INTERFACE CONTROL DOCUMENT FOR THE ICU/DPU PROTOCOL FOR THE ULTRA VIOLET OPTICAL TELESCOPE

Document No.03691-DPUICD-01
Rev 1 Chg 8
September, 2003

SwRI Project No. 15-03691

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REVISION NOTICE

Version Identifier	Date of Issue	Summary of Changes
WIP113000	November 30, 2000	Draft version for use in teleconference conducted on December 19, 2000.
WIP122800	December 28, 2000	Final draft for comments prior to baseline. Changes from prior version include: • Clarified interface operational concept. • Changed some fields in the Mode command. • Removed most TBDs. • Deleted DPU Shutup command. • Deleted Tracking Report, Tracking Frame Switch, DCI Event Error, and No Good Guide Stars messages. • Editorial updates.
Rev 0 Chg 0	February 14, 2001	Initial release for signoff version • Incorporated minor review comments from WIP122800 version. Major changes limited to addition of ACK/NAK for ICU to DPU commands and special handling for NAK/NAK timeout on Mode Command. Also embellished the Operational Concept section.
Rev 0 Chg 1	February 19, 2001	Initial baseline. • Incorporates minor comments received from release-for-signoff Rev 0 Chg 0.
Rev 1 Chg 0	June 14, 2001	Incorporates the following changes: • Updated the list of Referenced Documents. • Made various corrections/clarifications in the Operational Concept section. • Update list of analog values reported in the Heartbeat message. • Incorporated changes to the Mode command as affected by updated definitions of FoM messages. • Updated ordering of filters in Mode command. • Added a second window to the XRT Position command. • Changed function codes for purge queues and reboot DPU commands. • Added SSI interface interword and interblock gap timing specifications. • Added analog-to-digital value conversions in Appendix A. • Added total length information to each command/message. • Misc. editorial and formatting improvements.
Rev 1 Chg 1	September, 2001	• Revised Mode Command fields • Clarified command verification/retry protocols. • Inserted Function Code in ACK/NACK. • Added NoOp command. • Updated A/D conversions.
Rev1 Chg2	October, 2001	• Clarified definitions of some Mode fields. • Added Detector Window fields to Mode. • Updated Appendix A.
Rev1 Chg3	February, 2002	• Minor cleanup edits. • Added section describing valid Mode Command configurations.
Rev1 Chg4	February, 2002	• Minor cleanup edits.
Rev1 Chg5	February, 2003	• Added submode 4; added LWL sub-field to Binning Level.

Rev1 Chg6	March, 2003	• Added missing ranges to Mode fields; resolved TBRs & TBDs.
Rev1 Chg7	April, 2003	• Added zero as valid Binning Level field value.
Rev1 Chg8	September, 2003	• Added note to 3.3.10.1. • Added footnotes to clarify meaning of window Position fields in Mode and XRT Position commands.
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LIST OF TBDs/TBRs

This document contains information that is as complete as possible. Where final numerical values or data structures are not available, best estimates are given and noted **TBR** (To Be Reviewed). Items which are not yet defined are noted **TBD** (To Be Determined). The following table summarizes the TBD/TBR items in this revision of the document, and supplements the revision notice above.

Section	Description

1.1 SCOPE

The purpose of this document is to clearly define the software protocol to be used in communications between the Ultra Violet Optical Telescope (UVOT) Interface Control Unit (ICU) and the Data Processing Unit (DPU). The messages defined in this document are transmitted over the synchronous serial interface (SSI). This document will be used as the basis for all information exchanges and command processing between the ICU and the DPU.

1.1 Overview

The UVOT Instrument consists of the Telescope, the Instrument Control Unit (ICU), and the Data Processing Unit (DPU). The ICU controls the overall operation of the UVOT. The DPU serves as a data processing slave to the ICU. The ICU controls the activities of the DPU using commands transmitted over a synchronous serial interface (SSI), and the DPU reports progress and status to the ICU over the same interface.

The UVOT contains a 256x256 CCD array which detects the arrival of photons. The UVOT is designed such that the arrival of a photon in a given CCD pixel can be further resolved to a location within an 8x8 array using a centroiding process. The CCD array, along with the Telescope Module (TM) high voltage power, thermal, and filter position are all controlled by the ICU. The ICU also commands the DPU into the proper processing configuration for a given exposure.

The DPU carries out all data processing activities on the detector event data as commanded by the ICU. The arrival of photons are reported to the DPU as 24-bit detector events containing either the x and y coordinates of the photon within the resulting 2048x2048 image area, or engineering information. Detector event data is sent directly to the DPU from the TM via the Data Capture Interface (DCI). The DPU compresses science and engineering data using a loss-less compression algorithm, forms CCSDS Source Packets, and transmits the packets to the spacecraft over the MIL-STD-1553B interface.

1.2 Protocol Rationale

The philosophy behind the organization of the protocol described in this document is based on the following goals:

1. Minimize messaging between the ICU and DPU so that the protocol remains simple.
2. Facilitate smooth transitions between operational modes and clearly resolve event data to its mode, while allowing for the DPU to get behind in the event stream when necessary.
3. Provide a foundation for deterministic operation.
4. Provide flexibility in the control of the DPU by the ICU.
5. Define a protocol which will facilitate the use of the spacecraft interface for the transmission of the messages defined during ground testing.

The above goals are accomplished by simple and consistent protocol. The protocol clearly conveys required mode and status information between ICU and DPU to maintain full operational synchronization.

1.3 Referenced Documents

The following documents, of the exact issue shown, were referenced as indicated during the development of this SRS. The applicability statement associated with each document reference indicates *Superceding* if the referenced document supersedes this document in the event of a conflict.

Document ID:	1143-EI-S19121
Originator:	Spectrum Astro, Inc.
Issue:	Rev - (25 AUGUST 2000)
Title:	Swift 1553 Bus Protocol Interface Control Document
Applicability:	Specifies the allocation of application identifiers (APIDs) to the DPU and ICU which were referenced in the assignment of APIDs to messages in this ICD.

Document ID:	1143-EI-S22904
Originator:	Spectrum Astro, Inc.
Issue:	Rev - (06 JUNE 2001)
Title:	Spacecraft to Payload Telecommand Interface Control Document
Applicability:	Defines the various messages which will be transmitted between the Spacecraft and the various Instruments.

Document ID:	GSFC 410.4-ICD-0006
Originator:	Goddard Space Flight Center, Greenbelt MD
Issue:	Version 1.03 (April 12, 2002)
Title:	Swift Onboard Operational Messaging Interface Document
Applicability:	Defines the messages to be transmitted by the Burst Alert Telescope (BAT) and Figure of Merit (FoM), and which describes the concept of operations for the Swift observatory.

Document ID:	SWIFT-UVOT-002
Originator:	Penn State University, State College PA
Issue:	Rev 0 Chg 0 (July 2000)
Title:	Swift Instrument Specification for the Ultra Violet Optical Telescope
Applicability:	Specifies the science requirements for the UVOT, and describes the science and engineering modes of operation.

