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TRIPLE REDUNDANT COMPUTER SYSTEM/DISPLAY AND KEYBOARD SUBSYSTEM INTERFACE

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FOREWORD

This final report covers the work performed by the Autonetics Division of Rockwell International Corporation under Task 2A of Contract NAS9-12876 entitled "LSI Fabrication of the Voter-Comparator-Switch, 1st Phase." Task 2A was amended into the Contract NAS9-12876 by modification No. 1S dated October 31, 1972. Task 2A is to define the interface between a Display and Keyboard Subsystem and a Triple Redundant Computer System.

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1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of this study was to define a means of interfacing the redundant Display and Keyboard Subsystem with the Triple Redundant Computer System (TRCS) as defined in NASA/Autonetics Contract NAS9-12893. The Display and Keyboard Subsystem and interface concept were to pattern after Space Shuttle design. The Autonetics Space Shuttle control and display studies accomplished under Contract NAS9-12266 for NASA MSC and currently being accomplished in support of Rockwell International, Space Division, are reflected in the interfacing approach described in this report.

1.2 WORK ACCOMPLISHED

The study was performed in three phases: (1) TRCS configuration and characteristics identification, (2) Display and Keyboard Subsystem configuration and characteristics identification, and (3) Interface approach definition.

1.3 REPORT CONTENT

Section 2.0 describes the TRCS. Section 3.0 covers the Display and Keyboard Subsystem. Section 4.0 describes the interface approach.

2.0 TRIPLE REDUNDANT COMPUTER SYSTEM

2.1 BACKGROUND

Autonetics has developed a Triple Redundant Computer System (TRCS) in support to the NASA Space Shuttle activities under Contract NAS9-12893. The fundamental purpose of the TRCS system is as a tool to investigate and evaluate methods of attaining a triple redundant, digital flight control system for the Shuttle. The design ground rules for the TRCS specified a fail operational/fail safe system in which a single failure would not degrade the operational performance and a second subsequent failure, detected or undetected, would not create an unsafe flight condition.

The usual method of achieving a triple redundant flight control system utilizes three of everything (i.e., three pitch rate gyros, three air data sensors, three accelerometers, three flight control computers, etc.) to form three independent commands for each control channel. The three independent commands are generally compared and passed by some form of selection logic within the servo actuator. The requirement for independent command generation precludes any cross strapping of sensor data between flight control computers. Consequently, when a failure occurs within one of the redundant paths, the entire path is lost and the flight control system reverts to a simple redundant system (two independent paths).

The objective of the TRCS contractual effort was to integrate three D216 computers into a TRCS by accomplishing the following tasks:

1) Develop the necessary software required to implement the TRCS.
2) Design and fabricate an I/O processor (IOP) to provide the data interface between the computers and the sensors/servo actuators via a multiplex bus system produced by NASA.

2.2 TRCS CONFIGURATION

An overall block diagram of the TRCS is shown in Figure 2-1. The three flight control computers operate on data received from the sensor subsystems and generate commands for the control mechanisms. The flight control sensors are all triple redundant with the exception of the single IMU. However, the IMU data is received over three independent and separate multiplex systems. The other sensors include the rotation hand controller, attitude rate gyros (three axis), air data subsystem, and guidance commands from the guidance computers. The present state of the TRCS does not include the guidance computers, and consequently position data (range to go and altitude) are input from the air data subsystem. The flight control computers each generate and transmit commands to the elevons, rudder, speed brake, and reaction control system (RCS). The servo commands are force averaged in the elevon, rudder and speed brake actuators. This continues until one command becomes out of tolerance with respect to the other redundant commands. At that point the servo actuator to which these commands were transmitted disengages the faulty channel and continues operation with the remaining two redundant commands. Similar voting is performed for the RCS electronically.

The TRCS description up to this point follows fairly closely the standard approach to designing a triple redundant control system. The TRCS differs by utilizing the digital computer capability to perform a redundant data management operation on all sensor data. In order to implement this data management function, it was necessary that (1) all three computers receive all three sets of sensor data, (2) the three computers be synchronized, and (3) a single computer failure would not affect the operation of the other two computers.

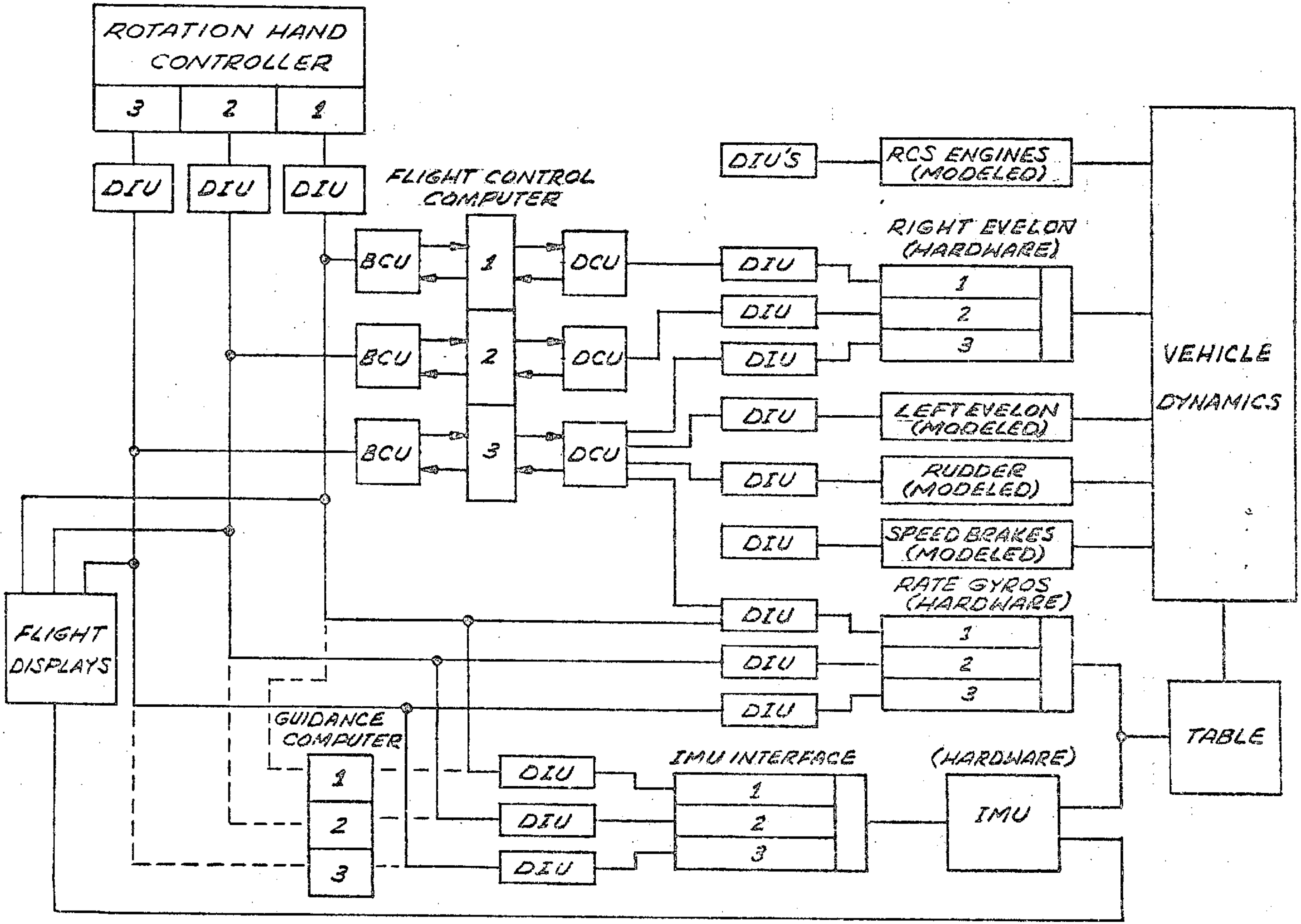


FIGURE 2-1
TRCS BLOCK DIAGRAM

2.3 TRCS OPERATION

Figure 2-2 shows a more detailed block diagram of the computer/IOP interface with the sensors and actuators, and Figure 2-3 shows the organization of the IOP. The three flight control computers are synchronized within a few microseconds through a software mechanization every 40 msec. After synchronization, each computer issues a discrete request to its associated IOP for data input. According to a program stored in the IOP from the computer at power up, each IOP then proceeds to request data from its associated sensors. The data requests are transmitted to the Digital Interface Units (DIU) via the Bus Control Unit (BCU) and multiplex bus. The digital data returns along the same transmission path and is stored in the I/O buffer within the IOP. At the same time, the same data is transmitted to the exchange buffer (A) or (B) of the other IOP's. Consequently, when the data input is complete to the IOP, all three sets of sensor data are then input to the computer via direct memory addressing (DMA) under control of the IOP. A similar operation is actuated during output so that each computer has access to the flight control commands generated by the other computers in addition to its own. The output commands are compared within each computer for monitoring only. Any disengagement of redundant commands is accomplished manually or by the servo actuator, not by computer commands.

