TIMED

(Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics)

Guidance & Control Software

Interface Control Document

7363-9372
Software and Data Systems Group
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Table of Contents

1. Introduction

1.1 Purpose

This Interface Control Document (ICD) document defines the software interfaces of the TIMED Guidance and Control flight software.

1.2 Scope

This document forms part of the TIMED G&C Subsystem design folder as it pertains to software interfaces. It includes a top level description of the G&C subsystem, and provides a road-map to the various documents that define specific interfaces. Thus, this document is an umbrella ICD, with the subordinate ICDs being included by reference.

1.3 Acronyms and Abbreviations

AFC	Attitude Flight Computer
AST	Autonomous Star Tracker
AIU	Attitude Interface Unit
BC	Bus Controller
C&DH	Command and Data Handling
G&C	Guidance and Control
GNS	GPS Navigation Subsystem
ICD	Interface Control Document
IRU	Inertial Reference Unit
RT	Remote Terminal
S/C	Spacecraft
TASTIE	TIMED Attitude System Test & Integration Equipment

2. G&C Subsystem Overview

Figure 2.1 is a simplified block diagram of the G&C subsystem and shows the major components.

A MIL-STD-1553 serial data bus (called the G&C bus) is the primary internal interface between the components of the subsystem. The power subsystem's relays are designed such that one AIU is always powered. Both may be powered simultaneously, but it is impossible to turn both off. There are relays that determine which of the two AIUs controls the reaction wheels and torque rods; these relays are ganged together such that an AIU either controls all or none of the attitude actuators. A relay telltale tells each AIU whether it has control of the actuators. The active AIU, i.e., the one in control of the actuators, serves as the G&C bus controller and thus manages all bus traffic.

The autonomous star trackers and the IRUs provide their data to the AFC through RT-to-RT transfers on the G&C bus. The magnetometers, sun sensors, reaction wheels and magnetic torque coils are not directly connected to the G&C 1553 bus. These components have discrete interfaces, composed of analog and/or digital inputs and outputs that are directly connected to the AIU. The AIU must gather the sensor data and pass them to the AFC in periodic messages. The AFC responds to the input messages from the AIU with appropriate output messages. These messages contain actuator data that the AIU then writes to the actuators' interfaces. In this way, the AIU creates a virtual connection between these sensors and actuators and the AFC by way of the G&C bus.