Document ID:	XMM-OM/MSSL/SP/0007.08
Originator:	Mullard Space Science Laboratory, University College, London
Issue:	8
Title:	XMM-OM Electrical Interfaces Specification
Applicability:	Specifies the hardware interface and timing of the SSI interface on the XMM-OM mission, which is being reused on Swift as the communication bus between the ICU and the DPU.

Document ID:	XMM-OM/MSSL/ML/0011.4
Originator:	Mullard Space Science Laboratory, University College, London
Issue:	4
Title:	XMM-OM User Manual: ICU-DPU Protocol Definitions
Applicability:	Specifies the protocol used over the SSI interface on the XMM-OM mission, which was referenced during the development of this ICD.

2. OPERATIONAL CONCEPT

The following sections describe the operational concept applicable to the interface between the ICU and the DPU.

2.1 Startup Synchronization

The following sections describe how the DPU and ICU are synchronized in various startup scenarios.

2.1.1 Initial Power On

The DPU is a slave to the ICU, and so the DPU provides a Heartbeat messages to the ICU. Because the ICU and the DPU are powered on simultaneously, the ICU must wait a sufficient amount of time for the DPU to boot prior to expecting Heartbeat messages. The DPU transmits a Boot Complete message to the ICU once the DPU boot process is complete, and the ICU should not expect Heartbeat messages until this message has been transmitted. The DPU requires approximately 150 seconds to test memory, load the FSW into DRAM, and spawn and initialize the FSW tasks. So, the DPU will transmit the Boot Complete message and commence Heartbeat messages within approximately 2.5 minutes of a power-on.

If the ICU is able to differentiate a power-on from a watchdog reset, the ICU may await arrival of the Boot Complete message prior to expecting Heartbeat messages. However, since the ICU must also handle the situation in which the ICU reboots while the DPU is operational (see next section), it is probably simpler for the ICU to merely wait the worst case DPU boot time prior to expecting Heartbeat messages. Because the DPU watchdog timer times out in approximately 30 seconds, the ICU should wait 3 minutes prior to expecting Heartbeat messages (30 second watchdog timeout plus 150 second boot time).

2.1.2 ICU Reboots While DPU Operational

If the ICU and DPU are operational and the ICU reboots, the ICU will not know whether the DPU has also rebooted. The ICU should assume that the DPU also rebooted, and wait the full 3 minutes (see prior section) for the DPU to begin sending Heartbeat messages. The ICU should not await a Boot Complete message from the DPU, since if the DPU in fact did not reboot, it will already be sending Heartbeat messages.

2.1.3 DPU Reboots While ICU Operational

The ICU expects a Heartbeat message from the DPU every 10 seconds, but delays taking action until 20 consecutive Heartbeat messages have been missed. This provides sufficient time for the DPU to complete one reboot cycle. If the ICU and DPU are operational and the DPU reboots, the ICU will begin missing Heartbeat messages, and then will receive a Boot Complete message. In response, the ICU will signal an error condition in housekeeping and will execute a recovery action encoded in a relative time sequence (RTS). The ICU could suspend observations until ground contact resolves the cause of the reboot. However, because the DPU boots up into a state in which it is ready to conduct observations, the ICU could resume the current observation at the appropriate milestone by sending the DPU a Mode command.

2.2 Observation Handshaking

The ICU conducts observations by controlling the TM detector and the DPU. The DPU is commanded into a particular observation mode for a particular exposure time via the Mode command from the ICU. The DPU responds when ready to receive events using the Mode Ready message to the ICU. When the ICU has received a Mode Ready response, it will turn on the flow of TM detector events for the commanded exposure time, and then turn the flow of TM detector events off again. When all the events for a given Mode have been processed, the DPU responds using the Mode Complete message to the ICU. The DPU may get behind in the event stream (such as when preparing the Finding Chart), and so timestamps the Mode command upon receipt in order to locate the place in the event stream at which the mode transition should be effected. For this reason, the ICU is not required to wait for a Mode Complete message before commanding a subsequent mode. In the event the ICU needs the DPU to cease an exposure before the commanded exposure time, the ICU can command the DPU to Stop the exposure or Abort the exposure. A Stop exposure command causes the DPU to select an appropriate but immediate place in the event stream at which to cease the exposure and to complete and forward data products. An Abort exposure command causes the DPU to immediately stop processing events, discard any in-progress data products, and purge science and compression queues. The DPU responds to the ICU with a Mode Complete message in response to either of these commands. If the DPU receives a Stop Mode or Abort Mode command, the DPU will also discard any pending Mode commands, and will transmit a Mode Complete for each discarded Mode command.

The following sections provide generic and high level examples of the protocol at work under two operational scenarios. In the first scenario, the ICU and DPU coordinate to carry out a non-planned Gamma Ray Burst (GRB) observation. The second scenario gives an overview of how the ICU and DPU coordinate to carry out a pre-planned observation. The UVOT, as used below, denotes the Telescope Module, the ICU, and the DPU.

2.2.1 Planned Observation Example

To carry out a planned observation, the ICU will command the DPU to a particular science or engineering observation mode for a particular exposure time via the Mode command. The DPU responds with a Mode Ready message and collects and processes events in accordance with the commanded Mode for the commanded exposure time. The data products produced in the mode are dependant on the Mode command parameters. When the DPU completes the exposure, the DPU transmits a Mode Complete message to the ICU, returns to the Idle mode, and discards any incoming TM detector events.

2.2.2 Non-planned Observation Example

Initially, in a non-planned scenario, the DPU will most likely already be processing events for a planned observation. When a GRB occurs, the Burst Alert Telescope will send out a notification message to all the instruments within one second. If a Request for Slew occurs, the ICU will ready the DPU for the impending slew by sending the DPU a Stop Mode command. The DPU shall remain in Idle mode while the spacecraft slews to its new position, and continue compressing and transmitting any remaining queued data products to the spacecraft. When the spacecraft is within 10 arcmin of the target, the spacecraft will notify the ICU. In order to make room for the higher-priority burst data, the ICU will then send the DPU an Abort Mode command (which will cause the DPU to purge its output queues) followed immediately by a Mode command to begin a “settling exposure” in Event Mode. The UVOT is notified once the spacecraft has settled on the target, at which time the ICU sends a Stop Mode to the DPU followed immediately by a Mode command to begin a “finding chart exposure”. When the finding chart exposure has completed, the ICU may issue successive Mode commands to the DPU in order to process additional detector events acquired in different filters. In this way, the UVOT conducts the burst observation sequence by exchanging Mode, Mode Ready, and Mode Complete messages between the DPU and the ICU. When the DPU has completed processing the final Mode command in the observation transmitted by the ICU, the DPU will enter the Idle mode at which time the non-planned observation is considered complete. Data products produced by the DPU are sent directly to the spacecraft over the MIL-STD-1553 interface. The exact data products produced by the DPU are dependent on the mode as established by the Mode command sent to the DPU by the ICU. The following timing diagram illustrates a non-planned observation. **Note:** the timing diagram is intended to show relative ordering of the various events and messages, rather than absolute or relative timing to any accuracy. For example, the diagram appears to show a large time gap between the completion of the transient phase exposure taken during the slew settle period, and the initial 100 second finding chart exposure taken following slew settle. This gap is actually very small (approximately 0.5 seconds) to accommodate a filter wheel move in the transition from slew to slew settle.

