FINAL REPORT

APOLLO GUIDANCE COMPUTER PROGRAM BLOCK I (100) AND BLOCK II

SR70-4053

31 DECEMBER 1969

PERIOD COVERED

25 JULY 1964 THROUGH 31 DECEMBER 1969

PREPARED FOR

AC ELECTRONICS

DIVISION OF GENERAL MOTORS CORPORATION

MILWAUKEE, WISCONSIN 53201

PREPARED BY

RAYTHEON COMPANY

EQUIPMENT DIVISION

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NASA CR 108361

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Prepared For

AC ELECTRONICS
Division of General Motors Corporation
Milwaukee, Wisconsin 53201

Subcontract Purchase Order FNP 12775.
(A Subcontract under NASA Prime Contract NAS 9-497)

Prepared By

RAYTHEON COMPANY
EQUIPMENT DIVISION
Sudbury Engineering Facility
Sudbury, Massachusetts 01776

FOREWORD

Raytheon Company's Apollo Program effort was fulfilled under purchase order FNP 12775 and covered the period from 25 July 1964 through 31 December 1969.

References are Statements of Work

a. Block I and Block I(100) series Guidance Computer, Simulation Computer, and Associated Ground Support Equipment, dated 1 December 1964; and revisions thereto.

b. SOW 32-31-21, Block II/LM Apollo Guidance Computer, and Associated Airborne, Simulation, and Ground Support Equipment, dated 1 September 1967.

In accordance with the requirements of references a. and b. this final report is submitted covering the period of 25 July 1964 through 31 December 1969.

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SECTION 1

INTRODUCTION

This document is submitted as the Final Report under Purchase Order FNP 12775, a subcontract by AC Electronics under prime contract NAS 9-497 with the National Aeronautics and Space Administration. The scope of the contract included design effort and the development and fabrication of Apollo Guidance Computer subsystems and associated Ground Support Equipment. This effort was accomplished under the direction of AC Electronics, and in association with the Massachusetts Institute of Technology which was responsible for the overall design.

The program progressed in three increments: Block I(0), Block I(100) and Block II. The early Block I phase was devoted primarily to research and development and is covered in this report to provide a design baseline and to maintain continuity with the development of eventual flight systems. In the Block I(100) phase, flight qualified systems and the associated support equipment were produced. Block I(100) systems were used in early unmanned Earth orbital flights.

The Block II phase resulted in the final design and development of the flight systems utilized in lunar missions.

This report is devoted primarily to equipment delivered and the Engineering, Manufacturing, and Reliability and Quality Assurance effort provided during the program. Highlights of significant events, problems encountered, and their solutions are described in each section. Detailed reports documenting events in depth have been provided periodically throughout the program.

SECTION 2

EQUIPMENT

This section covers the description and leading particulars of the major Airborne and Ground Support Equipments which were built and delivered under the Apollo contract.

2.1 BLOCK I(O)

2.1.1 PHYSICAL CHARACTERISTICS

The Computer Subsystem consists of the Apollo Guidance Computer (Figures 2-1 and 2-2), the Main Panel Display and Keyboard (Figure 2-2), and the Navigation Panel Display and Keyboard (Figure 2-2). Figure 2-3 is a block diagram of the guidance and navigation (G&N) system.

2.1.1.1 Apollo Guidance Computers

The Apollo Guidance Computer (AGC) is approximately 19 inches wide, 24 inches deep, and 7 inches high (a detailed sketch is shown in Figure 2-4). The AGC consists of three plugin tray assemblies and an end connector assembly which are mounted on a base coldplate. The base coldplate, which is part of the spacecraft, is an aluminum alloy, liquid-cooled, honeycombed structure designed to dissipate the heat emitted from the AGC. The end connector assembly is bolted to the base coldplate and provides support for the plugin tray assemblies. The three plugin tray assemblies consist of one memory tray assembly, one logic tray assembly, and one G&N harness assembly.

The memory tray assembly (Figure 2-5) consists of two panels which are mounted vertically on the coldplate and bolted back to back. The right panel contains 11 horizontally mounted and two vertically mounted modules. The left panel contains six horizontally mounted and nine vertically mounted modules.

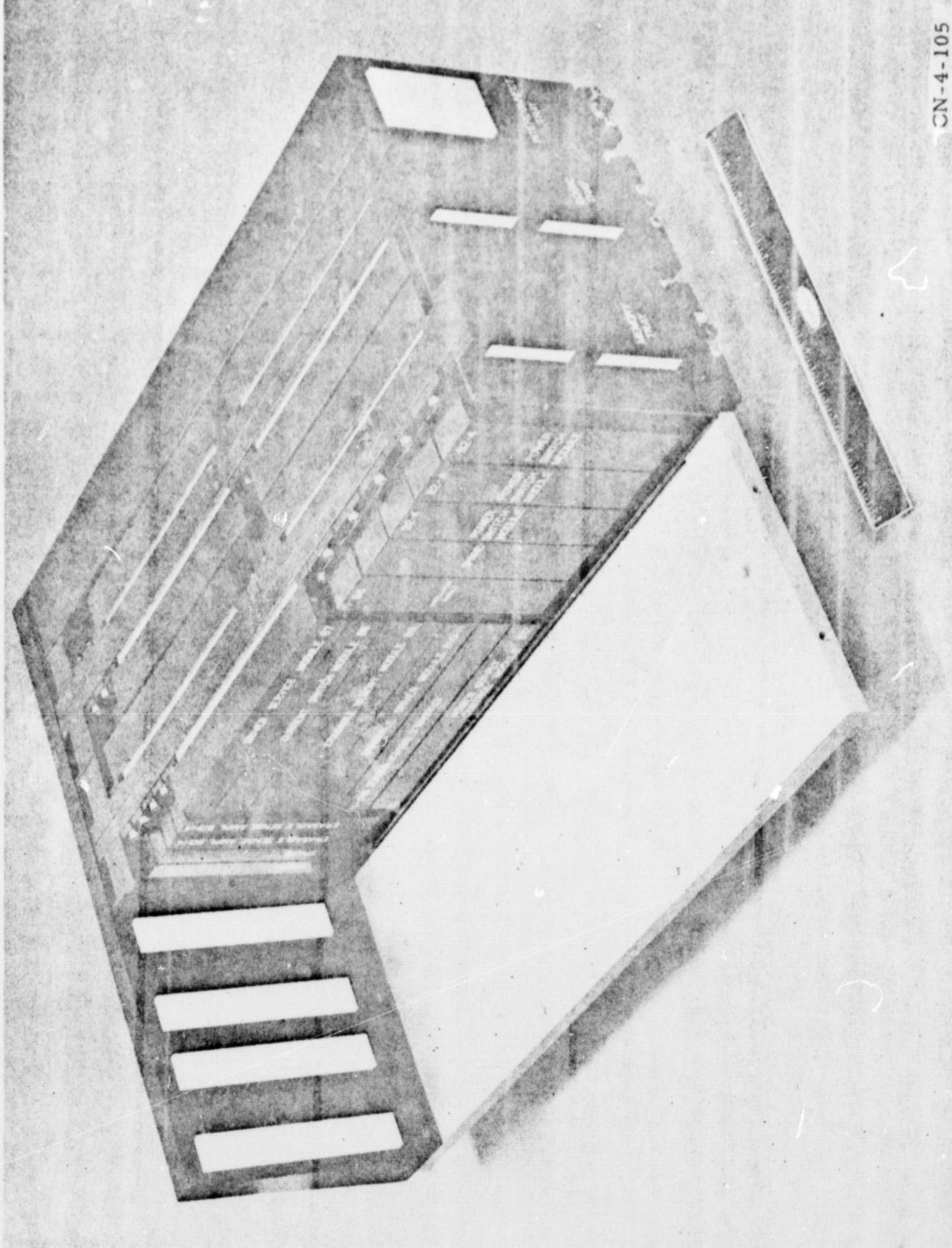

Figure 2-1 Block I(0) Apollo Guidance Computer

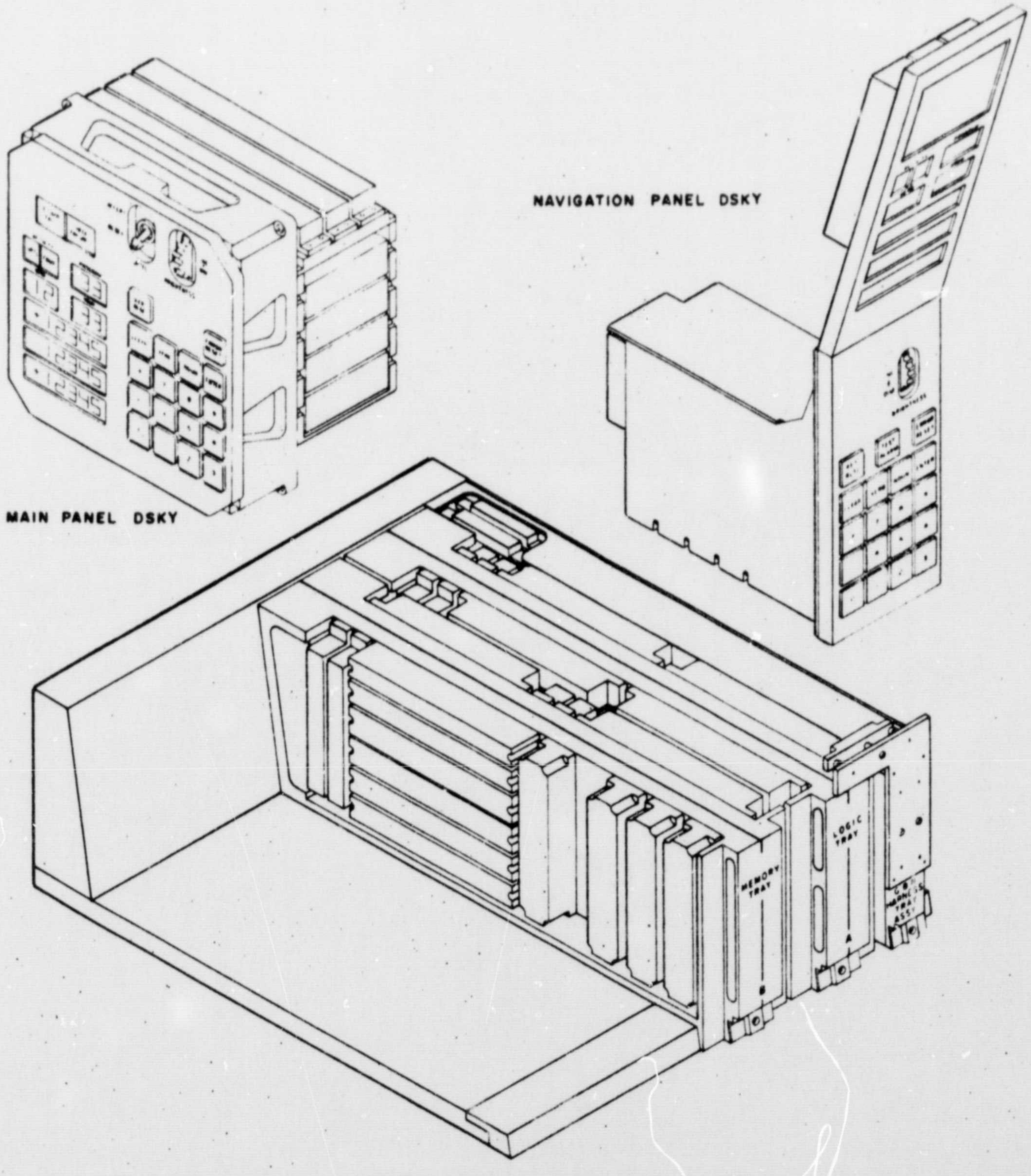

Figure 2-2 Computer Subsystem Equipment, Block I(O)