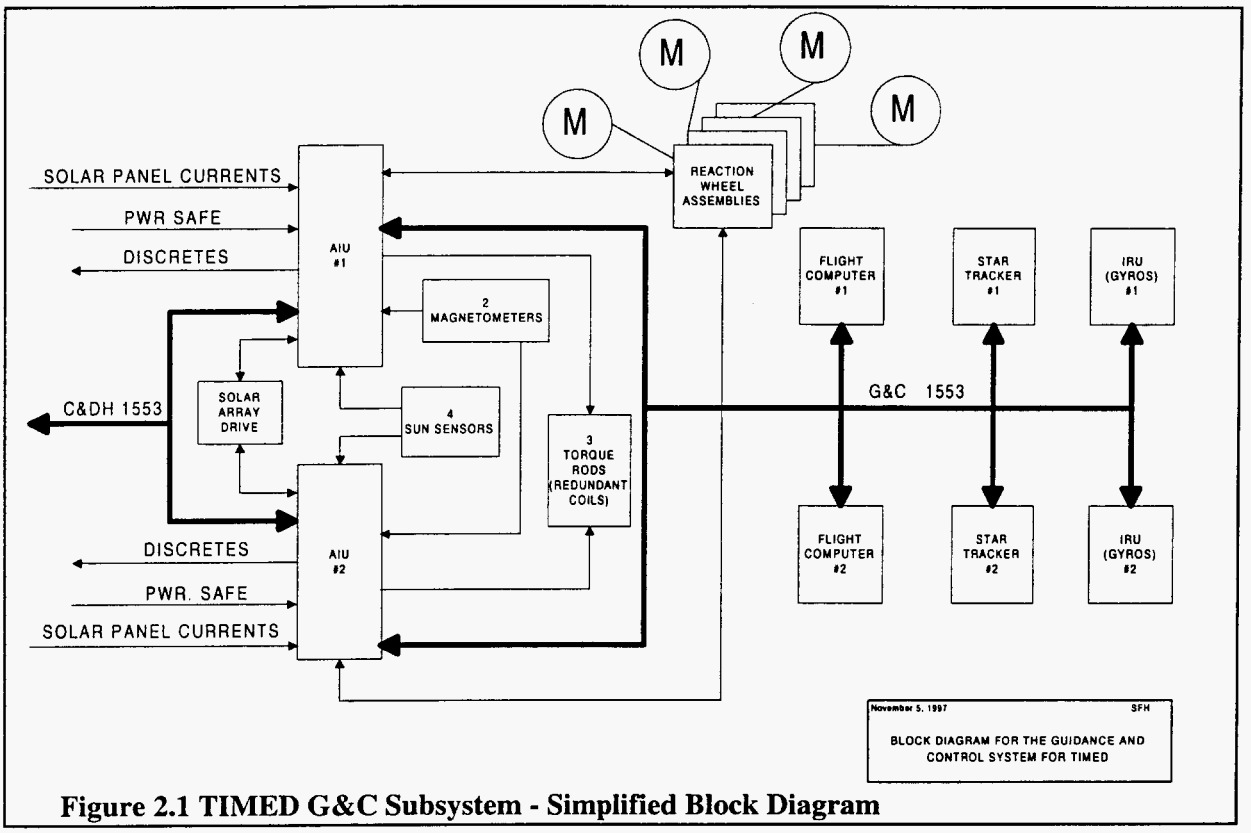

Figure 2.1 TIMED G&C Subsystem - Simplified Block Diagram

A second MIL-STD-1553 bus, the C&DH bus, provides the primary external interface for the G&C subsystem. The G&C's command and telemetry interfaces are implemented by having the AIUs participate as Remote Terminals on the C&DH 1553 bus. The ground may address a command packet to either AIU1, AIU2, the

active AIU, or the inactive AIU. Each command packet contains exactly one command message. The command message contains a destination code followed by one or more commands. The possible destinations are AIU 1 or 2, AFC 1 or 2, active AIU or AFC, or inactive AIU or AFC. Only the active AIU can perform routing of command messages. The inactive AIU can only process command messages destined for itself. Commands to the ASTs are packaged on the ground inside commands to the AIU. The AIU extracts the AST command from the enveloping AIU command, and forwards the AST command to its proper destination over the G&C bus. Similarly, the active AIU gathers telemetry from other G&C components via the G&C 1553 bus and forwards telemetry to the C&DH over its 1553 bus.

Each AIU includes the following interfaces:

1. MIL-STD-1553 bus interface for the C&DH 1553 bus with 32K words of RAM buffer.
2. MIL-STD-1553 bus interface for the G&C 1553 bus with 32K words of RAM buffer.
3. Inputs from two magnetometers, with three A/D inputs per magnetometer plus a redundant value.
4. Inputs from four sun sensors, with four A/D inputs per sun sensor.
5. An A/D wheel speed input from each of four wheels.
6. An A/D input of solar array current from each of two solar array wings.
7. An A/D input of solar array position from each of two solar array wings.
8. A digital output of solar array position for each of two wings (direction and magnitude (number of steps for pulse train)).
9. A D/A output of wheel torque for each of four wheels.
10. Redundant power system input discretes (hard LVSS).
11. Redundant IEM input discretes (soft LVSS / sun-safe).
12. Output discretes, four to each IEM.
13. An output to turn on/off each (two total) solar array drive.
14. An output to turn on/off each (two total) IRU.
15. Eight relay commands for each of three torque rods - on/off, and polarity(positive/negative), for both the primary and secondary coil.

3. Interfaces

Detailed interface specifications are contained in separate documents because of the variety of authors and vendors involved. These documents are included by reference in this document.

3.1 Command and Data Handling 1553 Bus

The definitive source for information on this interface is:

> TIMED Command and Data Handling 1553 Bus Specification
> APL Document 7363-9111, Version 3.1, April 21, 1999.

The C&DH bus is documented from the point of view of the bus controller, i.e., the C&DH subsystem. The document contains information about all of the bus transactions, not just G&C -related activities.

Additional notes about this interface from the perspective of the AIU are provided below.

