ADAPTIVE POWER MANAGEMENT
A HIERARCHICAL/DISTRIBUTED SYSTEM

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ABSTRACT

The automatic control of electrical system (ACES) for aircraft shipboard applications was first demonstrated at the Westinghouse Aerospace Electrical Division in 1970 [4]. This system was implemented on a single computer which controlled the hardware directly with discrete signals. Presently Hierarchical and Distributed computer architectures are being evaluated [3, 14], to perform the ACES task. Westinghouse is pursuing a combined Hierarchical/Distributed architecture for its Adaptive Power Management (APM) system [5]. The Hierarchical network performs system control, conflict resolution, and top level resource monitoring and adaption/reconfiguration. The Distributed network performs the system Input/Output functions, all direct control and coordination of the peripherial hardware and the adaption/reconfiguration of their resource/control tables (see Figure 10). In addition, APM complies with the Air Forces requirement to use the standard DAIS AN/AYK-15A processor [10, 11]; the standard higher order programming langauge as defined in MIL-STD-1589 [12], and interface and data bus multiplex system standard MIL-STD-1553B [8, 9].

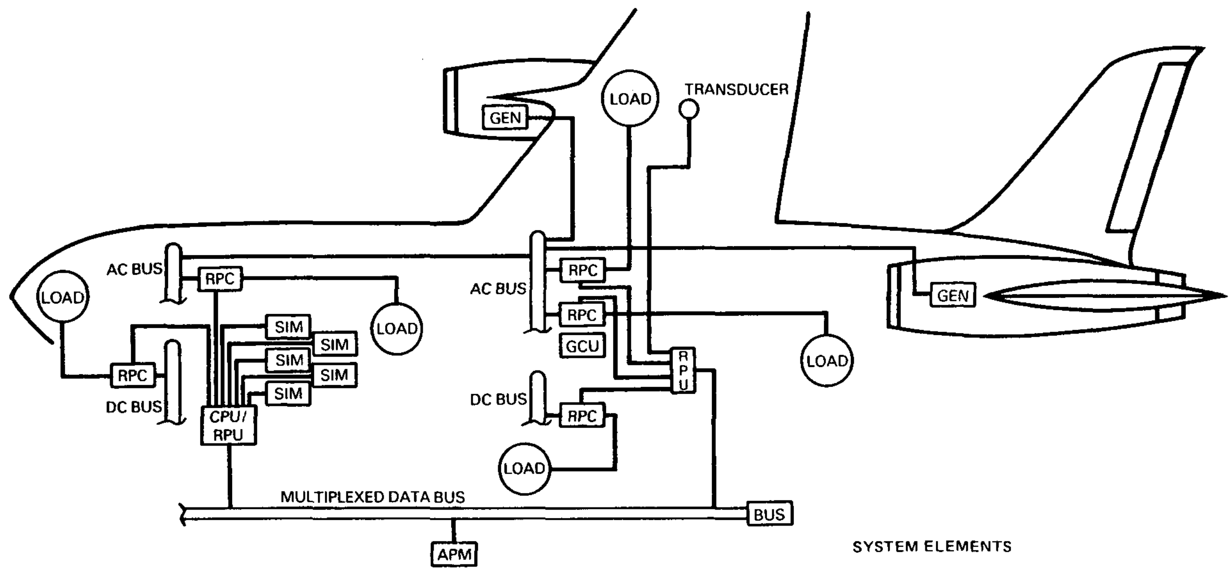
INTRODUCTION

The Adaptive Power Management (APM) System for the airframe shown in Figure 1 provides remote management and control of the power distribution system. To fulfill this function, the APM system receives input command signals from transducers and Switch/Indicator Modules (SIMs) on a multiplexed data bus via Command Processing Units (PU). Within the APM computer, these inputs are combined with Generator Control Unit (GCU) data, Command Equipment Requirement (CER) and Load Management tables to produce Macro Hardware (Macro) commands. These macros are transmitted over the multiplexed data bus to the Remote PUs which control the Remote Power Controllers (RPCs) and their physical loads. Within the Remote PUs, the Macro Hardware Command is decoded to provide specific RPC hardware commands. These RPC commands are transmitted to the loads and then status is polled to provide the data required at the Remote PU for evaluation of specific Boolean equations that confirm the completion of a corresponding APM Macro Hardware Command. In a Hierarchical fashion, the APM polles the Remote PU Macro complete status to determine if all requirements have been satisfied and outputs the results to the originating Command PU and corresponding flight control switch.

An additional feature of the APM system is its capability to adapt/reconfigure the network for power generation unit failures and hardware load failures at the Remote PU level and lower. The first failure type results in the APM system transmitting the Macro to the backup rather than primary Remote PU while the second involves reconfiguring the Remote PU's resource and control tables relative to the load failure.

HIERARCHICAL/DISTRIBUTED SYSTEM

This Hierarchical/Distributed system utilizes two DAIS computers (APM and Bus System) and two networks of Processing Units microcomputers (Command PU and Remote PU). The control of all aircraft system commands is centralized at the APM while the control of all communications is centralized at the Bus System. The Command PU's and Remote PU's are independent processing devices which are activated by hierarchical commands. In the current APM system, the APM computer also assumes a Command PU's tasks so as to maximize the usage of the DAIS computer and provide for manual override via this I/O peripherial. As shown in Figure 2, the APM system's functional tasks are grouped such that the APM accepts the Command PU's command inputs, resolves Command PU input conflicts (i.e., a command to lower landing



SYSTEM ELEMENTS

APM:	ADAPTIVE POWER MANAGEMENT
BUS:	BUS CONTROLLER UNIT
CPU:	COMMAND PU
GCU:	GENERATOR CONTROL UNIT
RPC:	REMOTE POWER CONTROLLER
RPU:	REMOTE PU
SIM:	SWITCH/INDICATOR MODULE