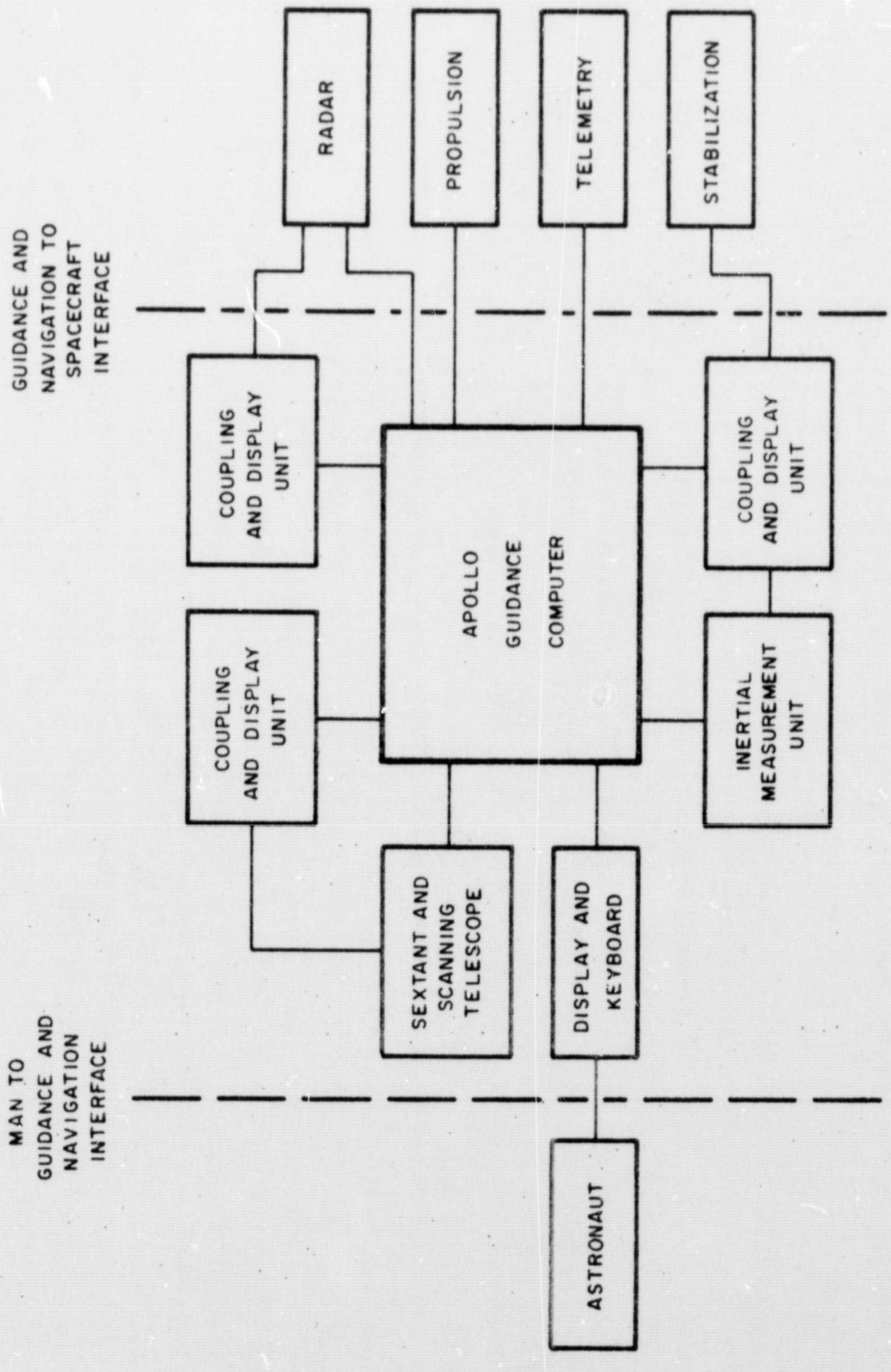

Figure 2-3 Apollo G&N System

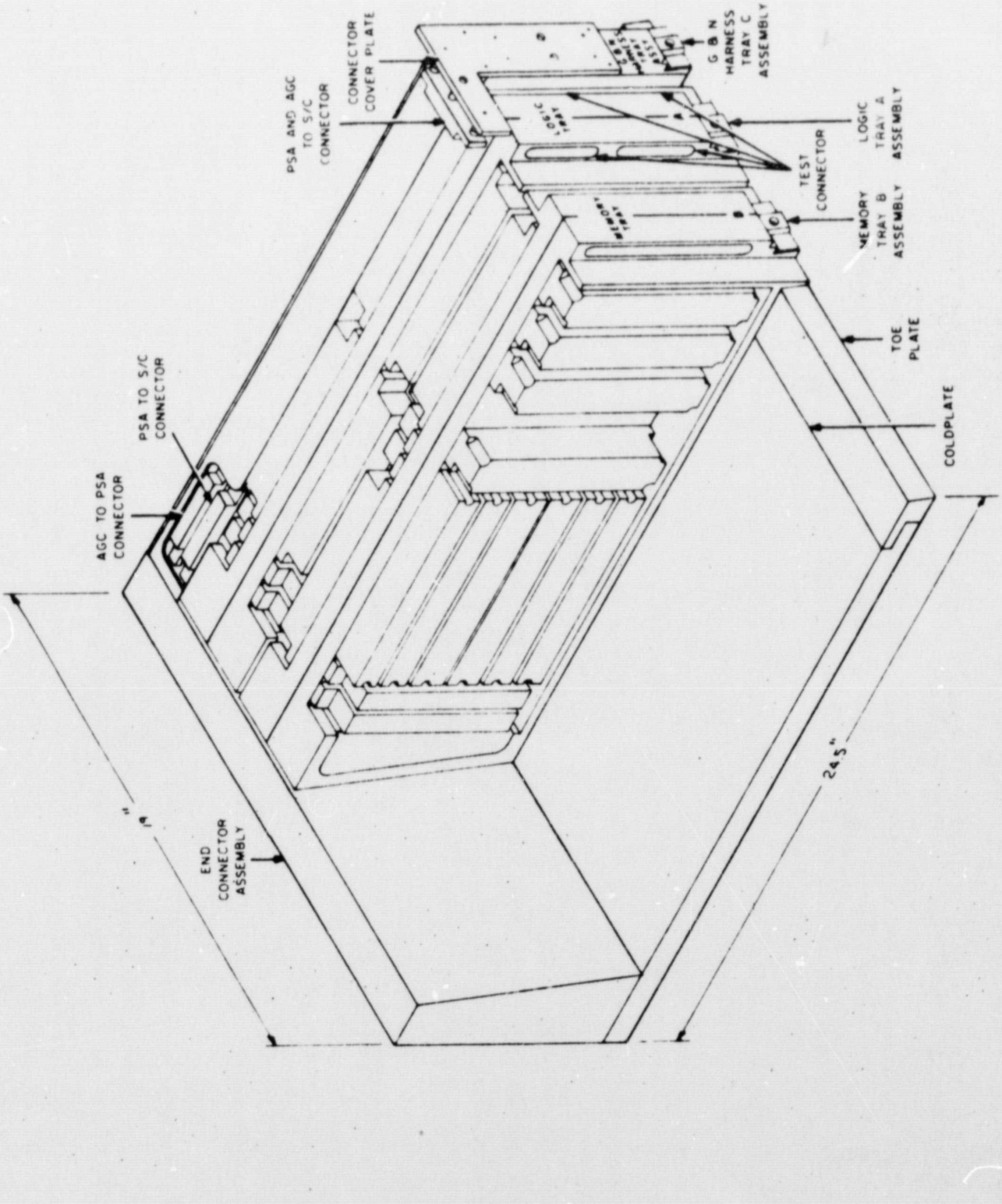

Figure 2-4 Apollo Guidance Computer Sketch

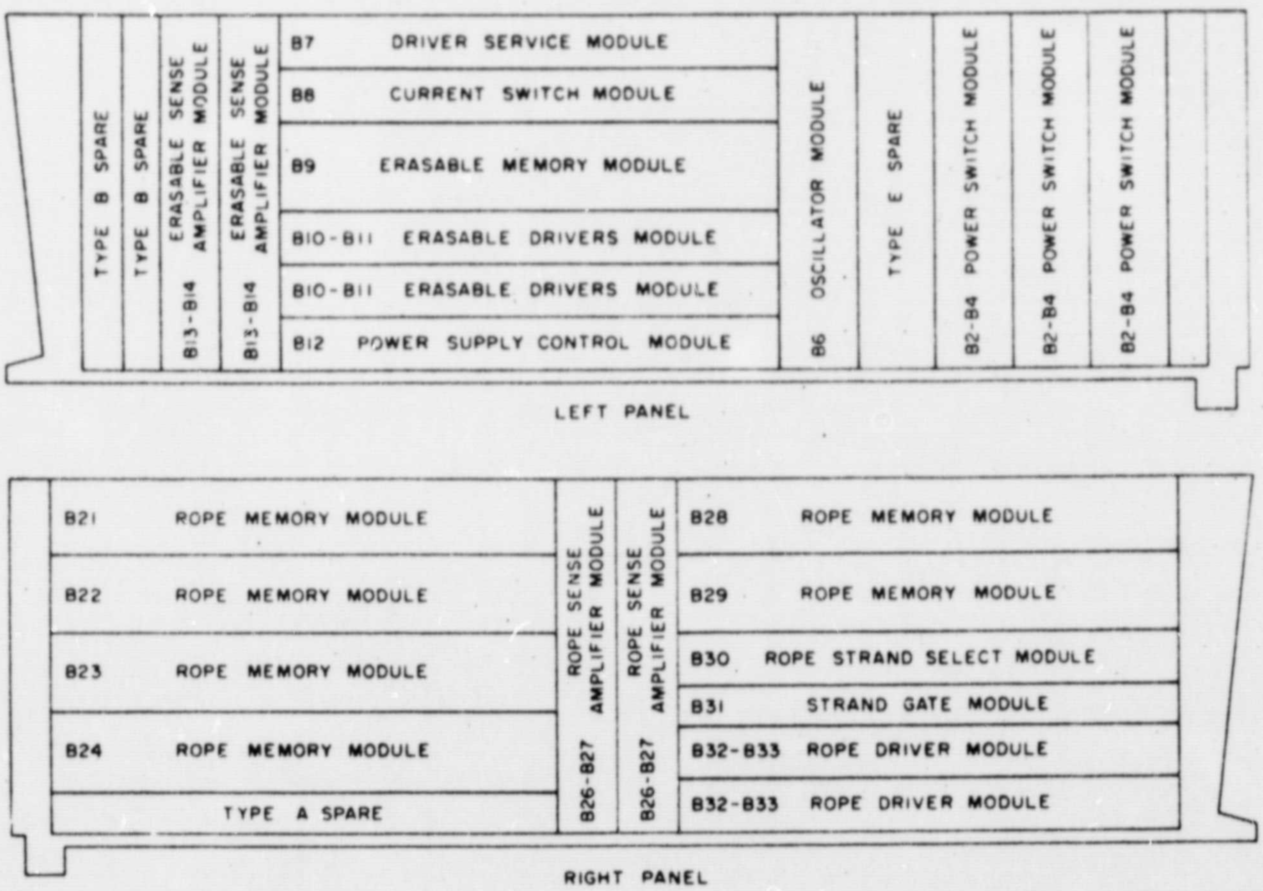

Figure 2-5 Memory Tray Assembly

The logic tray assembly (Figure 2-6) consists of two panels. Each panel contains 18 horizontally mounted and two vertically mounted modules. Two test connectors located on the logic tray assembly provide connection between the AGC and Ground Support Equipment (Computer Test Set).