There are two AIU's attached to the C&DH 1553 bus, the "Active AIU" and the "Inactive AIU". The Active AIU is the one currently controlling the spacecraft; the Inactive AIU (if powered on) is only running in standby. All message types can be sent to either AIU, and the C&DH shall communicate with both AIUs always, although the major message traffic is with the Active AIU.

Note that the Active AIU is communicating with both the Active AFC and the Inactive AFC (if it's powered on) via the G&C 1553 Bus. Therefore it is relaying data to/from these two other devices.

3.1.1 C&DH to AIU Messages

The C&DH transmits the following message types to the AIU(s):

- Time Sync Message (plus other misc. mode codes)
- GNS-to-GC Data Message
- Command_Packet_Segment Message(s)
- Data Wraparound In Message
- CUC Time/EOF Message

Note: 1553 Subaddress assignments for these messages are given in Table 3-4 of the C&DH bus specification.

3.1.2 AIU to C&DH Messages

The C&DH needs to "pull" the following message types from the AIU(s):

- Vector Message (plus other misc. mode codes)
- Housekeeping Message
- S/C Attitude Message
- (Normal) Telemetry Packet Message(s)
- (Diagnostic) Telemetry Packet Message(s)
- Data Wraparound Out Message

Note: 1553 Subaddress assignments for these messages are given in Table 3-4 of the C&DH bus specification.

3.1.3 Bus/Message Timing

The C&DH Bus Controller will operate the 1553 bus using a 1 Second Major Frame. There will be eight 125 ms Minor Frames in each Major Frame. The Bus Controller (BC) will divide up its communications requirements into the 8 Minor Frames, however the AIU(s) shall be (mainly) concerned with the 1 second Major Frame. That is, the AIU shall prepare all outgoing data and make it available to the C&DH once per second, and it shall inspect and process all incoming data once per second (reception of the Dead-Time Message shall trigger this processing). This will allow the AIU to run the control laws algorithms with more predictability, and allow it to concentrate on controlling its own G&C 1553 bus. See Appendix A of the C&DH bus specification for a full description of bus timing.

3.1.4 Time Sync and Time Messages

At the very beginning of the C&DH Major Frame the BC will send each AIU the "Time Sync Message". This message shall be the special 1553 Mode Code Command "Sync with Data Word". The purpose of this message is to reset a hardware clock within the AIU(s). This clock is used by the AIU software to accurately track the offset into the current CUC second. This high-resolution clock is needed to time-tag any attitude information inserted into the G&C's telemetry packets and into the S/C Attitude Message.

The BC will send this message at a very regular offset into each Major Frame, first to AIU #1 and then to AIU #2. Lab testing shall determine exactly what the nominal time offset actually is (to each AIU). This offset value shall be hard-coded into the BC's software, and is the value that is sent as the data word in the "Sync with Data Word" Mode Command. As part of its normal processing when this Mode Command is received, the AIU's 1553 controller chip shall load its hardware clock with this data word value, thus resetting it with an accurate value representing the offset into the current 1 second CUC. (This 16-bit clock has a 64 uSec lsb and is free running).

At some later time in the Major Frame the BC shall send the CUC Time Message to each AIU. This 3-word message shall contain a 32-bit count of the CUC in seconds in the first 2-words. This value shall correspond to the CUC value for the NEXT second. The AIU shall use this 32-bit value along with the 16-bit 64 usec hardware clock to accurately time-tag attitude and telemetry data.

Note that, at the time of arrival of the Time Sync message, the AIU shall already have the CUC seconds (received in the prior Major Frame). Therefore the AIU shall hold and store the received CUC seconds until the next Time Sync, and then update its global copy of CUC so that the 3 words remain properly correlated.

The AIU shall provide a means of autonomously maintaining CUC seconds in the absence of the C&DH, by auto-incrementing CUC seconds based on its own internal 1-second G&C Bus cycle timing.

The third word (word 2) of the message has several flags. One is the "Time Valid" flag; if this flag is not set then the AIU shall not use the given CUC Time.

Another flag in word 2 is the "Real-Time Downlink" flag. This indicates that the C&DH is preparing TLM frames for downlink in real-time, and that we should include any special RT TLM as our first regular packet; all other packets shall be sent to the recorder as usual.