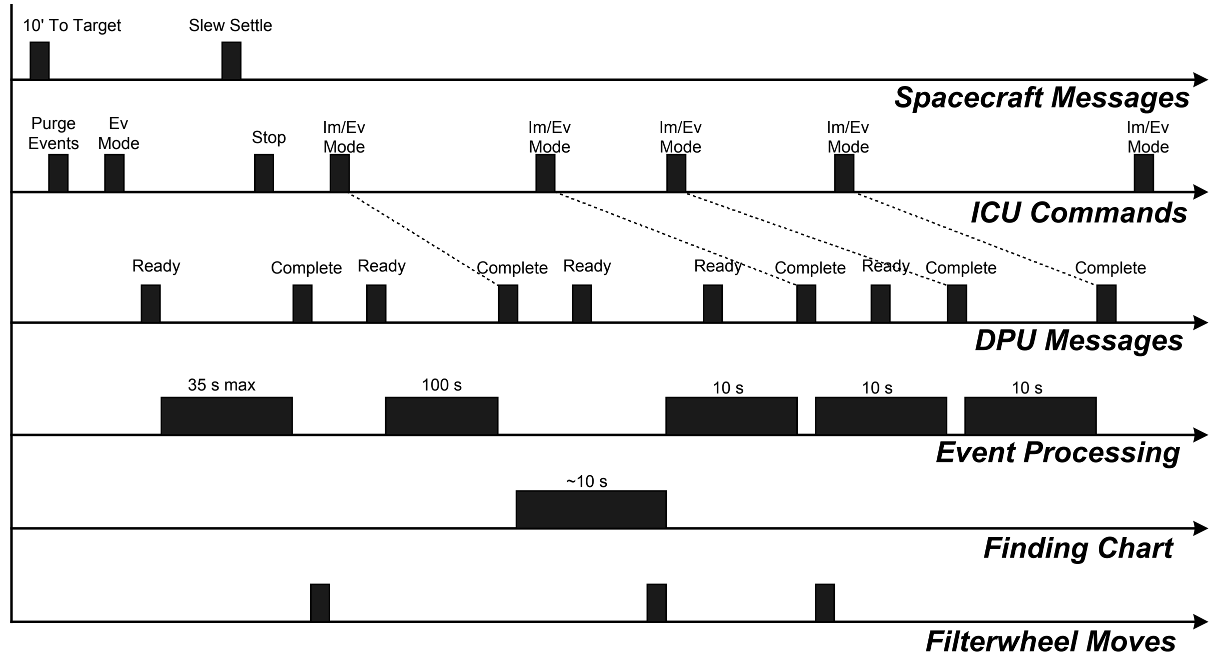

Figure 1. Non-Planned Observation Timing Diagram

2.3 Error Handling

The DPU is a processing slave to the ICU. Because the DPU is not responsible for the health and safety of the detector in any way, this ICD does not provide any sophisticated mechanisms by which the ICU can autonomously diagnose a DPU problem or formulate any automated response based on that diagnosis. In the event the DPU fails to respond to the ICU as specified by this ICD, the ICU will invoke a pre-programmed relative time sequence (RTS), which is selected according to the nature of the error (e.g. failed to respond to command, failed to transmit Heartbeat for required period, etc.). The only specific recovery command provided for in this ICD is the DPU Reboot command. However, the ICU may utilize other commands in order to establish or re-establish synchronization with the DPU (see next section).

2.4 Command and Message Verification

Because the ICU serves as the Instrument master, and the DPU serves as the Instrument processing slave, communications from the ICU to the DPU are formatted as CCSDS Telecommand Packets, and are referred to as *commands* in this ICD. Conversely, communications from the DPU to the ICU are formatted as CCSDS Telemetry Packets, and are referred to as *messages* in this ICD. The specific implementation of these formats are designed to match those defined for the interface with the spacecraft, as described in document 1143-EI-S19121, Swift 1553 Bus Protocol Interface Control Document. This not only eliminates the need to define a second command/message format, but also facilitates the ability to transmit these same commands and messages using the spacecraft simulator during ground testing. However, because the SSI interface does not have hardware-level message verification and message retry like 1553 does, some mechanism for ensuring message integrity is warranted. The following sections describe the concept for command and message verification.

2.4.1 Verification of Commands From ICU to DPU

Within one second of receiving a command from the ICU, the DPU will validate the correctness of the command's checksum and then will acknowledge (ACK) the command if the checksum is valid, or not-acknowledge (NAK) the command if the checksum is invalid. The DPU will additionally verify the execution of a Mode Command by responding with a Mode Ready message within three seconds.

If the ICU does not receive the nominal verification message(s) it will execute an appropriate command retry protocol from the list below:

- For any command, if the ICU receives a NAK the ICU will resend the command. If the resent command is also not properly acknowledged, the ICU will set an error flag and execute a programmable recovery sequence.
- For any non-Mode Command, if the ICU does not receive an ACK/NAK within one second, the ICU will resend the command. . If the resent command is also not properly acknowledged, the ICU will set an error flag and execute a programmable recovery sequence.
- For a Mode Command, if the ICU fails to receive an ACK/NAK within one second, the ICU will send a Stop Mode Command and then resend the Mode Command. If the resent Mode Command is also not properly acknowledged, the ICU will set an error flag and execute a programmable recovery sequence.
- For a Mode Command, if the ICU receives an ACK, but then fails to receive a Mode Ready Command within three seconds, the ICU will send a Stop Mode Command and then resend the Mode Command. If the resent Mode Command is also not properly acknowledged, the ICU will set an error flag and execute a programmable recovery sequence.

The reason for handling the Mode command differently than the other commands is to ensure that the ICU and the DPU remain synchronized with regard to the DPU's activities. In an error scenario, it is possible for the ICU to fail to receive an ACK/NAK and/or a Mode Ready response, when in fact a Mode command was successfully received by the DPU. If that were to occur, and the ICU resent the Mode command without an intervening Stop Mode command, the DPU would incorrectly assume that the ICU had asked the DPU to conduct two successive exposures in the same mode.

Until a command is properly acknowledged or the appropriate retry protocol is exhausted, the ICU will not try to issue a new command to the DPU, i.e. the verification handshakes of two commands shall not overlap.