The G&N harness tray assembly provides connection of the AGC to the Power and Servo Assembly (PSA) and the spacecraft and also provides connections between the PSA and the spacecraft.

The micrologic modules (Figure 2-7) consist of micrologic elements which are miniaturized semiconductor packages mounted in TO-47 cans. The cans contain the necessary resistors and transistors diffused onto a single silicon chip.

The micrologic modules used in the plugin tray assemblies of the AGC contain a maximum of 120 integrated NOR elements per module. The module (Figure 2-7) is 9 3/4 inches long, 1 inch wide, and 1 1/2 inches

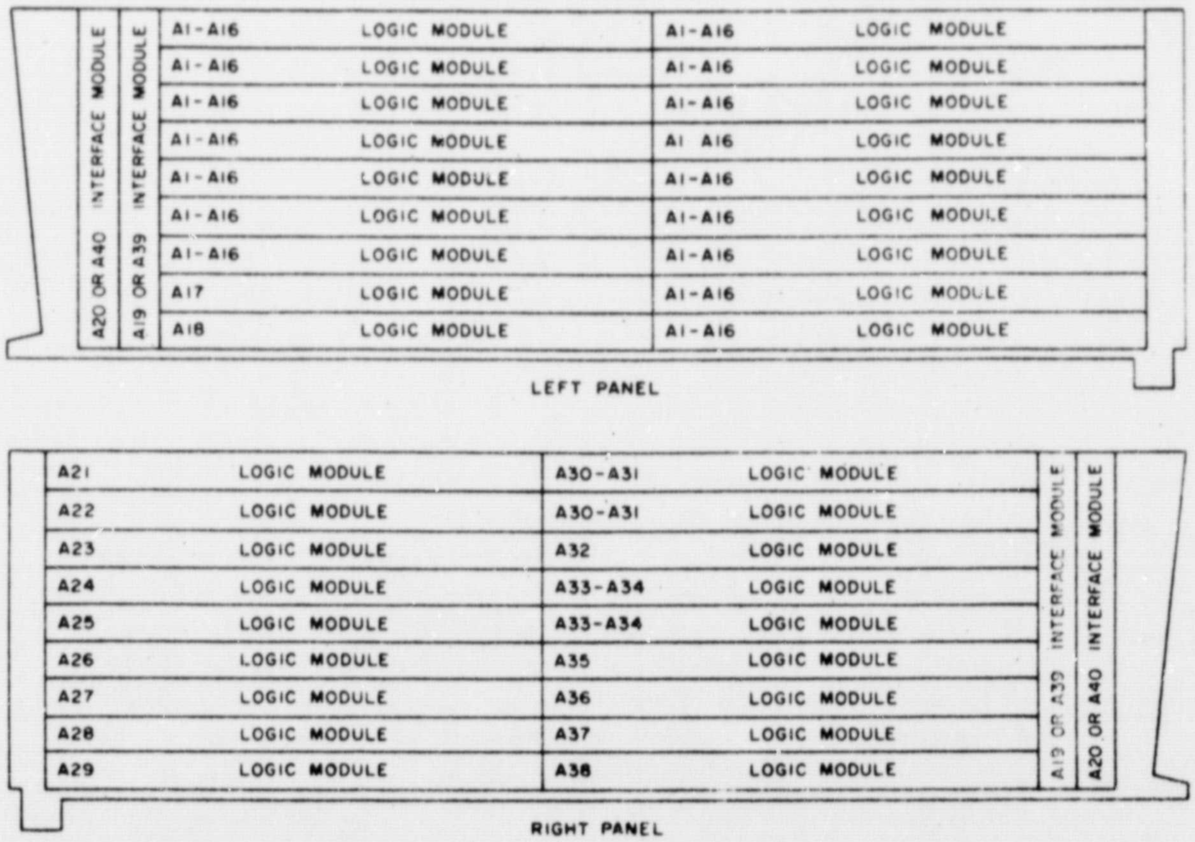

Figure 2-6 Logic Tray Assembly

deep and is constructed of a hard anodized magnesium H-beam header, which divides the module into two sections. The elements mounted on the module are interconnected by a folded matrix which is connected to male connector pins through a flat inner matrix. The complete assembly is potted with urethane foam.

2.1.1.2 Navigation Panel Display and Keyboard

The Navigation Panel Display and Keyboard (Navigation Panel DSKY) (Figure 2-8) is approximately 22 inches high, 6 inches wide, and 14 inches deep. The DSKY is divided into two sections: one for the display and one for the keyboard. The display section contains 12 failure lights, eight operation display lights, and 18 data display lights. Mounted in the rear of the display section are three interchangeable decoding modules. The keyboard section contains 19 keys and a brightness control. Mounted on the rear of the keyboard is a case containing four interchangeable relay trays and a power supply module. Each relay

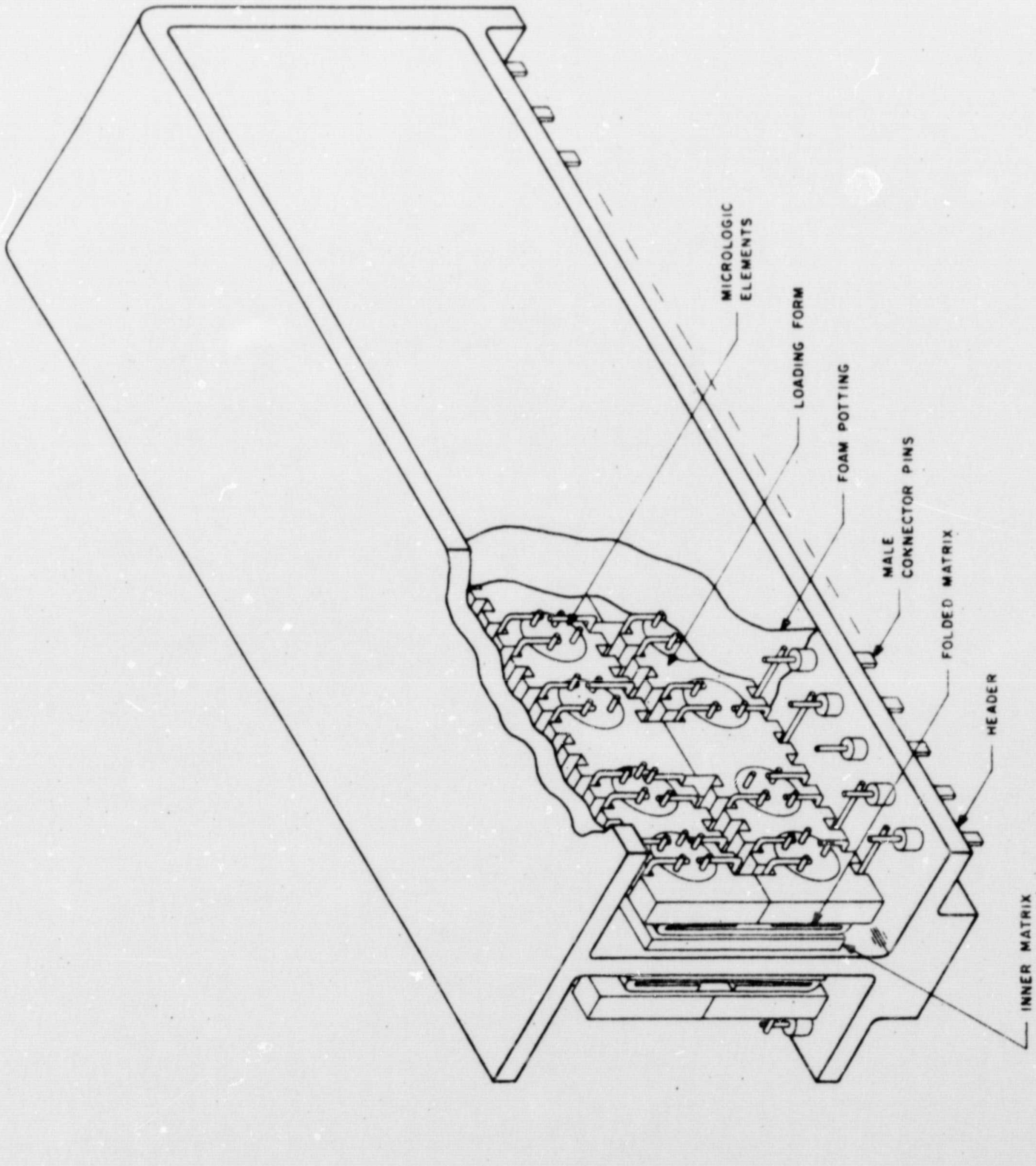

Figure 2-7 Typical Module Construction

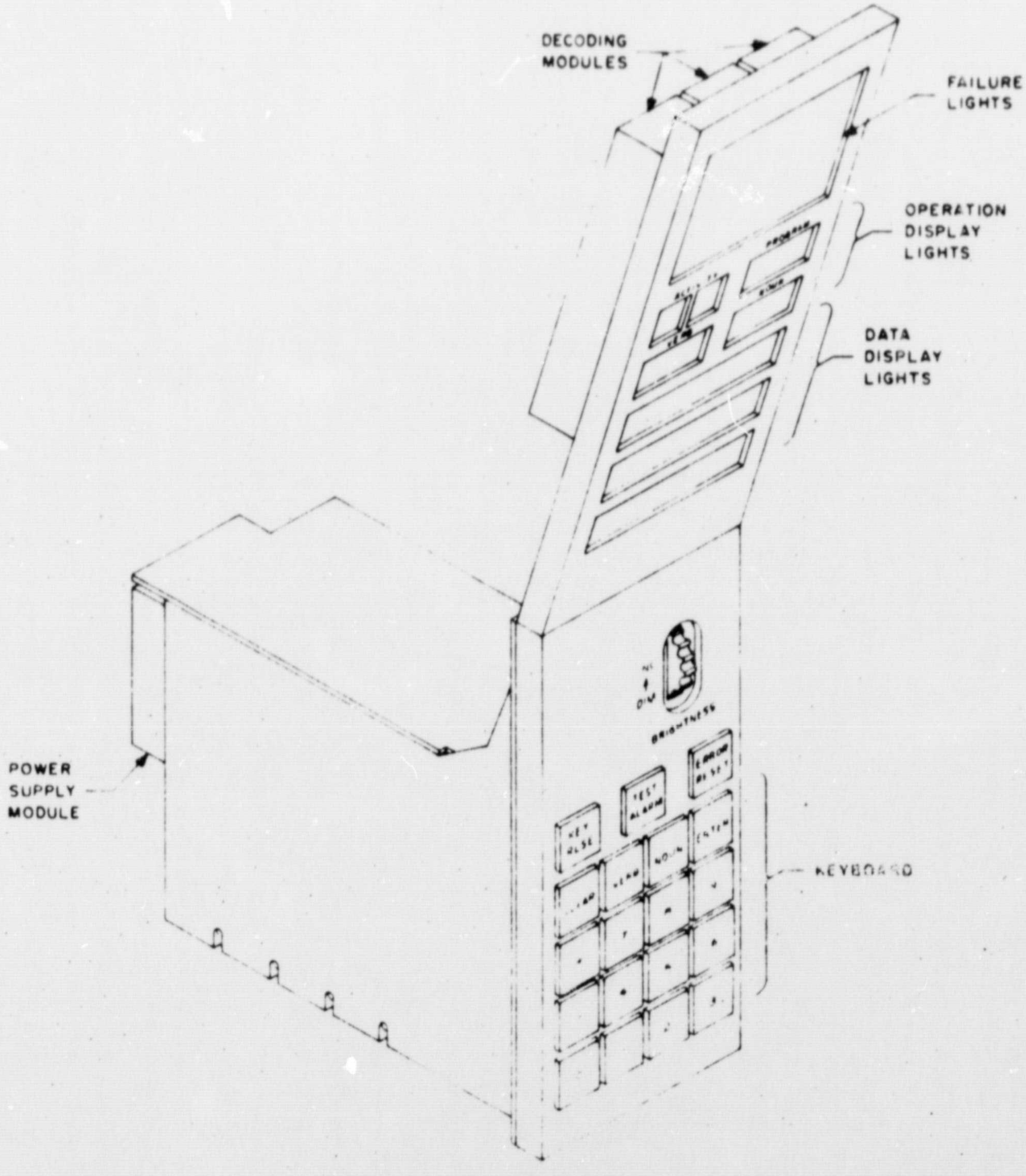

Figure 2-8 Navigation Panel Display and Keyboard (DSKY)

tray consists of seven modules, each of which contains six relays. The power supply module furnishes the voltage to light the various displays.