3.1.5 GNS-to-GC Data Message

Once per second the BC shall forward this message from the GNS subsystem to the Active AIU. It contains GPS/Navigation data needed by the G&C Subsystem; most of the data is used by the AFC, not the AIU.

This message contains the following information:

- Field Validity and Warning Flags
- Time Tag
- Spacecraft Position and Velocity (J2000.0)
- Sun Unit Vector (J2000.0)

The actual message format/length is defined in Table 3-22 of the C&DH bus specification.

3.1.6 Command_Packet_Segment Message(s)

Background:

The C&DH receives Uplink Transfer Frames via the RF Uplink. This uplink runs at 2048 bits/sec. Embedded within these TF's are Command Packets. A Cmd_Pkt has a 3 word header and a data body of up to 2000 words. This implies that a (full sized) Cmd_Pkt will take 16-17 seconds to be received (a short one might take only 1 second). When a complete Cmd_Pkt is received the C&DH decodes the App ID portion of the packet header to determine which subsystem is to receive the Cmd_Pkt. It then forwards the entire Cmd_Pkt (header and body) to that subsystem; depending on its size this transfer may take several seconds. The 11-bit App ID's for the G&C System are:

```
bit A98 7654 3210    CMD
-----------------    ----
    001 0000 0000    G&C 1
    001 1000 0000    G&C 2
    010 0000 0000    Active G&C
    010 1000 0000    Inactive G&C
```

Note that packets for an AFC would typically be addressed to App ID 0x0200, the "Active G&C".

Command Packet Segment Messages:

When the C&DH receives a Cmd_Pkt for a G&C subsystem it shall pad the packet out (with words set to 0x0000) to a multiple of 32 words. It shall then send the packet across the 1553 bus to an AIU as a series of 32-word transfers. The BC may make up to 32 of these 32-word transfers in each Major Frame, therefore it may take more than a single major frame to transfer a large packet. Conversely, it may be possible for the C&DH to receive several small Cmd_Pkts in a single second, and in this case the C&DH may send more than one Cmd_Pkt to an AIU in a second. The AIU shall not restrict itself to only a single Cmd_Pkt per second. The content of each individual bus transfer is simply a segment of the stream, and has no fixed format. The AIU shall assume that any number of words, 0 to 1024, may be sent in any second, and that these words contain any number of embedded Cmd_Pkts.

At the end of the second (after dead-time notification) the AIU shall examine the words sent from the C&DH to see if a complete Cmd_Pkt(s) has been transferred; if so, they shall be processed, otherwise those words shall be buffered and any words received next frame shall be appended and the check performed again at the end of the next second.

We've allotted up to 1024 words of buffer space for these messages, on a single (indexed) subaddress. Note that each individual message has no specific format, but is always exactly 32 words in length.

3.1.7 Data Wraparound In/Out Messages

The AIU shall program its 1553 controller chip to allow for a data wraparound test. The In message and Out message buffers shall be one-and-the-same. Whatever the C&DH sends in the In message can be read back via the Out message. The buffer is 32 words long. Both the Active and Inactive AIU's support these messages.

3.1.8 CUC Time/EOF Message (Dead Time Signal)

Near the end of the Major Frame the BC shall send a 3-word EOF Message to each AIU. This message should be the very last message sent to each AIU, and should be sent as early as possible before the actual end of the Major Frame. This message shall signal the AIU to halt its 1553 chip and begin processing all data received during the current Major Frame. The AIU shall also prepare the 1553 chip for the next cycle, re-enabling it and then filling any outgoing buffers for the next cycle.

Note that the EOF Message *is* the CUC Time Message, as explained above under "Time Sync".

The C&DH should send this message at least 25 ms prior to the beginning of the next cycle, to allow the AIU(s) enough time to reset for the next cycle.

This message is three words in length, containing the 32-bit CUC Seconds, msw followed by lsw, plus a special flags word. See Table 3-18 of the C&DH 1553 Bus Specification.

3.1.9 Vector Message

Early in the 1 second Major Frame cycle the BC shall pull each AIU's Vector Message (this shall be the first "message pull" performed with each AIU). The Vector Message shall use the special 1553 Mode Command "Transmit Vector Message Word" command.

