds). The structure of the message is shown in Table 7.

Table 7: Contents of Memory Status Message

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0C81** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x481)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x0065**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Observation Segment	1	Observation Segment assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
S/C Clock Time at Last Boot	6	S/C Clock Time at Last Boot
UTC_Delta	6	UTC Correction
RSC Single-Bit Error Count	4	RSC Single-Bit Error Count
Last 2 RSC Single-Bit Errors	8	Last 2 RSC Single-Bit Error Locations
RSC Multiple-Bit Error Count	4	RSC Multiple-Bit Error Count
Last 2 RSC Multiple-Bit Errors	8	Last 2 RSC Multiple-Bit Error Locations
Double Words read	4	Cumulative count of double-words read by scrubber
EDAC TCB	22	EDAC Memory Scrubber Task Control Block
Log TCB	22	VxWorks® Log Task Control Block
Spares	6	
Checksum	2	
Total	**108**	

2.3 XRT Task Status Message

The XRT will monitor the status of the Flight Software (FSW), and will produce a low-rate packet describing the FSW task status (at a nominal period of 254 seconds). The structure of the message is shown in Table 8.

Table 8: Contents of XRT Task Status Message

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0C82** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x482)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x00DF**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Observation Segment	1	Observation Segment assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
Data Collection Time	6	S/C time of data collection
UTC_Delta	6	UTC Correction
Exception Handler ID	4	Exception Handler Task Control Block - Task ID
Exception Handler Status	1	Exception Handler TCB - Status
Exception Handler Stack Pointe	4	Exception Handler TCB - Stack Pointer
Exception Handler Program Cr	4	Exception Handler TCB - Program Counter
Exception Handler Delay	4	Exception Handler TCB - Delay
Exception Handler Priority	1	Exception Handler TCB - Priority
Exception Handler Errno	4	Exception Handler TCB - Errno
PP TCB	22	Periodic Processing Task Control Block
CCM TCB	22	Command and Control Task Control Block
SCUI TCB	22	SCU Interface Task Control Block
DCC TCB	22	Data Collection Control Task Control Block
CCD TCB	22	CCD Interface Task Control Block
ERP TCB	22	Event Recognition Processor Task Control Block
TAM TCB	22	Telescope Alignment Monitor Task Control Block
Shell TCB	22	VxWorks® Shell Task Control Block
Spares	2	
Checksum	2	
Total	**230**	

2.4 XRT Errors/Events Message

The XRT will generate an XRT Errors/Events Message when one or more errors is detected in one of the running tasks or an event (such as a memory upload) completes. The message can be generated at a high rate (nominal period of 10 seconds). The structure of the message is shown in Table 9.

Table 9: Contents of XRT Errors/Events Message

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0C83** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x483)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x00DF**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Observation Number	1	Observation Number assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
Data Collection time	6	Spacecraft time when error occurred.
UTC_Delta	6	UTC Correction
Current Error Count	4	Count of Errors/Events in this Packet
Cumulative Error Count	4	Cumulative Count of Errors/Events
Last 48 Error/Event Numbers	192	Last 48 Error/Event Numbers
Checksum	2	
Total	**230**	

2.5 XRT Analog HK Message

The XRT will monitor 120 analog input channels with 12-bit precision with a commandable sampling frequency. The structure of the message is shown in Table 10.

Table 10: Contents of XRT Analog HK Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C84** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x484)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x00DF**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data collection time	6		S/C time of data collection (or error)
UTC_Delta	6		UTC Correction
RA	4	FP	RA (J2000) of pointing direction (degrees)
Dec	4	FP	Dec (J2000) of pointing direction (degrees)
Roll	4	FP	Roll angle (degrees)
ACS Flags	1	BY	Bilevel ACS Status: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
XRT State	1	BY	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
XRT Mode Flags	1	BY	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
XRT Waveform	1	BY	CCD Waveform ID
Count Rate	4	FP	Count Rate measured by ERP
Analog HK	180		120 channels of 12 bit housekeeping data
Checksum	2	UI	
Total	**230**		BY = Byte FP = Floating Point UI = Unsigned Integer

2.6 XRT Periodic Processing Message

This message includes information about the Periodic Processing software. The message is normally only sent by diagnostic command. The structure of the message is shown in Table 11.

Table 11: Contents of XRT Periodic Processing Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Message ID	2	UI	**0x0C85** (See Section 4.1.1 and Figure 4-7 of the
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Message Leng	2	UI	**0x0065**
CCSDS Secondary Header	6		Time of CCSDS Message formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
UTC_SECONDS #1	4	UI	UTC Time in seconds
UTC_SUBSECONDS #1	2	UI	UTC Subseconds in units of 20 us (0-49999)
UTC_Delta_Sec	4	UI	UTC Correction
UTC_Delta_Subsec	2	UI	UTC Correction
Range Table Address	4	UI	Address of table for range checking
Health Table Address	4	UI	Address of table for task checking
Analog HK Table Address	4	UI	Address of Analog HK data structure
Error Count	4	UI	Cumulative count of Errors/Events
Send Test Message	1	BY	Boolean - Send Test Data
Send to TDRSS	1	BY	Boolean - Echo Messages to TDRSS?
Use Tertiary Header	1	BY	Boolean - Add tertiary header?
Use Hard Defaults	1	BY	Boolean - Were hard-coded defaults used?
TEC Rate	2	UI	Rate in seconds
TEC Offset	2	UI	Offset in seconds
THC Rate	2	UI	Rate in seconds
THC Offset	2	UI	Offset in seconds
BHC Rate	2	UI	Rate in seconds
BHC Offset	2	UI	Offset in seconds
TAM Rate	2	UI	Rate in seconds
TAM Offset	2	UI	Offset in seconds
Startup Message Rate	2	UI	Rate in seconds
Startup Message Offset	2	UI	Offset in seconds
Memory Status Msg Rate	2	UI	Rate in seconds
Memory Status Msg Offset	2	UI	Offset in seconds
Task Status Rate	2	UI	Rate in seconds
Task Status Offset	2	UI	Offset in seconds

Table 11: Contents of XRT Periodic Processing Message (cont.)

Error/Event Message Rate	2	UI	Rate in seconds
Error/Event Message Offset	2	UI	Offset in seconds
Analog HK Message Rate	2	UI	Rate in seconds
Analog HK Message Offset	2	UI	Offset in seconds
Command Statistics Msg Rate	2	UI	Rate in seconds
Command Statistics Msg Offs.	2	UI	Offset in seconds
THC Message Rate	2	UI	Rate in seconds
THC Message Offset	2	UI	Offset in seconds
Periodic Processing Msg Rate	2	UI	Rate in seconds
Periodic Processing Msg Offs.	2	UI	Offset in seconds
CCD Message Rate	2	UI	Rate in seconds
CCD Message Offset	2	UI	Offset in seconds
X_DUMP_RATE	2	UI	Rate in seconds
X_DUMP_OFFSET	2	UI	Offset in seconds
Spares	2		
Checksum	2		
Total	**108**	BY = Byte	
		UI = Unsigned Integer	
		FP = Floating Point	

2.7 XRT Mode Change Message

The XRT will generate an XRT Mode Change Packet whenever it changes observing/reporting modes. The structure of the message is shown in Table 12.

Table 12: Contents of XRT Mode Change Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C86** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x486)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x0035**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection time	6		S/C time of mode change
UTC_Delta	6		UTC Correction
RA	4	FP	RA (J2000) of pointing direction (degrees)
Dec	4	FP	Dec (J2000) of pointing direction (degrees)
Roll	4	FP	Roll angle (degrees)
ACS Flags	1	BY	Bilevel ACS Status: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN SAFE MODE
XRT State	1	BY	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
XRT Mode	1	BY	Current XRT Mode: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
XRT Waveform ID	1	UI	Unique ID of XRT Sequencer Waveform
XRT Count Rate	4	FP	Count rate determined by ERP
Spares	10		
Checksum	2	UI	
Total	**60**	BY = Byte UI = Unsigned Integer FP = Floating Point	

2.8 XRT Memory Dump Message

This Real-Time telemetry packet permits the XRT to dump any desired small section of memory. It is initiated by special telecommand. The output data format is given in Table 13.

Table 13: Contents of XRT Memory Dump Message

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0C87** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x487)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x00DF**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Starting Address	4	Address of first word of dump
Bytes Transmitted	2	Cumulative bytes transmitted
Bytes Requested	2	Total bytes in dump
Data Width	1	Data width (1,2, or 4 bytes)
Type ID	1	Type ID
Block Number	1	Block Number
Data Dump	205	Data dump from memory
Checksum	2	
Total	**230**	

NOTE: Memory dumps can also be transmitted through the science data channel via AP_ID 0x0547. See Section 5.1 for details.

2.9 XRT Command Statistics Message

This packet is used to telemeter statistics related to command execution. It normally comes out a low-rate when not in contact with Malindi. When in command contact, its frequency can be increased. The format is shown in Table 14.

Table 14: Contents of XRT Command Statistics Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C88** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x488)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x00DF**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Target ID	2	UI	Unique ID of this Target, assigned by FoM
Observation Number	2	UI	Observation Number assigned by FoM
Data Collection Time	6		S/C Time of Data Collection
UTC_Delta	6		UTC Correction
CCM Command Received	2		Cumulative Count of Received
CCM Command Executed	2		Cumulative Count of Executed
CCM Command Rejected	2		Cumulative Count of Rejected
CCM Last Reject Fcodes	2		Last Reject Function Codes
PP Command Statistics	8		Same information as CCM
THC Command Statistics	8		Same information as CCM
BHC Command Statistics	8		Same information as CCM
DCC Command Statistics	8		Same information as CCM
ERP Command Statistics	8		Same information as CCM
TAM Command Statistics	8		Same information as CCM
TEC Command Statistics	8		Same information as CCM
XRT Command Received	4		Cumulative Count of Received
XRT Command Executed	4		Cumulative Count of Executed
XRT Command Rejected	4		Cumulative Count of Rejected
XRT Last Reject Headers	8		Headers of Last Rejected XRT Command
SC Command Received	4		Cumulative Count of Received
SC Command Executed	4		Cumulative Count of Executed
SC Command Rejected	4		Cumulative Count of Rejected
SC Last Reject Headers	8		Headers of Last Rejected SC Command
FoM Command Received	4		Cumulative Count of Received
FoM Command Executed	4		Cumulative Count of Executed
FoM Command Rejected	4		Cumulative Count of Rejected
FoM Last Reject Headers	8		Headers of Last Rejected FoM Command

Table 14: Contents of XRT Command Statistics Message (cont.)

SITIMETONE Received	4	Cumulative Count of Received
SITIMETONE Executed	4	Cumulative Count of Executed
SITIMETONE Rejected	4	Cumulative Count of Rejected
Last SCLK_SECONDS	4	SCLK_SECONDS from Last SITIMETONE
Echo Lower AP_ID	2	Lower Bound for Command Echo
Echo Upper AP_ID	2	Upper Bound for Command Echo
RED AP_ID	2	Application ID for Red State
RED Function Code	1	Function Code for Red State
XRT State	1	XRT State
SCUI Poll Rate	4	SCUI Poll Rate
SCUI Buffer Rate	4	SCUI Buffer Rate
SCUI Low Priority Buffer Size	4	Low Priority Queue Size in Bytes
SCUI High Priority Buffer Size	4	High Priority Queue Size in Bytes
SCUI Low Priority Buffer Dept	4	Current Bytes on Low Priority Queue
SCUI High Priority Buffer Dep	4	Current Bytes on High Priority Queue
SCUI Bytes Sent	4	Bytes Transmitted since last Report
SCUI STPDU Sent	4	STPDUs sent since last Report
SCUI Commands Received	2	Cumulative Commands Received
SCUI Commands Rejected	2	Cumulative Commands Rejected
Spares	16	
Checksum	2	
Total	**230**	BY = Byte UI = Unsigned Integer FP = Floating Point

2.10 XRT Command Echo Message

The XRT will generate an XRT Command Echo Message when a telecommand is received and Command Echo is enabled. The structure of this message is shown in Table 15.

Table 15: Contents of the XRT Command Echo Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C89** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x489)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x0057**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection time	6		S/C time of mode change
UTC_Delta	6		UTC Correction
Echo Telecommand	62		Telecommand
Rejected Flag	1	BY	TRUE if rejected, FALSE if executed
Spares	1	BY	
Checksum	2	UI	
Total	**94**	BY = Byte UI = Unsigned Integer FP = Floating Point	

2.11 Telemetry Interface Test Message

The Telemetry Interface Test Message is designed to provide a simple way of verifying the correct operation of the Swift/XRT Telemetry Interface. This message is sent via telecommand /X_HK_TEST_EN, which disables the normal analog HK message at 0x0484. An incrementing byte count is transmitted in this packet to verify that the telemetry interface is working correctly (starting with 0).

Table 16: Contents of the XRT Telemetry Interface Test Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C8A** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x48A)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x00DF**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data collection time	6		S/C time of data collection (or error)
UTC_Delta	6		UTC Correction
RA	4	FP	RA (J2000) of pointing direction (degrees)
Dec	4	FP	Dec (J2000) of pointing direction (degrees)
Roll	4	FP	Roll angle (degrees)
ACS Flags	1	BY	Bilevel ACS Status: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
XRT State	1	BY	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
XRT Mode Flags	1	BY	XRT Readout Mode For Last CCD Frame: 1 = Null; 6 = Windowed Timing 2 = Short Image; 7 = Photon-Counting 3 = Long Image; 8 = Raw Data 4 = Piled-up Photodiode; 9 = Bias Map 5 = Low Rate Photodiode; 10 = Stop
XRT Waveform	1	BY	CCD Waveform ID
Count Rate	4	FP	Count Rate measured by ERP
Subtotal:	**48**		

Table 16: Contents of the XRT Telemetry Interface Test Message (cont.)

ITEM	Size (bytes)	Type	Comments
Test Byte 0	1		0x00
Test Byte 1	1		0x01
Test Byte 2	1		0x02
Test Byte 3	1		0x03
Test Byte 4	1		0x04
Test Byte 5	1		0x05
Test Byte 6	1		0x06
Test Byte 7	1		0x07
Test Byte 8	1		0x08
Test Byte 9	1		0x09
Test Byte 10	1		0x0a
Test Byte 11	1		0x0b
Test Byte 12	1		0x0c
Test Byte 13	1		0x0d
Test Byte 14	1		0x0e
Test Byte 15	1		0x0f
Test Byte 16	1		0x10
•	•		•
•	•		•
•	•		•
Test Byte 175	1		0xae
Test Byte 176	1		0xaf
Test Byte 177	1		0xb0
Test Byte 178	1		0xb1
Test Byte 179	1		0xb2
Test Byte 180	1		0xb3
Checksum	2	UI	0x45e4
Total	**230**	BY = Byte FP = Floating Point UI = Unsigned Integer	

2.12 XRT Tube Heater Control Message

This message includes information about the Tube Heater Control software. The structure of the message is shown in Table 17.