2.1.1.2 Main Panel Display and Keyboard

The Main Panel Display and Keyboard (Main Panel DSKY) (Figure 2-9) is approximately 10 inches high, 9 inches wide, and 7 inches deep. The front panel of the Main Panel DSKY contains 18 keys, two failure lights, eight operation display lights, 18 data display lights, a brightness control, and a toggle switch.

2.1.2 ELECTRICAL CHARACTERISTICS

The AGC portion of the Computer Subsystem is divided into seven functional areas: a Timer, Sequence Generator, Central Processor, Input-Output, Priority Control, Memory, and Power circuits. The seven functional areas of the AGC plus the Navigation Panel DSKY and the Main Panel DSKY form nine functional areas of the Computer Subsystem.

2.2 BLOCK I(100)

This subsection describes the Block I(100) computer hardware.

2.2.1 PHYSICAL CHARACTERISTICS

The computer subsystem (Figure 2-10) consists of the AGC and two DSKY's. The AGC is the main part of the computer subsystem. It is an automatic, electronic, digital computer with parallel internal transfer, and a static, random access, core-type memory. The DSKYs provide a two-way communication capability between the astronaut and the AGC and are functionally identical with a few exceptions. The following is a brief description of each major component.

2.2.1.1 Apollo Guidance Computer

The AGC consists of logic and memory tray assemblies bolted back to back. The tray assemblies, as a unit, measure approximately 22 inches long by 15 inches wide by 5 1/2 inches deep. The unit is mounted on a base coldplate which is a part of the spacecraft. The base coldplate is an aluminum alloy, liquid cooled, honeycombed structure which dissipates heat generated by the AGC.

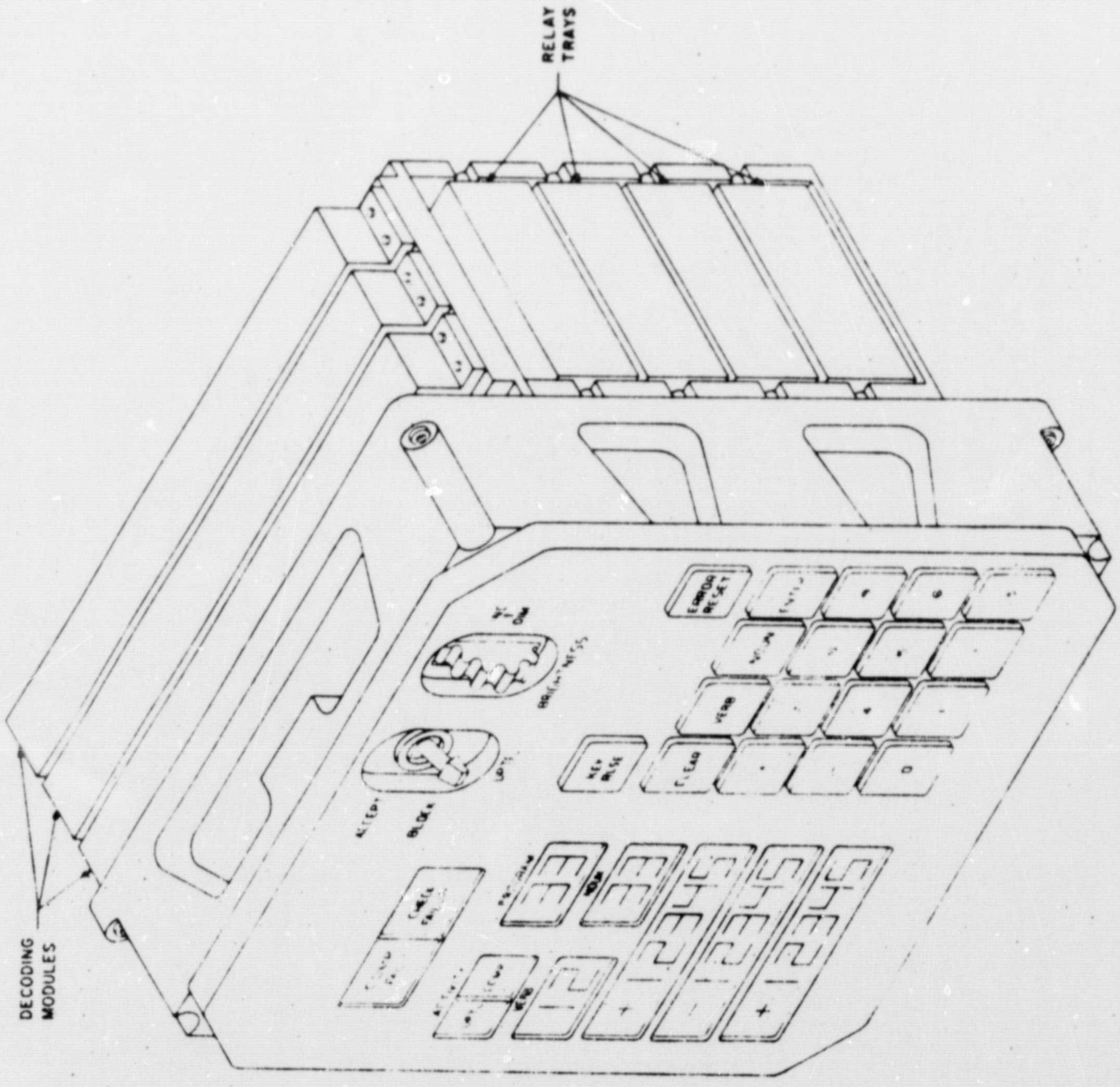

Figure 2-9 Main Panel Display and Keyboard (DSKY)

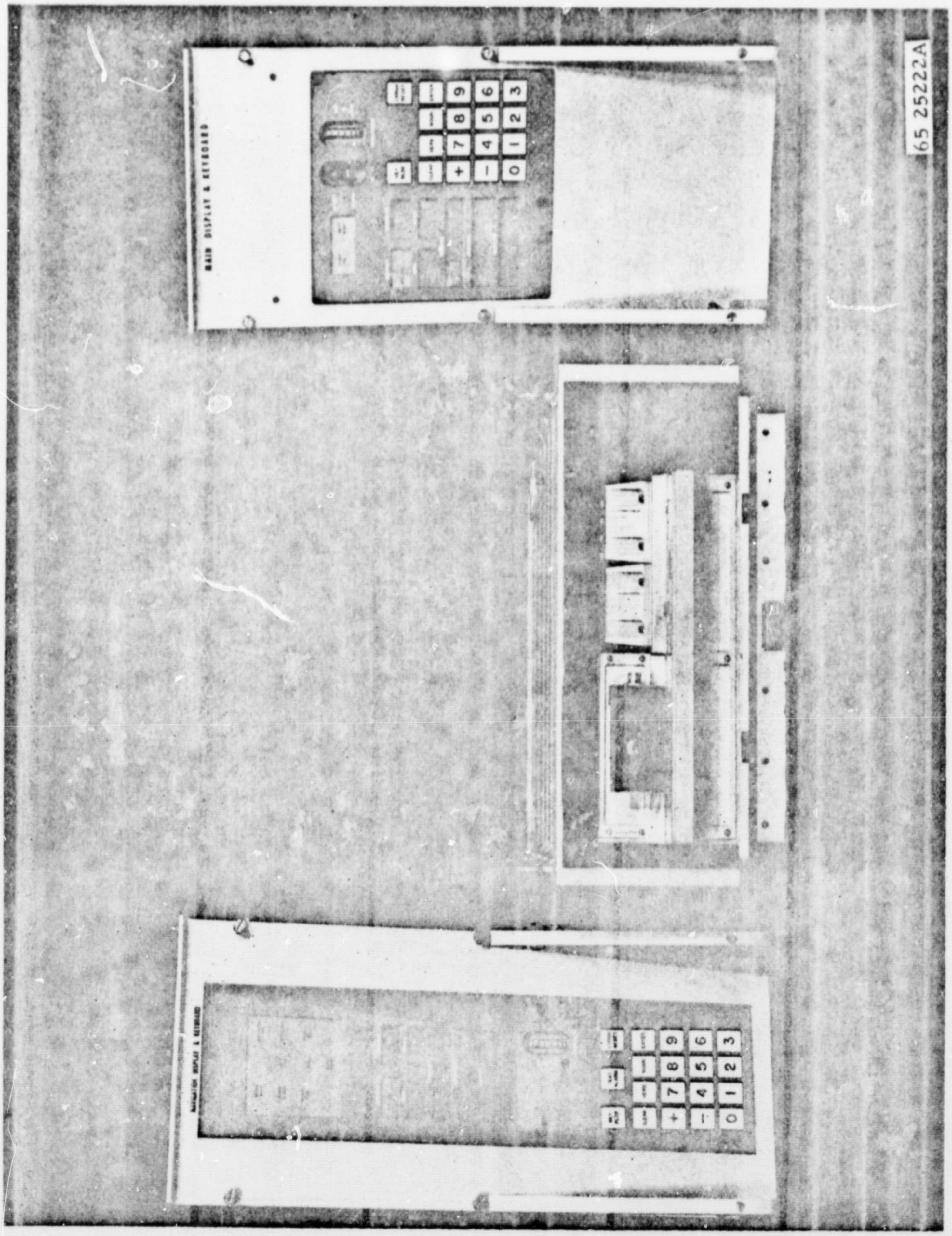

Figure 2-10 Computer Subsystem Equipment, Block I(100)

The logic tray Assembly (Figure 2-11) contains 40 modules: 36 logic modules (in rows of nine) and four interface modules (packaged at the ends). The memory tray B assembly (Figure 2-12) contains 25 modules. A STBY/ON (Standby) switch mounted on the front of tray B provides a standby mode of operation for conservation of power.

Table 2-1 summarizes for reference pertinent characteristics of the AGC.

2.2.1.2 Navigation Panel Display and Keyboard

The AGC navigation panel DSKY measures approximately 22 inches high by 6 inches wide by 14 inches deep. It is divided into two sections: one section for displays and one section for the keyboard. The display section contains 12 failure indication lights, eight operation display lights and 18 data display lights. Three interchangeable decoding modules are mounted at the rear of the display section. The keyboard section contains 19 keys and a brightness control. A case containing four interchangeable relay trays and a power supply module is mounted on the rear of the keyboard. Each of the relay trays consists of seven modules and each module contains six relays. The power supply module supplies the voltage required to light the display indicators.

2.2.1.3 Main Panel Display and Keyboard

The AGC main panel DSKY measures approximately 10 inches high by 9 inches wide by 7 inches deep and is mounted in the left hand side of the main panel of the command module. The front panel contains 18 keys, two failure indication lights, a brightness control and a toggle switch. The decoding modules, relay trays and power supply are the same as the navigation panel DSKY.