FIGURE 1. POWER DISTRIBUTION SYSTEM

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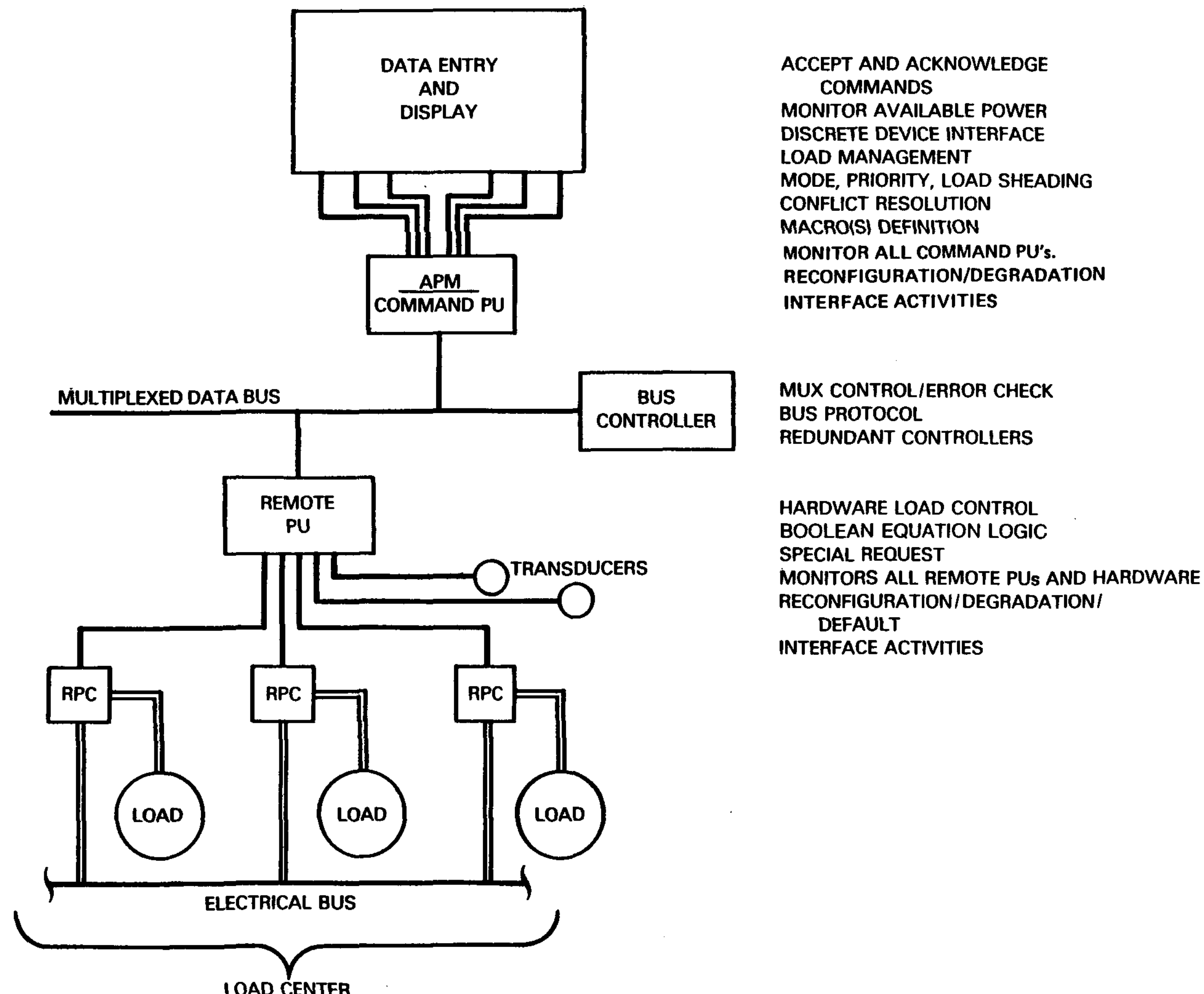

FIGURE 2 GENERALIZED APM'S HIERARCHICAL SYSTEM FUNCTIONAL TASK ASSIGNMENT

gear while cruising at MACH 1), analyzes the resulting Command PU input commands in terms of the load management scheme and power available and generates Macro Hardware Commands. The Bus System uses a poll-bid command/response [5] to accept control of all communications transmissions (i.e., request, commands and data). The Remote PU and Command PU networks activate/deactivate their hardware and solve their command and load Boolean equations.

ADAPTIVE POWER MANAGEMENT SOFTWARE SYSTEM

The Adaptive Power Management (APM) System as shown in figure 2 has four distinct functional software systems (APM, Command PU, Bus System, and Remote PU). Each of these functional software systems has the software structure shown in Figure 3 as follows:

(1) A functional level which either responds to command inputs (Command PU),and generates Macro Hardware Commands (APM), commands transmissions (Bus System), or activates the corresponding hardware (Remote PU).

(2) An adaptive/reconfiguration level which monitors and reconfigures the network's resources and control tables.

(3) An executive system level [13] which enables task to be executed asynchronously and enables the discrete networks to function as a synchronized system.

For each of the APM system's four networks (APM, Bus System, Command PU and Remote PU) the functional level's software accesses different hardware and has a totally different APM system function. The adaptive level software exists at three levels: APM, Command PU and Remote PU. The adaptive logic and the format of their hardware monitor's tables is identical. However, the content of each table is totally different. For example, the APM monitors all Command PUs, a Command PU monitors the Flight Control inputs and the Remote PUs at the level below the Command PU; and the Remote PU monitors the hardware/RPC(s) at the level below the Remote PU. The basic executive system software for all subnetworks is similar except for the routines that perform specific hardware interfaces and unique interrupt handler functions.

As implied by Figure 3, the executive system is required for either of the other innerlevels to function. The adaptive level lies between the executive and application level since in responding to the application level's requirements, it generates a number of executive system level activities.

The following three sections provide an overview of each functional system followed by a detailed description of their software structure and task breakdown.

ADAPTIVE POWER MANAGEMENT/COMMAND PU

In the current Adaptive Power Management (APM) system configuration, the Command PU functional tasks are combined with the APMs to generate the software structure shown in Figure 4. The interrupts or task stimulators are shown as inputs above the executive. Their priority is as shown starting at the left. The numbers shown inside the executive above a specific task correspond to functional tasks in Figure 2. Synchronization (Task I) accepts a two second update message from the Bus System and aligns the computer system to within sixty four microseconds. High Priority I/O processing (Task II) is a high speed interrupt handler that identifies the message type and bids for its processing task. The Macro Response Processing (Task III) decodes Remote PU inputs and generates the corresponding Command PU to flight control command. Command Input Processing (Task IV) assures the system that the status of each command device (SIM/Transducer) is updated and stored at the appropriate rate. Mode Definition processing (Task Va) combines the inputs from the command input processor and the input interrupt handler to determine the APM

system's mode. The major modes are: Start-up, Taxi, Take-Off, Climb, Cruise, Landing. Submodes for each major mode are: Normal, Power Source Failure, Reduced/Steady State Power Level. Load Management processing (Task Vb) analyzes the command inputs relative to the available power and hardware load requirements. This involves merging the multiple hardware commands, processing for conflicting commands and adjusting for equipment failures. The load management system's output is a list of commands and the corresponding equipment. Macro Hardware Command (Macro) Generation (Task Vc) reduces the load management's outputs into a