2.4.2 Verification of Messages From DPU to ICU

Again, since the DPU is a slave to the ICU, communications from the DPU to the ICU are referred to as messages. In order to maintain simplicity in the protocol and in the DPU software, the ICU will not ACK/NAK messages sent by the DPU. The valid messages which can be sent from the DPU to the ICU are listed below, along with a rationale for not requiring an ACK/NAK

- Heartbeat - if one is missed or corrupted, another will be sent within 10 seconds.
- Mode Ready - if this message is missed or corrupted, the ICU will respond as described above.
- Mode Complete - this is primarily an informational message used to track completion of exposures. If missed or corrupted, it will not interfere with the observation.
- Channel Boundaries - this message is generated in response to a commanded engineering mode, which is expected to be conducted during ground contact. Occasional failure to receive this message is not considered critical, and the engineering mode can be rerun later when the failure is discovered.
- DPU Boot Complete - this is primarily an informational message.
- Upload Start - this is primarily an informational message.
- Upload End - this is primarily an informational message.

3. PROTOCOL DEFINITION

This section describes the protocol used to coordinate data processing activities between the ICU and the DPU. The following section describes the formats and conventions applicable to commands and messages. Then, a section will be presented which defines ICU to DPU commands followed by a section which defines DPU to ICU messages.

3.1 Command and Message Formats

The following subsections detail the specific format attributes assigned to commands and messages. **All commands and messages transmitted between the DPU and the ICU are big-endian.**

3.1.1 Command Format Specification (ICU to DPU)

The following subsections detail the specific format attributes assigned to commands transmitted from the ICU to the DPU. Format attributes include the header format, encoding method, and checksum properties. The maximum length of a complete command, including header, command parameters, and checksum is 62 bytes.

3.1.1.1 Command Header Format

All commands from the ICU to the DPU shall be formatted according to the following definition, which is identical to the definition of a CCSDS Telecommand Packet, with additional specifications as defined by document 1143-EI-S19121, Swift 1553 Bus Protocol Interface Control Document.

Version (3 bits) Type (1 bit) Sec Header (1 bit) APID (11 bits)	Seq Flags (2 bit) Seq Count (14 bits)	Packet Length	Secondary Header: Reserved (8 bits) Function Code (8 bits)	Command Parameters	Checksum
16 bits	16 bits	16 bits	16 bits	Variable	16 bits

Table 1. ICU to DPU Command Format

3.1.1.2 Command Identifier Encoding Method

The APID and Function Code shall be used together to encode/decode the command. The APID must be in the range 0x660 - 0x67F, which is the UVOT ICU Telecommand Range. The valid function code range is 0x00 - 0xFF. In order that the DPU can receive commands from either the ICU or directly from the spacecraft, command opcodes shall be interpreted by the DPU using the least significant 4 bits (nibble) of the APID and the 8-bit function code. For ICU to DPU commands, the least significant nibble of the APID shall be 0xA. Therefore, the command APIDs will be either 0x66A or 0x67A (the ICU uses two different APIDs to distinguish real-time commands from stored commands.

The format of the Command Identifier is illustrated in the following table:

Command Identifier			
0x0	APID LS Nibble (0xA)	Function Code MS Nibble	Function Code LS Nibble

Table 2. APID + Function Code Command Identifier

3.1.1.3 Packet Length

The packet length field within the CCSDS header is identical to the definition given in document 1143-EI-S19121. This field is set to the sum of the bytes within the Secondary Header, Command Parameters, and Checksum fields minus one.

3.1.1.4 Checksum Properties

The properties of the checksum computation are identical to those specified in document 1143-EI-S19121:

> *The checksum shall be a modulo 65536 addition of each octet of the CCSDS packet header, secondary header and application data fields, excluding the 2 octets of the checksum field. The checksum is a 2-byte big-endian unsigned integer.*

3.1.2 Message Format Specification (DPU to ICU)

The following subsections detail the specific format attributes assigned to messages. Format attributes include the header format, encoding method, and checksum properties. The maximum length of a complete message, including header, application data, and checksum is 62 bytes.

3.1.2.1 Message Header Format

All messages from the DPU to the ICU shall be formatted according to the following definition, which is identical to the definition of a CCSDS Telemetry Packet, with additional specifications as defined by document 1143-EI-S19121 and the addition of protocol elements specific to the interface between the ICU and the DPU.

Version (3 bits) Type (1 bit) Sec Header (1 bit) APID (11 bits)	Seq Flags (2 bit) Seq Count (14 bits)	Packet Length	Secondary Header: Collection Timestamp (1st) Seconds (32 bits) (2nd)Sub-seconds (16 bits)	Application Data Message ID (16 bits) + Variable data in 16-bit multiples	Checksum
16 bits	16 bits	16 bits	48 bits	Variable	16 bits

Table 3. DPU to ICU Message Format

3.1.2.2 Message Identifier Encoding Method

The APID 0x380 + *y*, where *y* is a Function Code index, shall be sent in the header of every message to the ICU in order to enable the ICU with the ability to determine the origin of its current telemetry item.

In order to facilitate ICU FSW reuse, the DPU FSW shall embed a unique 16-bit message identifier within the application data field. This message identifier will be located at the first two bytes of the application data field. This Message ID shall be defined as 0x0C00 + *y*, where *y* is the function code index described above.

3.1.2.3 Packet Length

The packet length field within the CCSDS header is identical to the definition given in document 1143-EI-S19121. This field is set to the sum of the bytes within the Secondary Header, Application Data, and Checksum fields minus one.

3.1.2.4 Checksum Properties

The checksum shall consist of the modulo 65536 addition of each byte *within the application data field only*[RLK1]. The checksum is a 2-byte big-endian unsigned integer that will be appended to the end of the message packet. The checksum is not computed over its location in the application data field.

3.2 ICU to DPU Commands

The following section describes the set of commands which shall be used for all communication from the ICU to the DPU. The code in parenthesis next to each command is the Command Identifier described in section 3.1.1.2.

3.2.1 Mode Command (0xA05)

3.2.1.1 Command Description

The Mode command shall be used to command the DPU into a particular science or engineering event processing mode. The mode shall become effective after the DPU has sent the Mode Ready message to the ICU.

The UVOT DPU has a total of eight modes in three categories, which are listed below. Additional information about each mode may be found in the DPU Software Design Specification.

