NASA Standard Communications and Data Handling Subsystem

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Summary — At the 1975 International Telemetering Conference Charles F. Trevathan discussed the Multimission Modular Spacecraft (MMS) in general and the Communications and Data Handling (C&DH) subsystem in particular. The National Aeronautics and Space Administration's Goddard Space Flight Center (NASA GSFC) Is managing the MMS program and is integrating the first spacecraft, the Solar Maximum Mission, in-house. Contracts have been let for the Modular Power Subsystem (MPS), Attitude Control Subsystem (ACS) and the Communications and Data Handling (C&DH) Subsystem. The C&DH subsystem provides the command and telemetry link between the spacecraft and the terrestrial system; distributes commands to and collects telemetry from all spacecraft systems via a duplex serial multiplex data bus and Remote Interface Units (RIU's); and contains on board computation capability. The C&DH is a single 4 x 4 x 1-1/2 foot module. The staffed module weighs 270 pounds including 60 pounds of mission unique equipment. The future for this kind of versatile hardware is exceptionally bright as it is cost effective and its modular structure permits repair, refurbishment and even modification/dating in space.

Introduction — During the early development of space exploration the risks and costs associated with delivering a payload to orbit justified custom design of each spacecraft to exact the maximum benefit from each modicum of weight in orbit. As the rocket systems have matured and become more reliable this efficient but expensive approach has had to be modified to save money. Although program planners had been reflecting the new philosophy (primarily by trying to utilize left over hardware) for some time, the major impetus came with the announcement and implementation of the NASA Low Cost Program in 1973. One of the thrusts towards cost savings by this office has been the declaration of certain items of hardware as NASA Standard. The most ambitious task in the standardization of flight equipment has been the development of the Multimission Modular Spacecraft(MMS). The potential cost savings from implementation of the MMS are impressive. Estimates have been made that Design, Development, Test and Engineering (DDT&E) savings realized from utilizing MMS in preference to a custom design amount to half the DDT&E costs. It has also been shown that coupled with the

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The C&DH Module is being built by Fairchild Space & Electronics Company for NASA Goddard Space Flight Center on Contract NAS5-23846.

Space Transportation System (STS, Shuttle) the on orbit refurbish/service compatibility of the MMS will result in typical logistic savings of one third.[2]

Although the MMS is designed to take maximum advantage of the STS capabilities it is compatible with conventional launch vehicles and, in fact, will first be flown on a Delta for the Solar Maximum Mission in the fall of 1978.

In 1975 the MMS and its Communication and Data Handling Subsystem (C&DH) were discussed at this International Telemetering Conference Session VII, "Workshop on Data System Standards".[3] Now, two years later, as the concept is being reduced to practice it is appropriate to describe the C&DH module and its capabilities.

<u>Functional Description</u> — C&DH is the MMS Module that provides a telemetry and command link between the host spacecraft and the ground facility. Additionally it provides onboard computation capability. Communication between the C&DH and the host spacecraft equipment is via a redundant, duplex, multiplex data bus and Remote Interface Units (RIU) located in or near the user equipments.

Operation of the system is best described with the aid of the simplified block diagram, Figure 1.

Command — Ground commands, either direct or via the Tracking and Data Relay Satellite System (TDRSS), are received on the spacecraft antenna (which is not part of the C&DH). The signal is routed to the transponder receiver where it is received, detected and presented as a baseband pulse train to the Standard Telemetry and Command Components (STACC) Central Unit (CU). As both transponder receivers are always on line the CU has duplicate received command inputs. Both of these inputs are decoded (deconvolved) and an error-free signal selected for further processing. The selected decoded command is verified and sent out on the redundant supervisory bus to all Remote Interface Units (RIU). Figure 2 shows the command word format. Bits C2 thru C6 address the command to the correct RIU. The RIU has been assigned its address by means of a coding plug which individualizes the otherwise identical units. Three types of command messages are provided:

1. Serial magnitude command which provides a 16 bit serial pulse stream to any one of 8 destinations.

2. Pulse command which provides a 28 volt pulse and selects one of 64 ground returns.

Host S/C 2.048 Mbps and 100 Hz to 3 MHz Date Sources

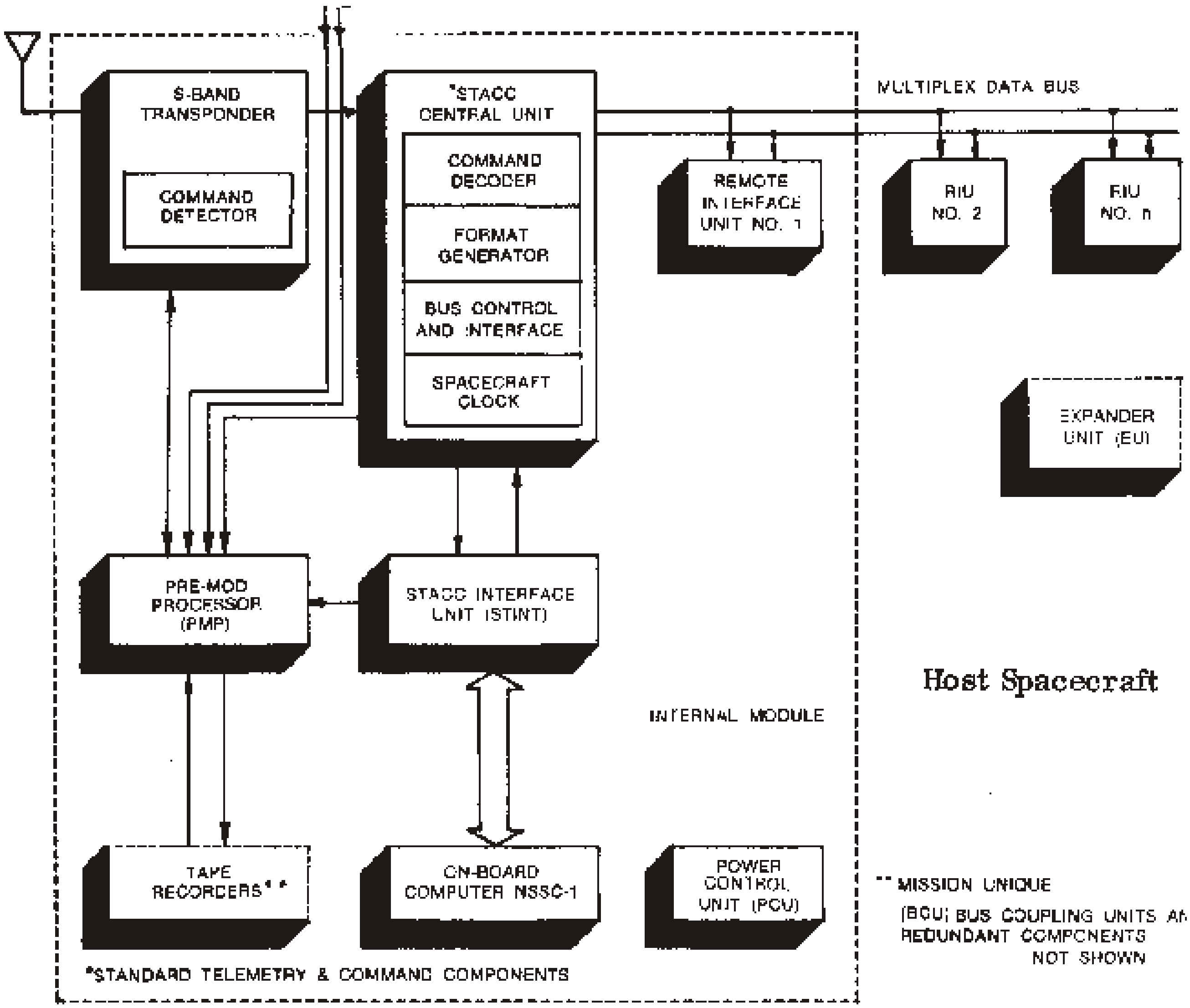

Figure 1. SIMPLIFIED C&DH SUBSYSTEM BLOCK DIAGRAM

3. Telemetry address, which is, in effect a call for telemetry. Selecting one of 64 inputs per RIU and specifying one of four signal types:

- 8 bit A to D converted analog.
- bit A to D converted conditioned analog.
- bit serial digital
- Bilevel 8 channels, sequentially sampled.