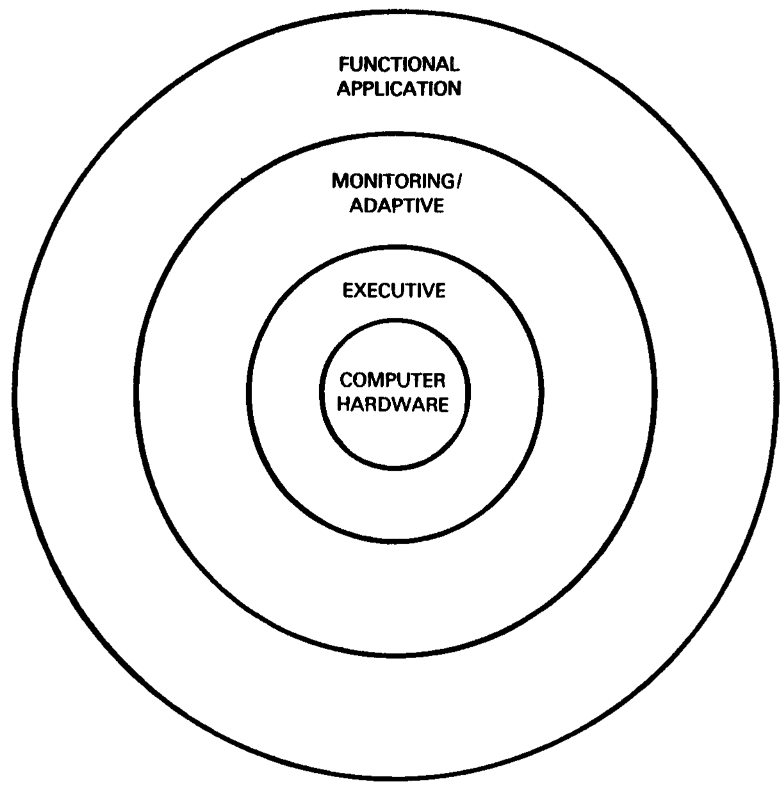

FIGURE 3 FUNCTIONAL PU SOFTWARE STRUCTURE

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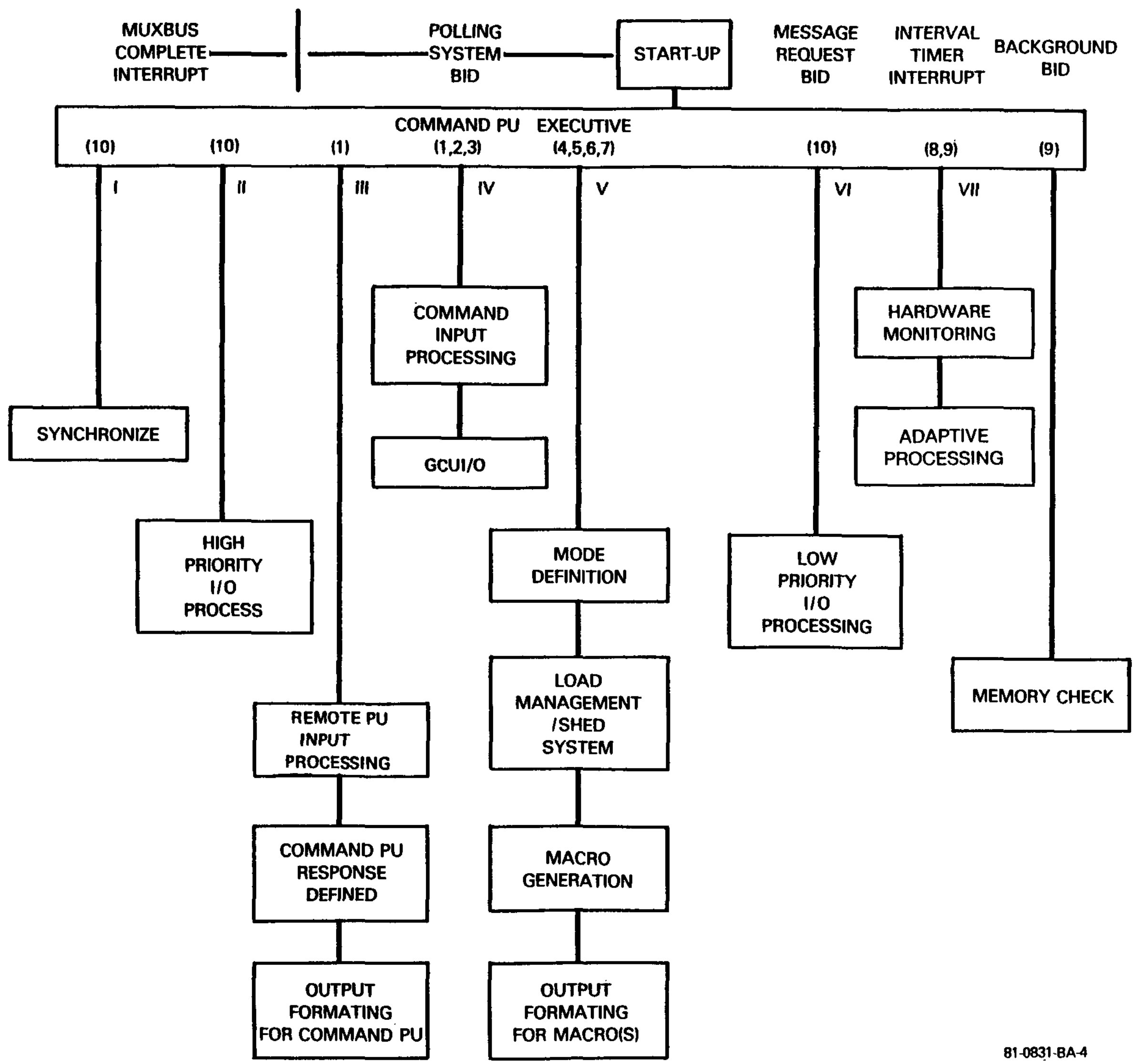

FIGURE 4 COMMAND PU SOFTWARE STRUCTURE

set of commands that can be transmitted to the Remote PU. There are two types of Remote PU commmands: control and service. The control command assigns the Remote PU the responsibility of activating local hardware and solving the corresponding Boolean equation which determines the successful completion of the Macro. The service command requests that the Remote PU activate hardware and transmit the hardware's status to the control Remote PU. The data defining the Remote PU's capabilities and available resources is provided from the executive system's data management system. Macro Output Formating (Task Vd) accepts the Macro commands, control and service Remote PU list and stores the Macro information in the appropriate transmit message. Low priority processing (Task VI) formats and decodes the normal messages. Monitoring and adaptive processing (Task VII) initiates watchdog timer for critical life support events and upon their interrupting the system, generates adaptive processing to reconfigure the network so as to service the life support event. Memory checking (Task VIII) verifies the instruction memory, instruction execution, and I/O wraparound capabilities.