Table 17: Contents of XRT Tube Heater Control Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C8B** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x48B)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x00DF**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data collection time	6		S/C time of data collection (or error)
UTC_Delta	6		UTC Correction
Forward Heater #1 On Point	2	UI	Set Point In Counts
Forward Heater #1 Off Point	2	UI	Set Point In Counts
Forward Heater #16 On Point	2	UI	Set Point In Counts
Forward Heater #16 Off Point	2	UI	Set Point In Counts
Forward Heater #3 On Point	2	UI	Set Point In Counts
Forward Heater #3 Off Point	2	UI	Set Point In Counts
Forward Heater #14 On Point	2	UI	Set Point In Counts
Forward Heater #14 Off Point	2	UI	Set Point In Counts
Forward Heater #5 On Point	2	UI	Set Point In Counts
Forward Heater #5 Off Point	2	UI	Set Point In Counts
Forward Heater #12 On Point	2	UI	Set Point In Counts
Forward Heater #12 Off Point	2	UI	Set Point In Counts
Forward Heater #7 On Point	2	UI	Set Point In Counts
Forward Heater #7 Off Point	2	UI	Set Point In Counts
Forward Heater #10 On Point	2	UI	Set Point In Counts
Forward Heater #10 Off Point	2	UI	Set Point In Counts
OBIF Heater #1 On Point	2	UI	Set Point In Counts
OBIF Heater #1 Off Point	2	UI	Set Point In Counts
OBIF Heater #4 On Point	2	UI	Set Point In Counts
OBIF Heater #4 Off Point	2	UI	Set Point In Counts
Rear Heater #1 On Point	2	UI	Set Point In Counts
Rear Heater #1 Off Point	2	UI	Set Point In Counts
Rear Heater #16 On Point	2	UI	Set Point In Counts
Rear Heater #16 Off Point	2	UI	Set Point In Counts

Table 17: Contents of XRT Tube Heater Control Message (cont.)

Rear Heater #3 On Point	2	UI	Set Point In Counts
Rear Heater #3 Off Point	2	UI	Set Point In Counts
Rear Heater #14 On Point	2	UI	Set Point In Counts
Rear Heater #14 Off Point	2	UI	Set Point In Counts
Rear Heater #5 On Point	2	UI	Set Point In Counts
Rear Heater #5 Off Point	2	UI	Set Point In Counts
Rear Heater #12 On Point	2	UI	Set Point In Counts
Rear Heater #12 Off Point	2	UI	Set Point In Counts
Rear Heater #7 On Point	2	UI	Set Point In Counts
Rear Heater #7 Off Point	2	UI	Set Point In Counts
Rear Heater #10 On Point	2	UI	Set Point In Counts
Rear Heater #10 Off Point	2	UI	Set Point In Counts
Forward Heater #2 On Point	2	UI	Set Point In Counts
Forward Heater #2 Off Point	2	UI	Set Point In Counts
Forward Heater #15 On Point	2	UI	Set Point In Counts
Forward Heater #15 Off Point	2	UI	Set Point In Counts
Forward Heater #4 On Point	2	UI	Set Point In Counts
Forward Heater #4 Off Point	2	UI	Set Point In Counts
Forward Heater #13 On Point	2	UI	Set Point In Counts
Forward Heater #13 Off Point	2	UI	Set Point In Counts
Forward Heater #6 On Point	2	UI	Set Point In Counts
Forward Heater #6 Off Point	2	UI	Set Point In Counts
Forward Heater #11 On Point	2	UI	Set Point In Counts
Forward Heater #11 Off Point	2	UI	Set Point In Counts
Forward Heater #8 On Point	2	UI	Set Point In Counts
Forward Heater #8 Off Point	2	UI	Set Point In Counts
Forward Heater #9 On Point	2	UI	Set Point In Counts
Forward Heater #9 Off Point	2	UI	Set Point In Counts
OBIF Heater #2 On Point	2	UI	Set Point In Counts
OBIF Heater #2 Off Point	2	UI	Set Point In Counts
OBIF Heater #3 On Point	2	UI	Set Point In Counts
OBIF Heater #3 Off Point	2	UI	Set Point In Counts
Rear Heater #2 On Point	2	UI	Set Point In Counts

Table 17: Contents of XRT Tube Heater Control Message (cont.)

Rear Heater #2 Off Point	2	UI	Set Point In Counts
Rear Heater #15 On Point	2	UI	Set Point In Counts
Rear Heater #15 Off Point	2	UI	Set Point In Counts
Rear Heater #4 On Point	2	UI	Set Point In Counts
Rear Heater #4 Off Point	2	UI	Set Point In Counts
Rear Heater #13 On Point	2	UI	Set Point In Counts
Rear Heater #13 Off Point	2	UI	Set Point In Counts
Rear Heater #6 On Point	2	UI	Set Point In Counts
Rear Heater #6 Off Point	2	UI	Set Point In Counts
Rear Heater #11 On Point	2	UI	Set Point In Counts
Rear Heater #11 Off Point	2	UI	Set Point In Counts
Rear Heater #8 On Point	2	UI	Set Point In Counts
Rear Heater #8 Off Point	2	UI	Set Point In Counts
Rear Heater #9 On Point	2	UI	Set Point In Counts
Rear Heater #9 Off Point	2	UI	Set Point In Counts
Power Limit	1	BY	Limit in Watts
Heaters Limit	1	BY	Maximum number of heaters on
Manual Control	1	BY	Boolean - Tube Heaters are under Manual Control
Use Bus Voltage Flag	1	BY	Boolean - Use Bus Voltage/Power Limiting
Mask All #1	2	UI	Mask of all heater used, bank 1
Mask All #2	2	UI	Mask of all heater used, bank 2
Mask All #3	2	UI	Mask of all heater used, bank 3
Mask On #1	2	UI	Mask of all heater on, bank 1
Mask On #2	2	UI	Mask of all heater on, bank 2
Mask On #3	2	UI	Mask of all heater on, bank 3
Power Sum	2	UI	Computer Total Heater Power (hundredths of Watts)
Round Robin Index	1	BY	Current index of start heater for algorithm
Heaters Currently On	1	BY	Number of heaters currently on
Needs Heat Array	36		Boolean - TRUE if heater needs heat
Checksum	2	UI	
Total	**230**	BY = Byte	
		UI = Unsigned Integer	
		FP = Floating Point	

2.13 XRT CCD Interface Message

This message includes information about the CCD Interface software. The structure of the message is shown in Table 18.

Table 18: Contents of XRT CCD Interface Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C8C** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x48C)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x004F**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection time	6		S/C time of mode change
UTC_Delta	6		UTC Correction
Mode Control Table Address	4	UI	Base Address of Mode Control Table
DAC Table Address	4	UI	Base Address of DAC Table
Count Rate	4	FP	Count Rate measured by ERP
Reports Processed Count	4	UI	Reports Processed since entering Auto State
Reports Rejected Count	4	UI	Reports Rejected since entering Auto State
Mode Changes Count	4	UI	Mode Changes since entering Auto State
XRT State	1	BY	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
XRT Mode	1	BY	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
Sequencer ID	1	BY	Sequencer ID
Number of Modes	1	BY	Number of Nodes in Mode Control Table
Number of Test Nodes	1	BY	Number of Test Nodes
Spares	3		

Table 18: Contents of XRT CCD Interface Message (cont.)

Ring Buffer Address	4	UI	Base address of Data Buffer
End-Of-Line Count	4	UI	Cumulative count of lines since last reset
End-Of-Frame Count	4	UI	Cumulative count of frames since last reset
Hardware End-Of-Line Count	4	UI	Count of line currently in hardware FIFO
Error Number	4	UI	Last CCD Error
APMI Status	2	UI	Last APMI Status Word
Pixels Per Line	2	UI	Number of pixels per line for current mode
Lines Per Wake	1	UI	Lines per wake
Frame Mode Flag	1	BY	Boolean - TRUE if in frame mode
EOF Flag	1	BY	Boolean - EOF detected
Reset Flag	1	BY	Boolean - interface has been reset
Checksum	2	UI	
Total	**90**	BY = Byte	
		UI = Unsigned Integer	
		FP = Floating Point	

2.14 XRT TEC Power Supply Status Message

This message includes information about the status of the TEC Power Supply control software (task TEC). The structure of the message is shown in Table 19.

Table 19: TEC Power Supply Status Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C8D** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x48D)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x00DF**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data collection time	6		S/C time of data collection (or error)
UTC_Delta	6		UTC Correction
Auto Cool Interval	2	UI	Interval in Seconds
Auto Cool Max Voltage Change	2	UI	Maximum Allowable Voltage Change in Counts
Auto Cool Set Point	2	UI	Temperature Set Point in Counts
Auto Cool Hysteresis	2	UI	Temperature Hysteresis in Counts
Auto Cool Ramp Rate	2	UI	Temperature Ramp Rate per Interval in Counts
Auto Cool Temp Sensor Sel	2	UI	Focal Plane Camera Temperature Sensor Selected
Auto Heat Interval	2	UI	Interval in Seconds
Auto Heat Max Voltage Change	2	UI	Maximum Allowable Voltage Change in Counts
Auto Heat Set Point	2	UI	Temperature Set Point in Counts
Auto Heat Hysteresis	2	UI	Temperature Hysteresis in Counts
Auto Heat Ramp Rate	2	UI	Temperature Ramp Rate per Interval in Counts
Auto Heat Temp Sensor Sel	2	UI	Focal Plane Camera Temperature Sensor Selected
Auto Heat Timeout	2	UI	Timeout, in Seconds, since last Heating Command
Manual Cool Interval	2	UI	Interval in Seconds
Manual Cool Setpoint	2	UI	Voltage Set Point in Counts
Manual Heat Interval	2	UI	Interval in Seconds
Manual Heat Setpoint	2	UI	Voltage Set Point in Counts
Manual Heat Timeout	2	UI	Timeout, in Seconds, since last Heating Command
TEC Control Mode	2	UI	0 = Power Off; 1 = Automatic Cooling; 2 = Automatic Heating; 3 = Manual Cooling; 4 = Manual Heating; 5,6,7,8 = Ramping to Power Off
Subtotal	66		

Table 19: TEC Power Supply Status Message (cont)

ITEM	Size (bytes)	Type	Comments
Current Interval	2	UI	Current Interval in Seconds
Current Max Voltage Change	2	UI	Current Maximum Allowable Voltage Change in Counts
Current Set Point	2	UI	Current Set Point in Counts
Current Hysteresis	2	UI	Current Hysteresis in Counts
Current Ramp Rate	2	UI	Current Temperature Ramp Rate per Interval in Counts
Current Temp Sensor Sel	2	UI	Current Focal Plane Camera Temp. Sensor Selected
Current Timeout	2	UI	Current Timeout, in Seconds, since last Heating Cmd.
Current Output Voltage	2	UI	Current TEC Power Supply Output Voltage
Current Output Current	2	UI	Current TEC Power Supply Output Current
Current Cold Finger Temp	2	UI	Current Cold Finger Temperature
Current Interval's CCD Temp 1	2	UI	Current CCD Temperature 1 in Counts
Current Interval's CCD Temp 2	2	UI	Current CCD Temperature 2 in Counts
Current Interval's CCD Temp	2	UI	Current CCD Temperature from the selected sensor
Previous Interval's Voltage	2	UI	TEC Voltage in Counts
Previous Interval's CCD Temp 1	2	UI	CCD Temperature 1 in Counts
Previous Interval's CCD Temp 2	2	UI	CCD Temperature 2 in Counts
Previous Interval's CCD Temp	2	UI	Previous CCD Temperature from the selected sensor
Cumulative Pot Increments	2	UI	Count of increments to TEC supply's potentiometer
Cumulative Pot Decrements	2	UI	Count of decrements to TEC supply's potentiometer
TEC Supply Primary Power	2	UI	0 = Off, 1 = On
Heating Relay Primay Power	2	UI	0 = Off, 1 = On
TEC Switcher Status	2	UI	0 = Shutdown, 1 = On
Heating Relay Status	2	UI	0 = Off, 1 = Heating on
Heating Timeout Remaining	2	UI	Seconds of Heating Remaining
Elapsed Interval	2	UI	Number of elapsed seconds in the current interval
Spares	2		
Checksum	2	UI	
Total	**120**	BY = Byte UI = Unsigned Integer FP = Floating Point	

2.15 XRT Baffle Heater Control Message

This message includes information about the Baffle Heater Control software. The structure of the message is shown in Table 20.

Table 20: Baffle Heater Control Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0C8E** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x48E)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x0050**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data collection time	6		S/C time of data collection (or error)
UTC Delta	6		UTC Correction
Control Heater #1 On Point	2	UI	Set Point In Counts
Control Heater #1 Off Point	2	UI	Set Point In Counts
Control Heater #1 Sensor	1	BY	Assigned Sensor Index
Control Heater #2 On Point	2	UI	Set Point In Counts
Control Heater #2 Off Point	2	UI	Set Point In Counts
Control Heater #2 Sensor	1	BY	Assigned Sensor Index
Control Htr #1 Redundant On Pt.	2	UI	Set Point In Counts
Control Htr #1 Redundant Off Pt.	2	UI	Set Point In Counts
Control Htr #1 Redundant Sensor	1	BY	Assigned Sensor Index
Control Htr #2 Redundant On Pt.	2	UI	Set Point In Counts
Control Htr #2 Redundant Off Pt.	2	UI	Set Point In Counts
Control Htr #2 Redundant Sensor	1	BY	Assigned Sensor Index
Manual Control	1	BY	Boolean - Baffle Heaters are under Manual Control
Mask All	2	UI	Mask of all heaters used (all are in bank 2).
Mask On	2	UI	Mask of all heaters on.
Heaters Currently On	1	BY	Number of heaters currently on
Control Heater #1 ID	1	BY	Power distribution system index
Control Heater #1 Needs Heat	1	BY	Boolean - Heater should be turned on (Auto Mode only).
Control Heater #2 ID	1	BY	Power distribution system index
Control Heater #2 Needs Heat	1	BY	Boolean - Heater should be turned on (Auto Mode only)
Control Heater #1 Redundant ID	1	BY	Power distribution system index
Control Heater #1 Rd. Needs Heat	1	BY	Boolean - Heater should be turned on (Auto Mode only)
Control Heater #2 Redundant ID	1	BY	Power distribution system index
Control Heater #2 Rd. Needs Heat	1	BY	Boolean - Heater should be turned on (Auto Mode only)
Spare	16		
Checksum	2	UI	
Total	**80**	BY = Byte UI = Unsigned Integer FP = Floating Point	

3 TDRSS TELEMETRY PACKETS

XRT TDRSS data packets are identified by AP_IDs in the range 0x4E0 - 0x53F (from 1143-EI-S19121, Swift 1553 ICD, Table 4-2). There are several distinct types of XRT TDRSS Data Packets, each with a different AP_ID, as shown in Table 21.

The XRT produces the following types of data packets for transmission to the ground via TDRSS:

Table 21: TDRSS Messages

AP ID	Message Type	Message Size (bytes)	# Packets
0x4E0	XRT Position	64	1
0x4E1	XRT Spectrum	2230	3
0x4E2	XRT Image	2800	3
0x4E3	XRT Spectrum Message after Level 0 processing	2230	1
0x4E4	XRT Image Message after Level 0 processing	2800	1
0x4F0	XRT Centroiding Error	60	1
0x500	XRT Emergency	958	1

Each of these messages is described further in the following sections.

All multi-byte fields in XRT telemetry records are in big-endian order: MSB,LSB for two byte fields; MSB(3), Byte2, Byte 1, LSB(0) for four-byte fields.