The contents of the vector message data word shall contain a series of buffer counts and status flags. These counts shall indicate how many outgoing messages that AIU has prepared for the BC. The AIU shall assume that the BC will pull the specified number of messages sometime during the current Major Frame, but it does not care exactly when. At the end of the Major Frame (when the Dead Time Message is received) that AIU shall assume that all specified messages were pulled, and the buffer space will be reused.

Vector Message word format (same as Table 3-10 in the C&DH 1553 Bus Specification):

```
(msb)  bits 15-12:  number of 131-word diagnostic packets, 0 to 8.
       bit  11-10:  spare
       bits 9-8:    number of 131-word telemetry  packets, 0 to 3.
       bit  7:      spare
       bit  6:      1=S/C Attitude Msg is valid, 0=not
       bit  5:      spare
       bit  4:      1=Bootstrap ROM Program is running, 0=not.
       bit  3:      1=Operational   Program is running, 0=not.
       bit  2:      1=Wheel Relays Are Enabled (ie, I'm Active), 0=not
       bit  1:      1=Fatal G&C Bus Error, 0=not
(lsb)  bit  0:      toggle-bit, alternates with each new vector msg
```

Notes:

- bit 0 should be checked each second. It should be different from the last cycle, indicating that the msg contents have been updated by the AIU and they are not stale from last time. It also provides some AIU "health" feedback to the C&DH.

- bit 6 indicates if the contents of the S/C Att buffer have been updated. The C&DH can always pull the buffer at 1 Hz regardless, but should only use the data if this bit is also set. The Boot program will never have S/C Att, so it would never set this bit. The Operational Program _MAY_ be unable to produce a valid S/C Att message, and this flag shall be used to indicate that. Note that the message itself may also have valid/not-valid flags embedded within, so this vector message bit may not really be required.

- bit 5 is spare.

- The Bootstrap ROM program shall always set bit 4 and clear bit 3.
- The Operational program shall always clear bit 4 and set bit 3.
- Other programs (TBD) shall set a different bit pattern here.

- bit 2 indicates that this AIU has detected that the wheel relays are set "toward" it, (ie, it's the G&C BC, the Active AIU)

- bit 1 is used by the Active AIU to signal to the C&DH that it has detected a failure while operating the G&C Bus, and that the C&DH should try to switch AIUs. The AIU shall remain active and continue to run the G&C bus until it is switched away.

3.1.10 Housekeeping Message

The BC shall pull each AIU's housekeeping message once per second; each AIU shall always make an HK message available.

The HK message is always 16 words long. The Active AIU shall make use of all 16 words, and expects that they all shall (eventually) be seen on the ground. The Inactive AIU shall only rely on the first 8 words being delivered to the ground, and only once every 8 seconds.

We've allotted up to 32 words for this message, on a single subaddress. The actual message length is 16 words. The format is defined in the following document:

> AFC Design Specification/User's Guide
> APL Document Number 7363-9380, September 2000

3.1.11 Spacecraft Attitude Message

The BC shall pull the Active AIU's Spacecraft Attitude message once per second from the Active AIU only. The Active AIU's requirements should dictate that it's always available, but the Inactive AIU will not have this message available (if the Boot program is running it will not be available). A bit in the vector message indicates

if the buffer is valid. Also, a header flag word in this message indicates the validity of the various message fields (the inactive AIU shall always set these to "not valid").

Note that the attitude specified shall have a 3-word hi-res time-tag, 32-bit CUC seconds, plus 16-bit 64-usec offset within the second.

The contents of this message contains positional information that was transformed/derived from the GNS-to-GC Message that was received in the last Major Frame, as well as internally computed G&C attitude information.

We've allotted up to 64 words for this message, on 2 consecutive subaddresses. The actual message format/length is 64 words. See Appendix B of the C&DH bus specification.

3.1.12 Telemetry Message(s)

The BC shall pull the vector message-specified number of 131-word Normal Telemetry Packets from each AIU. These TLM Packets may have originated in the AIU or an AFC; standard TLM Packet header fields shall identify the source. Note that the C&DH shall always pull 0, 131, 262, or 393 words (0 to 3 packets).