In addition to inputting flight control data to the computers, the IOP acquires data for the Performance Monitoring System (PMS). The PMS data, including data from the computer, is stored in a buffer memory within the IOP for access by the PM system. In addition, a fifth buffer memory is provided for electronic display processing (EDP). The EDP also provides for an examination of the computer memory word by word.

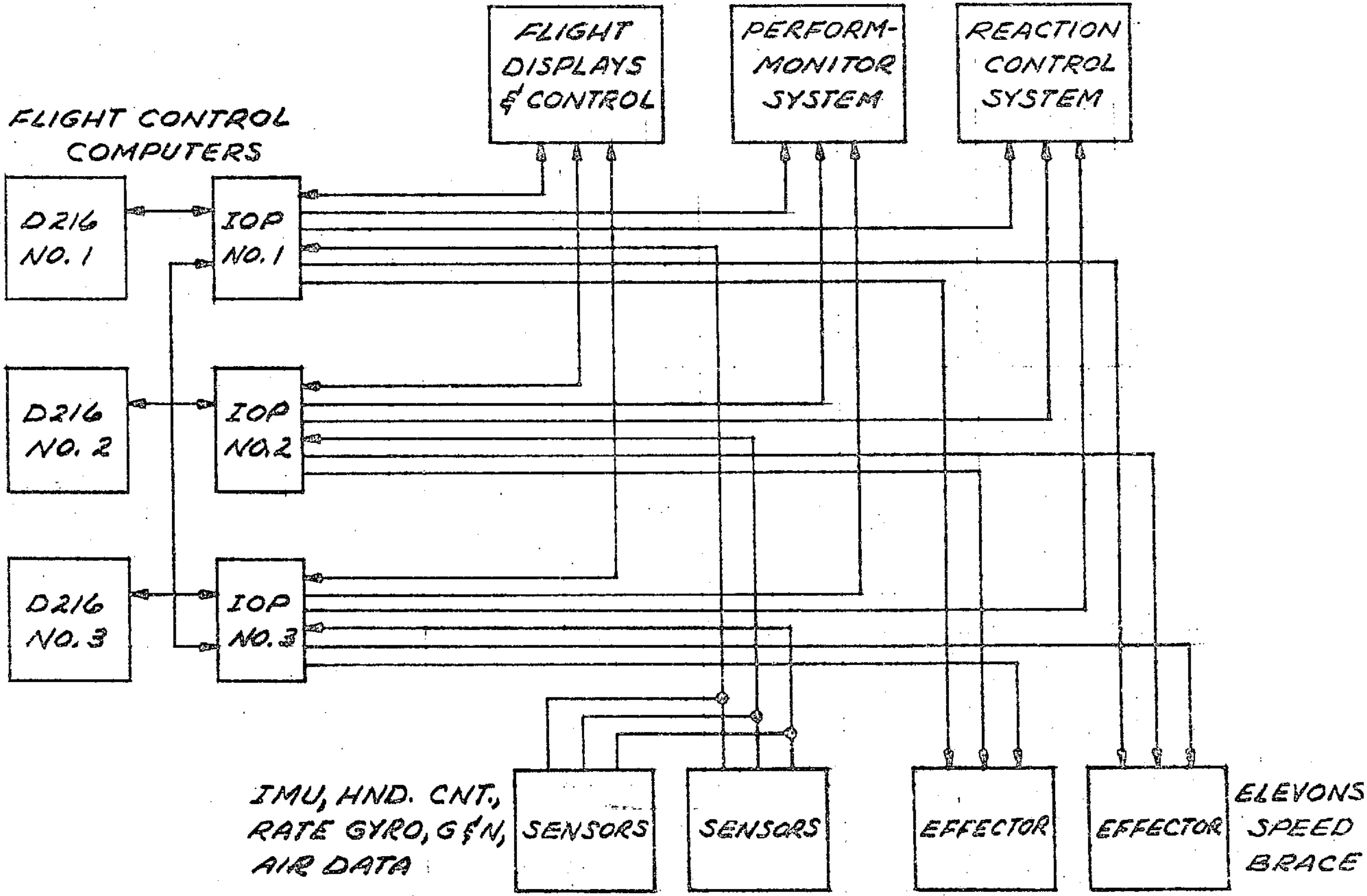


FIGURE 2-2

[illegible]/NASA DETAILED BLOCK DIAGRAM

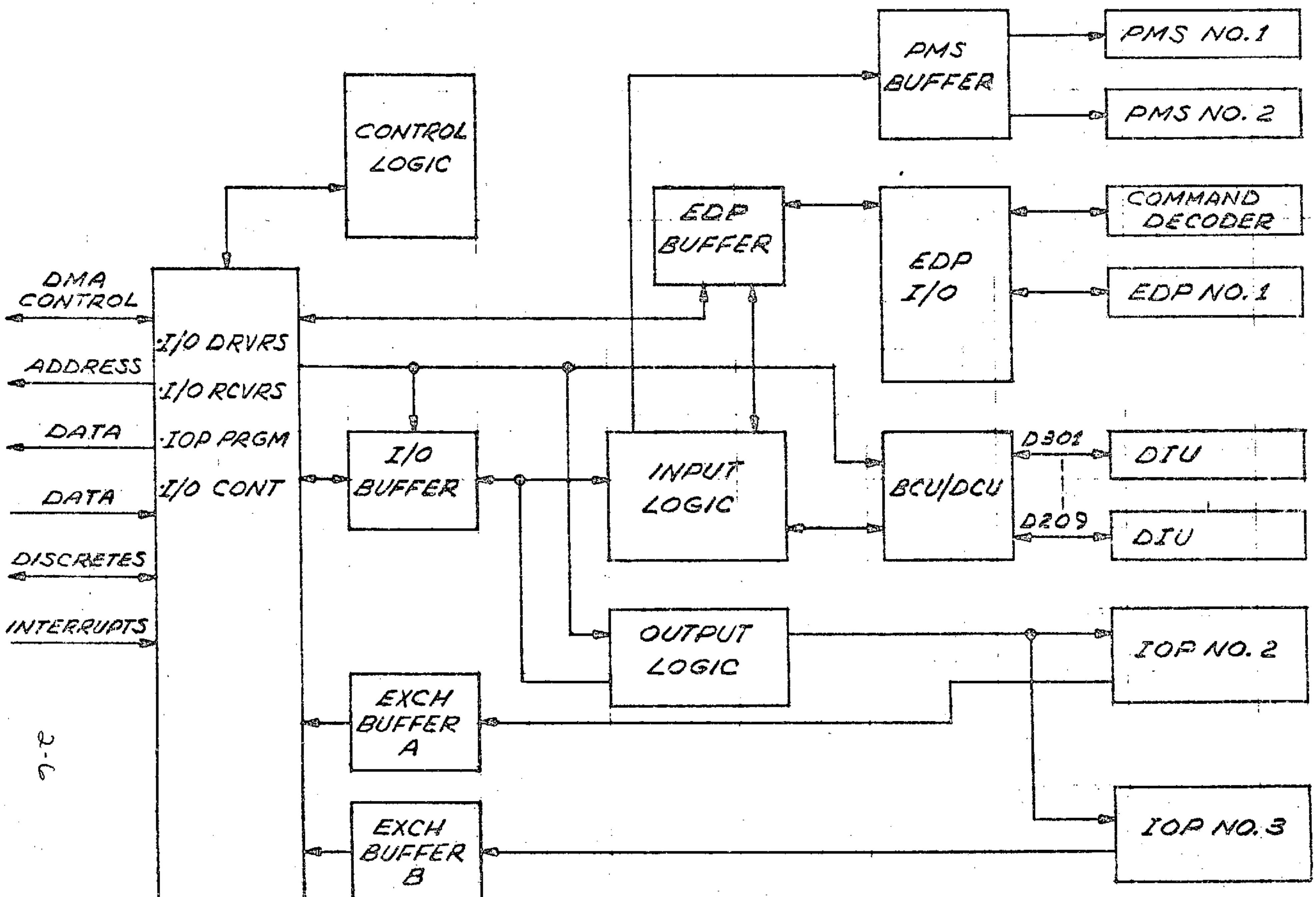


FIGURE 2-3
IOP BLOCK DIAGRAM

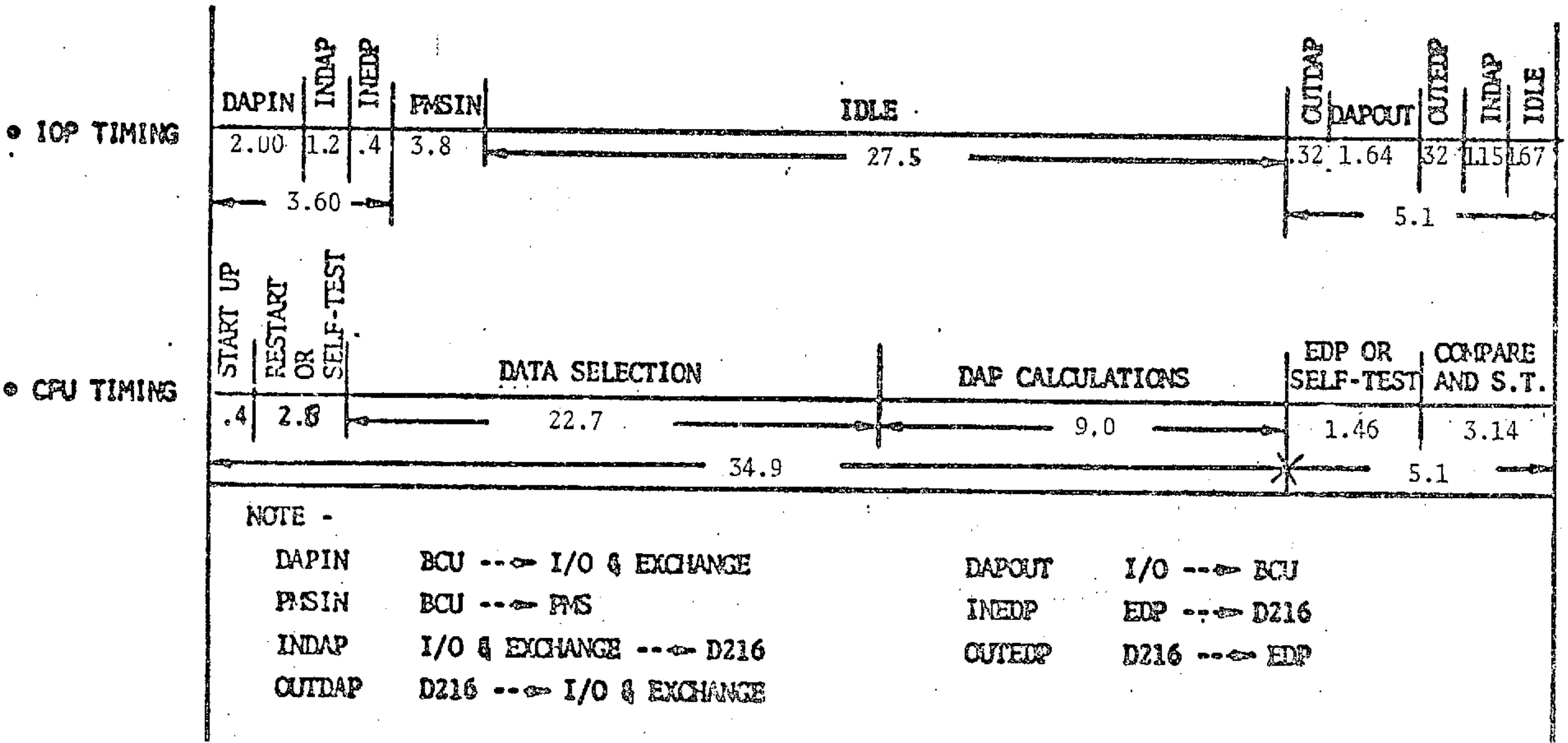
As long as all three computers and IOP's are operating, each computer has all three redundant sets of sensor data. If one of the computers or one IOP fails, the set of sensor data associated with that computer/IOP combination is lost to the other two computers; but both computers will continue with the remaining two sets of sensor data.

Synchronization of the three computers is accomplished with a flexible real-time software method involving discrete inputs, discrete outputs and interrupts. A master-slave relationship is not used since it would not meet the requirement of independence. With this method control is shared among any operating computer combination. This permits the elapsed time between consecutive cycles to vary within controlled limits for correction of individual computer clock variations. There is no compensation for accumulated time variations (with respect to real time) because it is not required by the system flight control mechanization.

A timing diagram of the IOP and computer operation over the 40 msec cycle time is shown in Figure 2-4. After the digital autopilot (DAP) data has been stored in the computer, a data selection/redundant data management function is performed.

2.4 DATA SELECTION

The data selection/redundancy management function maintains a hard failure list and a soft failure list dependent on testing of the three sets of redundant data. The tests include a difference test, rate test and a magnitude test. If a single variable, such as pitch rate from one attitude rate gyro, fails these tests, that sensor is placed on the soft failure list. If it fails the tests during enough subsequent cycles, it is put on the hard fail list and is not used thereafter until manually reset. However, if subsequent