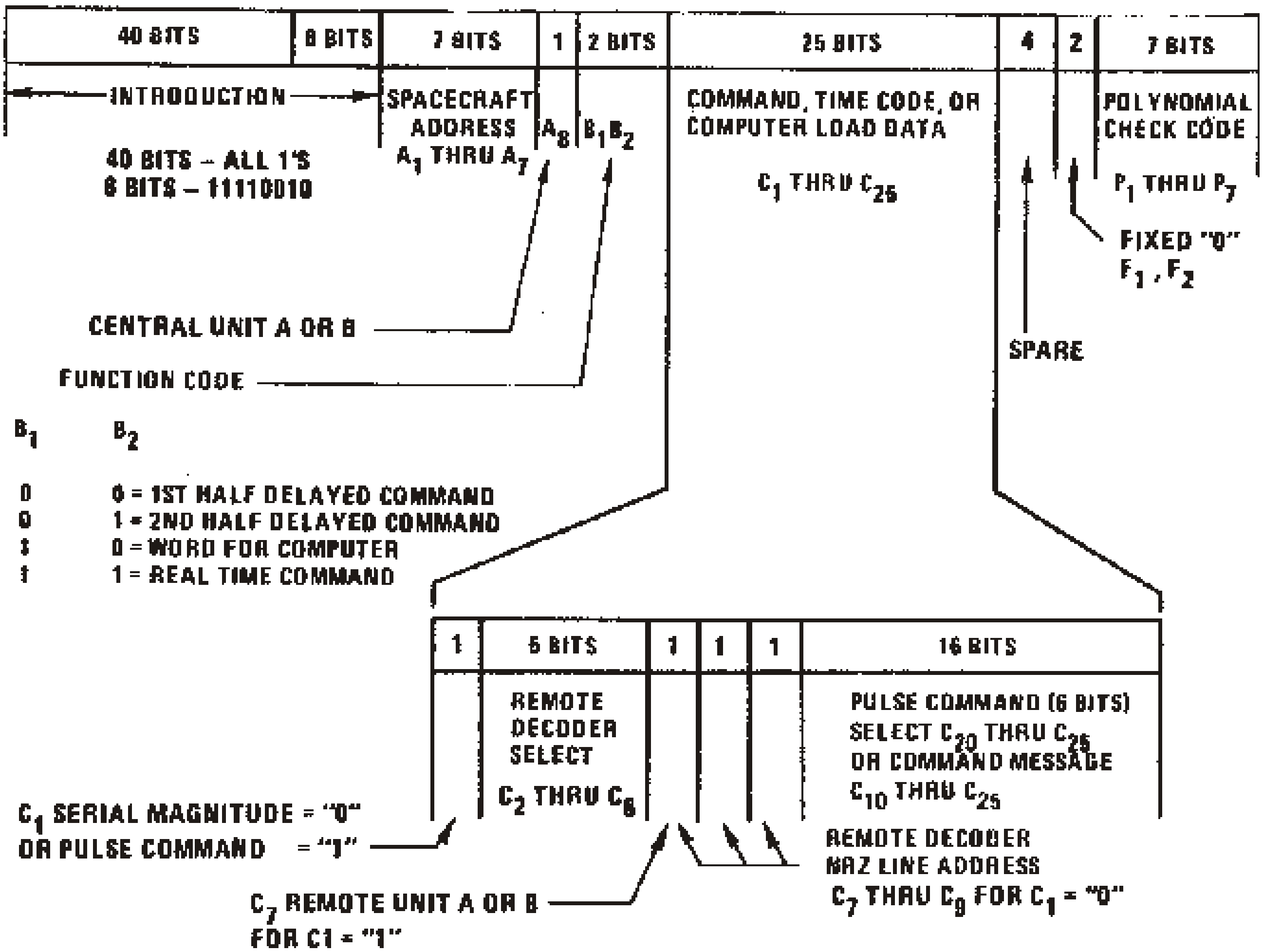

Figure 2. Command Word Format

Table 1 provides a summary of command formats, these are the formats on the supervisory bus and are derived from but are not identical to the received command format shown in Figure 2. In addition to real time ground commands the C&DH can operate with delayed ground commands stored in the computer or computer generated commands which are decision directed based upon on board data analyses.

Telemetry — Upon receipt of a type three message (telemetry address) the RIU delivers the users telemetry, suitably synchronized, to the reply line. Figure 3 portrays the multiplex data bus activity and table 2 describes the performance parameters. As can be seen the data bus and RIU's run at a constant 1.024 Mbps rate independent of the Spacecraft/Ground telemetry and command rates. The controlling 1024 MHz clock is generated within the Central Unit (CU) of the C&DH.