3.1 XRT Position Message

This message is a high priority telemetry message destined for the TDRSS link and is also sent as an RT-to-RT command for the other instruments. It provides the XRT position of the centroid of a new burst. The TDRS telemetry message occupies a single ST_PDU and shall consist of the following data fields:

Table 22: Contents of XRT Position Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0CE0** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E0)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x0039**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection time	6		S/C time of CCD Frame start
UTC_Delta	6		UTC Correction
RA	4	FP	Burst location RA (J2000) (degrees)
Dec	4	FP	Burst location Dec (J2000) (degrees)
Flux	4	FP	Integrated signal in target in one CCD Frame
Significance	4	FP	Floating Point Detection Significance
TAM X1	4	FP	X Position of TAM Image 1
TAM Y1	4	FP	Y Position of TAM Image 1
TAM X2	4	FP	X Position of TAM Image 2
TAM Y2	4	FP	Y Position of TAM Image 2
Amplifier Number	1	UB	Amplifier number for readout
Waveform	1	UB	Waveform number of readout
Checksum	2	UI	
Total	**64**		

3.2 XRT Spectrum Message

The XRT Spectrum Message contains a 1024 channel raw spectrum of the burst, collected by the ERP once the source count rate drops low enough to use timing mode. This message is sent using a segmented telemetry message utilizing three ST_PDs. This message uses AP_ID 0x4E1 in the raw telemetry (as shown below) and 0x4E3 following Level 0 processing. This message shall consist of the following data fields:

Table 23: Contents of XRT Spectrum Message

	ITEM	Size (bytes)	Type	Comments
Packet #1	CCSDS Header Packet ID	2	UI	**0x0CE1** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E1)
	CCSDS Hdr. Seq. Control	2	UI	**01**xxxxxxxxxxxxxxB (first packet of segmented message)
	CCSDS Hdr. Packet Lengtl	2	UI	**0x03B7**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
	Observation Segment	1	UI	Observation Segment assigned by FoM
	Target ID	3	UI	Unique ID of this Target, assigned by FoM
	Spectrum Start Time	6	UI	Start time of first CCD frame in spectrum
	UTC_Delta	6	UI	UTC Correction
	Packet Number	2	UI	**0x0001**
	RA (J2000)	4	FP	RA of image center (pixel 25,25) (degrees)
	Dec (J2000)	4	FP	Dec of image center (pixel 25, 25) (degrees)
	Spectrum Stop Time	6	UI	Stop time of last CCD frame in spectrum
	Spectrum	900	UI	Spectral Channels 1-450
	Livetime **	4	FP	Exposure time for spectrum
	Spares	8		
	Checksum	2	UI	
	Total	**958**		

** NOTE: calculated by adding up the exposure times for each individual frame collected.

Table 23: Contents of XRT Spectrum Message (cont.)

	ITEM	Size (bytes)	Type	Comments
Packet #2	CCSDS Header Packet ID	2	UI	**0x0CE1** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E1)
	CCSDS Hdr. Seq. Control	2	UI	**00**xxxxxxxxxxxxxxB (continuation packet)
	CCSDS Hdr. Packet Length	2	UI	**0x03B7**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
	Observation Segment	1	UI	Observation Segment assigned by FoM
	Target ID	3	UI	Unique ID of this Target, assigned by FoM
	Spectrum Start Time	6	UI	Start time of first CCD frame in spectrum
	UTC_Delta	6	UI	UTC Correction
	Packet Number	2	UI	**0x0002**
	Spectrum	900	UI	Spectral Channels 451-900
	Spares	26		Spare bytes
	Checksum	2	UI	
	Total	**958**		
Packet #3	CCSDS Header Packet ID	2	UI	**0x0CE1** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E1)
	CCSDS Hdr. Seq. Control	2	UI	**10**xxxxxxxxxxxxxxB (final packet of segmented mess
	CCSDS Hdr. Packet Length	2	UI	**0x03B7**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
	Observation Segment	1	UI	Observation Segment assigned by FoM
	Target ID	3	UI	Unique ID of this Target, assigned by FoM
	Spectrum Start Time	6	UI	Start time of first CCD frame in spectrum
	UTC_Delta	6	UI	UTC Correction
	Packet Number	2	UI	**0x0003**
	Spectrum	248	UI	Spectral Channels 901-1024
	Spares	34		Spare bytes
	Checksum	2	UI	
	Total	**314**		

3.3 XRT Postage-Stamp Image Message

The XRT Image Message contains a 51 x 51 pixel 8-bit image centered on the source centroid position. It shall consist of a segmented telemetry message utilizing three ST_PDUs. This message uses AP_ID 0x4E2 in the raw telemetry (as shown below) and 0x4E4 following Level 0 processing. It contains the following data fields:

Table 24: Contents of XRT Image Message

	ITEM	Size (bytes)	Data Type	Comments
Packet #1	CCSDS Header Packet ID	2	UI	**0x0CE2** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E2)
	CCSDS Hdr. Seq. Control	2	UI	**01**xxxxxxxxxxxxxxB (first packet of segmented message)
	CCSDS Hdr. Packet Length	2	UI	**0x03B7**
	CCSDS Secondary Header	6		Time of CCSDS Packet creation
	Observation Segment	1		Observation Segment assigned by FoM
	Target ID	3		Unique ID of this Target, assigned by FoM
	Data Collection time	6		S/C time of CCD frame start
	UTC_Delta	6		UTC Correction
	Packet Number	2	UI	**0x0001**
	CCD Frame Counter	4	UI	Sequential CCD Frame Counter
	RA (J2000)	4	FP	RA of image center (pixel 25,25) (degrees)
	Dec (J2000)	4	FP	Dec of image center (pixel 25, 25) (degrees)
	Roll	4	FP	Roll angle (degrees) of image
	RAWX	2	UI	X coordinate in CCD pixels of image center
	RAWY	2	UI	Y coordinate in CCD pixels of image center
	Gain	1	Byte	Inverse gain (data were divided by this value) (1, 2, 4, 8, or 16)
	Image	867	Byte	Rows 1-17 of image
	Centroid X	4	FP	Floating point centroid position in RAWX coord
	Centroid Y	4	FP	Floating point centroid position in RAWY coord
	Spare	30		
	Checksum	2	UI	
	Total	**958**		

Table 24: Contents of XRT Image Message (cont.)

	ITEM	Size (bytes)	Comments
Packet #2	CCSDS Header Packet ID	2	**0x0CE2** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E2)
	CCSDS Hdr. Seq. Control	2	**00**xxxxxxxxxxxxxxB (continuation packet)
	CCSDS Hdr. Packet Length	2	**0x03B7**
	CCSDS Secondary Header	6	Time of CCSDS Packet creation
	Observation Segment	1	Observation Segment assigned by FoM
	Target ID	3	Unique ID of this Target, assigned by FoM
	Data Collection time	6	S/C time of CCD Frame Start
	UTC_Delta	6	UTC Correction
	Packet Number	2	**0x0002**
	CCD Frame Counter	4	Sequential CCD Frame Counter
	Image	918	Rows 18-35 of image
	Spare	4	
	Checksum	2	
	Total	**958**	
Packet #3	CCSDS Header Packet ID	2	**0x0CE2** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4E2)
	CCSDS Hdr. Seq. Control	2	**10**xxxxxxxxxxxxxxB (final packet of segmented message)
	CCSDS Hdr. Packet Length	2	**0x036D**
	CCSDS Secondary Header	6	Time of CCSDS Packet creation
	Observation Segment	1	Observation Segment assigned by FoM
	Target ID	3	Unique ID of this Target, assigned by FoM
	Data Collection time	6	S/C time of CCD Frame Start
	UTC_Delta	6	UTC Correction
	Packet Number	2	**0x0003**
	CCD Frame Counter	4	Sequential CCD Frame Counter
	Image	816	Rows 36-51 of image
	Spare	32	
	Checksum	2	
	Total	**884**	

3.4 XRT Centroiding Error Message

If the XRT is unable to calculate a reliable centroid, either due to lack of an identifiable source in the FOV (insufficient photons), because the algorithm did not converge within the specified number of iterations, or due to source confusion (standard deviation larger than expected for the PSF), it will generate an error message through TDRSS to notify the ground that no fine position will be forthcoming. (An RT-to-RT command is also generated to notify the other instruments of this error.) The format of the TDRS telemetry message is shown in Table 25. It occupies part of a single ST_PDU.

Table 25: Contents of XRT Centroid Error Message

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x0CF0** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x4F0)
CCSDS Header Seq. Cntrl	2	UI	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	UI	**0x0035**
CCSDS Secondary Header	6		Time of CCSDS packet formation
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection Time	6		S/C time of Frame Start
UTC_Delta	6		UTC Correction
RA	4	FP	RA (J2000) of pointing direction (degrees)
Dec	4	FP	Dec (J2000) of pointing direction (degrees)
Error Flag	2	UI	2 byte indication of reason for error condition: 1 = no source found in image 2 = algorithm did not converge 3 = standard deviation too large 0xFFFF = general error
Spare	20		
Checksum	2	UI	
Total	**60**		

3.5 XRT Emergency Message

An XRT Emergency Message is sent to TDRSS if the XRT encounters a condition that requires immediate ground intervention. The format of this message follows in Table 26. The format is the same as the Analog HK Message except that the header now uses a TDRSS Packet ID.

Table 26: Contents of XRT Emergency Message

ITEM	**Size (bytes)**	**Comments**
CCSDS Header Packet ID	2	**0x0D00** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x500)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x00DF**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Observation Segment	1	Observation Segment assigned by FoM
Target ID	3	Unique ID of this Target, assigned by FoM
Data collection time	6	S/C time of data collection (or error)
UTC_Delta	6	UTC Correction
RA	4	RA (J2000) of pointing direction (degrees)
Dec	4	Dec (J2000) of pointing direction (degrees)
Roll	4	Roll angle (degrees)
ACS Flags	1	ACS Flags: slewing, 10 arcmin, settled, SAA
XRT State	1	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
XRT Mode	1	XRT Readout Mode For Last CCD Frame: 1 = Null 2 = Short Image 3 = Long Image 4 = Piled-up Photodiode 5 = Low Rate Photodiode 6 = Windowed Timing 7 = Photon-Counting 8 = Raw Data 9 = Bias Map 10 = Stop
XRT Waveform	1	CCD Waveform ID
Error Number	4	Error Number
Analog HK	180	120 channels of 12 bit housekeeping data
Checksum	2	
Total	**230**	

3.6 TDRSS Housekeeping Telemetry Packets

XRT Real-Time Telemetry Packets can be echoed down the TDRSS link. TDRSS Housekeeping Telemetry packets are identified by AP_IDs in the range 0x530 - 0x53F, and are exact duplicates of the corresponding Real-Time Telemetry formats. These packets are summarized in Table 27.

Table 27: TDRSS HK Telemetry Data Packets

CCSDS Header ID	AP ID	Message Type	Message Size (bytes)	# Packets
0x0D30	0x530	XRT Startup	230	1
0x0D31	0x531	XRT Memory Status	108	1
0x0D32	0x532	XRT Task Status	230	1
0x0D33	0x533	XRT Errors/Events	230	1
0x0D34	0x534	XRT Analog HK	230	1
0x0D35	0x535	XRT Periodic Processing	108	1
0x0D36	0x536	XRT Mode Change	60	1
0x0D37	0x537	XRT Memory Dump Packet	Variable	1
0x0D38	0x538	XRT Command Statistics	230	1
0x0D39	0x539	XRT Command Echo	94	1
0x0D3A	0x53A	XRT Telemetry Test	230	1
0x0D3B	0x53B	XRT Tube Heater Control	230	1
0x0D3C	0x53C	XRT CCD Interface	90	1
0x0D3D	0x53D	XRT TEC PS Status	120	1
0x0D3E	0x53E	XRT Baffle Heater Control	80	1

Please refer to Section 2 for details on packet formats.

4 RT-TO-RT TELECOMMANDS

The XRT can generate telecommands to send to other instruments or to the spacecraft to provide information to them. The list of XRT-generated RT-to-RT Telecommands is given in Table 28.

Table 28: XRT Generated RT-to-RT Telecommands

Destination	AP ID	Function Code	Message Type	Message Size (bytes)	# Packets
Broadcast	0x705	0	XRT Position Message	60	1
Broadcast	0x705	1	XRT Position Error	56	1

When the XRT is first pointed at a new GRB, it attempts to find the position of the burst by performing a centroid computation on the X-ray image received. If it is successful, it sends an XRT Position Message to the TDRSS link and an XRTPOSITION telecommand to the other instruments as a broadcast RT-to-RT telecommand. If it is unable to locate the burst within 30 seconds, it sends an XRT Centroid Error Message to the TDRSS link and an XRTCENTROIDERR telecommand to the other instruments as a broadcast RT-to-RT telecommand. The formats of the RT-to-RT telecommands are described below.

All multi-byte fields in XRT telemetry records are in big-endian order: MSB,LSB for two byte fields; MSB(3), Byte2, Byte 1, LSB(0) for four-byte fields.

4.1 XRTPOSITION Telecommand

This is an RT-to-RT command broadcast to all other instruments. It provides the XRT position of the centroid of a new burst.

Table 29: Contents of XRTPOSITION Telecommand

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x1F05** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x705)
CCSDS Header Seq. Cntrl	2	UI	**1100000000000000**B
CCSDS Header Packet Length	2	UI	**0x0035**
CCSDS Secondary Header Type + Reserved	1	UI	**00000000**B
CCSDS Secondary Header Function Code	1	U1	**0x00** (Function code for XRTPOSITION)
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection time	6		S/C time of CCD Frame start
UTC_Delta	6		UTC Correction
RA	4	FP	Burst location RA (J2000) (degrees)
Dec	4	FP	Burst location Dec (J2000) (degrees)
Flux	4	FP	Integrated signal in target in one CCD Frame
Significance	4	FP	Floating Point Detection Significance
TAM X1	4	FP	X Position of TAM Image 1
TAM Y1	4	FP	Y Position of TAM Image 1
TAM X2	4	FP	X Position of TAM Image 2
TAM Y2	4	FP	Y Position of TAM Image 2
Amp Number	1	UB	Amplifier Number of readout
Waveform	1	UB	Waveform number of readout
Checksum	2	UI	
Total	**60**		

4.2 XRTCENTROIDERR Telecommand

If the XRT is unable to calculate a reliable centroid, either due to lack of an identifiable source in the FOV or due to source confusion, it will broadcast an RT-to-RT command to the other instruments. The format of the TDRS telemetry message is shown below:

Table 30: Contents of XRTCENTROIDERR Telecommand

ITEM	Size (bytes)	Type	Comments
CCSDS Header Packet ID	2	UI	**0x1F05** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x705)
CCSDS Header Seq. Cntrl	2	UI	**1100000000000000**B
CCSDS Header Packet Length	2	UI	**0x0031**
CCSDS Secondary Header Type + Reserved	1	UI	**00000000**B
CCSDS Secondary Header Function Code	1	UI	**0x01** (Function code for XRTCENTROIDERR)
Observation Segment	1	UI	Observation Segment assigned by FoM
Target ID	3	UI	Unique ID of this Target, assigned by FoM
Data Collection Time	6		S/C time of Frame Start
UTC_Delta	6		UTC Correction
RA	4	FP	RA (J2000) of pointing direction (degrees)
Dec	4	FP	Dec (J2000) of pointing direction (degrees)
Error Flag	2	UI	2 byte indication of reason for error condition: 1 = no source found in image 2 = source confusion - cannot identify target 3 = standard deviation too large
Spare	20		
Checksum	2	UI	
Total	**56**		

5 Solid-State Recorder Telemetry Packets

XRT data packets stored in the XRT partition of the Solid-State Recorder (SSR) are assigned AP_IDs in the range 0x540 - 0x59F (from 1143-EI-S19121, Swift 1553 ICD, Table 4-2). In practice, only two of these AP_IDs are used. Memory Dump Messages can be transmitted via AP_ID 0x547 (see Table 31 for format of this message). All XRT science data packets will use AP_ID 0x540.