The keyboards are used to manually insert or call up AGC data. The displays provide a visual readout of information being inserted into or extracted from the AGC, and AGC failure indications.

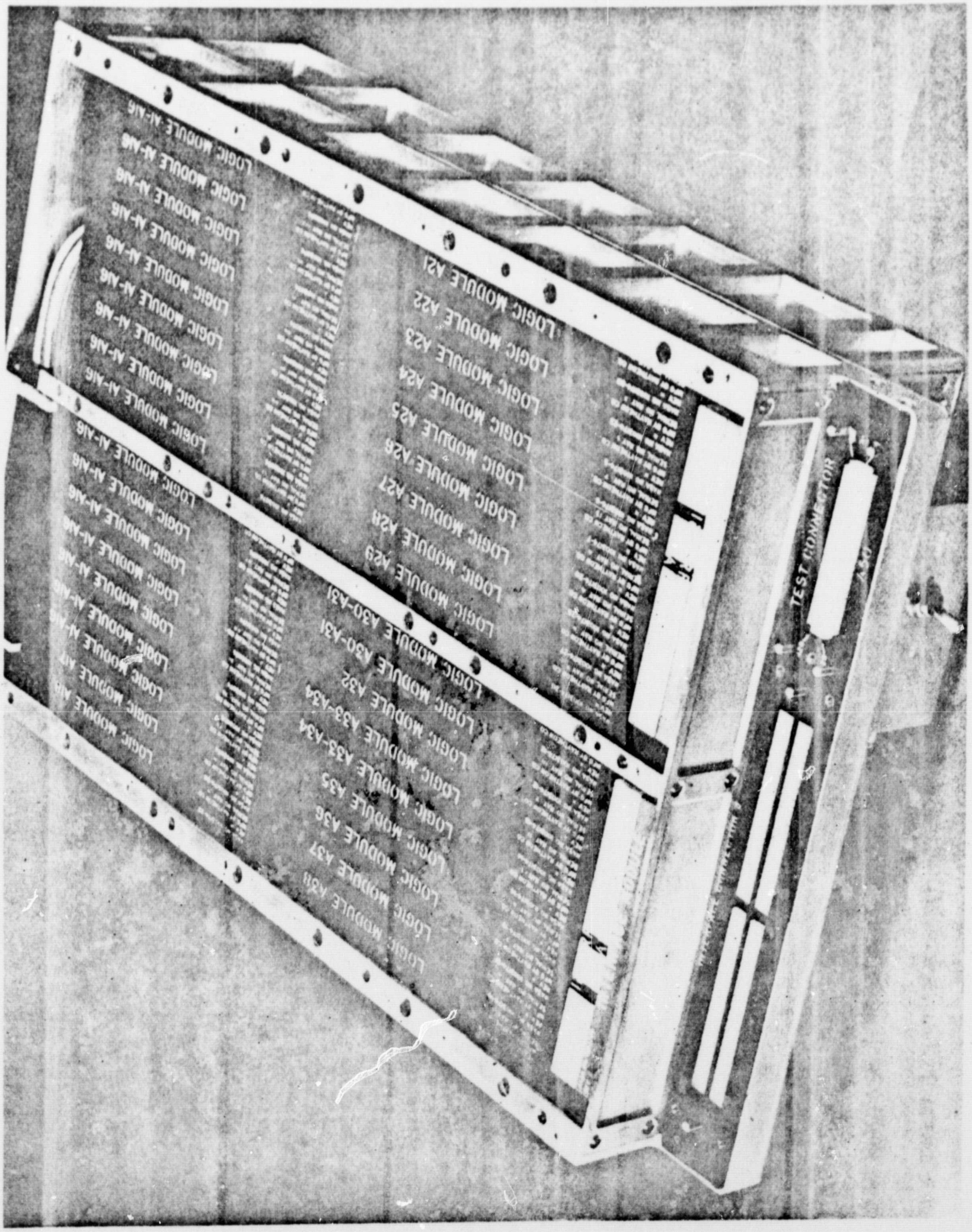

Figure 2-11 Block I(100) Tray A Logic Modules

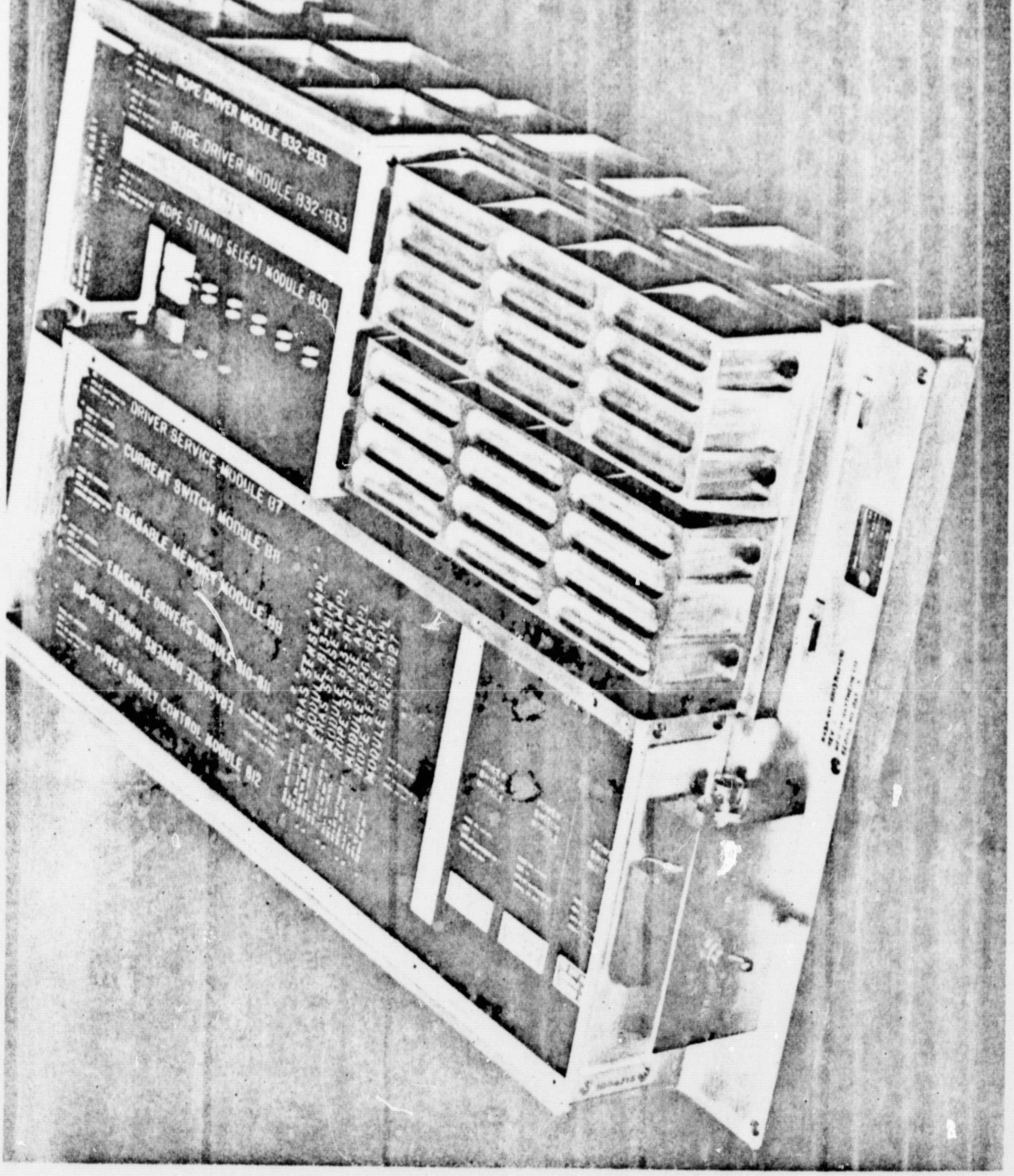

Figure 2-12 Block I(100) Tray B Memory Modules

TABLE 2-1

COMPUTER SUBSYSTEM CHARACTERISTICS

Characteristics	Description
Computer type	Automatic, electronic digital, general purpose
Internal transfer	Parallel
Memory	Random access
Erasable	Coincident current core type, capacity, 1008 words
Fixed	Core-rope type, capacity 24,576 words
Word length	(16) bits, including (1) parity and (1) sign bit
Number system	Binary one's complement
Hardware registers	17 total
Circuitry type	NOR micrologic
Regular instructions	11 total
Interrupt options	6
MCT (memory cycle time)	11.7 μs, equal to 12 "action" times
Add time	23 μs
Double precision add	234 μs
Multiply time	93 μs
Number of counters	20
Telemetry	Single error correcting pulse train, asynchronous to computer timing
Basic clock oscillator	2.048 MHz
AGC power supplies	One +3 V One +13 V
Logic	Positive
Parity	Odd

2.3 BLOCK II

2.3.1 PHYSICAL CHARACTERISTICS

The physical characteristics of the Block II subsystem differ from Block I(100) in that the Main Panel DSKY is redesigned and becomes a "universal" DSKY, used in both the main spacecraft and the Lunar Module (LM). The AGC differs in that a redesign incorporated the use of flat-pack-type integrated circuits (see Figure 2-13) resulting in increased capacity and capability while reducing the weight, yet maintaining the same external dimensions as the Block I(100) AGC.

2.3.1.1 Apollo Guidance Computer

The AGC (see Figure 2-14) is a parallel, single address, stored program, general purpose computer. The basic logic element is a dual 3-input NOR integrated circuit. Control pulses for instructions are synchronized by a 12-phase gating system operating at a 1 MHz clock speed. Arithmetic is performed in a binary, fixed-point, 1's complement number system. The basic instructions and single-precision arithmetic operations are based upon a 15-bit word length.

The basic control section of the AGC is the sequence generator which processes priority requests and decodes instructions into sequences of control pulses to the other computer sections. The central registers are all directly addressable, thus providing important programming freedom.

The main program and constant memory is of core rope design. This fixed, read only memory contains 36,864 16-bit words. The memory cycle time is 11.7 μs. The erasable, scratch pad memory is a coincident current core memory with a 2,048 word, 16-bit capacity.