Table 1. Summary of Command Formats

Bit Quantity	Function
3 MESSAGE	1 - 1/2 bits (+), 1 - 1/2 bits (-)
1 HEADER	Fixed logical "1"
3	Specifies 1 of 8 message types
	MESSAGE TYPE I (Ser. Mag. CMD)
5	Specifies one of 32 Remote Units
3	Specifies one of eight command lines
16	to user
1	Specifies magnitude command value parity
	MESSAGE TYPE II (Pulse CMD)
5	Specifies one of 32 remote units
1	Specifies remote unit A or B
12	Not used
6	Selects one of 64 outputs
1	Parity
	MESSAGE TYPE III (TM Address)
5	Specifies one of 32 remote units
1	Major frame rate
1	Minor frame rate
1	TM word rate
2	Specifies one of four signal types
5	Not used
3	Allows expansion to 256 inputs
6	Selects one of 64 inputs
1	Even parity

MESSAGE TYPES IV THRU VIII ARE NOT USED

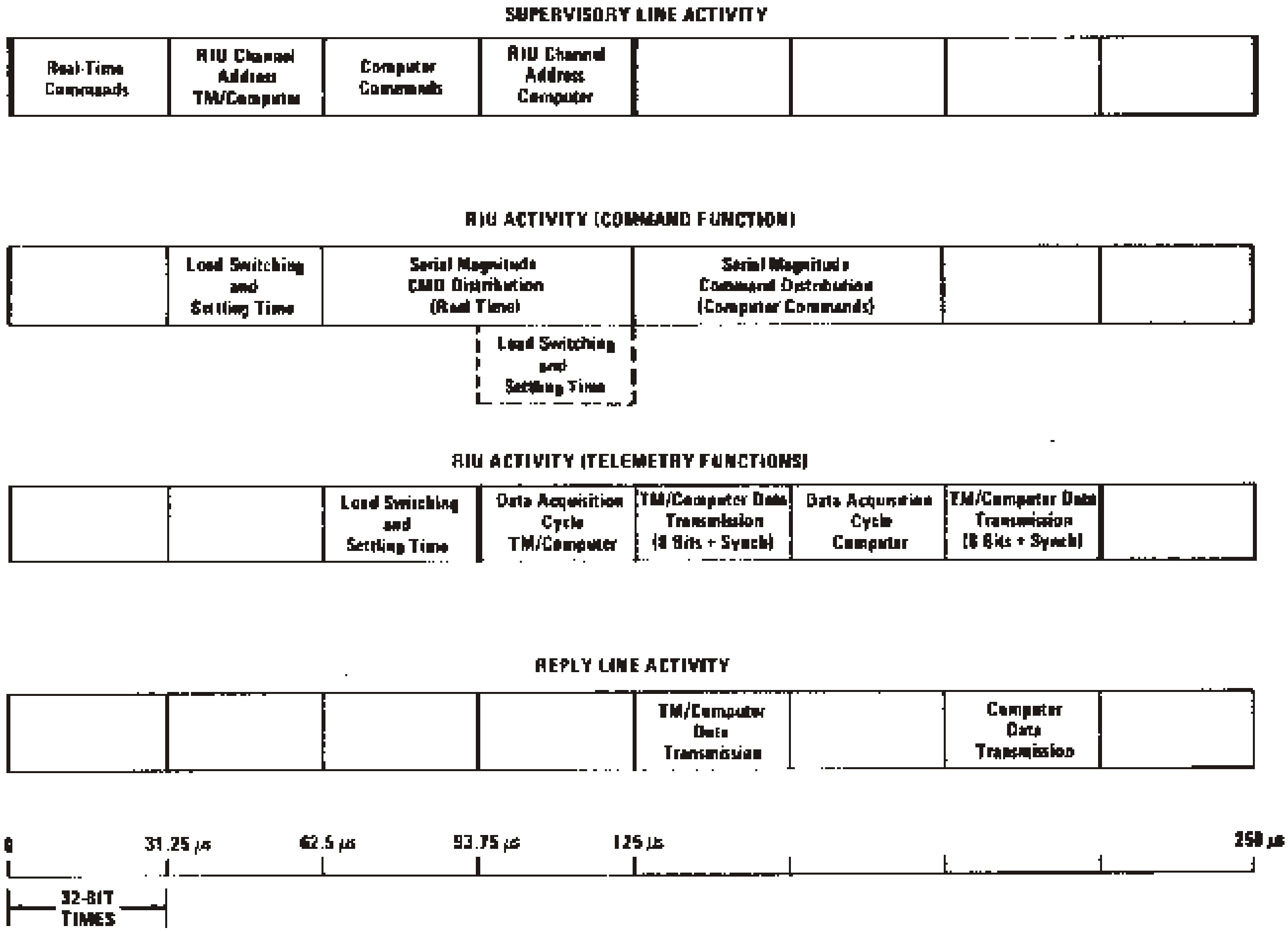

Figure 3 Multiplex Data Bus Activity

The Reply Line data is received in the CU. The received data can be either Telemetry on Computer scientific or engineering data for formatting and transmission or computer engineering data for on-board safety and control. The CU recognizes what type of message it is receiving and its source by correlating the reply with the command and address transmitted 96 bit spaces (93.75 usec) previously. All reply line data is formatted in the CU to adjust bit rate and provide "header" information. All data is available to the computer for information analysis, action, storage or any combination of the four.

Data to be telemetered is formatted for transmission in the CU. The CU ROM and micro-processor in the CU provide fixed telemetry formats. Flexible formats can be provided by an optional ROM and the microprocessor or the OBC. The capability exists to analyze data and vary the telemetry format to accommodate the information being handled. The data either real time or from memory is routed to a Pre-Modulator Processor (PMP) for encoding and then either presented to the Transponder for transmission or to mission unique tape recorders for storage.

Table 2
Multiplex Data Bus Performance Parameters

Bit rate:	1.024 mbps
Bit sync:	Biphase-L MSDADS
Word sync:	3 bits illegal code followed by Logical "1"
Word size:	32 bits on Supervisory Line
	9 bits on Reply Line 8 bits data plus leading 0
Word rate:	32 kwps maximum on Supervisory Line 16 kwps maximum on Reply Line
*Response time:	N-bit times to be specified where N $\leq$ 64.
Clock on Supervisory Line is continuous.	
Data on Reply Line are phased relative to Supervisory Line Clock.	
Up to 62 Remote Units may be tied on bus.	

*Response Time is defined as the time from the end of the message parity bit to the start of the return data sync word.