Times are in Milliseconds

Figure 2-4. TRCS Timing Diagram

samples indicate good data, that sensor is removed from the soft failure list. The utilization of the three sets of sensor data is either mid-value, average of two good values, average of three good values, single good value or past value depending on the results of the tests. Each data variable is examined in conjunction with its redundant counterparts. For instance, if pitch rate is found to be bad, the rate gyro assembly is not failed, just the pitch rate output.

Since the software program is identical for each computer and each computer has access to identical data input, the autopilot commands should be identical. The DAP characteristics are shown in Table 2-1.

Table 2-1. DAP CHARACTERISTICS

- Complete Digital Autopilot
- Multi-Mode
  - Manual - Direct, Rate Command, Rate Command Attitude Hold
  - Automatic -
- Phases - Booster TVC, Insertion TVC, Orbit RCS, Orbit TVC, Entry, Transition, Cruise, Roll Out
- Filtering Technique - Difference Equation (2nd Order/2nd Order)
- 25/second Iteration Rate
- 3-Axis Attitude Control Plus Speed Brake

3.0 DISPLAY AND KEYBOARD SUBSYSTEM

3.1 GENERAL

The Displays and Controls Subsystem (D&C) provides the information to pilot and manage both the mated vehicle and the orbiter vehicle and to handle payloads when in the payload bay and when in rendezvous. The D&C is organized into five crew stations, two forward facing primary flight stations, one aft facing payload handling station, a subsystem and power distribution station and a mission specialist station used for management and checkout of active payloads with CCTV monitors and remote handling equipment. CRT displays are used to display graphic and alphanumeric data. Dedicated hardware is provided for caution and warning functions.

Table 3-1 lists the equipments comprising the Displays and Controls Subsystems and their utilization by mission phase for a seven-day polar mission.

The purpose of this section is to identify the Display and Keyboard Subsystem (D&K) which is a component part of the D&C subsystem and is comprised of CRT's, display electronics and keyboards as indicated by the asterisks in Table 3-1. To be consistent with current Space Shuttle nomenclature, these equipments are hereafter referred to as Multifunction CRT Display Subsystem (MCDS).