Additional features of the AGC include:

a. Incremental Input Counters

b. Programmed Pulsed Outputs

c. Fixed Pulse Timing Outputs

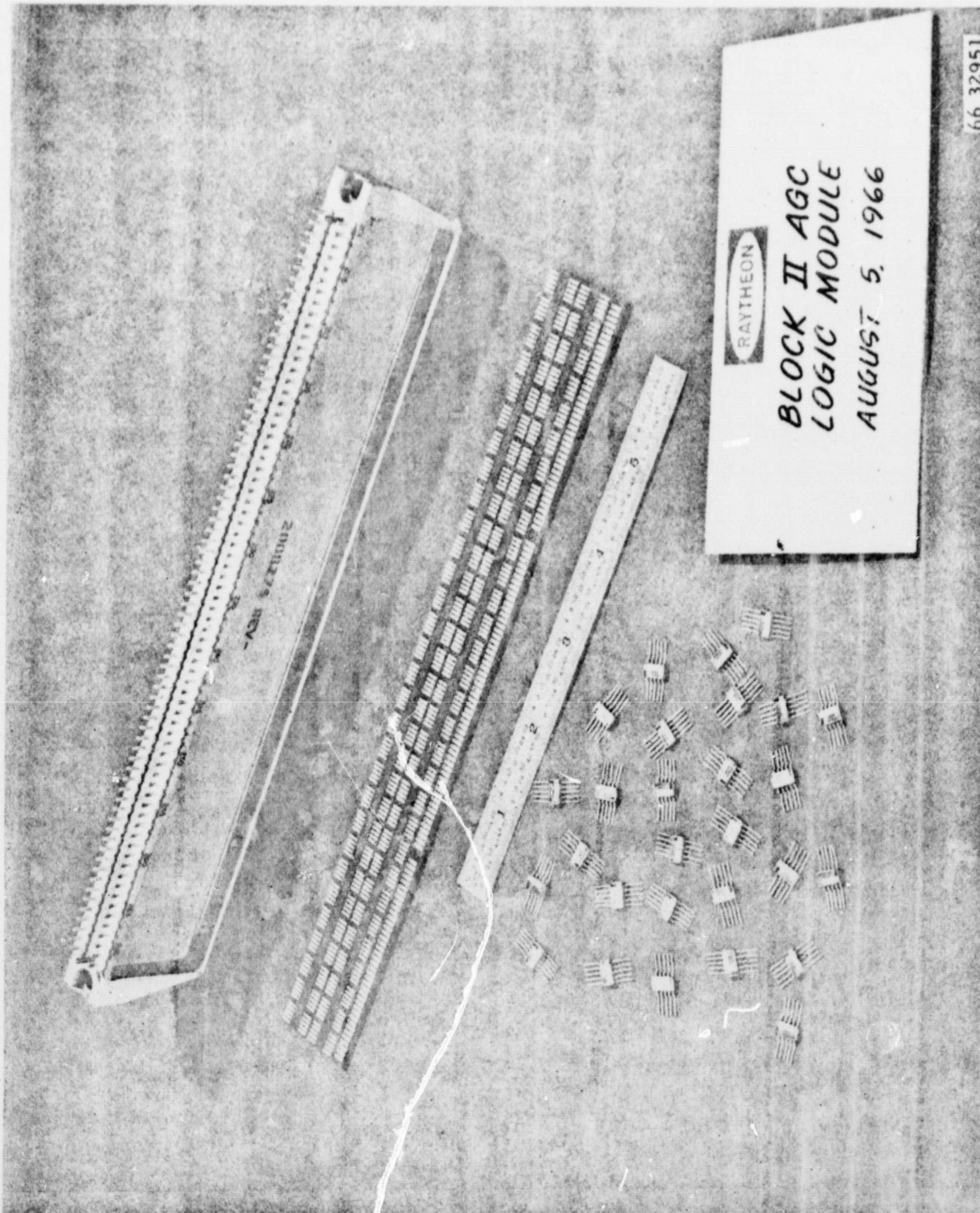

Figure 2-13 Block II Flatpack Integrated Circuit and Logic Module

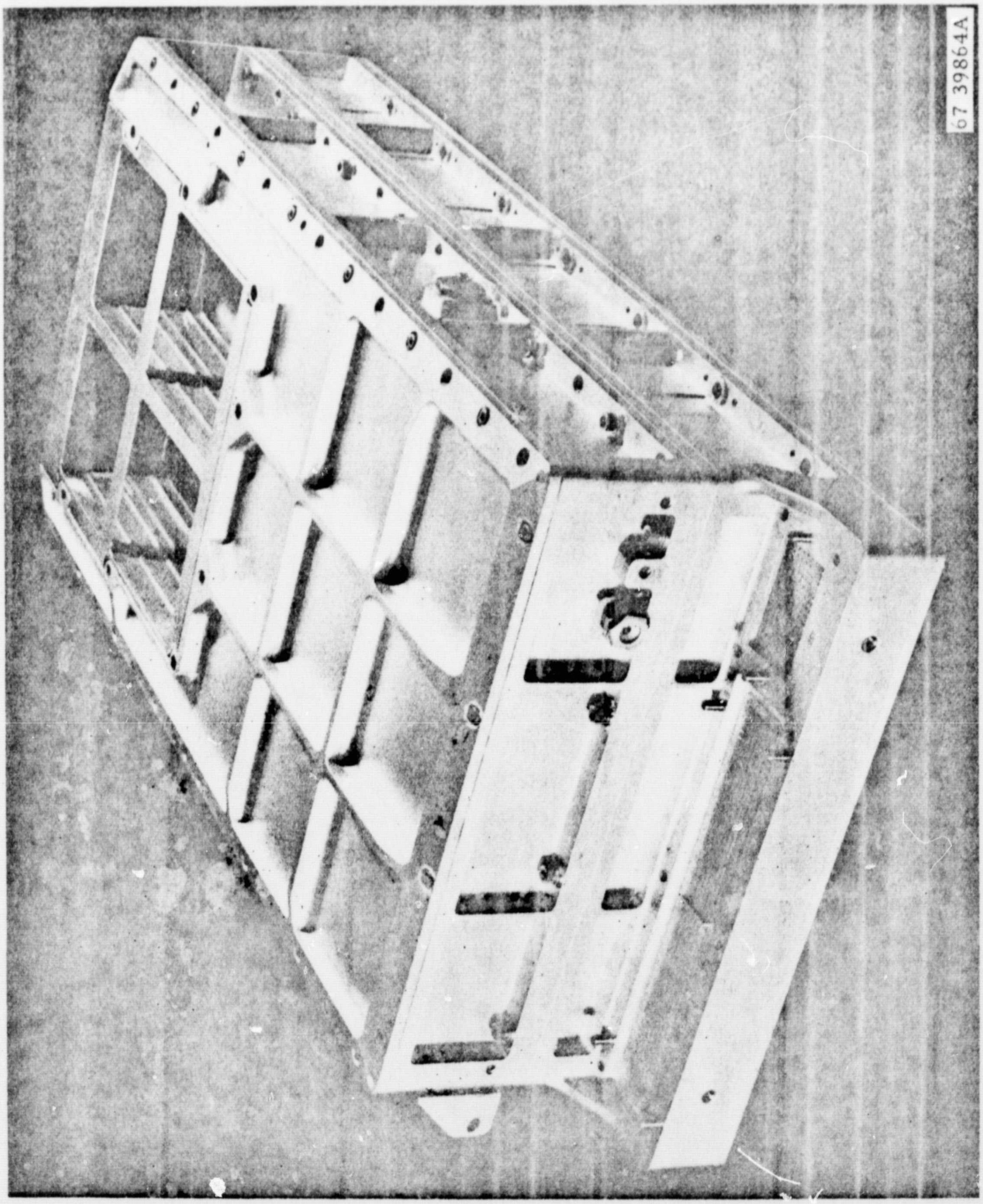

Figure 2-14 Block II Apollo Guidance Computer

d. Program Controlled Interrupts

e. Automatic Interrupts

f. Serial Telemetry Input and Output Channels

g. Automatic Fault Detection and Alarm

h. Dual Display and Keyboard Capability

i. Special Monitor and Test Circuitry.

The organization of the AGC provides the flexibility important to redesign and/or modification for any specific application. For example, a special interface channel and associated channel registers provide great I/O flexibility. The address structure readily allows reallocation of special and central registers, fixed memory and erasable memory.

Mechanically, the AGC is a hermetically sealed device, consisting of two trays which provide wirewrap interconnection for the various modules and connectors (see Figures 2-15, 2-16 and 2-17).

The necessary power supplies, logic, drive, interface and sense circuitry, erasable memory and alarm circuitry is packaged in potted modules which plug into the two trays.

The AGC includes a separate removable interconnect tray which houses the fixed memory modules and fixed memory jumper modules and contains two external connections; one which allows the AGC interface with the G&N system, and one which allows the AGC to interface with GSE or an auxiliary memory unit.

The AGC also includes the necessary cover to protect the test connector when not in use, and to protect the AGC from radiated noise pickup at the test connector. Table 2-2 lists the basic facts of the Block II AGC.

2.3.1.2 Display and Keyboard (DSKY)

The DSKY (see Figure 2-18) contains the electroluminescent panels, their power supply, some incandescent lamps, electronic circuits to run both the electroluminescent indicators and the incandescent indicators, and a keyboard. There are two DSKYs in the Command Module and one in

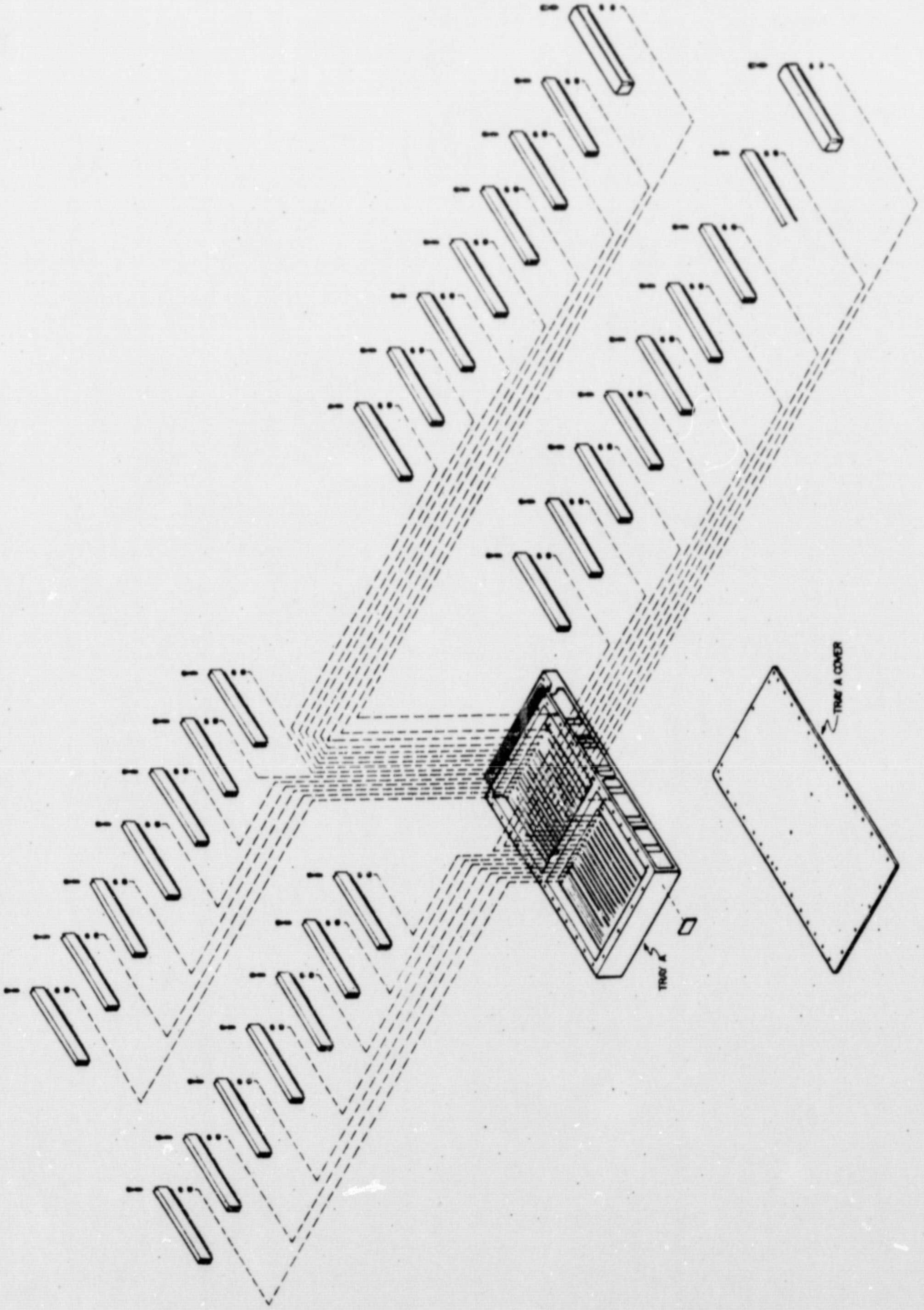

Figure 2-15 Block II Tray A (Logic Modules)