BUS CONTROLLER SYSTEM

The Bus System controls the transmission and reception of all data within the APM system. Since the APM system uses a DAIS computer interfaced with a MIL-STD-1553B MULTIPLEXED Bus System [8, 9, 10, 11], the Bus operates only in a command/respnse protocol with the master controller being situated at either a single Master Bus Controller and/or rotating through the Remote Controllers. The system has a maximum addressing capability of thirty two units accessible via either asynchronize/interruptive or normal non-intrusive messages. All message transmission parity checking and error correction (retransmission request) is handled by the bus hardware system and not the processing unit (i.e., APM, Bus System, Command PU, or Remote PU). Thus, the Bus System processor is totally dedicated to the execution of the bid-poll command/response protocol system [5].

The current APM system uses an independent Bus System to provide the communication flow shown in Figure 5. The commmand information flows in a hierarchical or vertical direction from the flight control hardware to the load hardware and back. The data information flows in a distributed or horizontal direction between the Command PUs or Remote PU. Table 1 presents the specific messages in an inter and intra message format. This grouping is used to emphasize the fact that if the Command PU network is removed from the APM system, the Remote PU network will continue to control the loads in a default configuration. Furthermore, if an Remote PU has an optional manual command override task, the Bus System/Remote PU could still perform the APM function on a very limited basis. The inter-network messages encompass the command and control system between disimilar device types. These messages will fulfill the following requirements: synchronization from the Bus System to Remote PU and Command PUs, Macro Hardware Commands from the Command PU to the Remote PU(s) and adaptive processing messages from the Command PU to the Remote PU(s). The intra-network messages encompass the direct input and output to the system's hardware and communications among similar devices. These messages fulfill the following requirements: activate/deactivate hardware (Command PU to Command Switch or Remote PU to Hardware Load), report hardware status, and adaptive processing messages from Command PU to Command PU or Remote PU to Remote PU. No asynchronize messages will be generated within the intra-message level because their message storage area is limited and restricted to inter-message processing.

The Bus System's software structure is shown in Figure 6. The interrupt system and Tasks I and V are similar to the APM/Command PU's. High Priority Message Request Processing (Task II) scans the request bits in a queued priority request message. For each set message bit, a corresponding priority message's transfer instruction is generated and stored in the Bus controllers message table. After all the priority request bits have been scanned, the queued priority request list's index will be decremented and control will be returned to the executive. Low Priority Message Request Processing (Task IV) is similar to Task II and generates low priority message instructions.

REMOTE PROCESSING UNIT SYSTEM

The Remote PU system accepts the Command PU's Macros, activates/ deactivates the appropriate hardware, solves Boolean equation to determine the status of the Macro and transmits the Macro's status back to the Command PU. The Remote PU software is structured as shown in Figure 7. The interrupt system and Tasks I, IV, V, and VI are similar to the APM/Command PU's. Macro processing (Task II) is subdivided as shown in Figure 8. An Remote PU designated as a controller activates hardware in a timely fashion, verifies that all required hardware is active, acknowledges hardware failures, requests reconfiguration, solves the Boolean equation and reports the solution to the APM system controller. An Remote PU designated as a service Remote PU activates the Macro's hardware and reports their status to the Remote PU controller. Automatic Remote Power Control Reset processing (Task III) reinitializes the appropriate commands to reactivate an RPC.