3.2 MULTIFUNCTION CRT DISPLAY SUBSYSTEM (MCDS)

3.2.1 Introduction

The fundamental purpose of the MCDS is to provide the means for the visual display of data to the individual crew stations. The MCDS is the bi-directional man/machine interface between the flight crew and the Data Processor Subsystem (DPS) or computers. The interface part of the DPS is the Input-Output Buffer

PHASE NUMBER

EQUIPMENT NAME	QTY	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Display Decoder/Driver Unit	2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Control Encoder/Coupler	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Perf. Mont. Annuciator Driver	1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caution & Warn. Elec.	1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rotation Hand Control	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trans. Hand Controller	3			X	X	X	X	X	X	X	X	X	X	X	X	X			
Manip. Hand Controller	2							X	X			X	X	X					
Manip. Hand Controller I/F	1							X	X			X	X	X					
Rudder Pedal Transducer Assy.	1																X	X	X
Speed Brake Controller	2																X	X	X
Master Thrust Controller	1	X	X	X															
Internal Lighting System	1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mission Timer	2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Event Timer	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gimbal Angle/Surf Position Ind.	1	X	X	X	X	X	X				X	X			X	X	X	X	X
"G" Meter	2	X	X	X													X	X	X
TAT Indicator	1																X	X	X
Beta Meter	1																X	X	X
Alpha Meter	1																X	X	X
Stand By Compass	1	TBD																	
Landing Gear Control	1																	X	X
Annuciator Light Matrix	9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Display Elect.	4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Keyboard	3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*CRT Display Unit	4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

LEGEND

X = UTILIZED

PHASE:

0 Countdown & Launch
1 Ascent & SRB Sep.
2 Orb. Injection
3 Att. Adjustment
4 Ext. Tank Sep. & Ign.
5 Orb. Maneuver
6 Payload Deployment
7 Payload Separation
8 Earth Survey
9 Rendezvous
10 Docking
11 Cargo Transfer
12 Undock & Separation
13 De-Orb.-OMS Burn
14 Entry Maneuver
15 Descent Maneuver
16 Final Approach
17 T.D. Rollout, Tow & Terminal

Table 3-1. Avionics Equipment Utilization List by Mission Phase 7-Day Polar Mission

(IOB). The IOB interfaces with the MCDS are via the Multiplexer Interface Assembly (MIA) in the IOB and the Display Electronics Unit (DEU) of the MCDS.

The man-machine interface consists functionally of the display of DPS and/or sensor data for crew use, a method to manually enter the data into the DPS and a method to manually command DPS processed events. Thus, a display capability and a keyboard capability are supplied. The keyboard capability is provided by a numeric keyboard with function keys added for the various control requirements. A block diagram of an integrated display for a typical crew station is shown in Figure 3-1.

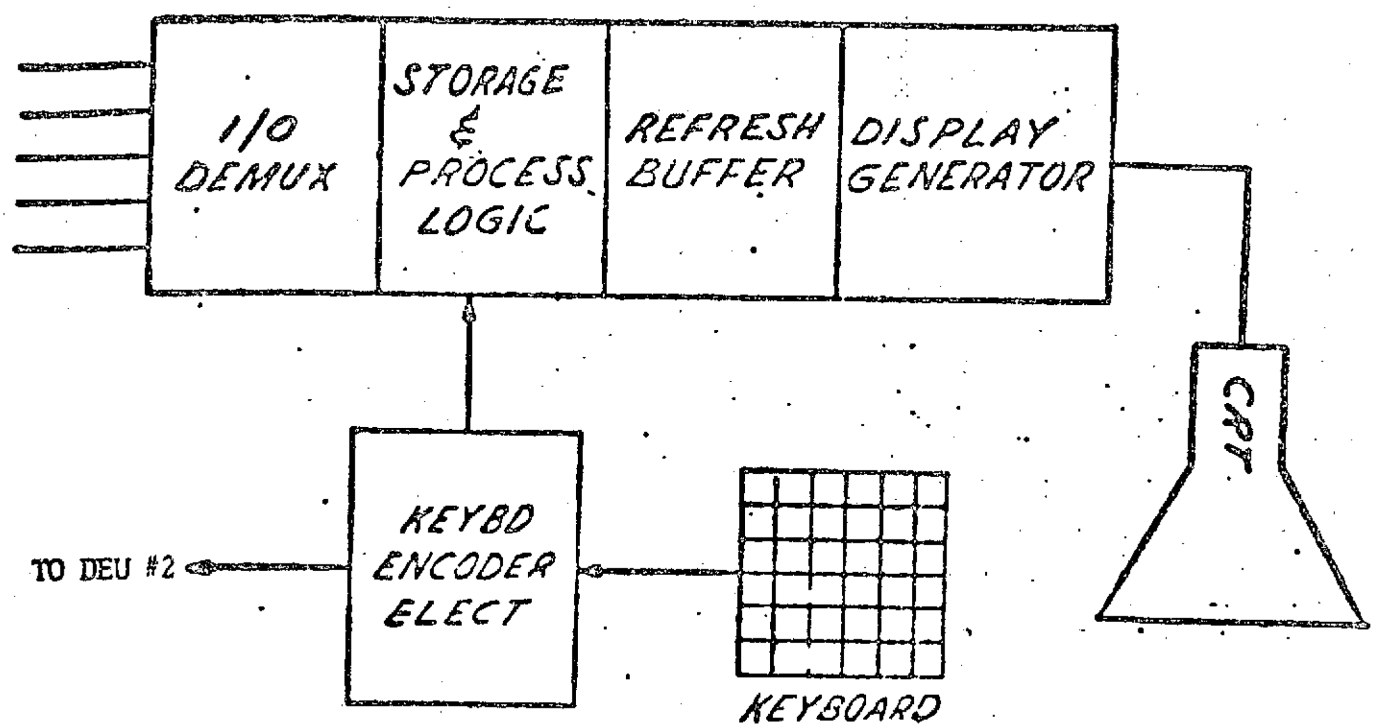


Figure 3-1. Typical Crew Station Integrated Display

3.2.2 Primary Baseline Requirements

The primary baseline requirements for the MCDS are summarized below.

Alphanumerics - Test and Tabular

16 x 32 + Title and Scratch Pad Lines

Graphics - Simple Vectors

Update - 2/sec

Refresh - 50 to 60/sec

Integral Refresh Buffer, Symbol Generation

Integral Field - Programmable ROM Storage for Critical Format Skeletons

3.2.3 Baseline Capabilities and Limitations

The capabilities and limitations of the baseline MCDS are tabularized below.

Can Do	Cannot Do
Quasi-Steady State Graphics	Dynamic Flight Formats e.g., EADI, EHSI
Graphics Involving Few Segments	Moving Map Displays High Update Rates
2 Sizes of Alpha Characters/Symbols	Superimposed Raster Direct Conic Generation
Blink (Intensity)	Rotation or Translation of Symbol Groups Computation - Scaling, Vector Resolution, Etc.

3.2.4 MCDS Description

3.2.4.1 General

The MCDS consists of the following units.

4 - Identical Display Electronics Units (DEU's)
4 - Identical CRT Display Units (CDU's)
3 - Identical Keyboard Units (KBU's)

The CDU's and KBU's are time shared with functions dedicated to Guidance Navigation and Control (GN&C), Payload Handling and Management (PLH/M) and Performance Monitoring Subsystem (PMS).

Provisions for the inclusion of a complete fifth display set have also been included for the purposes of payload management. Reference Figure 3-2 for the electrical interfaces between the MCDS and the DPS. The payload management display set is shown in broken lines.