- Idle Mode
- Science Modes: Event Mode, Image Mode, Image/Event Mode
- Engineering Modes: Raw Event List Mode, Channel Boundary Mode, Intensifier Characteristics Mode, Centroid Confirmation Mode

3.2.1.2 Command Parameters

Field Name	Description/Values	Size (bytes)
Mode	The Mode to be entered into by the DPU when this command is received. Possible values are: 0x02 = Event 0x03 = Image 0x04 = Image/Event 0x06 = Raw Event List Mode 0x07 = Channel Boundary Mode 0x09 = Intensifier Characteristics Mode 0x0A = Centroid Confirmation Mode	1
Sub-Mode Indicator	Bit array which indicates whether various sub-mode activities should be performed. The given activity should be performed if the indicated bit is set (logic one): 0x01 - Generate Finding Chart following exposure 0x02 - Save ACS messages during exposure 0x04 - Generate M/N images (when Mode=0x07) 0x10 - Perform tracking 0x20 - Generate Tracking Frame Switch data product	1
Exposure Length	The observation duration in seconds. Range: 0x0000 - 0xFFFF	2
Detector Electronics Output Format *Information only*	Current data format produced by the detector. 0x3 = Science, High Resolution Full Frame 0x4 = Engineering, M/N Data 0x6 = Engineering, Event Height Data (Event Energy Data also provided but should be discarded) As a matter of policy the ICU is not expected to use any other detector formats.	1
Binning Level	The lower 4 bits comprise a sub-field specifying the spatial binning to be used for images; four options exist-1x1, 2x2, 4x4, or discard image 0x0 = do not telemeter image 0x1 = 1x1 0x2 = 2x2 0x4 = 4x4 The upper 4 bits comprise a sub-field specifying the Long Word Length used for image compression, **minus 2**. The valid range of this sub-field is [0:15], i.e. 2<=long_word_length<=17.	1

Field Name	Description/Values	Size (bytes)
Filter ID *Information only*	The ID of the currently selected filter. Filter selected by ICU. 0 = Blocked 1 = Grism 1 (UV) 2 = UVW2 3 = V 4 = UVM2 5 = Grism 2 (Visible) 6 = UVW1 7 = U 8 = Magnifier 9 = B 10 = White 11 = Unknown	1
Target Type *Information only*	Target Type (Copied from FONEXTOBSINFO) 0x0 = Gamma Ray Burst (GRB) 0x1 = Target of Opportunity (ToO) 0x2 = Pre-Planned Target (PPT) 0x3 = Safe-Pointing (Provided by ICU if an observation is conducted during safe pointing)	1
Observation Number *Information only*	Target ID/Observation Segment (Copied from FONEXTOBSINFO) Least significant 24 bits contains a Target ID. A Target ID is associated with a single pointing location. This ID is set by the ground for pre-planned targets, and is set by the BAT/FoM for automated targets. Most significant 8 bits contains an Observation Segment that identifies which observation of this target is being conducted (is incremented each time this Target ID is separately observed).	4
Exposure Descriptor *Information only*	A label which the ICU may use to describe the mechanism that was used to configure the exposure. The format is described in the ICU documentation. The DPU merely forwards this descriptor into the telemetry produced for this exposure.	4
Image Position[A]	Desired **center** position of the Image Window specified as [x, y] coordinate pair in the detector coordinate system. For a full-field window specify position = (1024,1024). 1st two bytes = X position; Range: 0x0000 - 0x07FF 2nd two bytes = Y position; Range: 0x0000 - 0x07FF	4
Image Window Size	Size of the detector area, centered on the Image Position, over which to create an image. The window size is specified as x_width-by- y_height in detector pixels. 1st two bytes = X width; Range: 0x0000 - 0x0800 2nd two bytes = Y height; Range: 0x0000 - 0x0800	4
Event Position[A]	Desired **center** position of the Event Window specified as [x, y] coordinate pair in the detector coordinate system. For a full-field window specify position = (1024,1024). 1st two bytes = X position; Range: 0x0000 - 0x07FF 2nd two bytes = Y position; Range: 0x0000 - 0x07FF	4
Event Window Size	Size of the detector area, centered on the Event Position, over which to retain events (events outside this window will be discarded). The window size is specified as x_width x y_height in detector pixels. 1st two bytes = X width; Range: 0x0000 - 0x0800 2nd two bytes = Y height; Range: 0x0000 - 0x0800	4
Detector Window Position	**Origin** of the Detector Window configured in the telescope specified as [x, y] coordinate pair in the detector	2

[A] The window position should be the ICU's best estimate of the GRB position. The DPU is responsible for sliding the window as required to keep it fully on the active region of the detector (as defined by Detector Window fields). If the GRB coordinates fall outside the valid range of the field, the ICU should "clip" the coordinates so they are in range, i.e. move the position to the edge of the detector.

Field Name	Description/Values	Size (bytes)
	window coordinate system[B]. 1st byte = X origin; Range: 0x00 - 0x7F 2nd byte = Y origin; Range: 0x00 - 0x7F	
Detector Window Size	Size of the Detector Window configured in the telescope specified in detector window units[B]. 1st byte = X width; Range: 0x01 - 0x80 2nd byte = Y height; Range: 0x01 - 0x80	2
Finding Chart Control Word	Hook for ground to supply parameters to the Finding Chart algorithm. At the present time this field is not used.	4
Minimum Tracking Window Area	Minimum area of the detector (in detector pixels^2) that should be used for selecting guide stars. The DPU will select a hardware window for the DCI interface which encloses the specified Event Window and Image Window, enlarging it as needed within the specified Detector Window so that it covers the specified Minimum Tracking Window Area. Range:0 – 2048*2048	4
Tracking Frame Time	The desired tracking interval, in seconds. Range: 0x0000 - 0xFFFF	2
Number of Guide Stars	Number of guide stars to use if choosing guide stars for tracking Range: 0x00 - 0x10	2
Criteria Mask for Guide Stars	Selection criterion if choosing guide stars for tracking. 0x0001 = Centroid off center 0x0002 = Non-circular shape. 0x0004 = Star image too big. 0x0008 = Square moments too big. 0x0010 = Unequal square moments. 0x0020 = XY moment too big. 0x0040 = Not used. 0x0080 = Centroid in exclusion zone. 0x0100 = Star too bright. 0x0200 = Star too faint.	2
Short Spare 1	Spare 2-byte field	2
	Total Size of Parameters:	52
	Primary and Secondary Header Size:	8
	Checksum Size:	2
	Total Command Length:	**62**

3.2.1.3 Valid Command Configurations

Described below are the common Mode Command configurations (values in the command fields) that would be used in normal calibration & science operations. Other configurations are invalid, or are valid but would not normally be used.

Note that the following fields are listed as "information only" above, i.e. their values do not affect the operation of the DPU. They are included in the Mode command largely for the convenience of the ground data system.

- Detector Electronics Output Format: The DPU will report if the detector format does not match the format implied by the Mode field.
- Filter Id
- Target Type
- Observation Number
- Exposure Descriptor

[B] Each unit of the Detector Window coordinate system covers 16 detector pixels. For example, if the Detector Window Position is (0,2) and the Detector Window Size is (2,1) then the region which produces events is X∈[0,31], Y∈[32,47] in detector coordinates.

3.2.1.3.1 Channel Boundaries Exposure

The window parameters are ignored and the DCI interface is set to full field.