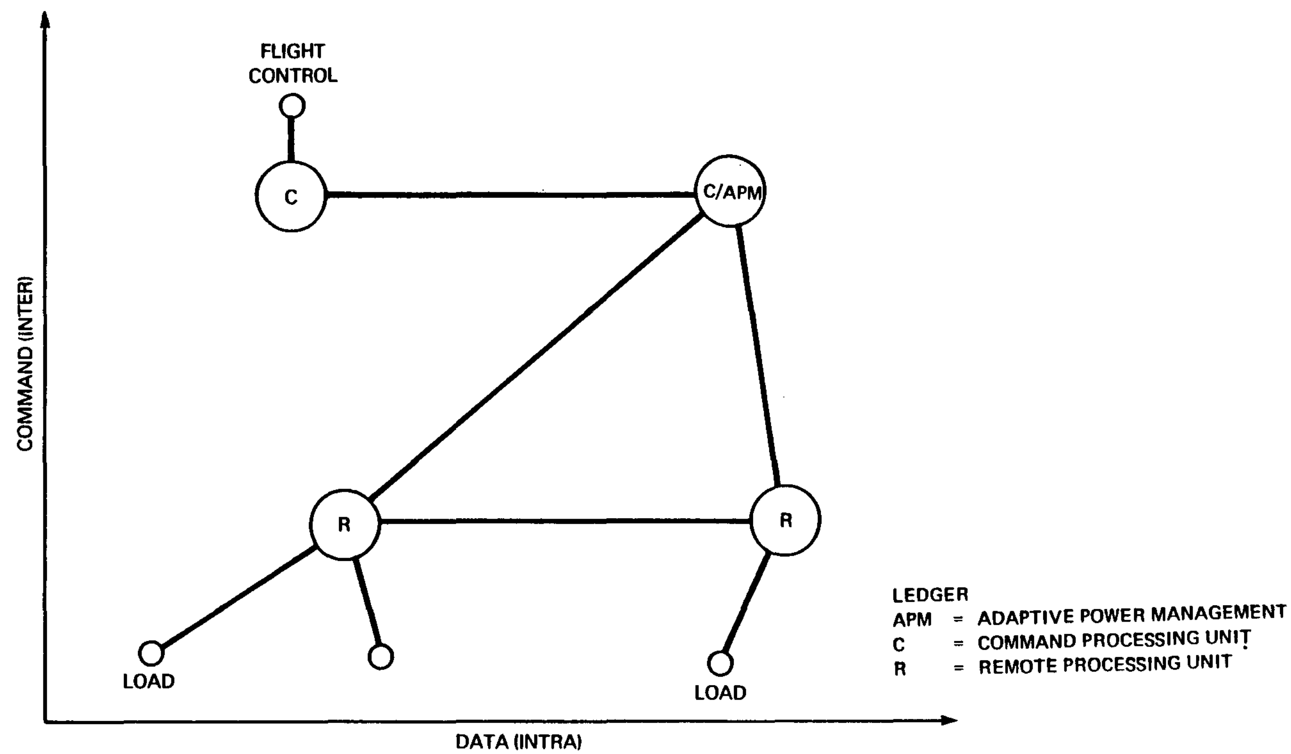

FIGURE 5 APM'S INFORMATION FLOW

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TABLE- 1. APM COMMUNICATION MATRIX

LEVEL	TRANSFER MECHANISM	MESSAGE ROUTE: CIO – RIO	CIO – MIO	CIO – CIO	MIO – RIO/CIO	RIO – RIO	RIO – MIO	RIO – CIO	MSG LENGTH	MESSAGE TITLE
INTER NETWORK	BROADCAST INTERRUPT									NOT USED
	ASYNCH (INTERRUPT)				X				1	POLLED MESSAGE REQUEST
		X							2	MACRO HARDWARE COMMAND (MACRO)
					X				1	SYNCHRONIZE (COARSE)
	NORMAL POLLING RATE HIGH							X	2	MACRO HARDWARE COMMAND RESPONSE
	NORMAL POLLING RATE LOW		X				X		2	LOW PRIORITY MESSAGE REQUEST
					X				1	SYNCHRONIZE(FINE)
		X						X	1	MONITOR COMMAND
		X						X	7	MONITOR STATUS RESPONSE
		X						X	1	ADAPT COMMAND
		X						X	!	ADAPT STATUS RESPONSE
INTRA NETWORK	BROADCAST									NOT USED
	ASYNCHRONIZE									NOT USED
	NORMAL POLLING RATE HIGH			X		X			1	HARDWARE STATUS REQUEST
				X		X			7	HARDWARE STATUS
	NORMAL POLLING RATE LOW			X		X			1	MONITOR COMMAND
				X		X			7	MONITOR STATUS RESPONSE
				X		X			1	ADAPT COMMAND
				X		X			1	ADAPT STATUS RESPONSE

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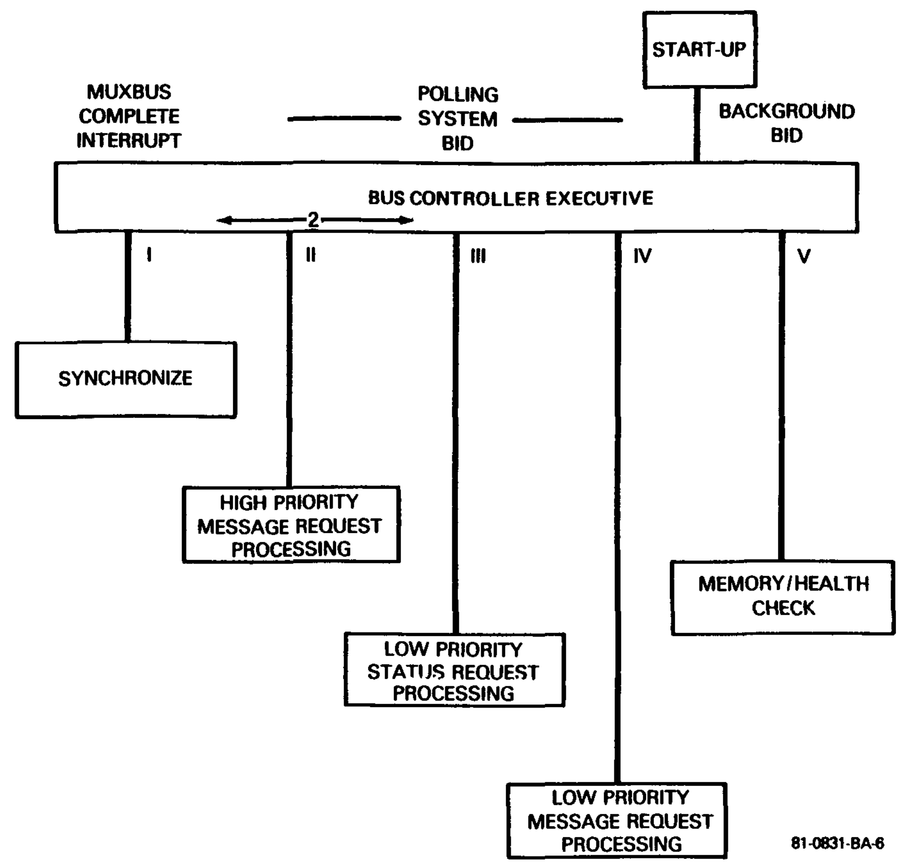