3.2.4.2 Display Electronics Unit (DEU)

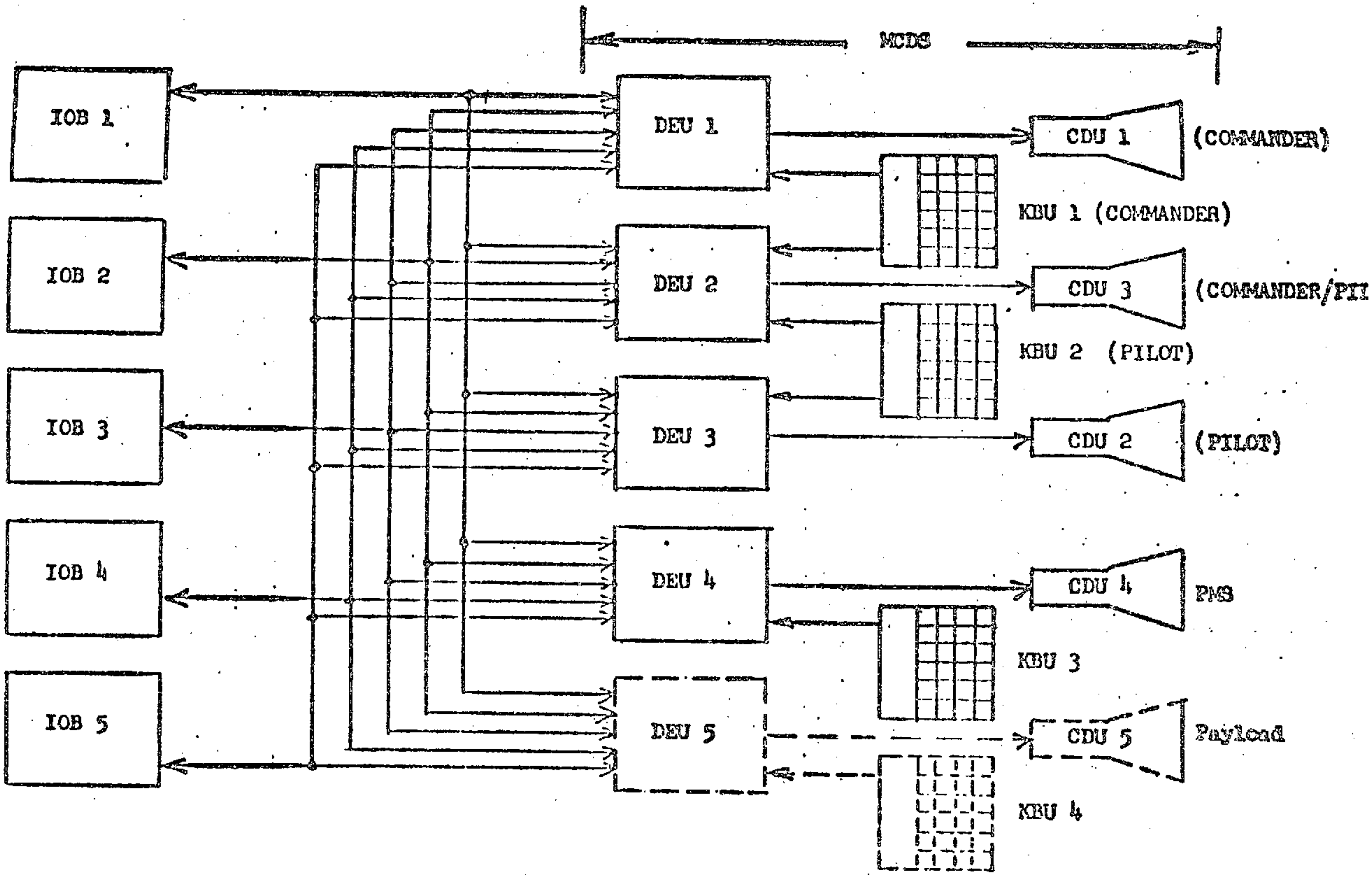
A. DEU Baseline Characteristic Summary. The baseline characteristics of the DEU are summarized below.

. INTERFACES
  - Serial Manchester (IOB)
  - Digital (Keyboard)
  - Differential Analog (DU)
  - Composite Video (Option)

. MEMORY
  - 1K x 16 bit Monolithic R/W
  - 4K x 16 bit Monolithic PROM

. SYMBOL GENERATION
  - A/N & 22 Special Symbols
  - Symbol Height 0.150" and 0.22", 0.75 Aspect
  - Vector Graphics
  - Tabular Format - 16 lines of 32 characters
  - Refresh 60 Hz
  - Symbol Gen. Time - Not defined
  - Settling Time - $\lessapprox$40μs
  - Vector Speed - Not Defined
  - Positioning Matrix 1024 x 853

B. Operational Description. The DEU receives data and commands from the DPS and from the KBU. These data and commands are processed to perform the required functions listed in Table 3-2.



MCDS Multifunction CRT Display Subsystem
DEU Display Electronics Unit
CDU CRT Display Unit
KBU Keyboard Unit

Figure 3-2. Multifunction CRT Display Subsystem Interconnection

Table 3-2. DEU Functions

1.	Receives and decodes computer supplied display data.
2.	Stores display instructions in the refresh buffer and then executes them.
3.	Provides ROM storage of the stroking information for the (64) character symbol set.
4.	Provides storage for format skeletons for critical displays (in programmable ROM's).
5.	Combines the static format (skeletons) and the dynamic data (changeable) in the display generation process.
6.	Fetches display skeletons from local storage.
7.	Receives, decodes and executes, when appropriate, display requests from the keyboard.
8.	Receives and displays computer input data entered via the keyboard.

In order to accomplish the functions outlined in Table 3-2, a block diagram, Figure 3-3, showing all the elemental functions was prepared to assist in the explanation of the theory of operation of the DEU.

The DEU receives data from one of the computers over one of the MUX channels at a time. The computer transmits all the data/instructions necessary for a display. The display is broken up into two distinct parts:

1. Static data - that part of the display that is constant and will only change when the display changes.
2. Dynamic data - that part of the display that does or could change with time.

The static data for the display is transmitted first and identified as such. Then the dynamic data for the display are transmitted.

The dynamic data can be updated (i.e., transmitted with changes) at a 2 Hz rate. The static and dynamic data are combined to complete

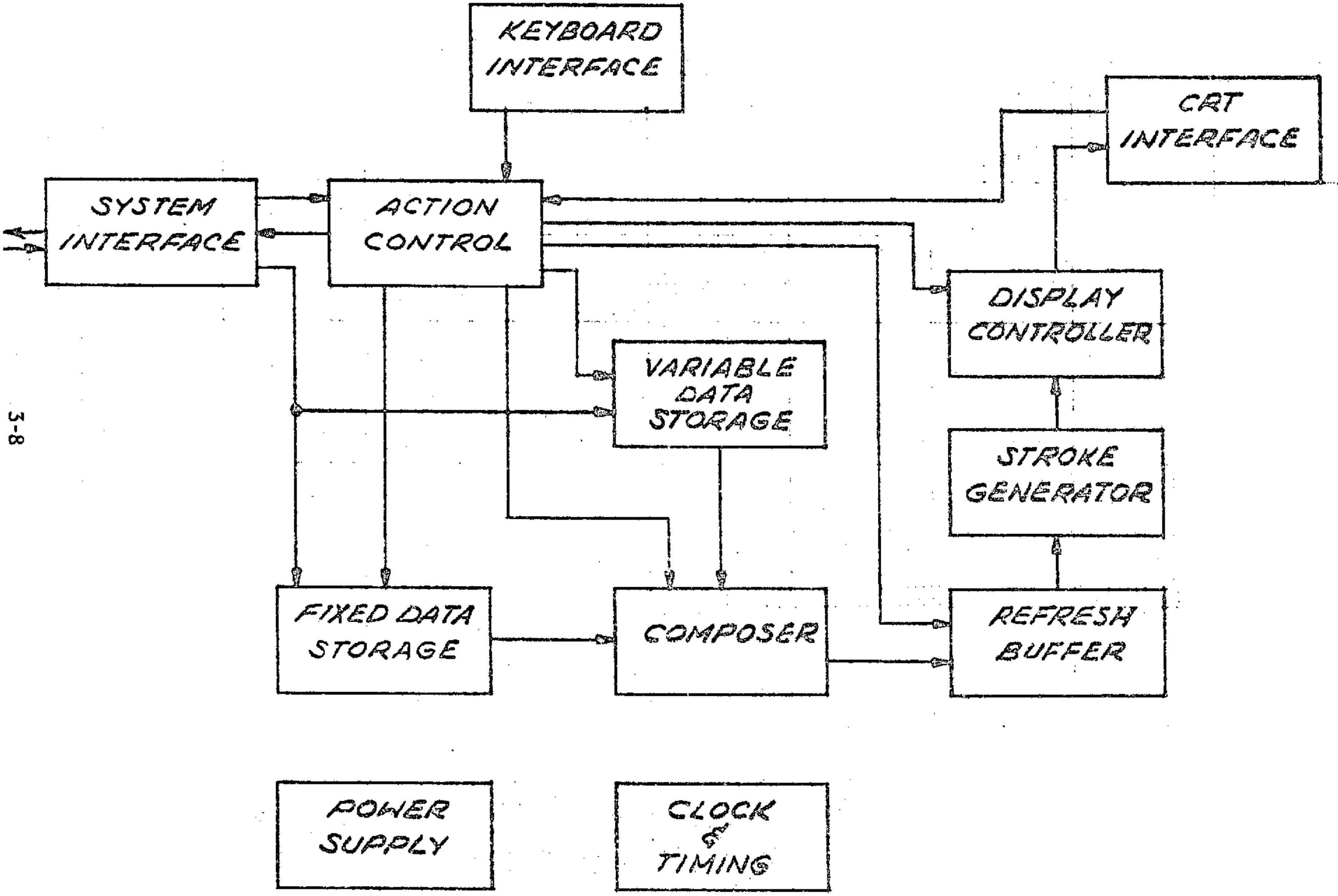


FIGURE 3-3.
DEU FUNCTIONAL BLOCK DIAGRAM

the display format before transmittal to the CRT display.