Field	Value
Mode	Channel Boundary Mode
Sub-mode	0 or 0x04
Binning level	NA
Event Window	NA
Image Window	NA
Detector Window	NA
Min Tracking Area	NA
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.2 Centroid Confirmation Exposure

The window parameters are ignored and the DCI interface is set to full field.

Field	Value
Mode	Centroid Confirmation Mode
Sub-mode	0
Binning Level	NA
Event Window	NA
Image Window	NA
Detector Window	NA
Min Tracking Area	NA
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.3 Intensifier Characteristics Exposure

The window parameters are ignored and the DCI interface is set to full field.

Field	Value
Mode	Intensifier Characteristics Mode
Sub-mode	0
Binning Level	NA
Event Window	NA
Image Window	NA
Detector Window	NA

Min Tracking Area	NA
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.4 Raw Event Exposure

The Event Window parameter is used to configure the DCI hardware window, which has 8-pixel resolution, but no software windowing is performed.

Field	Value
Mode	Raw Event Mode
Sub-mode	0
Binning Level	NA
Event Window	Any
Image Window	NA
Detector Window	NA
Min Tracking Area	0
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.5 Finding Chart Exposure

Field	Value
Mode	Image or Image/Event Mode
Sub-mode	required: 0x01; optional: 0x10,0x20
Binning Level	any
Event Window	Image/Event Mode: any; Image Mode: NA
Image Window	any (controls FOV of finding chart)
Detector Window	any
Min Tracking Area	any
FC Control	any
Tracking Frame Time	any
# Guide Stars	any
Guide Star Mask	any

3.2.1.3.6 Settling Exposure (spacecraft in motion)

Field	Value
Mode	Event Mode

Sub-mode	0x02[C]
Binning level	NA
Event Window	any
Image Window	NA
Detector Window	NA
Min Tracking Area	0
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.7 Pointed Normal Event Exposure

Field	Value
Mode	Event Mode
Sub-mode	0
Binning Level	NA
Event Window	any
Image Window	NA
Detector Window	NA
Min Tracking Area	0
FC Control	NA
Tracking Frame Time	NA
# Guide Stars	NA
Guide Star Mask	NA

3.2.1.3.8 Pointed Normal Image Exposure

Field	Value
Mode	Image Mode
Sub-mode	optional: 0x10, 0x20
Binning Level	any
Event Window	NA
Image Window	any
Detector Window	any
Min Tracking Area	any
FC Control	NA
Tracking Frame Time	any
# Guide Stars	any

[C] As of Feb 2002 the DPU ignores Sub-mode flag 0x02 (Save ACS Message).

Guide Star Mask	any

3.2.1.3.9 Pointed Normal Image/Event Exposure

Field	Value
Mode	Image/Event Mode
Sub-mode	optional: 0x10, 0x20
Binning Level	any
Event Window	any
Image Window	any
Detector Window	any
Min Tracking Area	any
FC Control	NA
Tracking Frame Time	any
# Guide Stars	any
Guide Star Mask	any

3.2.2 Stop Mode Command (0xA06)

3.2.2.1 Command Description

The Stop Mode command shall be used to command the DPU to immediately stop processing events, complete the current data product, discard any pending Mode commands, and enter Idle Mode where incoming events are discarded. The data product will include the actual exposure time and the number of frames. In response to this command, the DPU shall issue a Mode Complete message to the ICU after finishing the before-mentioned tasks, as well as a Mode Complete message for each discarded Mode command.

Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.2.3 Purge Compression Queue Command (0xA40)

3.2.3.1 Command Description

The Purge Compression Queue command shall be used to command the DPU to delete all data currently in the data compression queue. This command is not used in normal operations (the Abort Mode command results in the compression queue being purged).

3.2.3.2 Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.2.4 Purge Science Queue Command (0xA41)

3.2.4.1 Command Description

The Purge Science Queue command shall be used to command the DPU to delete all data currently in the science telemetry output queue (i.e., data pending transmission to the spacecraft). This command is not used in normal operations (the Abort Mode command results in the science queue being purged).

3.2.4.2 Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.2.5 XRT Position Command (0xA09)

3.2.5.1 Command Description

The XRT Position command shall be used to command the DPU to update the position and window parameters that it uses to spatially filter event data. Note that the 1553 protocol is such that the DPU will be sent a message containing this data over the 1553 bus; however the DPU will ignore the 1553 message in preference to the XRT Position command from the ICU. This is so that the ICU can determine whether to use the information, and since the ICU has the algorithm to convert the position information from RA/Dec format to the detector frame of reference.

3.2.5.2 Command Parameters

Field Name	Description/Values	Size (bytes)
Image Position[D]	Target position specified as [x, y] coordinate pair in the detector coordinate system. 1st two bytes = X position; Range: 0x0000 - 0x0800 2nd two bytes = Y position; Range: 0x0000 - 0x0800	4
Image Window Size	Size of the detector area, centered on the Image Position, over which to create an image. The window size is specified as x_width-by- y_height in detector pixels. 1st two bytes = X width; Range: 0x0000 - 0x0800 2nd two bytes = Y height; Range: 0x0000 - 0x0800	4
Event Position[D]	Target position specified as [x, y] coordinate pair in the detector coordinate system. 1st two bytes = X position; Range: 0x0000 - 0x0800 2nd two bytes = Y position; Range: 0x0000 - 0x0800	4
Event Window Size	Size of the detector area, centered on the Event Position, over which to retain events (events outside this window will be discarded). The window size is specified as x_width x y_height in detector pixels. 1st two bytes = X width; Range: 0x0000 - 0x0800 2nd two bytes = Y height; Range: 0x0000 - 0x0800	4
	Total Size of Parameters:	16
	Primary and Secondary Header Size:	8
	Checksum Size:	2
	Total Command Length:	**26**

3.2.6 Abort Mode Command (0xA0A)

3.2.6.1 Command Description

The Abort Mode command shall be used to command the DPU to abort all data processing immediately, purge telemetry and compression buffers, discard any pending Mode commands, and enter Idle Mode where incoming events are discarded. In response to this command, the DPU shall issue a Mode Complete message to the ICU after finishing the before-mentioned tasks, as well as a Mode Complete message for each discarded Mode command.

[D] The window position should be the ICU's best estimate of the GRB position. The DPU is responsible for sliding the window as required to keep it fully on the active region of the detector (as defined by Detector Window fields). If the GRB coordinates fall outside the valid range of the field, the ICU should "clip" the coordinates so they are in range, i.e. move the position to the edge of the detector.

3.2.6.2 Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.2.7 Reboot DPU Command (0xA42)

3.2.7.1 Command Description

The Reboot DPU command shall be used to command the DPU to reboot. In response, the DPU will send the DPU Boot Complete message to the ICU when the boot process has completed (refer to section 2.1).

3.2.7.2 Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.2.8 Deleted

3.2.9 NoOp Command (0xA24)

3.2.9.1 Command Description

The ICU may send the NoOp command to test the ICU/DPU command link. The DPU will ACK the NoOp command, but will take no additional action.