The Vector Message may specify up to 3 TLM packets available per second, from each AIU, however NORMALLY that high rate won't occur. The Active AIU is routing TLM from itself and both AFC's, so it is likely to have 3 packets very often, but the Inactive AIU only has a single packet from itself. However, during Memory Dump "mode" the Inactive AIU may generate 3 dump packets per second. Likewise, the AFC's may generate 3 dump packets per second, which the Active AIU would route. While the C&DH bus schedule shall accommodate 6 total packets per second from the G&C, the Mission Ops crew should be careful when commanding such a high rate so as not to overflow the recorder. (Note: the 1 Hz rate from each computer is primarily meant to support Memory Dump TLM records, which would occur for a fairly short period of time, say approx. 8-9 minutes to dump 64K words. Normal TLM rates would be more on the order of 1 packet per 30 seconds from each system).

We've allotted up to 393 words of buffer space for this message, on a single (indexed) subaddress.

3.1.13 Diagnostic Message(s)

The BC shall pull the vector message-specified number of Diagnostic TLM Packets from each AIU. These packets may have originated in the AIU or an FC. There may be up to 8 Diag TLM Packets per second from the Active AIU (a mix of its own and the two AFC's). The Inactive AIU shall be programmed to never present Diagnostic Packets to the C&DH.

Diagnostic Messages are a special type of TLM packet that the C&DH shall write to a specially reserved circular queue area of the recorder. These special TLM buffers normally are never transmitted to the ground by the C&DH, except when it (the C&DH) is specifically commanded to do so. Note that the C&DH is responsible for managing the recorder queue.

We've allotted up to 1048 words of buffer space for this message, on a single (indexed) subaddress.

3.2 AIU Commands

The AIU's command definitions are contained in:

> TIMED Attitude Interface Unit Command and Telemetry Specifications
> APL Document 7363-9374, August 2000

3.3 AIU Telemetry

An excellent overview of G&C-generated telemetry is contained in the following APL-internal memo:

> TIMED Guidance and Control (G&C) Telemetry
> APL Memorandum SRS-98-086, May 7, 1998

G&C housekeeping telemetry is discussed in the following APL-internal memo:

> TIMED Guidance and Control Housekeeping Telemetry
> APL Memorandum SRS-98-067, April 16, 1998

The definitive source of the AIU's housekeeping and packetized telemetry definitions are contained in:

> TIMED Attitude Interface Unit Command and Telemetry Specifications
> APL Document 7363-9374, August 2000

3.4 AIU Analog, Digital, and Discrete Interfaces

The AIU's analog, digital, and discrete interfaces are specified in:

> TIMED Attitude Interface Unit Hardware Description
> APL Document 7363-9376, June 1998

3.5 Guidance & Control 1553 Bus

The G&C bus, as discussed in the overview, is the primary internal interface among the G&C components. The bus is fully described in:

> TIMED Guidance & Control 1553 Bus Interface Control Document
> APL Document 7363-9373, May 2000

3.6 AFC Commands

The AFC's commands are defined in the following document:

> TIMED Attitude Flight Computer Design Specification/User's Guide
> APL Document 7363-9380, September 2000

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> TIMED Guidance and Control Housekeeping Telemetry
> APL Memorandum SRS-98-067, April 16, 1998

The definitive source for the AFC's housekeeping and packetized telemetry definitions is the following document:

> TIMED Attitude Flight Computer Design Specification/User's Guide
> APL Document 7363-9380, September 2000

3.8 AST Interfaces

The star tracker interface specifications are contained in the following vendor documents:

> TIMED Autonomous Star Tracker Primary Packet Description, Lockheed Martin Missiles and Space Advanced Technology Center, 2A05850, 10 April 1998
>
> TIMED Autonomous Star Tracker Command and Data Interface, Lockheed Martin Missiles and Space Advanced Technology Center, 2A05849, 10 April 1998
>
> TIMED Autonomous Star Tracker Handbook (Operator Reference Only), P489427, 9 March 1998

3.9 IRU Interface

The gyro interface specifications are contained in the following vendor document:

> Radiation Hardened Miniature Inertial Measurement Unit (MIMU) Inertial Reference Unit (IRU) Interface Control Document, Specification No. ICDYG9666C, Honeywell Space Systems Group, September 9, 1996