FIGURE 6 BUS CONTROLLER SOFTWARE STRUCTURE

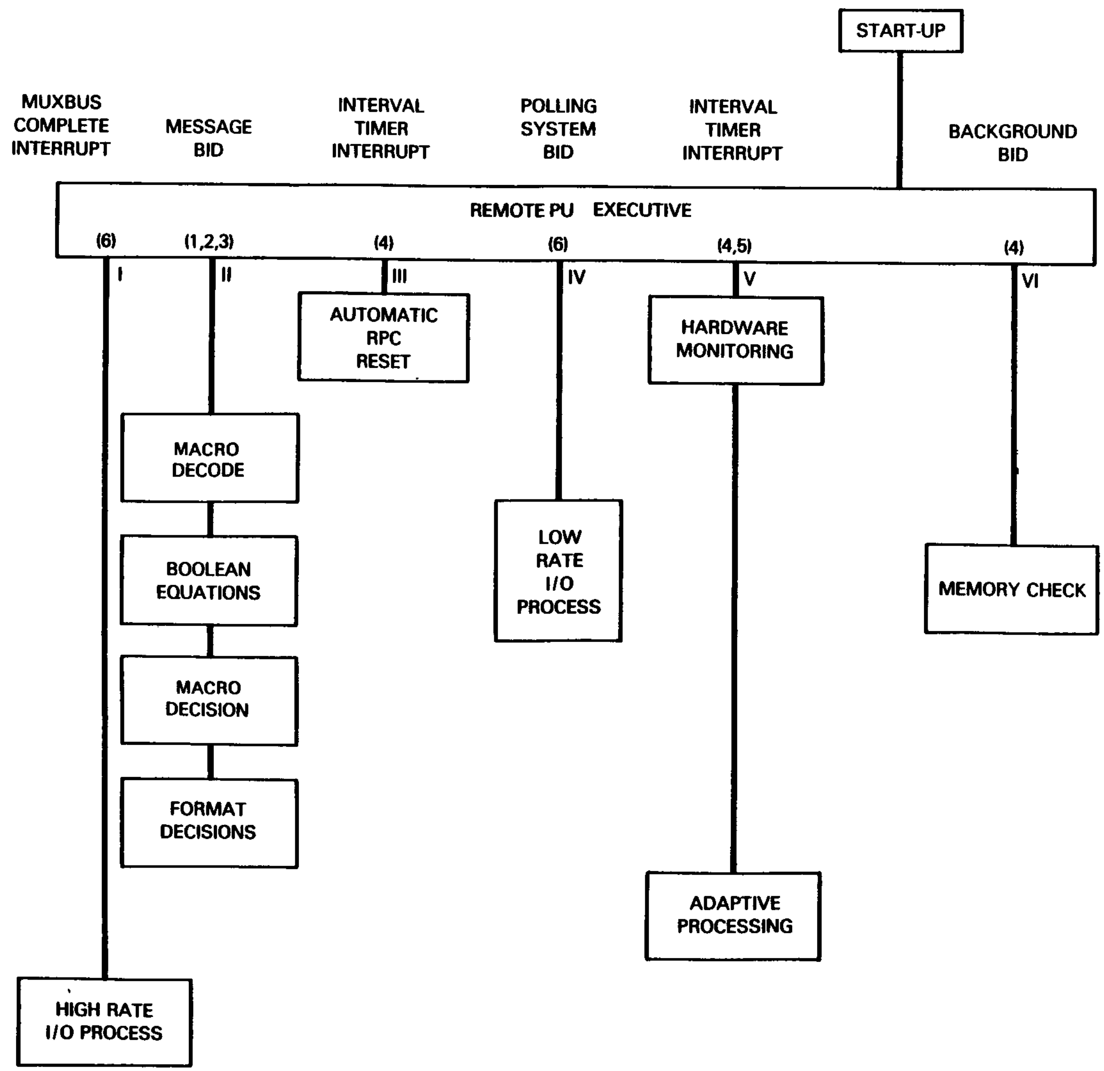

FIGURE 7 REMOTE PU SOFTWARE STRUCTURE

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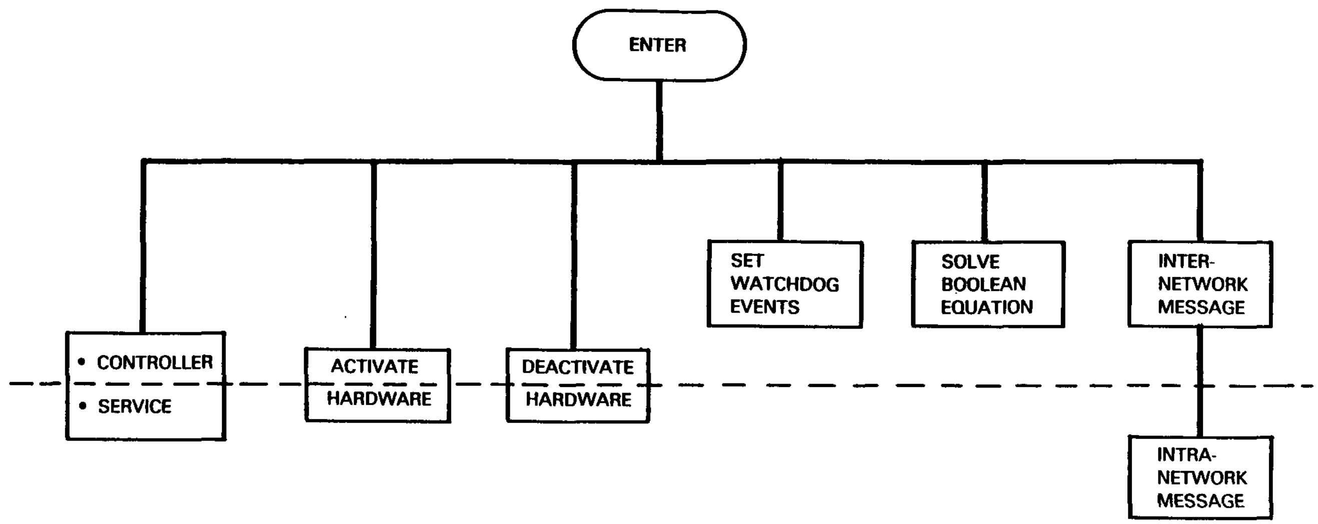

FIGURE 8 REMOTE PU's MACRO FUNCTIONAL TASK BREAKDOWN

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MONITORING AND ADAPTIVE SYSTEM

To increase the reliability of the APM System with regards to hardware failures and provide graceful Degradation, a Monitoring and Adaptive (M&A) System exists to reconfigure the networks [2] (i.e., assign input and/or output channels to different devices). The monitoring task is responsible for identifying hardware failures which reveal themselves as an inconsistence in the hardware status reported by several different I/O data paths. As shown
in Figure 9, there are three levels in the hierarchical background monitoring processing (APM, Command PU, and Remote PU). The logic at each level is identical in that the hierarchical Input/Output devices will control the M&A process while the lower level devices will service their commands. Within each level a unit failure can be determined by commanding the lower units to report the status of a specific command. If the lower unit's responses do not agree, the unit is further checked against other units. This enables the monitoring APM, Command PU and Remote PU to determine if the failure is: (1) The unit, (2) The hardware channel, (3) The hardware beyond the channel.