5.1 SSR Memory Dump Packets

Memory dumps can be made to the Solid-State Recorder (SSR), which permits larger dump sizes than permitted by the RT-to-RT packets. The format for SSR Memory Dump packets is shown in Table 31.

Table 31: Contents of SSR Memory Dump Telemetry Packet

ITEM	Size (bytes)	Comments
CCSDS Header Packet ID	2	**0x0D47** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x547)
CCSDS Header Seq. Cntrl	2	**11**xxxxxxxxxxxxxxB
CCSDS Header Packet Length	2	**0x03B7**
CCSDS Secondary Header	6	Time of CCSDS packet formation
Starting Address	4	Address of first word of dump
Bytes Transmitted	2	Cumulative bytes transmitted
Bytes Requested	2	Total bytes in dump
Data Width	1	Data width (1,2, or 4 bytes)
Type ID	1	Type ID
Block Number	1	Block Number
Data Dump	933	Data dump from memory
Checksum	2	
Total	**958**	

5.2 XRT Science Data

The science data contains a number of different data formats and record types within it. In order to use our telemetry bandwidth efficiently, we pack the science data into CCSDS packets with maximum filling, and unpack the data using special purpose ground processing software, rather than having ITOS separate the data packets. We use the Swift Large Data Structures protocol to pack the data into CCSDS packets.

For the purposes of this document, we will refer to each XRT data product as a Data Record. Each Data Record begins with a header containing a unique Record ID (also referred to as a Header ID), which is usually followed by data. Some Data Records have fixed format. In others, the number of bytes in a Data Record is variable, depending on the amount of data generated during the time interval covered by the Data Record. There are several distinct types of XRT Data Records, each identified by a unique Header ID, as shown in Table 32.

Table 32: XRT Science Data Record Types

Header ID	Name	Header Size (bytes)
0xFEC07B92	Snapshot Header	48
0x807353E0	Image Mode CCD Frame	158
0x8073819B	Piled-up Photodiode Mode CCD Frame	158
0x8073B918	Low-Rate Photodiode Mode Frame	158
0x8073F0AA	Windowed Timing Mode CCD Frame	158
0x8073AB6F	Photon-Counting Mode CCD Frame	176
0x80730F0F	Raw CCD Frame	158
0x8073F0F0	CCD Bias Frame	158
0xE019B74A	Bad Pixel Table	TBD
0xFEC029B7	Snapshot Trailer	5118
0xED94037F	Snapshot Trailer End Marker	4
0x4E074E07	EOT Marker	4

Each of these Data Records is described further in the following sections.

All multi-byte fields in XRT telemetry records are in big-endian order: MSB,LSB for two byte fields; MSB(Byte3), Byte2, Byte1, LSB(Byte0) for four-byte fields.

5.3 Science Data Format

The Swift mission is event-driven: the mission schedule is determined by the random occurrence of gamma-ray bursts (GRBs). Because of our observational constraints (Swift cannot point within 30 degrees of the Earth) we can never observe a single target for an entire orbit. Our normal mode of operations, therefore, will be to "ping-pong" between several (typically 3-4) targets per orbit in order to avoid violating the observing constraints. A new burst can occur at any random time during the observation of an "old" GRB/afterglow.

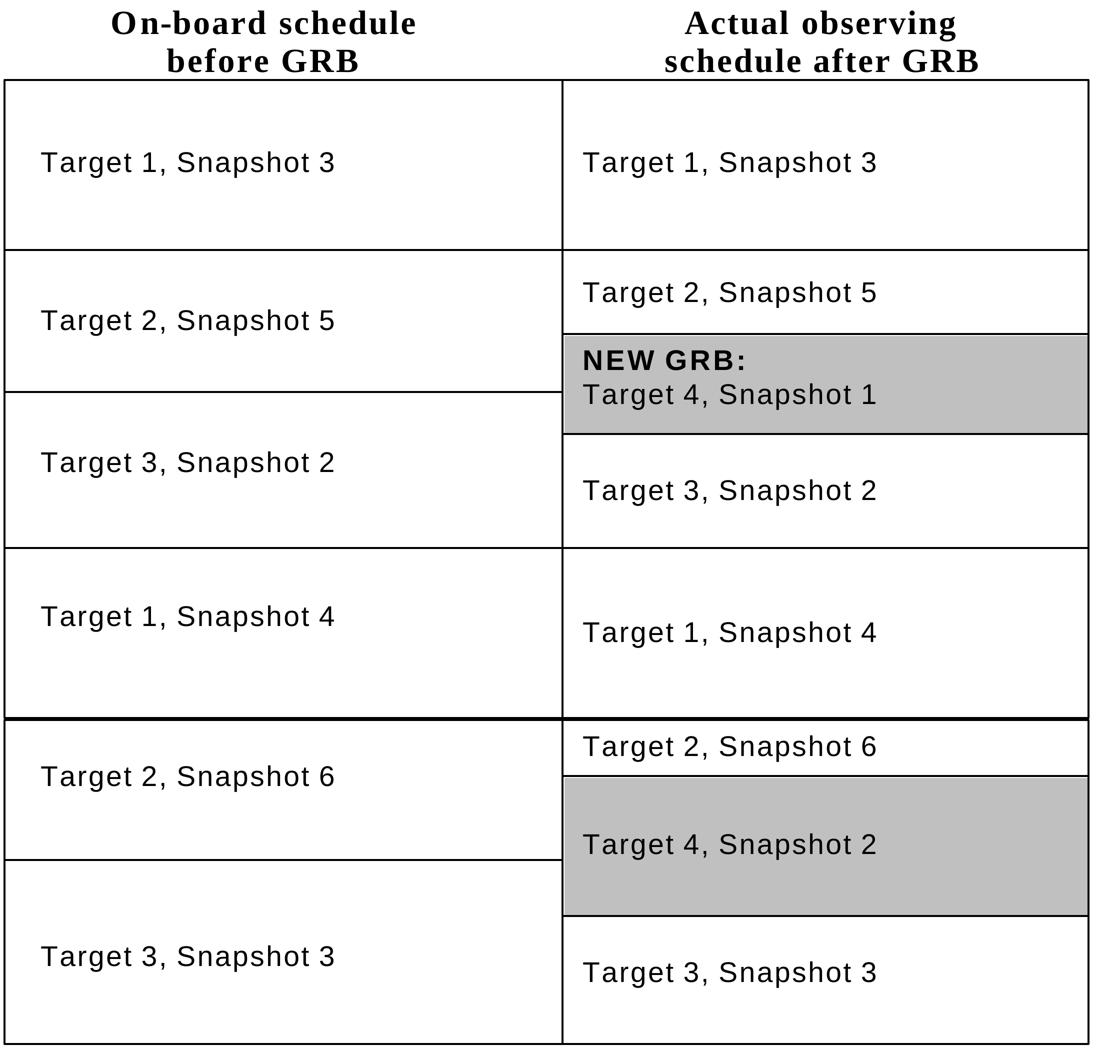

Figure 6: Typical Swift Observation Sequence

A typical observation sequence, therefore, might look something like Figure 6. We are using the following terminology:

- Snapshot: a single continuous observation of a given target
- Observation Segment: a series of snapshots of a single target, taken over a period of ~ 1-2 days. Observation segment numbers are stored in the Tertiary Header.

The on-board schedule kept by the Figure of Merit process is shown schematically in the left-hand column, and consists of several observations of previously observed recent GRBs. During this observing sequence, a new GRB occurs (an Automated Target), resulting in the modified schedule shown in the right-hand column. The new GRB occurs during Snapshot 5 of Target 2, resulting in a truncated snapshot of this target. The GRB Automated Target observation (Snapshot 1 of the new Target 4) continues until terminated by an impending constraint violation. The schedule then reverts to Snapshot 2 of Target 3, which is now shorter than originally planned. Snapshot 6 of Target 2 is even shorter than Snapshot 5, because the FoM schedules an observation of the new Target 4 as soon as it becomes visible.

Each target is therefore observed multiple times, with the same Observation Segment Number assigned to each snapshot of the same target. These multiple observations of each target must be recombined during ground processing to obtain the complete data set for a given target.

The XRT Science Data flow is shown schematically in Figure 7. Each Snapshot is organized as a group of data records beginning with a Snapshot Header and ending with a Snapshot Trailer. The science data are packed into CCSDS packets, with up to 942 bytes of science data in each packet, using the Swift Large Data Structures protocol (the first 10 data bytes of each packet are taken up with header information as shown in Figure 7). The observation is terminated with a Snapshot Trailer, followed by a copy of the Snapshot Header from the current snapshot. This redundant header helps to reconstruct the science data should the playback of the snapshot be split across two downlink passes. The next snapshot begins with a new Snapshot Header in the following CCSDS packet. Whole CCSDS packets are combined by the SCUI software module into 960-Byte ST_PDU packets, for transmission over the spacecraft's 1553 bus.

Within a snapshot the data are organized as a series of Data Records. Data Records may consist of either a fixed-size Record, or a fixed-size Header followed by a variable number of Records. For example, a Postage Stamp is a fixed-size Data Record containing image data, while a Photon-Counting Mode CCD Frame record has variable length, with the length given in the fixed-length header. The various Data Record formats are described in the remainder of this section. In general, the Data Record headers are transmitted as a single CCSDS packet, while the accompanying data are split between multiple packets.

The tables in the following sections show the entire data structure as transmitted by the XRT to the spacecraft C&DH system, including both CCSDS headers (shown in gray) and LDP headers (shown in blue). The CCSDS headers and LDP headers will be stripped off by software at the SDC, leaving just the actual LDP structures to be processed into FITS files for further analysis.

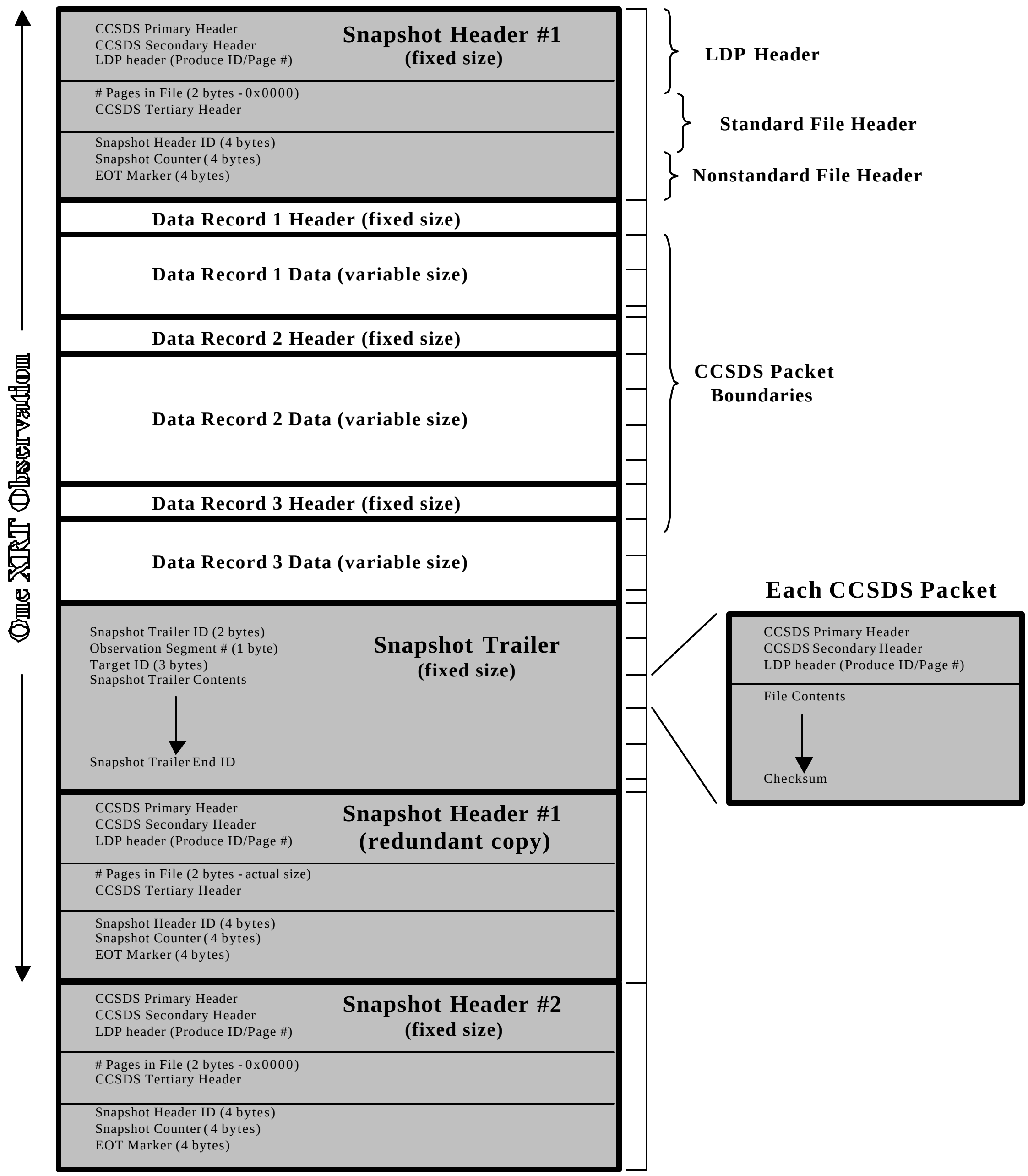

Figure 7: Science Data Telemetry Format

5.4 Snapshot Header

The Snapshot Header marks the beginning and end of a snapshot. (It is the LDP header.) The format is shown in Table 33. The Snapshot Header Counter is a unique 4-byte identifier that increments through the mission for each new snapshot (resets at reboot).

Table 33: XRT Snapshot Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS HDR	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x0029**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
Standard LDP Header	16	Total Pages in File	2	Unsigned Integer	Total number of pages within snapshot LDP (will be zero for Snapshot Header at beginning of LDP, but filled in for Snapshot Header Copy at end of LDP)
	18	Observation Segment	1	0x00 <= Value <= 0xFF	Observation Segment assigned by FoM
	19	Target ID	3	0x000000 <= Value <= 0xFFFFFF	Unique ID of this Target, assigned by FoM
	22	Data Collection time	6	4 bytes S/C seconds, 2 bytes subseconds	S/C time of header creation
	28	UTC_Delta	6	4 bytes S/C seconds, 2 bytes subseconds	UTC Correction
1	34	Snapshot Header ID	4	0xFEC07B92	Indicates Beginning of Snapshot
2	38	Snapshot Count	4	0x00000000 <= Value <= 0xFFFFFFFF	Sequential Number of this Snapshot
3	42	EOT Marker	4	0x00000000	End Of Transmission Marker (zero for Snapshot Header at beginning of LDP
	46	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding
		TOTAL	**48**		
		SIZE IN K (K = 1024)	**0.05**		

5.5 Image Mode CCD Frame Record

The Image Mode CCD Frame Record is the format used to store the data from an Image Mode CCD frame. An Image Mode Frame Record consists of a fixed-format Image Mode Frame Header followed by a variable number of pixel values, for those pixels exceeding the Lower Level Discriminator threshold.

5.5.1 Image Mode Frame Header

The format of the Image Mode CCD Frame Header is shown in Table 34.