The telemetry transmission consists of a major frame divided into 128 minor frames. Each minor frame contains 128 8 bit words. Table 3 gives the word assignments for Multimission Modular Spacecraft applications.

Table 3 MMS TLM Format Fixed Word Assignments

Minor Frame Word No.	Bit No.	Function
0-2		Sync word (pattern to be specified by GSFC)
3	0,1,2	Bit rate
	3,4	Format ID
	5	Central Unit A/B
	6	Real-time/computer dump data
	7	CU signal presence
4-31		Data
32		Subcom
33		Subcom
34	0	Receiver (RCVR) - A lock status
	1	RCVR-A TDRSS/STDN mode
	2	RCVR-B lock status
	3	RCVR-B TDRSS/STDN mode
	4,5	Det. A inlock, det. -B inlock
	6,7	CU-A command reject, CU-B command reject
* 35		Computer data word (RT or TR)
36-63		Data
64		Spacecraft Clock (8 LSB from Selected CU, 16 MSB in subcom)
65		Frame Counter
66		Command Counter (selected CU)
67	0	Dwell mode
	1-7	Dwell ID
68-95		Data
96-99		Subcom
100-127		Data

*Word 35 in the COMP DUMP data is a STINT generated word indicating HARDWARE/ SOFTWARE DUMP and dumped bank ID.

Table 4

On-Board Computer Characteristics

Word length	18 bits, 5 bits instruction ID, 1-bit index, 12-bits oper and fetch
Execution speed	2µs cycle time, 4µs add, 32µs multiply, and 60µs divide
Memory capacity	Four 8192 word modules for total of 32, 768 words. (Expandable to 64 K in 8 K modules containing two 4 K banks each.)
Processor interrupts	16 levels of priority interrupt
Direct memory access	16-cycle steal channels, maximum I/O rate of 100K words/second
Memory write protection	Allowable storage areas are assigned in segments of 128 words
Input/output	I/O is achieved through time multiplexing of existing telemetry and command hardware
Program load and dump	Any 4 K memory bank can be loaded and dumped via command and telemetry without software bootstrap
Power	45-watts maximum (computing with full memory complement)
Instructions	55
Accumulator	One - 36 bits
Index register	One
Direct addressing	All 4 K words in any bank

Computation — A salient feature of the C&DH is the inclusion of an on board computer (OBC), the NASA Standard Spacecraft Computer (NSSC). Table 4 summarizes the characteristics of the OBC. The C&DH utilizes this facility to: Store Commands for execution, (delayed commands); Provide flexible telemetry format control; Control spacecraft autonomous operation (independent of ground control); Perform attitude control law computations; Monitor spacecraft and payload system health and safety; Control TDRSS antenna pointing; and finally to generate summary telemetry messages.