The static data may also be fetched from PROM storage within the DEU. In this case, the DEU recognizes the format request code and displays the appropriate one. The DEU has the capability to store 4K x 16 bit words. Initially, this is RAM (loadable from an outside source) and is used to debug the skeletons. After the skeletons are developed, the method of storage will be PROM.

The DEU to IOB interface is by means of two transformer coupled half duplexed serial lines which constitute a full duplexed channel. The signal form is Manchester encoded 1 MHz self-clocking. A check method is included such that each message includes an 11-bit error Protection Code (EPC) which must be generated by the sender and checked by the receiver. The interface levels are normal T^2L with the transmission line being twin-ax or twisted, shielded pair with 70 ohn characteristic impedance. The basic block diagram of the transmitter/receiver unit is shown in Figure 3-4.

C. Functional Requirements/Packaging. The functional requirements listed below, if combined into similar implied hardware (i.e., storage control, etc.) would produce the block function packaging configuration represented in the DEU Block Diagram, Figure 3-5.

1. Interface with IOB
   - A. Receive and decode MIA messages
   - B. Compose and transmit MIA messages
   - C. Detect and generate error
2. Interface with Keyboard Electronics
   - A. Receive serial clocked keystroke data
   - B. (Optional) Transmit clock to the keyboard
   - C. (Optional) Supply power for keyboard electronics