Table 34: Image Mode Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS HDR	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x0091
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	CCD Image Mode Frame Header ID	4	0x807353E0	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Count Rate	4	IEEE Floating Point	Count rate determined by ERP
		Subtotal:	48		

Table 34: Image Mode Frame Header (cont.)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	!Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row readout
46	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row readout
47	132	Nominal CCD Exposure Time	4	2 bytes of S/C seconds, 2 bytes of XRT subseconds	Nominal Exposure Time of Image Area
48	136	N_pixels	2	Unsigned Integer	Number of pixel records following the header
49	138	Lower Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Pixel Threshold used for this Frame (DN)
50	140	Number Of Pixels > LLD	4	Unsigned Long Integer	# pixels above the LLD
51	144	Not Used	2	N/A	ULD (not used)
52	146	Not Used	4	N/A	Not used (slows down processing)
53	150	Amp	1	Byte	Amp Number (1 or 2)
54	151	Spare	1	Byte	Spare byte
55	152	NCOLS	2	Unsigned Integer	Number of columns in image
56	154	NROWS	2	Unsigned Integer	Number or rows in image
57	156	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all previous bytes in packet
		TOTAL	**158**		
		SIZE IN K (K = 1024)	**0.15**		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Readout Times. The "count rate" in this mode is defined as N_pixels divided by the nominal exposure time, where N_pixels is the number of pixels above the LLD.

5.5.2 Image Mode Data Packet Format

The Image Mode Header is followed by one or more CCSDS data packets, each containing up to 235 32-bit unsigned integer data words, one for each pixel above the threshold. The structure of the CCSDS data packets is shown in Table 35.

Table 35: Image Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-235	1 - 235, 32-bit pixel data words	940	Unsigned Long Integer	32-bit unsigned long integers containing pixel data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

Only data for pixels above the Lower Level Discriminator (LLD) are telemetered. The number of pixel records following the Image Mode Frame Header is given in the Frame Header (Item 48: N_pixels). The size of the last data packet depends on the number of pixels telemetered (it is not padded after the last data value).

5.5.3 CCD Pixel Format for Image Mode Data Packets

Each data word contains a 12-bit pixel value in the low 12 bits and 20 bits of position information, packed into a 32-bit unsigned integer. The bit assignment for the CCD pixel data in Image Mode is shown in Table 36. The bit packing sequence for each pixel is shown in Table 37.

Table 36: Image Mode CCD Pixel Bit Assignment

ITEM	# Bits
CCD Column (RAWX: 0-599)	10
CCD Row (RAWY: 0-601)	10
Pixel Value (DN)	12
Total	**32**

Table 37: Image Mode Pixel Bit Packing Sequence

	Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)
Byte 0	X9	X8	X7	X6	X5	X4	X3	X2
Byte 1	X1	X0	Y9	Y8	Y7	Y6	Y5	Y4
Byte 2	Y3	Y2	Y1	Y0	P11	P10	P9	P8
Byte 3	P7	P6	P5	P4	P3	P2	P1	P0

Where X represents the pixel RAWX coordinate (0-599), Y represents the pixel RAWY coordinate (0-601), and P represents the pixel value in DN. (See Appendix A for definition of RAWX/RAWY coordinates.)

5.6 Piled-up Photodiode Mode CCD Frame Record

The Piled-up Photodiode Mode CCD Frame Record is the format used to store the data from a Photodiode Mode CCD timing "frame" for which more than 50% of the pixels exceed the LLD. Although data taken in Photodiode Mode have no inherent frame structure, for convenience we break the telemetry data into frames consisting of a Photodiode Mode Frame Header followed by event data. It takes about 8 seconds to complete one of these frames. At the end of the frame, the "count rate" is re-evaluated.

5.6.1 Piled-up Photodiode Mode Frame Header

The format of the Piled-up Photodiode Mode CCD Frame Header is shown in Table 38.

Table 38: Piled-up Photodiode Mode Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x0091
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16 bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Piled-up Photodiode Frame Header ID	4	0x8073819B	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State Flags for this frame: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Count Rate	4	IEEE Floating Point	Count rate determined by ERP
		Subtotal:	48		

Table 38: Piled-up Photodiode Mode Frame Header (cont.)

#	OFF	DESCRIPTION	BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	!Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row readout in "frame"
46	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row readout in "frame"
47	132	Nominal Exposure Time	4	2 bytes of seconds, 2 bytes of subseconds (units of 20 microseconds)	Nominal CCD frame time for this mode, used to calculate count rate
48	136	Spare	2	0x0000	
49	138	Lower Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Pixel Threshold used for this Frame (DN)
50	140	N > LLD	4	Unsigned Long Integer	Number Of Pixels Greater Than LLD (not used)
51	144	Upper Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Upper Level Discriminator (DN)
52	146	N > ULD	4	Unsigned Long Integer	Number of Pixels Greater Than ULD (not used)
53	150	Amp	1	Byte	Amp Number (1 or 2)
54	151	Spare	1	Byte	Spare byte
55	152	N_Pixels	4	Unsigned Long Integer	Number of pixels following header
		Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all previous bytes in packet
		TOTAL	**158**		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Readout Times. See XRT-PSU-037 for detailed description of how to calculate event arrival times. The "count rate" in this mode is defined as N_Pixels divided by the nominal exposure time, where N_Pixels is the number of pixels following the header. All pixels are telemetered (N>LLD and N>ULD are calculated but are not used in this mode).

5.6.2 Piled-up Photodiode Mode Data Packet Format

The Piled-up Photodiode Mode Frame Header is followed by 379,862 16 bit integers data words, organized as 602 “rows”, each “row” containing 631 pixels. (There is no inherent row/column structure to photodiode mode data, but the pixels do have End of Line and End of Frame bits set as shown in Table 40). The data words are broken up into multiple CCSDS packets as needed. Up to 470 16-bit data words will be formatted into each CSSDS packet as shown in Table 39.

Table 39: Piled-up Photodiode Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-470	1 - 470, 16-bit pixel data words	940	0x0000 <= Value <= 0xFFFF	16-bit unsigned integers containing pixel data or Mission Elapsed Timer data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

The pixels are arranged in the same order that they are read out of the camera, except that MET data words are discarded. The first pixel of the first frame of data in this mode is a garbage pixel. The next five are the guard pixels and contain no sky signal. (The exposure time for the first six pixels of the first “frame” is zero.) The next 602 pixels are from the Framestore Area of the CCD and also have zero exposure to the sky but have monotonically increasing exposure to background events (from Framestore Area). Pixels 608 – 1807 have monotonically increasing exposure for both sky and background. The rest of the pixels in the first frame (and all of the pixels in subsequent frames) have constant sky exposure and constant background exposure. See XRT-PSU-037 for details.

5.6.3 Pixel Data for Piled-up Photodiode Mode

The format of the 16-bit data words is shown in Table 40. Each 16-bit data word contains a 12-bit pixel value in the high 12 bits and 4 tag bits in the least significant bits. The last pixel in each "row" will be marked with an end of line tag; the last pixel in the last "row" of the frame will be marked with both an end of line and end of frame tag.

Table 40: Piled-up Photodiode Mode Pixel Data Bit Format

B15 msb	B14	B13	B12	B11	B10	B09	B08	B07	B06	B05	B04	B03	B02	B01	B00 lsb	Desc.
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	0	0	0	Normal Pixel Data Format
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	1	1	0	Pixel Data with End of Line and End of Frame
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	1	0	0	Pixel Data with End of Line
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	0	1	0	Pixel Data with End of Frame

5.7 Low Rate Photodiode Mode CCD Frame Record

The Low Rate Photodiode Mode CCD Frame Record is the format used to store the data from a Photodiode Mode CCD timing "frame" for which fewer than 50% of the pixels exceed the LLD. Although data taken in Photodiode Mode have no inherent frame structure, for convenience we break the telemetry data into frames consisting of a Photodiode Mode Frame Header followed by event data. Each "frame" contains the events from 379,862 CCD pixels.

5.7.1 Low Rate Photodiode Mode Frame Header

The format of the Low Rate Photodiode Mode CCD Frame Header is shown in Table 41.

Table 41: Low Rate Photodiode Mode Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x0091
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Low Rate Photodiode Frame Header ID	4	0x8073B918	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State Flags for this frame: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Count Rate	4	IEEE Floating Point	Count rate determined by ERP
		Subtotal:	48		

Table 41: Low Rate Photodiode Mode Frame Header (cont.)

#	OFF	DESCRIPTION	BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	!Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row readout in "frame"
46	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row readout in "frame"
47	132	Nominal Exposure Time	4	2 bytes of seconds, 2 bytes of subseconds (units of 20 microseconds)	Nominal CCD frame time for this mode, used to calculate count rate
48	136	Spare	2	0x0000	spare bytes
49	138	Lower Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Pixel Threshold used for this Frame (DN)
50	140	N > LLD	4	Unsigned Long Integer	Number Of Pixels Greater Than LLD
51	144	Upper Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Upper Level Discriminator (DN)
52	146	N > ULD	4	Unsigned Long Integer	Number of Pixels Greater Than ULD
53	150	Amp	1	Byte	Amp Number (1 or 2)
54	151	Spare	1	0x00	Spare byte
55	152	N_Pixels	4	Unsigned Long Integer	Number of pixels following header
	156	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all previous bytes in packet
		TOTAL	**158**		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Read-out Times. See XRT-PSU-037 for detailed description of how to calculate event arrival times. The "count rate" in this mode is defined as N_Pixels divided by the nominal exposure time, where N_Pixels is the number of pixels > LLD and ≤ ULD.

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5.7.2 Low Rate Photodiode Mode Data Packet Format

The Low Rate Photodiode Mode Header is followed by one or more CCSDS data packets, each containing up to 235 32-bit unsigned integer data words, one for each pixel above the threshold. The structure of the CCSDS data packets is shown in Table 42.

Table 42: Low Rate Photodiode Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-235	1 - 235, 32-bit pixel data words	940	Unsigned Long Integer	32-bit unsigned long integers containing pixel data or Mission Elapsed Timer data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

Only data for pixels above the Lower Level Discriminator (LLD) and below the Upper Level Discriminator (ULD) are telemetered. The number of pixel records following the Low Rate Photodiode Mode Frame Header is given in the Frame Header (Offset 152: N_Pixels). The size of the last data packet depends on the number of pixels telemetered.

5.7.3 Low Rate Photodiode Mode Pixel Data Format

If the fraction of pixels exceeding the LLD is less than 50%, it is more efficient to transmit the individual pixels instead of the entire frame. The pixel format for this case is shown in Table 43. It requires four bytes per event. The bit sequence is shown in Table 44, where the bytes are numbered in the order in which they appear in the telemetry stream (most significant byte first).

Table 43: Low Rate Photodiode Mode Pixel Bit Assignment

ITEM	# Bits
Pixel Offset from Frame Header	20
Pixel Value (DN)	12
Total	**32**

Table 44: LR Photodiode Mode Pixel Bit Packing Sequence

	Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)
Byte 0 (MSB)	O19	O18	O17	O16	O15	O14	O13	O12
Byte 1	O11	O10	O9	O8	O7	O6	O5	O4
Byte 2	O3	O2	O1	O0	P11	P10	P9	P8
Byte 3 (LSB)	P7	P6	P5	P4	P3	P2	P1	P0

The pixels at the beginning of the first “frame” of Photodiode mode data are not quite the same as the rest of the pixels. The first pixel received in this mode (at offset 0) contains garbage. The next five are the guard pixels and contain no sky signal. So the exposure time for the first six pixels of the first “frame” is zero. The next 602 pixels are from the Framestore Area of the CCD and also have zero exposure to the sky but have monotonically increasing exposure to back-ground events (from Framestore Area). Pixels 608 – 1807 have monotonically increasing expo-sure for both sky and background. The rest of the pixels in the first frame (and all of the pixels in subsequent frames) have constant sky exposure and constant background exposure. See XRT-PSU-037 for details.

5.8 Windowed Timing Mode CCD Frame Record

The Windowed Timing Mode CCD Frame Record is the format used to store the data from a Windowed Timing Mode CCD "frame". Although data taken in Windowed Timing Mode have row structure but do not inherently have any frame structure, for convenience we break the telemetry data into "frames" consisting of a Windowed Timing Mode Frame Header followed by event data from 600 rows per "frame".

5.8.1 Windowed Timing Mode Frame Header

The structure of the Windowed Timing Mode Frame Header is shown in Table 45.

Table 45: Windowed Timing Mode Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x0091
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Windowed Timing Mode Frame Header ID	4	0x8073F0AA	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x0000 <= OBSID <= 0xFFFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x0000 <= ID <= 0xFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State Flags for this frame: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Count Rate	4	IEEE Floating Point	Count rate determined by ERP
		Subtotal:	48		

Table 45: Windowed Timing Mode Frame Header (cont.)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	!Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row in "frame"
46	126	Readut End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row in "frame"
47	132	Nominal Exposure Time	4	2 bytes of seconds, 2 bytes of subseconds (units of 20 microseconds)	Nominal CCD frame time for this mode, used to calculate count rate
48	136	N_Pixels	2	Unsigned Integer	Number of pixels following header
49	138	Lower Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Pixel Threshold used for this Frame (DN)
50	140	N > LLD	4	Unsigned Long Integer	Number Of Pixels Greater Than LLD
51	144	Upper Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Upper Level Discriminator (DN)
52	146	N > ULD	4	Unsigned Long Integer	Number of Pixels Greater Than ULD
53	150	Amp	1	Byte	Amp Number (1 or 2)
54	151	Spare	5	0x00	Array of spare bytes
	156	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all previous bytes in packet
		TOTAL	**158**		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Read-out Times. See XRT-PSU-037 for detailed description of how to calculate event arrival times. The "count rate" in this mode is defined as N_Pixels divided by the nominal exposure time, where N_Pixels is the number of pixels > LLD and ≤ ULD.

5.8.2 Windowed Timing Mode Data Packet Format

The Windowed Timing Mode Header is followed by one or more CCSDS data packets, each containing up to 235 32-bit unsigned integer data words, one for each pixel above the threshold. The structure of the CCSDS data packets is shown in Table 42.

Table 46: Windowed Timing Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-235	1 - 235, 32-bit pixel data words	940	Unsigned Long Integer	32-bit unsigned long integers containing pixel data or Mission Elapsed Timer data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

Only data for pixels above the Lower Level Discriminator (LLD) and below the Upper Level Discriminator (ULD) are telemetered. The number of pixel records following the Windowed Timing Mode Frame Header is given in the Frame Header (Offset 136: N_Pixels). The size of the last data packet depends on the number of pixels telemetered.

5.8.3 Windowed Timing Mode Pixel Data Format

In order to conserve telemetry, only pixels above the LLD (Event Threshold) and below the Upper Level Discriminator (ULD) are stored for telemetry. Each pixel telemetered is represented by a four byte packed record containing X, Y, and DN, as shown in Table 47. The bit sequence is shown in Table 48, where the bytes are numbered in the order in which they appear in the telemetry stream (most significant byte first). Pixel positions are given in raw coordinates (see Appendix A).

Table 47: Windowed Timing Mode Pixel Bit Assignment

ITEM	**# Bits**
CCD column (RAWX, 0-599)	10
Row since Header (Y, 0-599)	10
Pixel Value (DN)	12
Total	**32**

The number of pixel records is given in the Windowed Timing Mode Header (Offset 136: N_Pixels).