All communication with the computer is via the STACC Standard interface for computer (STINT).

Hardware Implementation — Figure 4 is a sketch which shows the layout of the C&DH module; it is 120 x 120 x 46 cm and weighs 122 kg including an allowance of 27 kg for mission unique equipment. The baseline equipment compliment consists of: Standard Telemetry and Command Components (STACC)-Central Unit (CU), Standard Interface for Computer (STINT), Remote Interface Unit (RIU) and its Expander Unit (EU); other NASA Standard Components - the NASA Standard Spacecraft Computer (NSSC) and a choice of NASA Standard Transponders; and two components developed particularly for the C&DH - the Power Control Unit (PCU) and Pre-Modulator Processor (PMP). The next few paragraphs will describe these items of hardware and their contribution to the functioning of the overall subsystem.

Transponder — Although the capability exists to easily adapt to other transponders the basic C&DH is Satellite Tracking and Data Network (STDN) and Tracking and Data Relay Satellite System (TDRSS) compatible and therefore can accept physically and electrically either of these transponders. The TDRSS unit also contains full STDN capability, it is 11 x 25 x 39 cm, weighs 7 kg and consumes 38 watts in the high power, 5.0 watt, transmitter mode. In addition to receiving commands and transmitting telemetry in S-band, it provides turnaround ranging. Redundant transponders are provided, both receivers are always on and both command outputs always being processed in the CU.

Central Unit (CU) — The heart of the C&DH is the CU. It is 11 x 18 x 17 cm, weighs 2.4 kg and consumes 11 wafts when operating at 64 kbps downlink telemetry and one watt in standby. It contains a microprocessor with suitable memories, RAM and ROM, the circuitry to operate and control the data bus, and the system clock. Two CU's are provided to maintain the complete redundancy of the system. Either CU can operate either of the redundant data buses.

Remote Interface Unit, Expander Unit, Bus Coupling Unit (RIU, EU, BCU) — The RIU interconnects the user equipment with the CU via the data bus. The actual connection between the RIU and the data bus uses the BCU which is nothing more than an isolation transformer with buffer resistors. The BCU both protects the bus from failures in the RIU and facilitates connecting each RIU into both redundant data busses. The BCU is 5 x 5 x 2 cm, weighs 100 grams and consumes no power. The RIU is normally in a standby state until it recognizes its address on the supervisory line.