3.2.9.2 Command Parameters

There are no parameters for this command. Total command length is 10 bytes (8 bytes for primary and secondary header, and 2 bytes for the checksum).

3.3 DPU to ICU Messages

The following messages shall be used for all communication from the DPU to the ICU. **Note:** The first code in parenthesis next to each message is the message APID, while the second code is the Message Identifier. Refer to section 3.1.2.2 for additional information.

3.3.1 Heartbeat Message (0x381, 0x0C01)

3.3.1.1 Message Description

This message serves to inform the ICU that the DPU is still alive. A failure of the ICU to receive a Heartbeat is to be interpreted that the DPU software or hardware has failed, or that the DPU is rebooting. Refer to section 2.1 for information regarding application of this message during startup synchronization. The ICU shall wait 200 seconds since the last Heartbeat was received before taking any error recovery actions (this will nominally equate to a failure of the DPU to transmit 20 consecutive Heartbeat messages).

3.3.1.2 Message Parameters

Field Name	Description/Values	Size (bytes)
Mode	Current Mode (see Mode Command)	1
Submode Indicator	Current Submode (see Mode Command)	1
Hardware Temperatures	Temperatures of ICU and DPU hardware modules, 2 bytes each containing a 12 bit A/D value. A counts to temperature conversion table provided in Appendix A. Power Supply Module A Power Supply Module B ICU CPU Module ICU Interface Module DPU Comm/Mem Module Reserved #1 Reserved #2	14
Voltages	DEM Voltages, 2 bytes each containing a 12 bit A/D value. Conversion and calibration for these values are provided in Appendix A. Power Supply A +5V Power Supply B +5V Power Supply A +12V Power Supply A -12V Power Supply +5V Reference Input Power Supply -5V Reference Input One Reserved Input	14
Event Parity Errors	A counter representing the number of event parity errors which have occurred over DCI since the last heartbeat message. If the counter reaches the maximum value of 65535, it will not rollover but will remain at the maximum value until the heartbeat is sent and then the counter will reset to zero.	2
Reserved	Reserved for future use	4
	Total Size of Parameters:	36
	Primary and Secondary Header Size:	12
	Message Identifier Size	2
	Checksum Size:	2
	Total Command Length:	**52**

The following apply to the analog-to-digital values:

- The 16-bit A/D values have 12-bits resolution (0x000 - 0xFFF). The value 0x000 represents the most negative extent of the A/D converter, 0x800 represents 0 V, and 0xfff is the most positive extent of the A/D converter.
- If the most significant bit of the 16-bit value (0x8000) is set, the value is invalid. This bit is set on each item at bootup only, and is negated as soon as the item receives its initial A/D value. Not all A/D values are updated at the same time.

- If the second most significant bit of the 16-bit value (0x4000) is set, the value is suspect (i.e. the conversion didn't complete as expected).

3.3.2 Deleted

3.3.3 Deleted

3.3.4 Mode Ready Message (0x384, 0x0C04)

3.3.4.1 Message Description

The Mode Ready message shall be sent to the ICU when the DPU is ready to acquire new event data in the most recently commanded mode. The ICU may enable the detector event flow upon receipt of this message. The ICU will invoke a pre-programmed RTS if the DPU fails to respond to a Mode Command with a Mode Ready message within 3 seconds.

3.3.4.2 Message Parameters

Field Name	Description/Values	Size (bytes)
Mode	New Mode that was received by the DPU in the most recent Mode command.	1
Submode Indicator	New Submode Indicator that was received by the DPU in the most recent Mode command.	1
	Total Size of Parameters:	2
	Primary and Secondary Header Size:	12
	Message Identifier Size	2
	Checksum Size:	2
	Total Command Length:	**18**

3.3.5 Mode Complete Message (0x385, 0x0C05)

3.3.5.1 Message Description

The Mode Complete message shall be sent to the ICU when all of the events for a commanded mode have been processed (although data products generated may remain in the data compression and/or science telemetry output queue). A completion status allows the ICU to determine exactly how the previously commanded mode has ended. These values and their interpretations are discussed below:

- NORMAL - The mode completed as commanded. A complete data product has been queued for compression and transmission to the ground.
- STOPPED - The mode completed early in response to a Stop Mode command. A truncated but valid data product has been queued for transmission to the ground.
- ABORTED - The mode completed early in response to an Abort Mode command. The data product(s) have been discarded.
- ERROR - The mode has completed due to an unexpected error. The data product, if generated, may be corrupted. A completion error status may be generated, *for example*, when frame boundaries cannot be identified due to a lack of a timestamp event, when an excessive number of event errors were encountered, or when the exposure cannot be completed due to a lack of memory.

3.3.5.2 Message Parameters

Field Name	Description/Values	Size (bytes)
Mode	New Mode that was received by the DPU in the most recent Mode command.	1
Submode Indicator	New Submode Indicator that was received by the DPU in the most recent Mode command.	1
Completion Status	Indicates how the mode was completed: 0x1 - Normal 0x2 - Stopped 0x4 - Aborted 0x8 - Error	2
	Total Size of Parameters:	4
	Primary and Secondary Header Size:	12
	Message Identifier Size	2
	Checksum Size:	2
	Total Command Length:	**20**

3.3.6 Channel Boundaries Message (0x386, 0x0C06)

3.3.6.1 Message Description

This message is sent to inform the ICU of the channel boundaries produced in the Channel Boundaries Engineering mode.

3.3.6.2 Message Parameters

Field Name	Description/Values	Size (bytes)
X boundaries	X Boundary calculated for all 9 channels Values are in range -1.0 to 1.0, multiplied by 1000 and rounded to the nearest 16-bit integer. 18 bytes are formatted as 9 channels * 2 bytes each	18
Y boundaries	Y Boundary calculated for all 9 channels Values are in range -1.0 to 1.0, multiplied by 1000 and rounded to the nearest 16-bit integer. 18 bytes are formatted as 9 channels * 2 bytes each	18
	Total Size of Parameters:	36
	Primary and Secondary Header Size:	12
	Message Identifier Size	2
	Checksum Size:	2
	Total Command Length:	**52**

3.3.7 Deleted

3.3.8 Deleted

3.3.9 DPU Boot Complete Message (0x389, 0x0C09)

3.3.9.1 Message Description

This message is sent to the ICU immediately after the DPU has completed the boot process and has spawned the FSW tasks. The ICU should not expect Heartbeat Messages until this message has been transmitted. This message will be issued within approximately 2.5 minutes of a power-on, and within approximately 3 minutes following a watchdog timeout. The DPU watchdog timer times out in approximately 30 seconds, and the DPU requires approximately 150 seconds to test memory, load the FSW into DRAM, and spawn and initialize the FSW tasks.