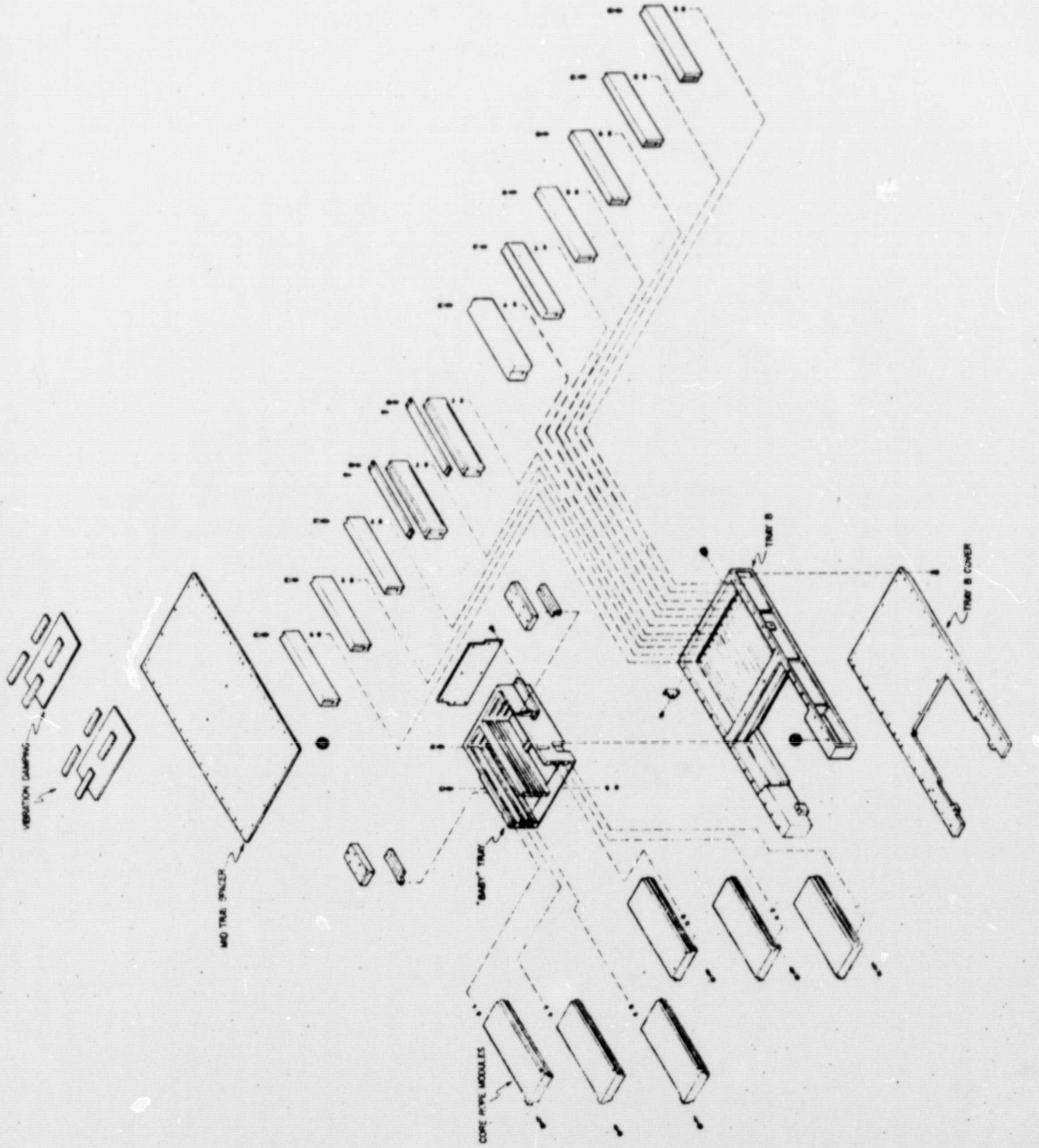

Figure 2-16 Block II Tray B

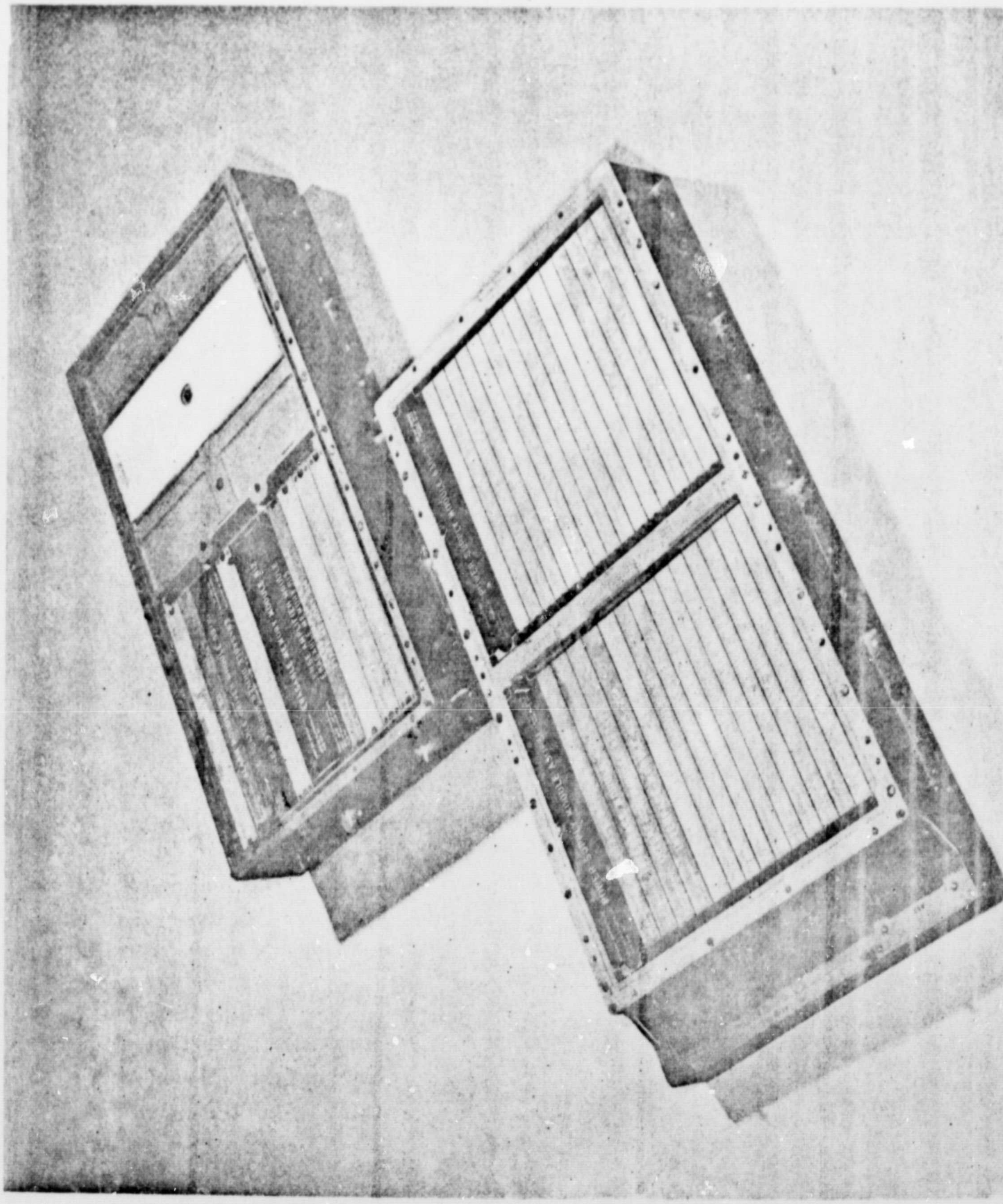

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Figure 2-17 AGC Plug-In Modules (Assembled and In Place)

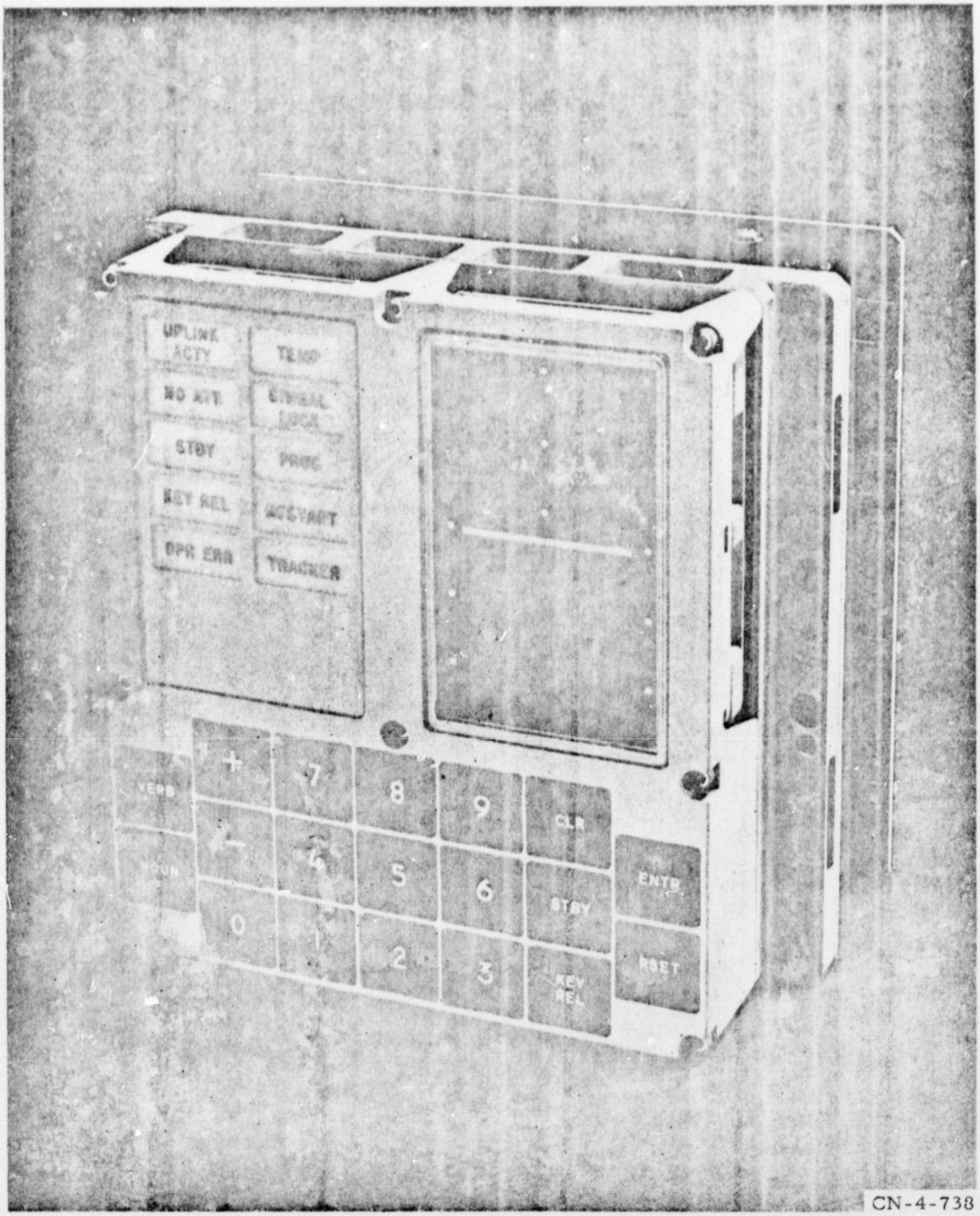

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Figure 2-18 Block II DSKY (Front Panel View)

TABLE 2-2

BLOCK II AGC PERTINENT STATISTICS

Organization	Parallel
Number System	1's complement
Power (Operating)	100 W
Power (Standby)	10 W
Clock Frequency	2 MHz
Memory (Fixed)	36,864 words
Memory (Erasable)	2048 words
Word Length	15 bits plus parity
Volume	Approximately 1 cubic foot
Weight	Approximately 70 lbs.
Add Time	24 μs
Double Precision Add	36 μs
Multiply Time	48 μs
Double Precision Mult.	480 μs
Divide Time	84 μs
Memory Density (NDRO)	3000 bits per cubic inch
Memory Density (DRO)	1000 bits per cubic inch

the Lunar Module, and their sole function is to provide communication between the G&N system (via the AGC) and the astronauts.