Because a high rate of hardware monitoring could overload the Bus System communications system, the hierarchical background monitoring is performed at a very low rate (i.e., 1/4 Hz) and augmented with an event driven monitor. This event driven monitor, initiates a watchdog interrupt with the generation and receipt of every Macro at an APM/Command PU and Remote PU respectively. Given that the system can not perform the Macro within the specified time period, the controlling device will initiate a nearest neighbor monitoring algorithm to determine the hardware failure. The watchdog timers are designed to generate event driven monitoring in a bottom-up manner. The adaptive system responds to hardware failure identified by the background or Macro event monitors by re-routing the Macro commands. This re-routing or system reconfiguration is performed by modifying the devices Resource/Control table shown in Figure 10. For example, if Remote PU #3 failed the adaptive processor would delete the Remote PU #3 reference in row two relative to Macro #1, Hardware #9. Thus all further requests to activate or deactivate Hardware #9 are via Remote PU #2.

EXECUTIVE SYSTEM

The executive system uses an interrupt driven executive similar to that used in Westinghouse's F-16 and DIVAD radar systems [13]. The interrupt system facilitates the processing of data when available as opposed to on a scheduled basis. Consequently the system's processing is asynchronous (i.e. event driven) rather than synchronous. Within the APM system, the executive for the APM/Command PU, Command PU(s), Bus System, and Remote PU(s) is very similar. The primary differences are the Data Management files (see Figure 10) and the special purpose interrupts and unique I/O interfaces.

APPLICATION

A functional schematic of the Vought Corporation's advanced technology electric control system for a multi-engine aircraft is shown in Figure 11 [6]. As summarized in the lower left corner, this system consists of four generators, a four processor-split bus APM system, thirty two load management centers (Command PU, Bus System, and Remote PU) and up to 1320 sensors and remote power controls/loads. Figure 12 shows the Vought system as it is defined within the APM concept which is identical in content to Figure 2, with the exception that a Command PU is not resident at the APM but totally separate.

SUMMARY

The Adaptive Power Management (APM) system described here is a hierarchical/ distributed system which centralizes the command and control of the power distribution system while off loading to each distributed network the responsibility of seeking the solution of the control's and load's Boolean equations. The DAIS/Data Bus Military Standards lend themselves to an independent Master Bus Controller with a poll-bid command-response protocol. Furthermore, the APM architecture facilitates the use of a hierarchical/ nearest neighbor monitoring and adaptive processing which is initiated by a background/Macro event, respectively. Finally the current APM structure does lend itself to future airframe applications such as Vought's concept for the advanced technology multi-engine aircraft.

- THREE LAYER
  - APM
  - COMMAND PU (C)
  - REMOTE PU (R)
- VERTICAL (HIERARCHICAL)
  - O.S. ORIGINATED AT A LOW RATE
- HORIZONTAL (NEAREST NEIGHBOR)
  - EVENT ORIGINATED AT PRIORITY RATE

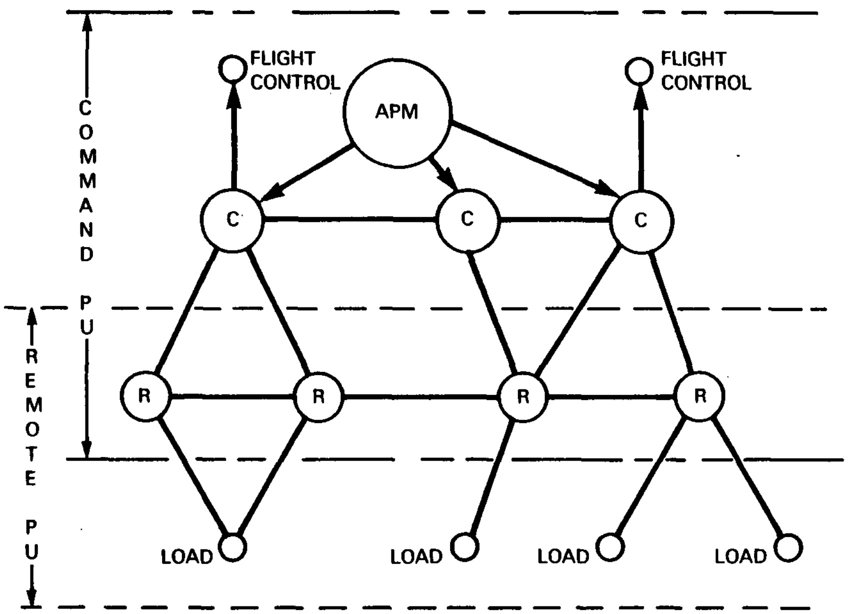

FIGURE 9 RECOMMENDED MONITORING SYSTEM

RESOURCE/CONTROL TABLE (REMOTE PU NO. 18)

MACRO	HARDWARE	DATA NEEDED REMOTE PU	DATA SUPPLIED REMOTE PU	BOOLEAN EQUATION	MAXIMUM TIME (μSEC)	DESCRIPTION
1	3	0 0				MACRO to be performed at this Remote PU using Boolean Equation No. 5 HRD No. 3, 41 are attached and Remote PU 3 will provide status for hardware No. 9
	9	3 2	0 0	5	400	
	41	0 0				
3	20	0 0				
	11	1 5	0 0	1	1600	
	2	0				
	4	4 0				
5	1	0 0				
	3	15 0	0 0	0	200	
8	14	0 0	1 8	0	100	MACRO 8 to be done at Remote PU No. 1
10	21	0 0	5 0	0	100	MACRO 10 to be done at Remote PU No. 5 Hardware is monitored and status reported. No Boolean Equation evaluation since = 0.
20	9	3 2				
	11	1 5	0 0	7	500	
	3	15 0				