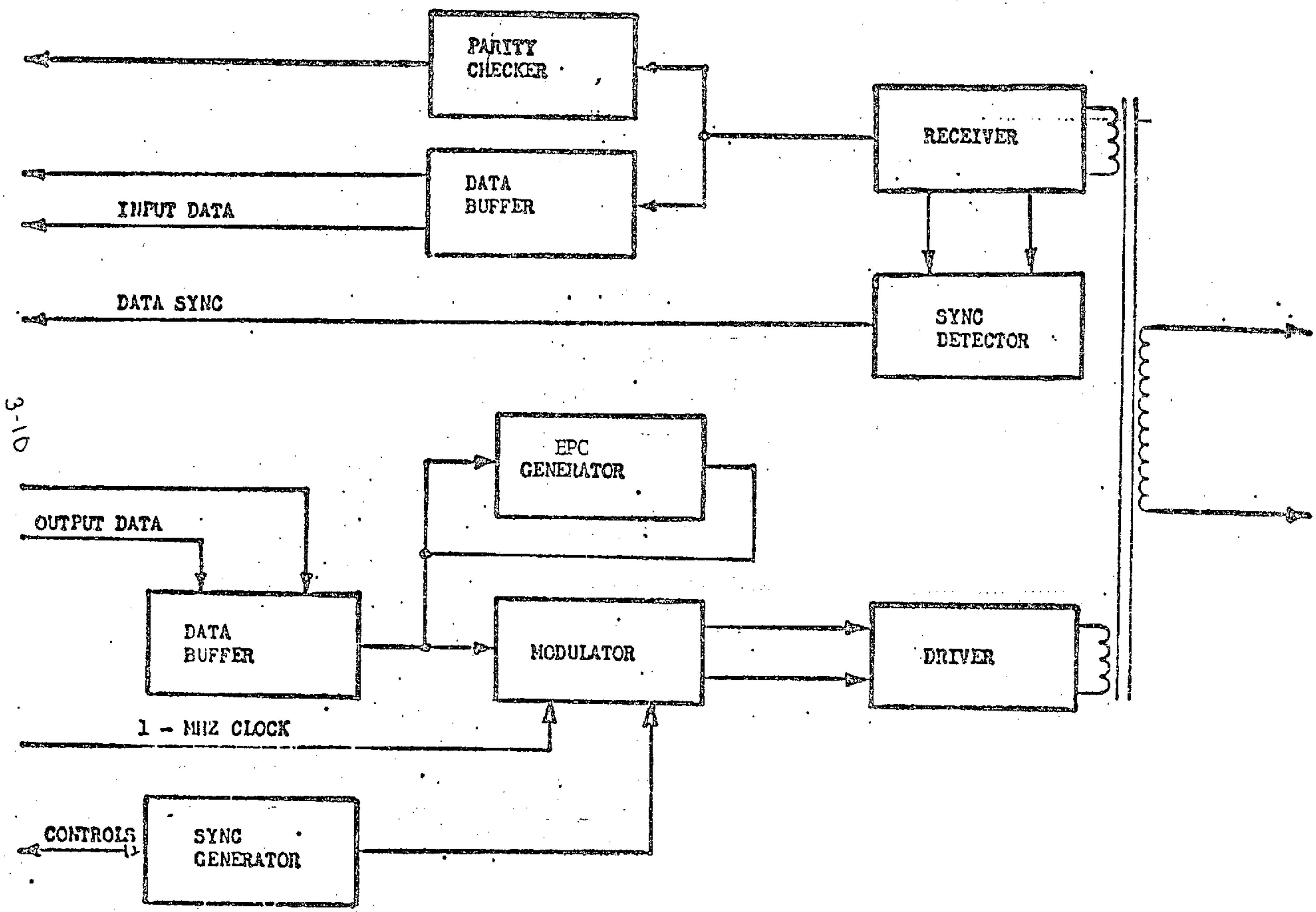


Figure 3-4. Transmitter/Receiver Unit Block Diagram

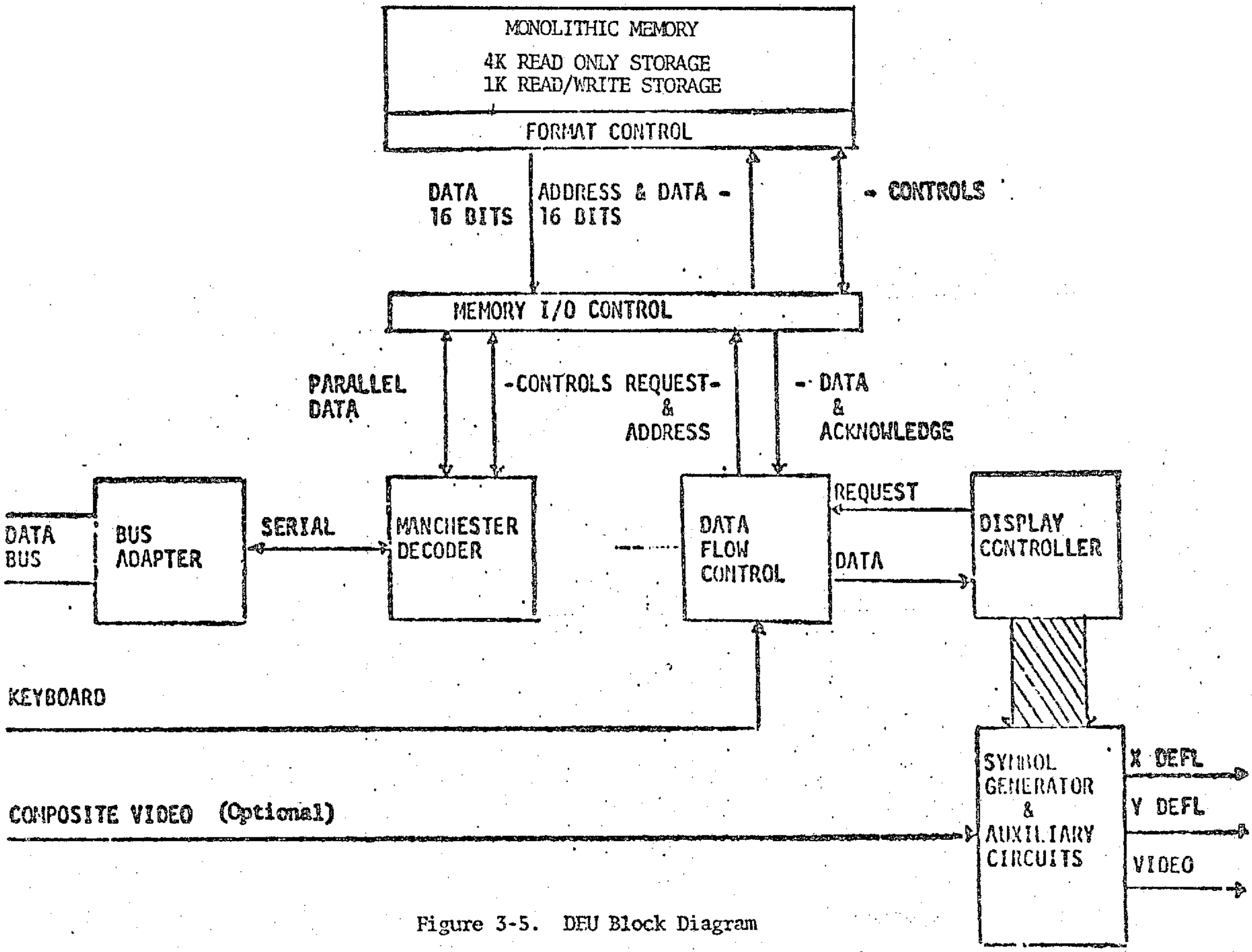


Figure 3-5. DEU Block Diagram

3. Storage
   A. RAM or register type storage for variable data, current image (i.e., refresh memory) and keyboard scratch pad
   B. ROM type for local storage of flight critical display skeletons
4. Data Handling
   A. Decode command messages from IOB
   B. Compose images from specified fixed and variable data
   C. Update variable data in current image; i.e., refresh memory
   D. Interpret keyboard characters
   E. Perform keyboard action sequence
   F. Compose message words for IOB
5. Interface with CRTU (or CDU)
   A. Provide XY deflection and Z intensity signals
   B. Accept CRTU-BITE outputs for reporting to the performance monitors system via an IOB
   C. Generate stroke data for deflection by means of data from refresh memory and character generator

3.2.4.3 Keyboard Unit (KBU)

A. Operational Description. The KBU provides the capability for the manual selection of mission profile data and performance monitoring data and provides for data entry update to the computer, as well as the data flow path to the MCDS.

B. Functional Requirements. The keyboard shall have ten numeric keys, two algebraic sign keys, a decimal point key and a minimum of 15 special function keys. The binary code assigned to each key is tabularized in Table 3-3.

With the exception of the "Display Designate" keys, all keys will be of the internally lighted momentary pushbutton type. The "Display Designate" keys will be of the push ON, push OFF type

Table 3-3. Binary Code Assignment to KBU Keys

Code	Key	Possible Function	Code	Key	Possible Function
00000	"0"		10000	Function #4	(Item)
00001	"1"		10001	#5	(Execute)
00010	"2"		10010	#6	(Space)
00011	"3"		10011	#7	(Clear)
00100	"4"		10100	#8	
00101	"5"		10101	#9	
00110	"6"		10110	#10	(Operate)
00111	"7"		10111	#11	(Stand By)
01000	"8"		11000	#12	(Repeat)
01001	"9"		11001	#13	(Acknowledge)
01010	"+"		11010	#14	(Designate I)
01011	"-"		11011	#15	(Designate II)
01100	"."				
01101	Function #1	(Critical Formats)			
01110	Function #2	(Other Formats)			
01111	Function #3	(Enter)			

button; and adequate interlocking will be provided to prevent designation of two displays simultaneously.

The KBU also includes the electronics to provide the necessary functions of roll over and anti-repeat interlocks, encoding, and serial transmission to the DEU. The method of power supply and clock source has not yet been determined. (It is recommended that both clock and power for the keyboard electronics be supplied from the DEU's on bus formatted distribution for redundancy.)

3.2.5 MCDS Functional Capability

3.2.5.1 Quiescent State

In the absence of any request for action from the KBU or from the DPS and no failure is present, the DEU provides signals as required to the DU to keep the present display refreshed. The Keyboard Interface and the DPS receiver are in a "Listen" mode and the DEU is in a state to respond to DU and internal BITE signals. The DEU maintains this state and produces no activity except the refresh function. If a portion of the display is to blink by former setup, this is considered part of the Refresh function.

3.2.5.2 Communication

The capability exists to transmit requests to the computers and to receive commands from the computers. Each transmission consists of a control word followed by a specified number of data words. A format for the control and data words is shown in Figure 3-6. The 16 data bits contained in the data word format are used to define the type of display character or vector to be derived from a stroke generator. Preliminary formats for this use are shown in Figure 3-7. The first four bits are a control code which determines the significance of the remaining 12 bits.

3.2.5.3 Keyboard Operations

The capability exists in the DEU to accept character information from the KBU, to interpret the character and take appropriate action. See Figure 3-8 for character assignments. The "appropriate actions" are not fully defined at this time except through inference. A capability exists to buffer KBU entries and display them on a scratch pad line so that the operator may visually check the entry. It is good practice to use this capability for as many of the keys as possible. It may be assumed, however, that at least one function will not, since something like "ENTER" is required to authorize action on the scratch pad data.

3.2.5.4 Display Functions

The DEU has the capability to generate, through stroke formats, a set of

COMMAND WORD

Bits	Function
1-3	Sync
4-7	MSG Control
8-12	Address
13	MIA Area
14-22	LRU Channel Address
23-27	No. of Words
28-38	Error Protection Code