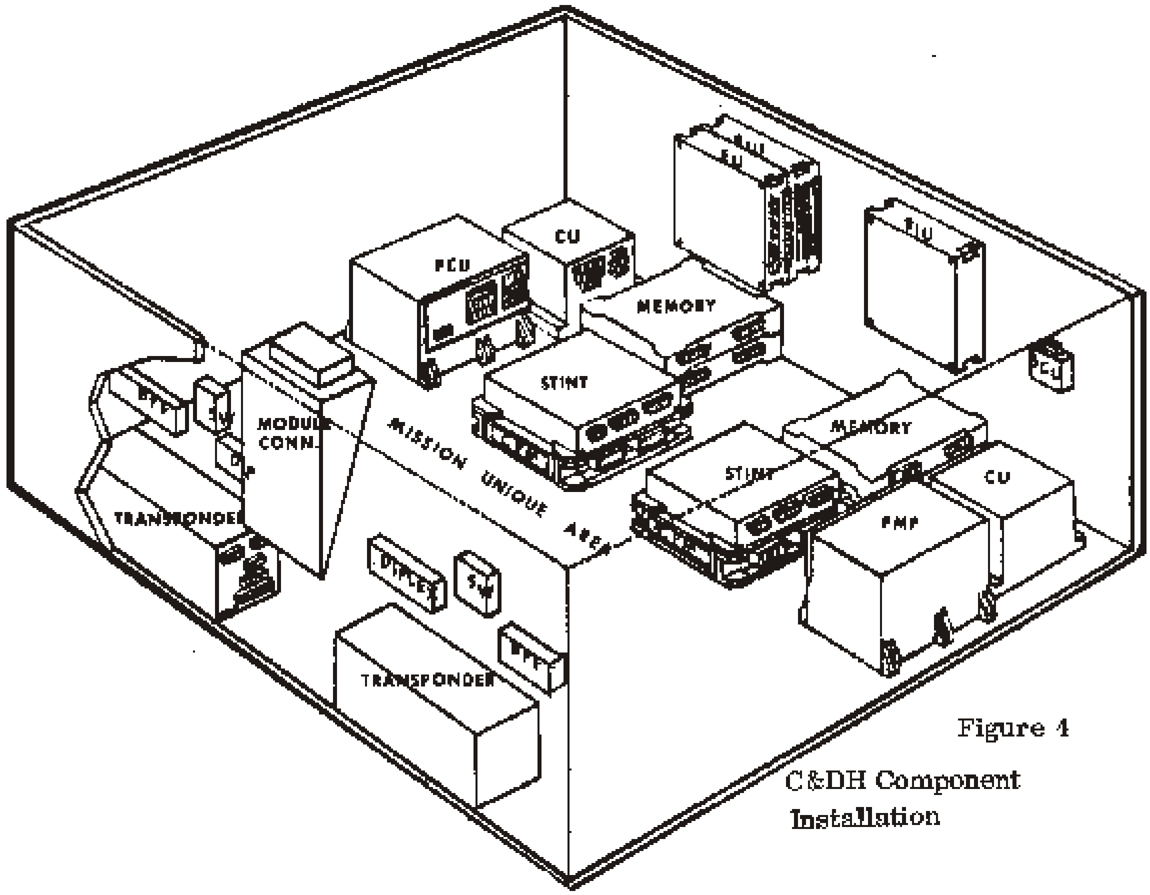

Figure 4

C&DH Component Installation

Abbreviations:

BCU	=	Bus Coupling Unit RIU to Data Bus
BPF	=	RF Band Pass Mlter
CPM	=	Computer Central Processor Module
CU	=	Standard Telemetry & Command Components Central Unit
DIP	=	RF Diplexer
EU	=	RIU Extender Unit
PCU	=	Power Control Unit
PMP	=	Pre-Modulator Processor
RIU	=	Remote Interface Unit
STINT	=	Standard Interface for Computer
SW	=	RF Switch

RIU’s may be interconnected in redundant pairs as means are provided to prevent having members of a pair interfere with each other. The RIU’s telemetry capability may be doubled by the addition of an EU. The RIU is 18 x 21 x 7 cm, weighs 1.7 kg and consumes 1.1 watts assuming one percent on time (99% standby). The EU can be stacked with the RIU, it is 4 cm high, weighs 0.9 kg and consumes 0.3 watts for the same duty cycle.

Computer, NASA Standard Spacecraft Computer (NSSC) — The On Board Computer (OBC) is a general purpose machine; its capabilities are outlined in Table 4. The Central Processor Unit (CPU) and the memory have the same 23 x 18 cm footprint, the CPU is 3.5 cm high and each 8k word memory is 4.2 cm high. The CPU weighs 1.4 kg and consumes 5.5 watts, the memory modules also weight 1.4 kg each and go from a standby power drain of .35 watts to 12 watts maximum when operating. All spacecraft telemetry is available to the computer enabling it to monitor spacecraft status and issue suitable commands. The NSSC is implemented in a redundant configuration.

Standard Interface for Computer (STINT) — The STINT provides the interface for all spacecraft signals to and from the OBC. It facilitates in flight reprogramming of the NSSC. Specific functions include: Distribution of stored commands, ground command of the computer, OBC telemetry format control, acquisition of data for NSSC use, exchange of data between computer and RIU's, memory loading and readout under software or hardware control. Each of the redundant STINT's is dedicated to one of the redundant CPU's. The STINT is 4 x 18 x 23 cm, weighs 1.1 kg and consumes 2.5 watts.

Pre-Modulator Processor (PMP) — The PMP is the telemetry interface for the transponders. All outgoing telemetry, regardless of origin is routed via the PMP. It accepts the following inputs:

- 1 to 64 kbps selectable NRZ-L, from the CU
- 32 kbps NRZ-L, OBC generated, from the STINT.
- 2.048 mbps, max, encoded data from external sources.
- 100 Hz to 3 MHz, analog signals from external sources.
- 1.024 mbps NRZ-L, from mission unique tape recorders. The PMP also routes 1-64 kbps data to the recorders.