Table 48: Windowed Timing Mode Pixel Bit Packing Sequence

	Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)
Byte 0 (MSB)	X9	X8	X7	X6	X5	X4	X3	X2
Byte 1	X1	X0	Y9	Y8	Y7	Y6	Y5	Y4
Byte 2	Y3	Y2	Y1	Y0	P11	P10	P9	P8
Byte 3 (LSB)	P7	P6	P5	P4	P3	P2	P1	P0

5.9 Photon-Counting Mode CCD Frame Record

The Photon-Counting Mode CCD Frame Record is the format used to store the data from a CCD frame taken in Photon-Counting Mode. A Photon-Counting Mode Frame Record consists of a fixed-format Photon-Counting Mode Frame Header followed by a variable number of X-ray event records.

Photon-Counting Mode employs a baseline row subtraction to correct for baseline levels and a bias frame subtraction in order to improve the spectral resolution. This calculation is done in floating point arithmetic. In order to obtain valid 12-bit unsigned data values after these corrections, a Baseline Offset value is added to each pixel value. This Baseline Offset must be subtracted from all pixel values during ground processing. The Baseline Offset used for each frame is given in the Photon-Counting Mode Frame Header. The amounts by which pixels underflow (<0) and overflow (>4095) the 12-bit data word after the Baseline Offset is added are telemetered in the frame header. These numbers should be monitored to determine whether the Baseline Offset value needs to be adjusted.

5.9.1 Photon-Counting Mode CCD Frame Header

The format of the Photon-Counting Mode CCD Frame Header is shown in Table 49.

Table 49: Photon-Counting Mode CCD Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x0091
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Photon-Counting Mode Frame Header ID	4	0x8073AB6F	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Count Rate	4	IEEE Floating Point	Count rate determined by ERP
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	x0000 <= Value <= 0x0FFF (0/+33	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	x0000 <= Value <= 0x0FFF (0/+33	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	x0000 <= Value <= 0x0FFF (0/+25	Reference Voltage for Amp 1
21	72	Vrd2	2	x0000 <= Value <= 0x0FFF (0/+25	Reference Voltage for Amp 2
22	74	Vog1	2	x0000 <= Value <= 0x0FFF (0/+12	Output Gate Voltage for Amp 1
23	76	Vog2	2	x0000 <= Value <= 0x0FFF (0/+12	Output Gate Voltage for Amp 2
24	78	1Rp1	2	x0000 <= Value <= 0x0FFF (0/+12	Serial Register clock phase 1 (left half)
25	80	1Rp2	2	x0000 <= Value <= 0x0FFF (0/+12	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	x0000 <= Value <= 0x0FFF (0/+12	Serial Register clock phase 3 (left half)
		Subtotal:	84		

Table 49: Photon-Counting Mode CCD Frame Header (cont.)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain A
	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain B
44	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row
45	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row
46	132	Nominal CCD Exposure Time	4	2 bytes of S/C seconds, 2 bytes of XRT subseconds	Nominal exposure time of CCD Image Area
47	136	Number of Events	2	Unsigned Integer	Number of Events following header
48	138	Lower Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Event Threshold used for this Frame (DN)
49	140	N > LLD	4	Unsigned Long Integer	Number Of Pixels Greater Than LLD
50	144	Upper Level Discriminator	2	0x0000 <= Value <= 0x0FFF	Upper Level Discriminator (DN)
51	146	N > ULD	4	Unsigned Long Integer	Number of Pixels Greater Than ULD
52	150	Split Threshold	2	0x0000 <= Value <= 0x0FFF	Threshold for splits in 3x3 neighborhood (DN)
53	152	Outer Ring Threshold	2	0x0000 <= Value <= 0x0FFF	Threshold for vetos in 5x5 outer ring (DN)
54	154	# Single	2	Unsigned Integer	Number of Single Pixel Events
55	156	# Split	2	Unsigned Integer	Number of Singly-Split Events
56	158	# Triples	2	Unsigned Integer	Number of Three Pixel Events
57	160	# Quad	2	Unsigned Integer	Number of Four Pixel Events
58	162	Window Half-Width	2	Unsigned Integer	Half-Width (X), in Pixels, of Centered Detection Window
59	164	Window Half-Height	2	Unsigned Integer	Half-Height (Y), in Pixels, of Centered Detection Window
60	166	Amp	1	Byte	
61	167	Baseline Offset	2	Unsigned Integer	Offset added to each pixel value (DN)
62	169	Pixel Overflow	2	Unsigned Integer	Amount by which brightest pixel overflows 4095
63	171	Pixel Underflow	2	Unsigned Integer	Amount by which faintest pixel underflows 0
64	173	Spare	3	0x00	Array of spare bytes
	176	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all previous bytes in packet
		TOTAL	**178**		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Readout Times. The count rate in this mode is defined as N_Events divided by the nominal exposure time.

5.9.2 Photon-Counting Mode Data Packet Format

The Photon-Counting Mode Header is followed by one or more CCSDS data packets, each containing up to 58 128-bit data records, one for each X-ray event. The structure of the CCSDS data packets is shown in Table 50.

Table 50: Photon-Counting Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-58	1 - 58, 128-bit event records	928	128-bit data record	X-ray event neighborhood (3x3)
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	946		

Only data for events that pass the Photon-Counting Event Recognition Algorithm are telemetered (see XRT-PSU-037 for a description of this algorithm). The number of event records following the Photon-Counting Mode Frame Header is given in the Frame Header (Item 47: Number of Events). The size of the last data packet depends on the number of events telemetered.

5.9.3 Photon-Counting Mode Event Data Format

In order to conserve telemetry, we define X-ray event records containing the information related to pixels containing valid X-ray events; only the event records are included in the telemetry data stream. The conditions defining valid X-ray events are discussed in connection with the X-ray Event Recognition Algorithm in PSU-XRT-037. Each event is represented by a 16-byte packed record containing (X, Y) of the central pixel in RAWX/RAWY coordinates (see Appendix A), and DN values of the 3x3 neighborhood centered on this pixel. The format is shown in Table 51, where X represents the RAWX position of the central pixel of the (3x3) neighborhood (0-599), Y represents the RAWY position of the central pixel (0-599), and A-J represent the nine neighborhood pixels, arranged in order as shown in Table 51 and Figure 8. Pixel E is the central pixel of the X-ray event. The bit sequence is shown in Table 52, where the bytes are numbered in the order in which they appear in the telemetry stream (most significant byte first).

Table 51: Photon-Counting Mode Event Bit Assignment

ITEM	# Bits
X position (RAWX: 0-599)	10
Y position (RAWY: 0-599)	10
DN for pixel A (X-1,Y-1)	12
DN for pixel B (X,Y-1)	12
DN for pixel C (X+1,Y-1)	12
DN for pixel D (X-1,Y)	12
DN for pixel E (X,Y)	12
DN for pixel F (X+1,Y)	12
DN for pixel G (X-1,Y+1)	12
DN for pixel H (X,Y+1)	12
DN for pixel J (X+1,Y+1)	12
Total	**128**

The number of event records is given in the Photon-Counting Mode Header (item 47).

G	H	J
D	E	F
A	B	C

Figure 8: Pixel Labelling Sequence for X-ray Event Neighborhood

Table 52: Photon-Counting Mode Event Bit Packing Sequence

	Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)
Byte 0 (MSB)	X9	X8	X7	X6	X5	X4	X3	X2
Byte 1	X1	X0	Y9	Y8	Y7	Y6	Y5	Y4
Byte 2	Y3	Y2	Y1	Y0	A11	A10	A9	A8
Byte 3	A7	A6	A5	A4	A3	A2	A1	A0
Byte 4	B11	B10	B9	B8	B7	B6	B5	B4
Byte 5	B3	B2	B1	B0	C11	C10	C9	C8
Byte 6	C7	C6	C5	C4	C3	C2	C1	C0
Byte 7	D11	D10	D9	D8	D7	D6	D5	D4
Byte 8	D3	D2	D1	D0	E11	E10	E9	E8
Byte 9	E7	E6	E5	E4	E3	E2	E1	E0
Byte 10	F11	F10	F9	F8	F7	F6	F5	F4
Byte 11	F3	F2	F1	F0	G11	G10	G9	G8
Byte 12	G7	G6	G5	G4	G3	G2	G1	G0
Byte 13	H11	H10	H9	H8	H7	H6	H5	H4
Byte 14	H3	H2	H1	H0	J11	J10	J9	J8
Byte 15 (LSB)	J7	J6	J5	J4	J3	J2	J1	J0

Bad pixels are tagged with TBD values.

5.10 Raw Image Mode CCD Frame Record

The XRT has a diagnostic mode in which it telemeters an entire raw CCD frame on command. The data are stored as a header followed by a complete CCD frame, including guard pixels, overclocked pixels, and MET words.

5.10.1 Raw Image Mode Frame Header

The header for raw image mode is shown in Table 53.

Table 53: Raw Image Mode CCD Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x0097**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Raw CCD Frame Header ID	4	0x80730F0F	Indicates Start Of CCD Frame Header
2	20	CCD Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Not Used	4	IEEE Floating Point	Count rate is not calculated for Raw mode
		Subtotal	48		

Table 53: Raw Image Mode CCD Frame Header (cont.)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	1Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of first CCD row
46	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of XRT subseconds	S/C Time at end of last CCD row
47	132	Nominal CCD Exposure Time	4	2 bytes of S/C seconds, 2 bytes of XRT subseconds	Nominal exposure time for CCD Image Area
48	136	Spare	4	0x00	
49	140	Number of Pixels	4	Unsigned Long Integer	Number of 16-bit Pixel Values following header
50	144	NCOL	2	Unsigned Integer	Number of columns in CCD image
51	146	NROWS	2	Unsigned Integer	Number of rows in CCD image
52	148	Spare	2	0x00	Array of spare bytes
53	150	Amp	1	Byte	Amp Number (1 or 2)
54	151	Spare	5	0x00	Spare bytes
	156	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	158		

See Appendix A for details of the CCD pixel layout. See Appendix B for interpretation of Read-out Times.

5.10.2 Raw Image Data Packet Format

The Raw Image Frame Header is followed by (nominally) 382,270 16-bit unsigned integer data words (exact number specified in the Frame Header). These data words are broken up into CCSDS packets as required. Up to 470 16-bit integers will be formatted into a CCSDS packet as shown in Table 54.

Table 54: Raw Image Mode Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-470	1 - 470, 16-bit pixel data words	940	0x0000 <= Value <= 0xFFFF	16-bit unsigned integers containing pixel data or Mission Elapsed Timer data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

The 382,270 data words are organized as 602 rows, each row containing 631 pixels followed by 4 MET values (for a total of 635 data words per row). The pixels are arranged in the same order that they are read out of the camera. The first pixel of the data array is therefore the guard pixel closest to the output amplifier (either the lower left pixel for Amp 0 or the lower right pixel for Amp 1). This is followed by the next pixel in the first row until all 635 data words from the first row have been included, after which the first pixel of the second row appears. Each row contains 5 guard pixels (not part of the image array), 600 imaging pixels, 5 more guard pixels, 21 over-clocked pixels, and 4 MET data words with time tags for the row (giving the spacecraft time at which the last pixel of the row is read out). See Appendix A for a description of the CCD pixel layout.

5.10.3 Raw Image Mode Pixel Bit Format

The format of the 16 bit data words in the Raw Image Mode Data Packets is shown in Table 55. Each 16-bit data word contains a 12-bit pixel value or a 12-bit Mission Elapsed Time (MET) value in the high 12 bits and 4 tag bits in the least significant bits. The last pixel in each row is marked with an end of line tag; the last pixel in the last row of the frame is marked with both an end of line and end of frame tag. Other tags will mark the MET values as shown in the Table.

Table 55: Raw Image Mode Pixel Data Bit Format

B15 msb	B14	B13	B12	B11	B10	B09	B08	B07	B06	B05	B04	B03	B02	B01	B00 lsb	Desc.
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	0	0	0	Normal Pixel Data Format
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	1	1	0	Pixel Data with End of Line and End of Frame
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	1	0	0	Pixel Data with End of Line
DATA11	DATA10	DATA09	DATA08	DATA07	DATA06	DATA05	DATA04	DATA03	DATA02	DATA01	DATA00	1	0	1	0	Pixel Data with End of Frame
LSB 11	LSB 10	LSB 09	LSB 08	LSB 07	LSB 06	LSB 05	LSB 04	LSB 03	LSB 02	LSB 01	LSB 00	0	0	0	1	12 LSBs of 24 LSBs of MET
LSB 23	LSB 22	LSB 21	LSB 20	LSB 19	LSB 18	LSB 17	LSB 16	LSB 15	LSB 14	LSB 13	LSB 12	0	0	1	1	12 MSBs of 24 LSBs of MET
MSB 11	MSB 10	MSB 09	MSB 08	MSB 07	MSB 06	MSB 05	MSB 04	MSB 03	MSB 02	MSB 01	MSB 00	0	1	0	1	12 LSBs of 24 MSBs of MET
MSB 23	MSB 22	MSB 21	MSB 20	MSB 19	MSB 18	MSB 17	MSB 16	MSB 15	MSB 14	MSB 13	MSB 12	0	1	1	1	12 MSBs of 24 MSBs of MET

5.11 CCD Bias Frame Record

CCD Bias frames can be telemetered on command, and consist of a Bias Frame Header followed by bias frame pixel data.

5.11.1 Bias Frame Header

The header for bias frames is shown in Table 56.

Table 56: CCD Bias Frame Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	0x0D40 (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	11xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	0x003F
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	CCD Bias Frame Header ID	4	0x8073F0F0	Indicates Start Of CCD Frame Header
2	20	CCD Bias Frame Counter	4	Unsigned Long Integer	Sequentially Number Each CCD Bias Frame
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	RA (J2000)	4	IEEE Floating Point	Right Ascention of this Frame
6	32	Dec (J2000)	4	IEEE Floating Point	Declination of this Frame
7	36	Roll	4	IEEE Floating Point	Roll angle of this Frame
8	40	ACS Bilevel Flags	1	0x00 <= Value <= 0xFF	ACS Status For This Frame: Bit 0: IS_SETTLED (LSB) Bit 1: IS_IN_10_ARCMIN Bit 2: IN_SAA_FLAG Bit 3: IN_SAFE_MODE
9	41	XRT State Flags	1	0x00 <= Value <= 0xFF	XRT State Flags for this frame: 0x11: Auto 0x22: Manual 0x44: Red
10	42	XRT Mode Flags	1	0x00 <= Value <= 0xFF	XRT Readout Mode For Last CCD Frame: 1 = Null 6 = Windowed Timing 2 = Short Image 7 = Photon-Counting 3 = Long Image 8 = Raw Data 4 = Piled-up Photodiode 9 = Bias Map 5 = Low Rate Photodiode 10 = Stop
11	43	CCD Waveform ID	1	0x00 <= Value <= 0xFF	Unique ID of CCD Waveform used
12	44	Spare	4	0x00	Spare bytes
		Subotal:	48		

Table 56: CCD Bias Frame Header (cont)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
13	48	TAM X1	4	IEEE Floating Point	X Position of TAM Image 1
14	52	TAM Y1	4	IEEE Floating Point	Y Position of TAM Image 1
15	56	TAM X2	4	IEEE Floating Point	X Position of TAM Image 2
16	60	TAM Y2	4	IEEE Floating Point	Y Position of TAM Image 2
17	64	CCD Temperature	2	0x0000 <= Value <= 0x0FFF	CCD Temperature for this Frame
18	66	Vod1	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 1 (left amp)
19	68	Vod2	2	0x0000 <= Value <= 0x0FFF (0/+33 V)	Output Drain Voltage for Amp 2 (right amp)
20	70	Vrd1	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 1
21	72	Vrd2	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Reference Voltage for Amp 2
22	74	Vog1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 1
23	76	Vog2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Output Gate Voltage for Amp 2
24	78	1Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (left half)
25	80	1Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (left half)
26	82	1Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (left half)
27	84	1pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 1
28	86	2pR	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Reset Gate Clock, amp 2
29	88	2Rp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 1 (right half)
30	90	2Rp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 2 (right half)
31	92	2Rp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Serial Register clock phase 3 (right half)
32	94	Vgr	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Guard Ring Bias Voltage
33	96	Vsub	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Substrate Bias Voltage
34	98	Vbackjun	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Back Junction Bias Voltage
35	100	Vid	2	0x0000 <= Value <= 0x0FFF (0/+25 V)	Input Diode Bias Voltage
36	102	Ip1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 1
37	104	Ip2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 2
38	106	Ip3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Image Area Parallel Clock Phase 3
39	108	Sp1	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 1
40	110	Sp2	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 2
41	112	Sp3	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Framestore Area Parallel Clock Phase 3
42	114	pIG	2	0x0000 <= Value <= 0x0FFF (0/+12 V)	Input Gate Clock
43	116	Vbaseline1	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain A
44	118	Vbaseline2	2	0x0000 <= Value <= 0x0FFF (0/+5 V)	Baseline Voltage for Signal Chain B
45	120	Readout Start Time	6	4 bytes of S/C seconds, 2 bytes of subseconds	S/C time at end of first row of first bias frame
46	126	Readout End Time	6	4 bytes of S/C seconds, 2 bytes of subseconds	S/C time at end of last row of last bias frame
47	132	Number of Bias Frames	4	Unsigned Long Integer	Total (cumulative) number of Bias Frames included in calculation of Bias Map
48	136	Amp	1	Byte	Amp Number (1 or 2)
49	137	Spare	9	0x00	Spare bytes
	146	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**148**		

See Appendix A for details of the CCD pixel layout.