3.3.9.2 Message Parameters

There are no additional parameters for this message. Total message length is 16 bytes (12 bytes for primary and secondary header, 2 bytes for message identifier, and 2 bytes for the checksum).

3.3.10 Upload Start Message (0x38A, 0x0C0A)

3.3.10.1 Message Description

This message is sent to the ICU immediately before the DPU starts an upload. The ICU should hold off commanding the DPU until the Upload End message is received. (Note: As of June 2003 the ICU is ignoring this message. We have no reason to believe that the DPU cannot perform uploads and process science data at the same time. DPU code uploads will take many ground passes, and we don't want the UVOT to remain idle all that time.)

3.3.10.2 Message Parameters

There are no additional parameters for this message. Total message length is 16 bytes (12 bytes for primary and secondary header, 2 bytes for message identifier, and 2 bytes for the checksum).

3.3.11 Upload End Message (0x38B, 0x0C0B)

3.3.11.1 Message Description

This message is sent to the ICU immediately after a DPU upload has ended. The ICU may now command the DPU normally.

3.3.11.2 Message Parameters

There are no additional parameters for this message. Total message length is 16 bytes (12 bytes for primary and secondary header, 2 bytes for message identifier, and 2 bytes for the checksum).

3.3.12 ACK/NAK Message (0x38F, 0x0C0F)

3.3.12.1 Message Description

The ACK/NAK message shall be sent to the ICU when the DPU receives a command from the ICU. An ACK shall be sent when the command passes its command checksum; else a NAK shall be sent.

3.3.12.2 Message Parameters

Field Name	Description/Values	Size (bytes)
ACK/NAK	Denotes acknowledgement or not-acknowledgement of the command. 0xFFFF - ACK 0x0000 - NAK	2
Command Identifier	Function Code of the command which was received.	2
	Total Size of Parameters:	4
	Primary and Secondary Header Size:	12
	Message Identifier Size	2
	Checksum Size:	2
	Total Command Length:	**20**

4. ELECTRICAL INTERFACE SPECIFICATIONS

The following sections describe the characteristics and timing of the electrical interface between the ICU and the DPU.

4.1 Electrical Interface Definition

Bi-directional communications between the ICU and DPU occur over the Synchronous Serial Interface (SSI). Both DPU and ICU are a source and sink of signals. The ICU is designated as the bus master. The SSI consists of five signals:

- SSI-DRX data ICU to DPU
- SSI-DTX data DPU to ICU
- SSI-CLX common clock of 125khz, generated in ICU
- SSI-FTX frame DPU to ICU
- SSI-FRX frame ICU to DPU

The digital interface signals are carried by differential lines.

4.2 Transmission Protocol

Data is transmitted across the SSI as follows:

- The SSI transmits data messages as blocks, which are comprised of a maximum of 31 16-bit words.
- An SSI frame is transmitting when the SSI-FTX signal becomes active high for 16 clock cycles starting with rising edge of SSI clock (i.e. after the processed clock signal goes high). All word bits are transmitted in that cycle.
- Words are transmitted with the most significant bit transmitted first.
- The interword gap (IWG) is defined as a gap between successive data words, and is a minimum of 1 clock cycle (8 microseconds), which can vary so long as it is less than the interblock gap.
- The interblock gap (IBG) is defined as a gap between successive data words which identifies the starting point of the next block. The following table defines the interblock gaps used by the ICU and the DPU, specified in milliseconds.

	ICU	**DPU**
Transmit IBG	8	6
Receive IBG	4	6

APPENDIX A
Analog Conversions

The following table provides conversions for the analog-to-digital (A/D) values contained in the Heartbeat message.

UVOT Analog Data (October 23, 2001)

Pattern for MUX	*Signal Name*	*Conversion*		
		SCM Flight S/N 001 (spare)	*SCM Flight S/N 002 (in DEM S/N 002 with ICU S/N ??)*	*SCM Flight S/N 003 (in DEM S/N 001 with ICU S/N ??)*
Voltages				
$0200	+5V Ref	EU = DN * 0.00283618 – 5.812	EU = DN * 0.00284464 – 5.810	EU = DN * 0.00282803 – 5.783
$0201	-5V Ref	EU = DN * 0.00283506 – 5.810	EU = DN * 0.00284446 – 5.809	EU = DN * 0.00282644 – 5.780
$0202	Analog1	EU = DN * 0.00283736 – 5.815	EU = DN * 0.00284437 – 5.809	EU = DN * 0.00282746 – 5.782
$0203	-12V	EU = DN * 0.00679996 – 13.935	EU = DN * 0.00683072 – 13.950	EU = DN * 0.00678933 – 13.884
$0204	+12V	EU = DN * 0.00679205 – 13.919	EU = DN * 0.00684097 – 13.971	EU = DN * 0.00679917 – 13.904
$0205	+5V	EU = DN * 0.00284077 – 5.822	EU = DN * 0.00284409 – 5.809	EU = DN * 0.00282927 – 5.786
$0206	+5V ICU	EU = DN * 0.00283419 – 5.808	EU = DN * 0.00284360 – 5.807	EU = DN * 0.00282643 – 5.780
Temperatures				
$031F	PSM Side B	EU = DN^5 * -2.88464e-14 + DN^4 * 4.40006E-10 + DN^3 * -2.67935e-6 + DN^2 * 0.008144463 + DN * -12.40439521 + 7645.20	EU = DN^5 * -3.1192e-14 + DN^4 * 4.7536e-10 + DN^3 * -2.88977e-6 + DN^2 * 0.00876174 + DN * -13.29564908 + 8150.93	EU = DN^5 * -2.85622e-14 + DN^4 * 4.36471e-10 + DN^3 * -2.66221e-6 + DN^2 * 0.008103923 + DN * -12.35727278 + 7623.29
$032F	PSM Side A	“	“	“
$033F	SCM	“	“	“
$03CF	+55 deg C Ref	“	“	“
$03DF	+25 deg C Ref	“	“	“
$03EF	-5 deg C Ref	“	“	“
$03FF	-35 deg C Ref	“	“	“
$035F	ICU CPU	NA (SCM spare)	Need conversions from MSSL	Need conversions from MSSL
$036F	ICU Interface	NA (SCM spare)	Need conversions from MSSL	Need conversions from MSSL

Notes:

- *DN* is the unsigned, 12-bit raw value (digital number) that is read from the A/D.
- *EU* is the converted engineering unit value. For voltages, the engineering unit is volts; for thermistor temperatures the final unit is deg C.
- The configuration for the A/D input and corresponding A/D output (DN) are the following:
  +5.00 V = 4095 0.0 V = 2048 -5.00 V = 0
- The full-scale raw value exiting the multiplexor is +5.12 V to -5.12 V which is scaled by 97.6% to +5.00 V to -5.00 V for A/D input. Individual channels are scaled additionally as indicated in the comments and notes. For voltage, the EU value corresponds to the original value before any scaling was performed.