Two fully redundant PMP's are housed in a single enclosure. Cross-strapping and switching for the redundant CU, STINT, and transponder interfaces is accomplished within the PMP. The dual unit is 17 x 20 x 23 cm, weighs 8.6 kg and draws 6 watts of power. Internal functions include convolutional encoding baseband multiplexing, biphase encoding and phase shift key modulating the telemetry on the C&DH generated 1.024 MHz carrier.

Power Control Unit (PCU) — The PCU is the C&DH module power supply. It provides redundant fusing, and on/off control to other C&DH components, in addition to supplying regulated power to the OBC and memories. Like the PMP it is in a redundant configuration, housed in a single enclosure 20 x 20 x 18 cm. It weighs 4 kg and at full load dissipates 17 watts. Input power is 28 ±7 volts outputs are 12V and ± 5 V all at ± 5%.

Duplex Data Bus — The data bus is a four wire system, a twisted shielded pair supervisory line, carrying commands, clock, etc. from the CU to the RIU's and another, reply line, carrying telemetry from the RIU's to the CU. Each pair is redundant and any combination of CU's, supervisory lines and reply lines can be activated. At the user end the BCU couples the RIU into both redundant pairs. The data bus is serial multiplexed with the traffic timing being controlled by the CU. The data bus services the C&DH components via the internal (to the C&DH) RIU.

Redundancy — As has been repeatedly stated above the C&DH is a fully redundant cross strapped system. In only two areas may this full redundancy be modified.

1. Computer memories, the capability exists to use the computer memory as a single unit or as redundant units.

2. RIU's; the C&DH is configured to work with 31 redundant pairs of external RIU's; however, there is no constraint forcing users to utilize more than one RIU per equipment.

Mounting — With the exception of the RIU's, STINTS and passive components all of the components are mounted directly to the louver controlled cold wall. All components, with the exception of the CPU's and memories which are stacked, including the harness may be individually removed, an essential ingredient for on orbit servicing.

Applications — NASA intends to utilize C&DH in two areas. As a module of the Multimission Modular Spacecraft (MMS) it will be used to support a series of missions starting with Solar Maximum Mission, in the fall of 1979, and including Land Sat D, Storm Sat and OFT (Orbital Flight Test) BuddySat . The latter will demonstrate retrieval of a satellite by the Shuttle. As a component of the OHP (OFT Hybrid Pallet) the C&DH will be used to support those payloads that stay with the Orbiter. Use of the C&DH enables the Orbiter to act as an automated Spacecraft, providing the capability to interface with the Shuttle by issuing commands to and taking telemetry from the pallet.

As application of the C&DH in NASA becomes a fact it is to be expected that other spacecraft designers will wish to take advantage of this standardized, reliable, cost effective approach for satellite command, telemetry and on board computation.

Conclusions — Standardization has been shown to result in real economies in design construction and operation of spacecraft. The NASA MMS is a versatile standardized spacecraft. One module, the C&DH provides telemetry command and on board computation. This module is so flexible that it will be applied to other missions that are not MMS. This is a good example of the long term planning of the NASA Low Cost Office bearing fruit in ways that were not originally anticipated.

Three factors, readily available reprogrammable space borne digital computation capability, the STS systems ability to service spacecraft on orbit, and the modular construction of the C&DH, combine to ensure that the subsystem will not become obsolete for many years and that the user may repair, refurbish or modify his satellite at any time even after launch.

These factors combined with the capability for autonomous operation (one might say that C&DH spacecraft have grown up and no longer need baby sitters) will create new standards for savings in lifetime total systems costs.

(1) Leo O. Richards, “Summary: The NASA Low Cost Program” Proceedings International Telemetering Conference 1975,Washington, D.C. P. 242

(2) Frank J. Cepollina and Ernest I. Pritchard, “STS Multimission Modular Spacecraft - A New Horizon in Social and Industrial Benefits”, Astronautics and Aeronautics Vol 15, No. 5, May 1977, PP. 36-43.

(3) Charles E. Trevathan, “Communications and Data Handling for the GSFC Modular Spacecraft” Proceedings International Telemetering Conference 1975, Washington, D. C. P. 243.