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5.11.2 Bias Frame Data Packet Format

The Bias Frame Header is followed by 360,000 16-bit signed integers, organized as 600 rows, each row containing 600 pixels. Only the image area pixels are included in the bias map (it does not include guard pixels, overclocked pixels, or MET data words). These data words are broken up into CCSDS packets as required. Up to 470 16-bit integers will be formatted into a CCSDS packet as shown in Table 54.

Table 57: Bias Frame Pixel Data Packet Format

#	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x000D - 0x03B7 (20 - 958 Bytes)**
	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	Product Number	2	0x0000 <= Value <= 0xFFFF	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	Page Number	2	0x0000 <= Value <= 0xFFFF	Sequential Page # within this snapshot LDP
1-470	1 - 470, 16-bit pixel data words	940	0x0000 <= Value <= 0xFFFF	16-bit signed integers containing pixel data
	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
	TOTAL	**958**		

The pixels are arranged in the same order that they are read out of the camera. The first pixel of the data array is therefore the image pixel closest to the output amplifier (either the lower left pixel for Amp 1 or the lower right pixel for Amp 2). This is followed by the next pixel in the first row until all 600 data words from the first row have been included, after which the first pixel of the second row appears. Each row contains 600 Image Area pixels.

5.12 Bad Pixel Table

TBD

5.13 Snapshot Trailer

The Snapshot Trailer indicates the end of a snapshot in the telemetry data stream. The Snapshot Trailer consists of six sequential CCSDS packets. The format of the Snapshot Trailer is shown in Table 59 through Table 64. It begins with an ID word followed by a counter that sequentially increments throughout the mission. This is followed by the Observation Segment Number and Target ID. The rest of the information in the Snapshot Trailer is diagnostic information giving average housekeeping values and characteristics of the instrument setup. These are designed to be used by the quick-look analysis to verify instrument setup parameters.

5.13.1 Snapshot Trailer End ID

The Snapshot Trailer End ID is a two byte value that indicates the end of the Snapshot Trailer. This is used to verify the header end in case the header is corrupted in the middle and bytes are lost.

Table 59: Snapshot Trailer (packet 1)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x03B7**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Snapshot Trailer ID	4	0xFEC029B7	Used To Indicate Start Of Snapshot Trailer
2	20	Snapshot Counter	4	Unsigned Long Integer	Sequentially Number Each Snapshot
3	24	Observation Segment	1	0x00 <= OBSID <= 0xFF	Unique Observation Segment number for each target observation interval
4	25	Target ID	3	0x000000 <= ID <= 0xFFFFFF	Unique ID for each target
5	28	Snapshot Start Time (seconds)	4	0x00000000 <= Clock <= 0xFFFFFFFF	S/C Clock Time of Snapshot Start in Seconds
6	32	Snapshot Start Time (subsec)	2	0x0000 <= Clock <= 0xFFFF	XRT Clock Time of Snapshot Start in Subsec
7	34	UTC_Delta_Sec	4	0x00000000 <= Delta. <= 0xFFFFFFFF	UTC Correction for Snapshot Start Time
8	38	UTC_Delta_Subsec	2	0x0000 <= Delta <= 0xFFFF	UTC Correction for Snapshot Start Time
9	40	Snapshot End Time	6	4 bytes S/C seconds, 2 bytes subseconds	S/C Clock Time of Snapshot End in Seconds
10	46	UTC_Delta_End	6	4 bytes S/C seconds, 2 bytes subseconds	UTC Correction for Snapshot End Time
11	52	RA (J2000)	4	IEEE Floating Point	Right Ascention of Target Direction
12	56	Dec (J2000)	4	IEEE Floating Point	Declination of Target Direction
13	60	Roll	4	IEEE Floating Point	Roll angle
14	64	CCD Temperature Set Point	2	0x000000 <= Value <= 0xFFFFFF	In DN units for RTD HK output
15	66	Spare	2	0x00	spare
16	68	128 Housekeeping Max Values	256	0x0000 <= Value <= 0x0FFF	Max Value during Observation of each HK Channel
17	324	128 Housekeeping Min Values	256	0x0000 <= Value <= 0x0FFF	Min Value during Observation of each HK Channel
18	580	First 94 Housekeeping Sums	376	IEEE Floating Point (F1234)	Sum of all samples for each HK Channel
	956	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**958**		
		SIZE IN K (K = 1024)	**0.94**		

Table 60: Snapshot Trailer (packet 2)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x03B7**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Last 34 Housekeeping Sums	136	IEEE Floating Point (F1234)	Sum of all samples for each HK Channel
2	152	128 Housekeeping Squared Sums	512	IEEE Floating Point (F1234)	Sum of Squares of all samples for each HK Chan.
3	664	HK Summation Loop Counter	4	Unsigned Long Integer	Number Of HK Samples Summed During This Observation
4	668	Bias Row #1	200	0x0000 <= Value <= 0x0FFF	Mean Row used for baseline subtraction (central 100 pixels)
5	868	Spares	88	0x00	spare bytes
	956	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**958**		

Table 61: Snapshot Trailer (packet 3)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x03B7**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Spares	312	0x00	Spare bytes
2	328	BR #1 ULD	2	0x0000 <= Value <= 0x0FFF	Upper Level Disriminator used for Bias Row #1
3	330	BR #1 RML	2	0x0000 <= Value <= 0x00FF	Running Mean Length used for Bias Row #1
4	332	BR #1 Column Offset	2	0x0000 <= Value <= 0x04FF	Start of Bias Row in RAWX coordinates
5	334	BR #1 Length	2	0x0000 <= Value <= 0x00FF	Bias Row #1 length (100)
6	336	BR #1 Amp	2	0x0000 <= Value <= 0x000F	Amp (1 or 2) used for Bias Row
7	338	Bias Row #2	200	0x0000 <= Value <= 0x0FFF	Mean Row used for baseline subtraction (central 100 pixels)
8	538	Spares	400	0x00	Spare bytes
9	938	BR #2 ULD	2	0x0000 <= Value <= 0x0FFF	Upper Level Disriminator used for Bias Row #2
10	940	BR #2 RML	2	0x0000 <= Value <= 0x00FF	Running Mean Length used for Bias Row #2
11	942	BR #2 Column Offset	2	0x0000 <= Value <= 0x04FF	Start of Bias Row in RAWX coordinates
12	944	BR #2 Length	2	0x0000 <= Value <= 0x00FF	Bias Row #1 length (100)
13	946	BR #2 Amp	2	0x0001 or 0x0002	Amp (1 or 2) used for Bias Row
14	948	Current BR Bias Row	2	0x0001 or 0x0002	Bias Row being used in Bias Row Mode
15	950	Current WT Bias Row	2	0x0001 or 0x0002	Bias Row being used by Windowed Timing Mode
16	952	WT Event Limit	2	0x0000 <= Value <= 0xFFFF	WT Mode Event Limit
17	954	WT Column Offset	2	0x0000 <= Value <= 0x04FF	First column of WT row in RAWX coordinates
	956	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**958**		

Table 62: Shapshot Trailer (packet 4)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x03B7**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	WT Mode Columns	2	0x0000 <= Value <= 0x00FF	Number of columns in WT Mode
2	18	Spares	50	0x00	Spare Bytes
3	68	First 444 bins of 1024 Bin Event Histogram	888	024 x 16 Bit Array of Unsigned Integer	Cumulative Histogram (1024 channels) of All Events in Snapshot
	956	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**958**		

Table 63: Shapshot Trailer (packet 5)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x03B7**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Middle 470 bins of 1024 Bin Event Histogram	940	024 x 16 Bit Array of Unsigned Integer	Cumulative Histogram (1024 channels) of All Events in Snapshot
	956	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**958**		
		SIZE IN K (K = 1024)	**0.94**		

Table 64: Shapshot Trailer (packet 6)

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS Header	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x013B**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
1	16	Last 110 bins of 1024 Bin Event Histogram	220	1024 x 16 Bit Array of Unsigned Integers	Cumulative Histogram (1024 channels) of All Events in Observation
2	236	First CCD Frame Number	4	Unsigned Long Integer	Number of first CCD frame in dump
3	240	First CCD Frame Start Time	6	4 bytes S/C seconds, 2 bytes XRT subseconds	Start time of first CCD frame in dump
4	246	Last CCD Frame Number	4	Unsigned Long Integer	Number of last CCD frame in dump
5	250	Last CCD Frame Start Time	6	4 bytes S/C seconds, 2 bytes XRT subseconds	Start time of last CCD frame in dump
6	256	Sum of TAM X1	4	IEEE Floating Point	Sum of all TAM X1 samples in observation
7	260	Sum of TAM Y1	4	IEEE Floating Point	Sum of all TAM Y1 samples in observation
8	264	Sum of TAM X1^2	4	IEEE Floating Point	Sum of squares of all TAM X1 samples
9	268	Sum of TAM Y1^2	4	IEEE Floating Point	Sum of squares of all TAM Y1 samples
10	272	Sum of TAM X2	4	IEEE Floating Point	Sum of all TAM X2 samples in observation
11	276	Sum of TAM Y2	4	IEEE Floating Point	Sum of all TAM Y2 samples in observation
12	280	Sum of TAM X2^2	4	IEEE Floating Point	Sum of squares of all TAM X2 samples
13	284	Sum of TAM Y2^2	4	IEEE Floating Point	Sum of squares of all TAM Y2 samples
14	288	Number of TAM samples	4	Unsigned Long Integer	Number of TAM samples in observation
15	292	Boresight X correction	4	IEEE Floating Point	Boresight correction in X or RA (TBD)
16	296	Boresight Y correction	4	IEEE Floating Point	Boresight correction in Y or Dec (TBD)
17	300	Spare	16	0x00	
18	316	Snapshot Trailer End ID	4	0xED94037F	
	320	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding Checksum
		TOTAL	**322**		
		SIZE IN K (K = 1024)	**0.31**		

5.14 Snapshot Header Copy

As shown in Figure 7, the data for a given Snapshot ends with a copy of the Snapshot Header. This redundant copy has the correct number of pages inserted, and has the EOT field filled. The format of the redundant copy is shown in Table 65.

Table 65: Redundant Snapshot Header

#	OFF-SET	DESCRIPTION	# OF BYTES	FORMAT	COMMENT
CCSDS HDR	0	CCSDS Header Packet ID	2	0x0000 <= Value <= 0xFFFF	**0x0D40** (See Section 4.1.1 and Figure 4-7 of the 1553 ICD. AP_ID = 0x540)
	2	CCSDS Header Seq. Cntrl	2	0x0000 <= Value <= 0xFFFF	**11**xxxxxxxxxxxxxxB
	4	CCSDS Header Packet Length	2	0x0000 <= Value <= 0xFFFF	**0x0029**
	6	CCSDS Secondary Header	6		Time of CCSDS packet formation
LDP HDR	12	Product Number	2	Unsigned Integer	Unique ID # for this snapshot LDP (least significant 16-bits of Snapshot Count)
	14	Page Number	2	Unsigned Integer	Sequential Page # within this snapshot LDP
Standard LDP Header	16	Total Pages in File	2	Unsigned Integer	Total number of pages within snapshot LDP
	18	Observation Segment	1	0x00 <= Value <= 0xFF	Observation Segment assigned by FoM
	19	Target ID	3	0x000000 <= Value <= 0xFFFFFF	Unique ID of this Target, assigned by FoM
	22	Data Collection time	6	4 bytes S/C seconds, 2 bytes subseconds	S/C time of header creation
	28	UTC_Delta	6	4 bytes S/C seconds, 2 bytes subseconds	UTC Correction
1	34	Snapshot Header ID	4	0xFEC07B92	Indicates Beginning of Snapshot
2	38	Snapshot Count	4	Unsigned Long Integer	Sequential Number of this Snapshot
3	42	EOT Marker	4	0x4E074E07	End Of Transmission Marker
	46	Checksum	2	0x0000 <= Value <= 0xFFFF	Sum of all Bytes in packet excluding
		TOTAL	**48**		
		SIZE IN K (K = 1024)	**0.05**		

APPENDIX A: XRT CCD PIXEL LAYOUT

The design of the XRT CCD is illustrated in
Figure 9. Instrument coordinates are indicated on the figure for orientation. There are two amplifiers: Amp 1 and Amp 2. Either one can read out the entire CCD by clocking the readout register in the appropriate direction. The output amplifier is selected by selecting the appropriate CCD readout waveform. The telecommand that sets up the waveforms includes an Amp Number parameter, but this parameter actually has no effect on the hardware, and is only used to put the Amp Number into the telemetry. Therefore it is possible for the Amp Number to be incorrect, if it does not correspond correctly to the readout waveform.