|← SYSTEM NETWORK →|

|← SYSTEM CONTROL →| |← SYSTEM CONTROL →|

FIGURE 10. DATA MANAGEMENT'S REMOTE PU FILE STRUCTURE

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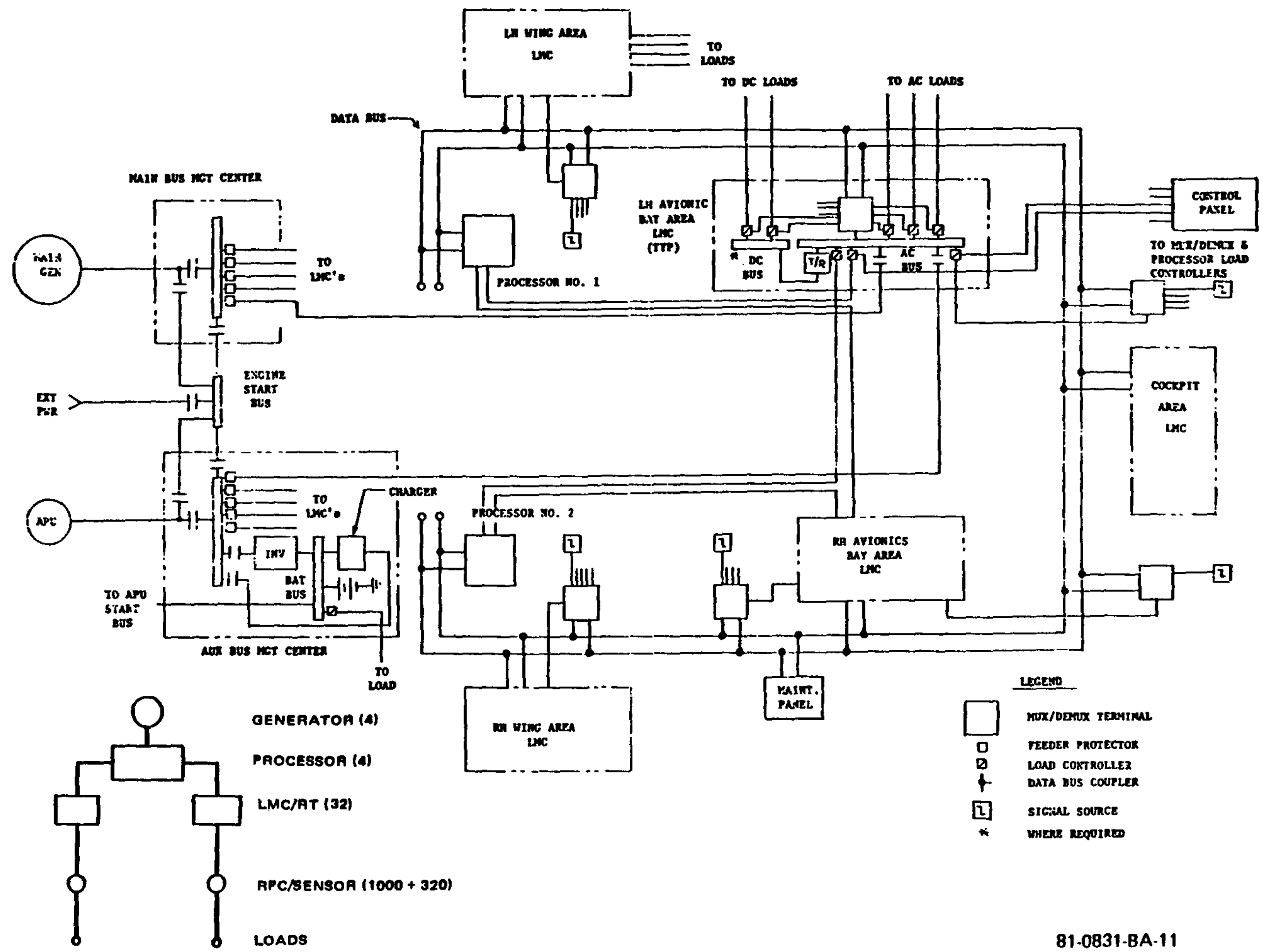

FIGURE 11. VOUGHT'S MULTI ENGINE CONTROL SYSTEM

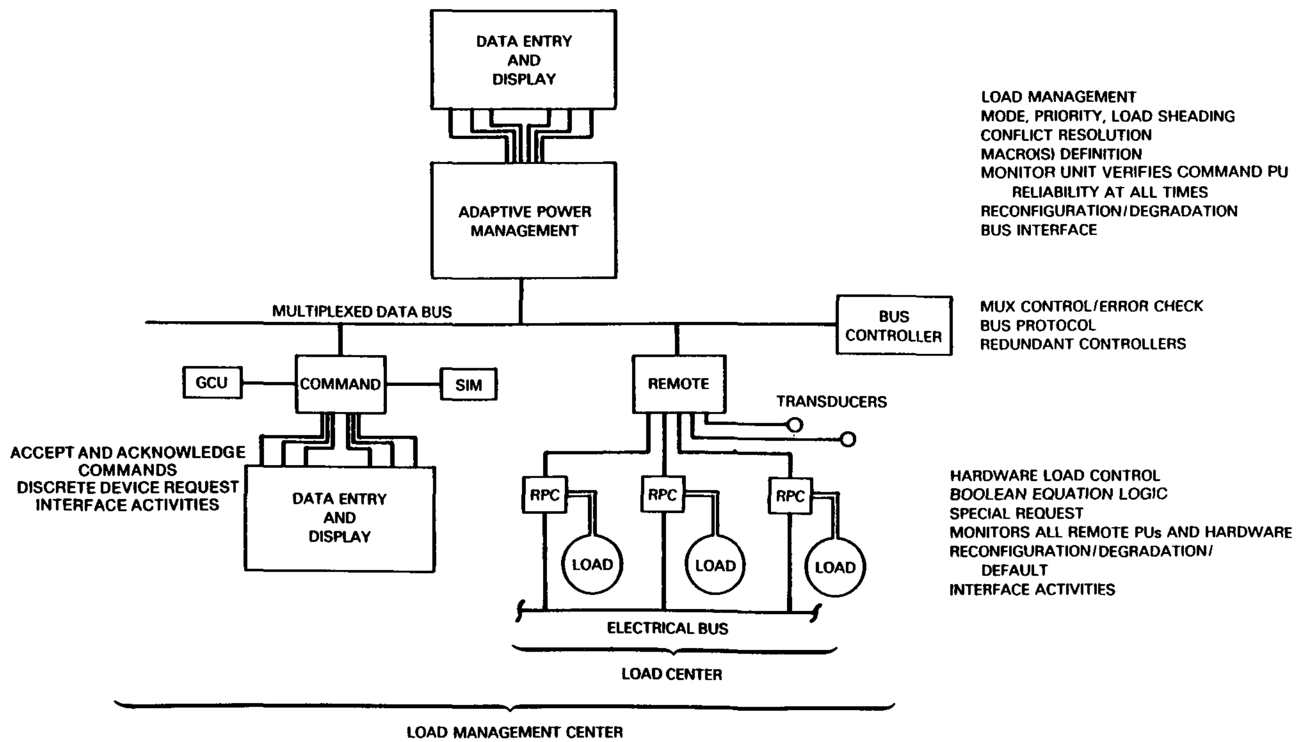

FIGURE 12 VOUGHT'S HIERARCHICAL SYSTEM FUNCTIONAL TASK ASSIGNMENT

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