DATA WORD

Bits	Function
1-3	Sync
4-11	Control Field
12-27	Data
28-38	Error Protection Code

Figure 3-6. DPS/MCDS Interface Word Formats

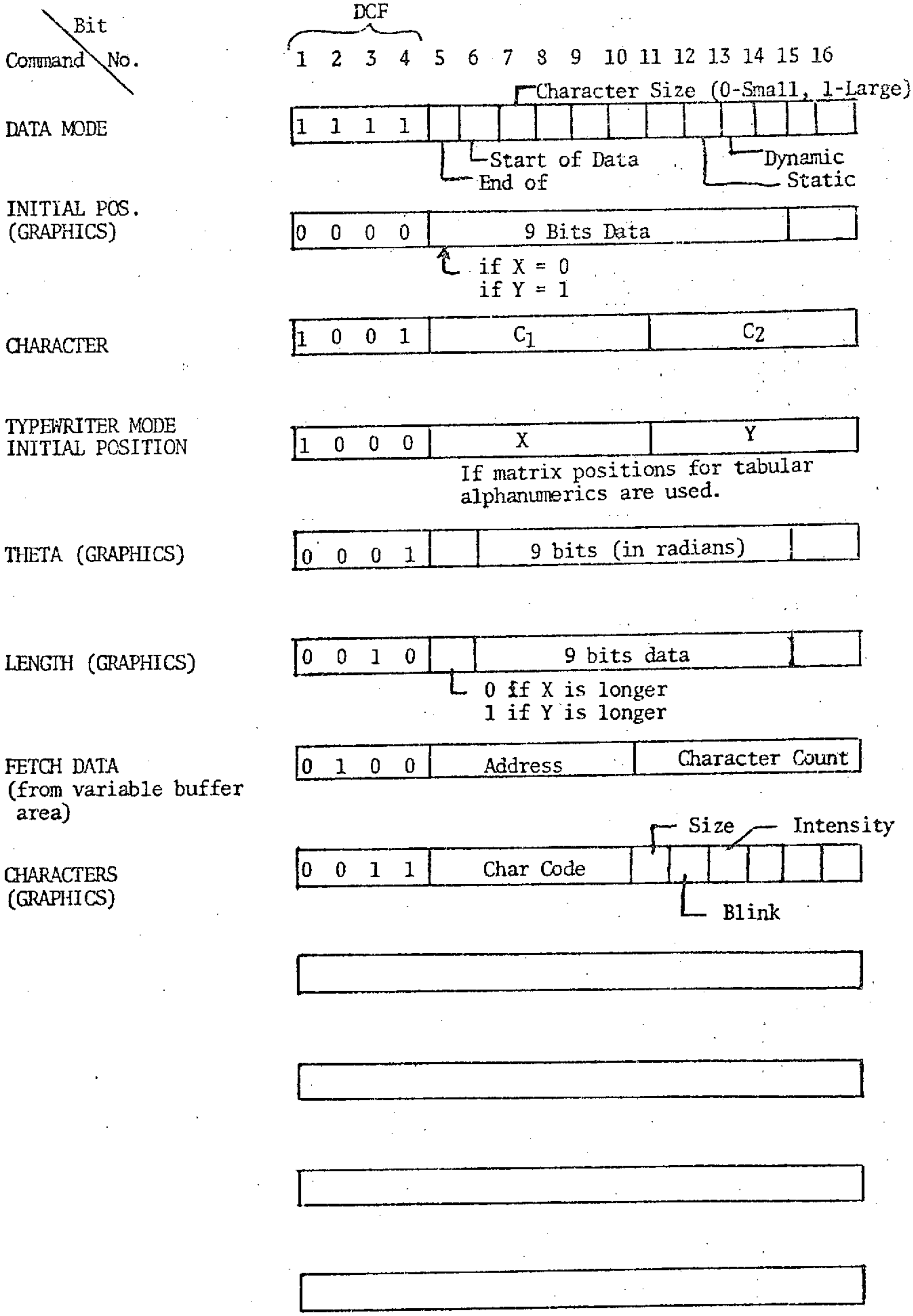


Figure 3-7. Basic Display Control Field Codes

(LSB)$_8$ \ (MSB)$_8$	0	1	2	3	4	5	6	7
0	0	8	G	Ø	W	,		
1	1	9	H	P	X	:		
2	2	A	I	Q	Y	*		
3	3	B	J	R	Z	(		
4	4	C	K	S	.	)		
5	5	D	L	T	+			
6	6	E	M	U	-		SPACE	CARRIAGE RET.
7	7	F	N	V	/		LINE SKIP	TAB

Figure 3-8. Character Code Assignments

required alphanumeric, special character and simple vector displays as well as intensity control for at least blink, normal and brightened intensities. The DEU also has the capability to combine fixed and variable data to refresh the display and to handle responses from BITE. The CDU has automatic features such as phosphor protect and intensity adjust to ambient conditions.

4.0 TRCS/DISPLAY AND KEYBOARD SUBSYSTEM INTERFACE

4.1 FUNCTIONAL INTERFACE

Table 4-1 outlines the functional requirements of the system. This discussion covers the functional aspects of the interface of the TRCS to the Display and Keyboard Subsystem.

A communications link exists between the TRCS Input-Output Box and the Display Electronics Unit. The DEU further communicates with the keyboards and the Display Unit. The computers, the IOB's and the communication channels are sufficiently redundant that they may be assumed operational for the following discussions. See Table 4-2 for message flow definitions.

4.2 TRCS FUNCTIONS

The TRCS system will receive messages from the DEU whenever the keyboard has requested a new display format. The TRCS shall supply a display skeleton from mass memory or a code word which identifies a skeleton stored in DEU memory. The TRCS will provide this transmission only once, then proceed with the following: a list of variable data is prepared in the TRCS and transmitted to the DEU. The list will include at least the system variables required for the present display. The lists may be grouped differently than the displays such that one list may be used for several displays if this is desirable. In any event the TRCS will establish the correct list from data in the original request from the DEU. The variables will be processed and provided in units required by the display and will be converted to binary or to BCD as established by the display requirements.

4.3 DEU FUNCTIONS

The DEU consists of interface circuitry, memory control logic and registers. Data are accepted from the keyboard which initiates a transfer

Table 4-1. Functional Requirements

CREW STATIONS

Four stations utilizing multifunction CRT's

Two forward facing primary flight	(3 CRT's and 2 Kybd's)
Subsystem Management	(1 CRT and 1 Kybd)
Mission Specialist	(1 CRT and 1 Kybd when payload requires)

FUNCTIONAL RELIABILITY

Functions essential to crew/vehicle safety	FO/FS
Functions nonessential to crew/vehicle safety	FS

75 to 100 of the total of 400 formats are essential to crew/vehicle safety

FUNCTIONAL OPERATION

Each keyboard can input to each computer

Each CRT can display from each computer

Each format can display on each CRT

All stations can operate simultaneously (display and data entry) with the same format

Essential format access time not more than 1 second

Nonessential format access time not more than 5 seconds

Keyboards have numeric and small number of special function keys

Normal operation by two-man flight crew

Safe return by single crewman from either seat

DATA RATES

Variable Data	2 per sec
Refresh	≥55 per sec

Table 4-2. Message Flow Definition

TRCS to Display System Messages 1. Data Lists 2. Display Format Skeletons 3. Data Requests 4. Action Request or Alert to an Option Notice Display System to TRCS Messages 1. Request for New Display Format 2. Response to Computer Request Keyboard to Display Messages 1. Numerical Data 2. Special Function Data 3. Configuration Control

of a display request from memory to the TRCS communication equipment. The TRCS then returns the skeleton (Display Program) which the DEU stores in its active memory. If the TRCS returns a code which identifies a skeleton contained in DEU cold memory, then the data in that code are used to set up an indirect addressing mode which causes the program (skeleton) to be the next executed. When the data list starts arriving from the TRCS, it is stored in DEU memory in accordance with reference addresses in a "dictionary" section of the skeleton.

Further functions of the DEU related to the man-machine interface must also be considered. In addition to number keys, there are several "Function" keys on the keyboard which are related to the manner in which the operator and the machine are to function together. These indicate some functional operations which are considered next.

Class A Actions - Operator requests a display to be called.

Data Required - Identification of the particular format desired - This ID may be complete in the keyboard message or may be implicit from the present display and an abbreviation keyboard response; i.e., "PROCEED," etc.

Class B Actions - Operator responds to a computer request.- This condition may result from data in the data list from the computer; i.e., a display entry is brightened or blinks, or a special request may come from the computer for a message to be displayed on a special "ALERT" line of the display. This keyboard response may be numerical data or an action authentication.

4.4 REDUNDANCY MANAGEMENT

All of the functions so far have been normal operating requirements. It is now noted that these operations may be required from more than one crew station and must be transferable between displays and keyboards to meet the minimum functional capability required in the presence of failures and varying crew work load. Redundancy management is simplified in display systems as opposed to some other subsystems because the displays are open loop; i.e., if a display fails, the operator does not look at/utilize it any more. The capability is required, however, to assign a keyboard to another display. The display electronics and display units are one for one, so no active redundancy management is required there. The keyboards are constrained to be non-single point failure, but that does not preclude a keyboard failure for the two fault fail safe case, which is required. However, if a keyboard has failed, both displays to which the remaining keyboard is assigned are still working since only two failures are assumed, and the conditions for safe return from one crew position are met. Thus, it is not necessary for the keyboard to be assigned to the third display.

Conflicts between normal use of displays such as "Handover" and non-nominal use such as reassigned keyboard may be resolved by use of the central display. Since this display is visible to both crewmen and controlled by either keyboard, cooperative interface functions can be handled procedurally.

Since DEU's are dedicated to DU's and keyboards have two push-latch-on mutually exclusive assignment keys, the physical display to computer interface is relatively simple. Each DEU has a hard wired address which is used as required to place coded messages on a bus or to recognize messages on bus for the particular unit.

4.5 DISPLAY/TRCS INTERFACE

The discussion thus far has pointed out that the functional characteristics are generalized to such an extent that the interface mechanization can be relatively simple, and the functional complexity is handled by firmware in a manner similar to computer programs. This is a good approach because the capabilities are included for other DEU functions. Messages to be transmitted are composed by the processor and stored in an identified memory location. The mode of the bus controller is then set by the processor and data is transmitted using processor interrupts when data is needed. For received messages the terminal equipment reads all messages on the bus. When a full message word is received, the address code is compared with hard wired address. Agreement issues a processor interrupt. The detailed functions of the interface mechanization are then controlled by program lists. Thus, the capability is provided to efficiently provide functions of variables as well as fixed functions.

The described manner of determining functional characteristics by means of firmware has some impact on the execution capability of the display processor This impact is minimal since only local instructions are required. The impact will be: more extensive interrupt capability and the firming up of a requirement for indefinite nesting of interrupts, indirect addresses and subroutines. This is not considered serious if a stored register architecture is used with a sufficiently high speed memory.