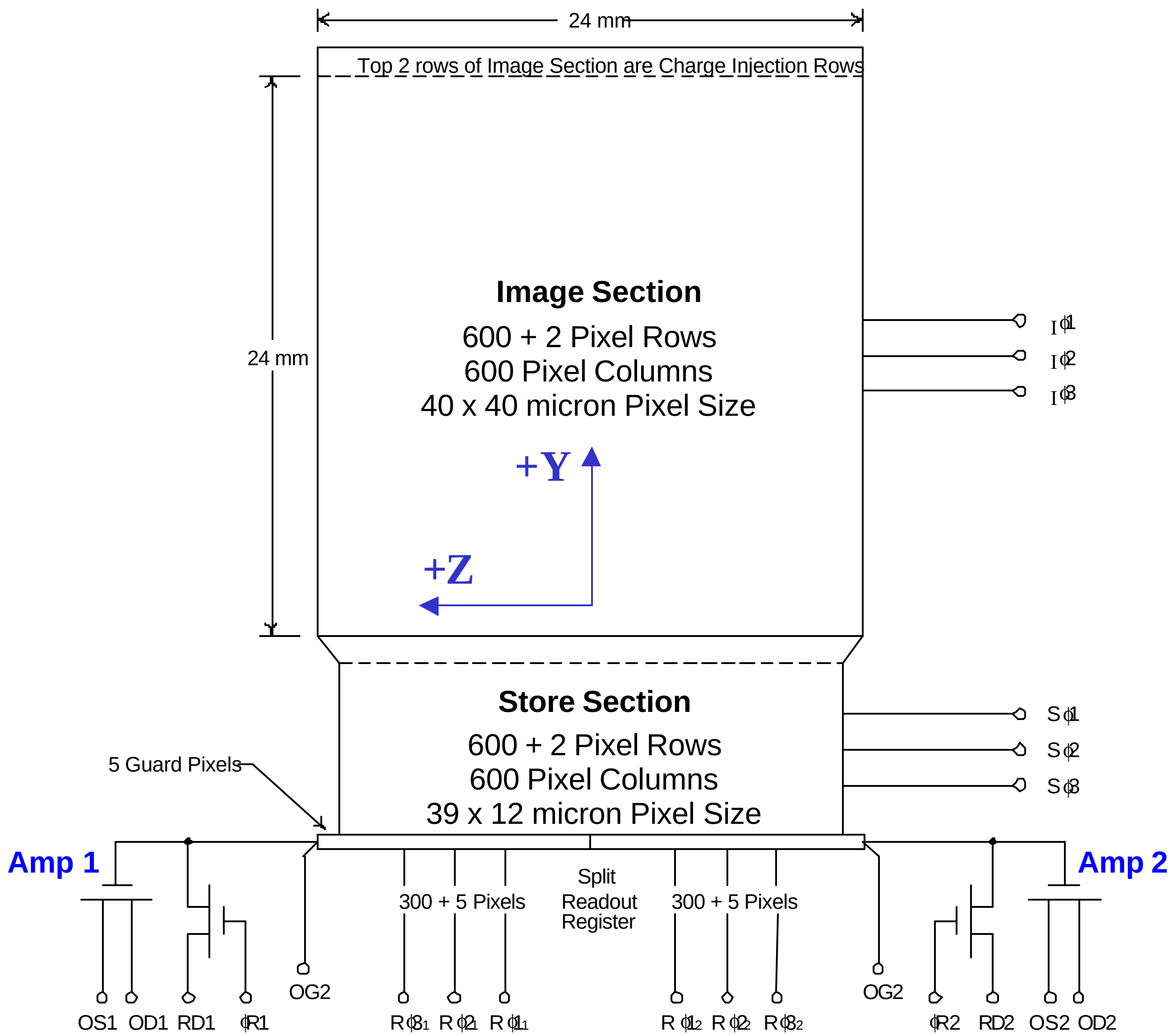

Figure 9: XRT MAT-22 CCD Layout, with Instrument Coordinates indicated

The XRT uses several different detector coordinate systems, defined as follows:

- CHIPX, CHIPY: coordinates used internally by some of the on-board software (e.g. photon-counting mode). Pixels are numbered (0:634, 0:601) as shown in Figure 10 and are relative to the output amplifier (in other words, the first pixel to reach the output amp is number 0). Pixels labeled "U" are not used. (The data in these pixels actually come from the previous row due to the pipelined architecture of the ADC.) Pixels labeled "G" are guard pixels and contain no charge. Pixels shown with "X" are used in Photon Counting mode for the 5x5 pixel event recognition. The overclocked pixels and the guard pixels on the right side of the image array are only used in Photon Counting mode. Columns 630-633 contain the Mission Elapsed Time (MET) time tag words (marked "T"). (In Windowed Timing mode, the MET pixels occur immediate after image pixel 353.)

- RAWX, RAWY: detector coordinates of the image area. Pixels are numbered (0:599, 0:601) and are relative to the output amp. The conversion from CHIP to RAW coords is:

  RAWX = CHIPX – 6 for ($6 \leq$ CHIPX ≤ 605)
  RAWY = CHIPY

  This is the coordinate system reported by the FSW in Image Mode, Low-Rate Photodiode Mode and Windowed Timing Mode.

- DETX, DETY: focal plane coordinates of image area in pixels, numbered (1:600, 1:602) so they can be compared with pixel numbers from image display software like *ds9*. Pixels are numbered relative to physical location on the CCD, not to amp readout. The conversion from RAW to DET coordinates is:
  - Amp 1:

    DETX = RAWX + 1
    DETY = RAWY + 1
  - Amp 2:

    DETX = 600 – RAWX
    DETY = RAWY + 1

- FOCX, FOCY: focal plane coordinates in mm from the center of the detector. The conversion from DET to FOC coordinates is

  FOCX = A + K*DETX
  FOCY = B + K*DETY

  where

  K = 0.0400 = pixel scale in mm/pixel
  A = -300.5 * K = pixel offset in mm
  B = -300.5 * K = pixel offset in mm

The numbering of CCD pixels in the CHIPX, CHIPY coordinate system is shown in Figure 10. Pixel (0,0) is always the pixel that is read out first, no matter which amplifier is used. These are therefore logical CCD pixel numbers rather than physical CCD pixel numbers. Due to a quirk of the analog to digital converter, the first pixel in each row is garbage and is ignored in all processing. The next five pixels are "guard" pixels, indicated by "G", which are pixels that exist in the readout register but not in the imaging array (see

Figure **9**). There are 5 more guard pixels at the end of the row, which are followed in turn by

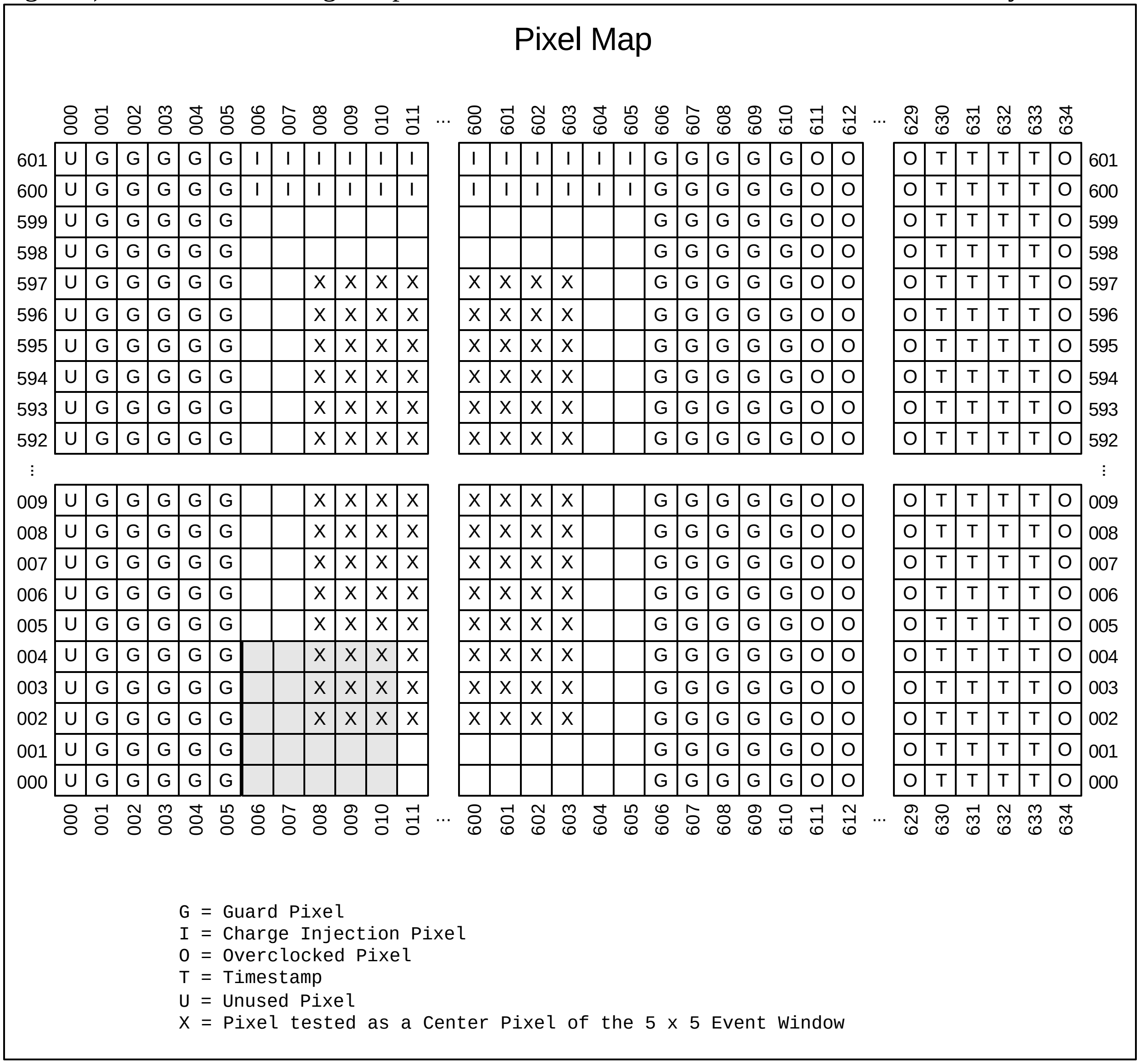

Figure 10: XRT CCD CHIPX/CHIPY **Pixel Numbering Scheme**

20 overclocked pixels that are used to establish the baseline level for the row. The last pixel in the row generates an “End of Line” signal to the hardware, which inserts the current spacecraft time into the data stream as a timestamp that occurs just before this final overclocked pixel.

As shown in Figure 10, the first row is numbered 0, and the first pixel read out in each row is numbered zero. The actual image area of the CCD occupies CHIPX/CHIPY pixels (6,0) to (605,601). These image pixels are numbered (0,0) through (599, 599) in the RAWX/RAWY co-ordinate system for telemetry purposes.

The portion of the CCD image analyzed by the event recognition processor for valid X-ray events in photon-counting mode is indicated by the “X” symbols. Photons arriving in the outer two rows and columns are ignored, as these pixels are used as a "veto layer" to remove cosmic ray events from the data stream. The 5x5 pixel event recognition neighborhood for pixel (8,2) is shaded.

The orientation of the CCD in the XRT instrument is indicated by the arrows on **Figure 9** showing the directions of the XRT Y and Z axes. The XRT axes are aligned with the spacecraft axes. The +X axis (which points from the detector through the mirror to the sky) is out of the paper in **Figure 9**.

APPENDIX B: XRT CCD READOUT TIMES

The XRT electronics hardware time-tags the end of each CCD readout line with the current spacecraft time from the XRT Realtime Clock. Because these times are directly measured by the hardware with high precision, the flight software uses them to time-tag the XRT data frames. However, some additional calculations must be performed on the ground to convert the Readout Times from the CCD frame headers to the actual start and stop times of the frames, or in the case of Timing Mode data, to time-tag each pixel.

Figure 11 shows the time sequence of a normal CCD readout (used for image and Photon-Counting modes and Raw Mode). The Nth image is exposed during readout of frame N-1. During the subsequent frame transfer the Nth frame is shifted into the framestore portion of the detector. Although this process is very rapid, strong sources will produce vertical streaks across the image during the frame transfer. Following the frame transfer, the N+1th frame is exposed while the Nth frame is read out. At the end of each row, the Mission Elapsed Time (MET) is read from the XRT Real-Time Clock and is inserted into the data stream. This time tags the end of each row. The MET associated with the first row of each frame is placed into the telemetry header of that frame as the "Readout Start" time. The MET associated with the last row is placed into the header as the "Readout Stop" time.

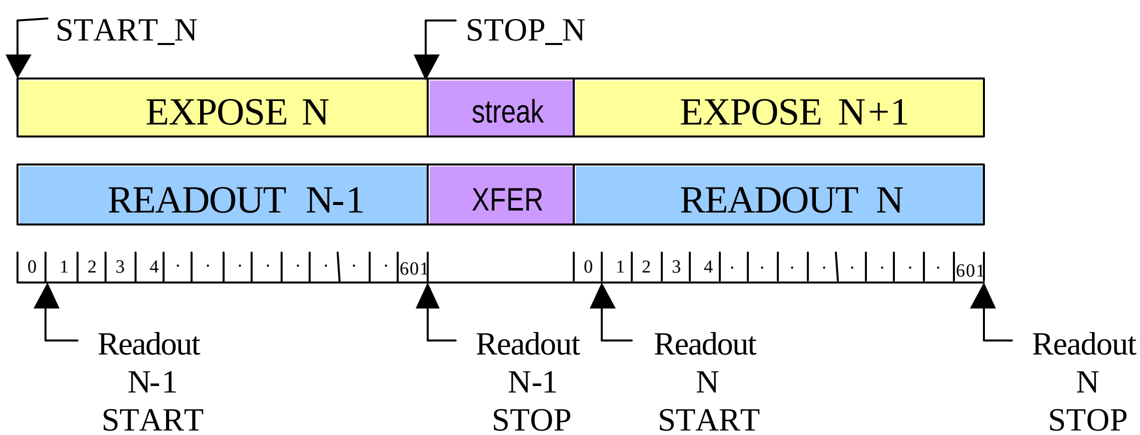

Figure 11: CCD Readout Timing (not to scale)

Because of the staggered timing of exposures and readouts, the Readout Stop time for the Nth frame actually corresponds to the end of the N+1th exposure. The actual exposure start and stop times for Frame N can be calculated from the following sequence of equations:

Row_Time = (Readout_N_STOP – Readout_N_Start) / (NROWS-1) ≈ 4.2 ms
XFER_Time = (Readout_N_START – Row_Time – Readout_N-1_STOP) ≈ 9 ms
Expose_Time = Readout_N_STOP – Readout_N_START + Row_Time ≈ 2.5 s
Start_N = Readout_N_START – Row_Time – XFER_Time – Expose_Time
Stop_N = Readout_N_START – Row_Time – XFER_Time

The timing modes work quite differently. Each "frame" corresponds to readout of 379,862 CCD pixels, treated as though they were 602 rows of 631 pixels each, with an end-of-line tag on the last pixel of each "row". At the end of each group of 631 pixels, the Mission Elapsed Time (MET) is read from the XRT Real-Time Clock and is inserted into the internal data stream (but not into the telemetry stream). This time tags the end of each "row". The MET associated with the first "row" of each "frame" is placed into the telemetry header of that "frame" as the "Readout Start" time. The MET associated with the last "row" is placed into the header as the "Readout Stop" time.

The time to transfer a single pixel of data in this mode is

Pixel_Time = (Readout_N_STOP – Readout_N_Start) / (631 x 601) ≈ 21.55 µs

The details of calculations for time-tagging photons in photodiode mode are given in XRT-PSU-037.

In Windowed Timing mode, each "frame" corresponds to readout of 600 CCD rows, with an end-of-line tag on the last pixel of each row. However, only events above threshold are actually stored in telemetry. At the end of each row, the Mission Elapsed Time (MET) is read from the XRT Real-Time Clock and is inserted into the internal data stream (but not into the telemetry stream). This time tags the end of each row. The MET associated with the first row of each "frame" is placed into the telemetry header of that "frame" as the "Readout Start" time. The MET associated with the last row is placed into the header as the "Readout Stop" time.

The time to transfer a row of data in Windowed Timing mode, which corresponds to the time resolution (since one output row of data in this mode covers the Half-Power Diameter of the mirrors), is given by

"Row"_Time = (Readout_N_STOP – Readout_N_Start) / (599) ≈ 1.19 ms

Details of time-tagging photons in Windowed Timing mode are given in XRT-PSU-037.