2.3.1.2.1 <u>Mechanical Design</u>

The DSKY is a dry nitrogen filled unit of two piece box-type structure in which all wiring interconnections from front to rear are contained. Six interchangeable indicator driver modules and a power supply contain the majority of electrical components and are plugged into connectors mounted on the rear portion of the structure. A rear cover is then placed over those modules to keep them enclosed in the nitrogen atmosphere. The rear structure also contains the AGC connector and a pressurizing fill valve.

Plugin indicator and alarm lights are mounted to the front, or display portion of the unit which also contains 19 push-button switches with luminescent lighting. The electrical components for this keyboard are housed in a module and mounted inside the unit. Finally, a front cover of eggcrate construction (to prevent unintentional activation of the switches) is placed over the units which are mounted to the front structure (see Figures 2-19 and 2-20).

A brief description of the basic components follows:

a. <u>Indicator Driver Module (IDM), Power Supply Module (PSM), and Keyboard Module</u>

Material: Magnesium, lightweight, and located in the humidity-free, dry, nitrogen atmosphere

Finish: Dow 17, dark anodize

Connector: Protected male Malco pins aligned and keyed by use of guide pins

Location: IDM and PSM plug-in to rear portion of unit after removal at rear cover. Keyboard module (plugin-type) located inside wiring area because of its related functions.

b. <u>Digital Indicator Light (Electroluminescent)</u>

The basic lamp is of glass-to-metal hermetic seal construction mounted in an encapsulated pluggable housing.

c. <u>Indicator Alarm Light (Incandescent)</u>

The incandescent lights are molded into acrylic plastic and mounted to an encapsulated, pressure-tight plugin-type header.

d. <u>Pushbutton Switches</u>

The switches are illuminated by panelescent lights and mounted pressure tight against front structure. The basic switch is encapsulated and mounted outside the pressurized area with wiring to the inside accomplished through glass-to-metal sealed discs.

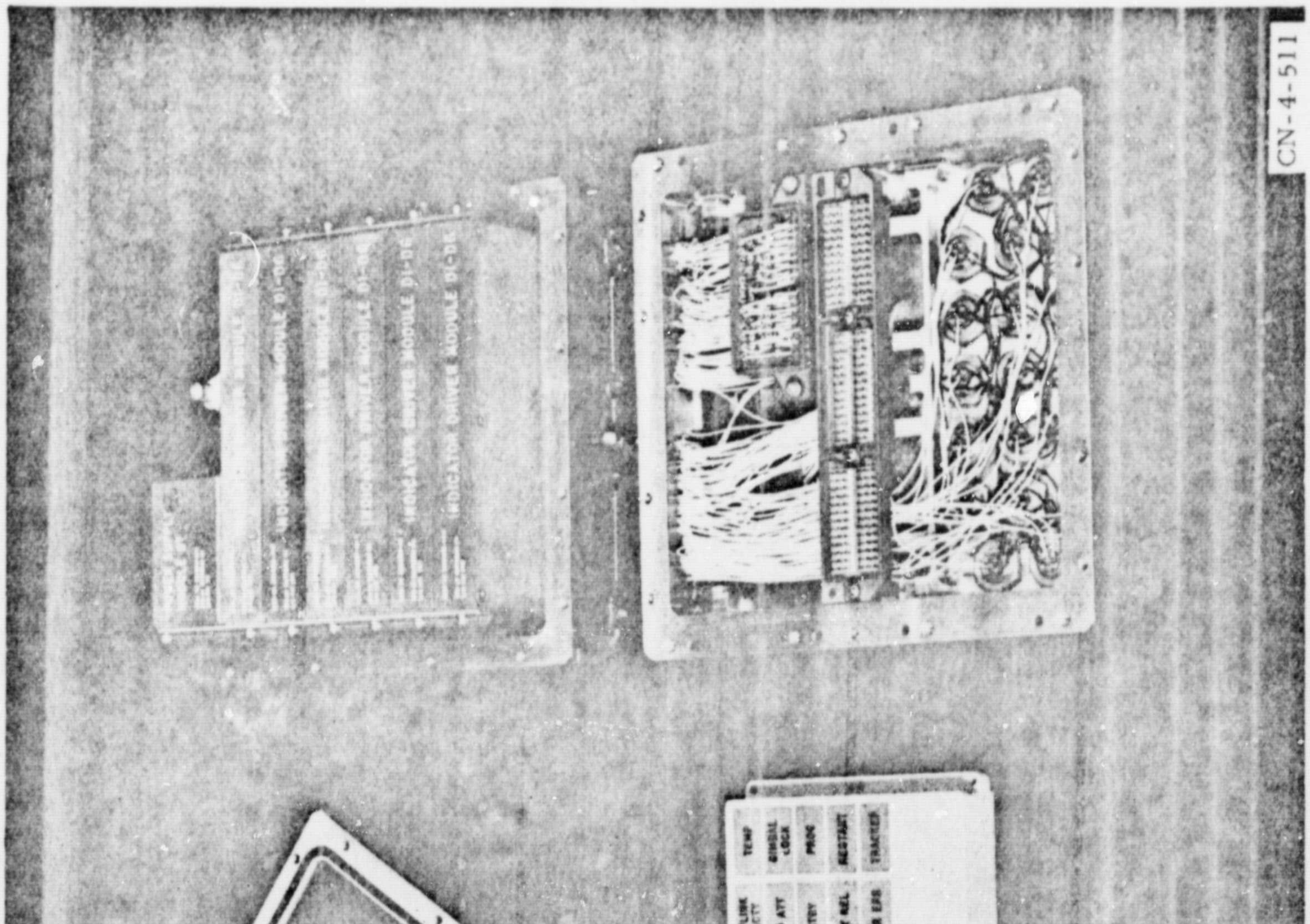

Figure 2-19 Block II DSKY Components

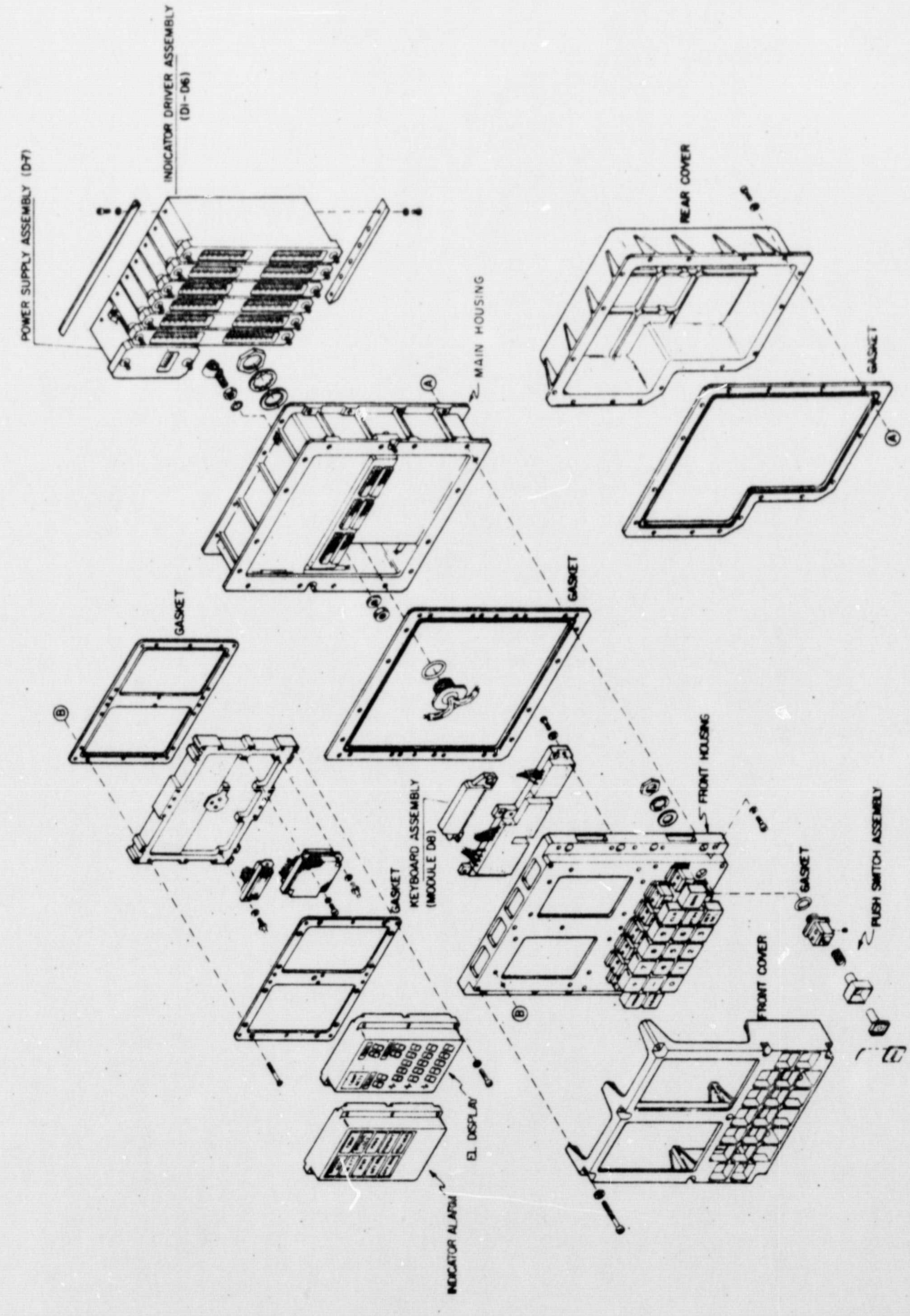

Figure 2-20 Block II DSKY (Exploded View)

e. Structure

The main structure is made of aluminum. The rear cover design incorporates structural ribbing inside the pressure area, and this design allows for a larger volume of nitrogen to be inserted into the unit. The rear structure, or wirewrap plate, receives a portion of its structural stiffness from the innerconnector. This method has also been followed in the design of the front housing.

Pressure sealing has been obtained by using Parker seal between the main structural components of the unit. Components external to the unit are mounted using "O" rings.

2.4 FIXED MEMORY

2.4.1 CORE ROPES

The fixed memory for the Block I(100) AGC consists of up to four core rope modules. The module quantity is dependent of the computer program (released by MIT/IL for specific application). Mounted on the Block I(100) Computer, the four rope modules are contained in two individual compartments with their own cover. Each core rope consists of magnetic cores permanently threaded by selection and sense wires. A full complement of four modules affords a total fixed memory capacity of 24,576 16-bit words.

The fixed memory for the Block II AGC subsystem is comprised of a maximum of six modules. The module quantities are also dependent on specific computer program prepared by MIT/IL. The modules are permanently wired for these programs for special purpose applications such as factory test, system test, and flight missions.

The core ropes are of a flat, modular configuration (see Figure 2-21) and are externally slide mounted in the AGC rope tray. Each core rope module has a storage of 6,144 16-bit words and contains the necessary magnetic cores, diodes, resistors, connectors and set, reset, sense, and clear wires (see Figure 2-22) to allow the module to operate in conjunction with other core rope and jumper modules as a fixed memory

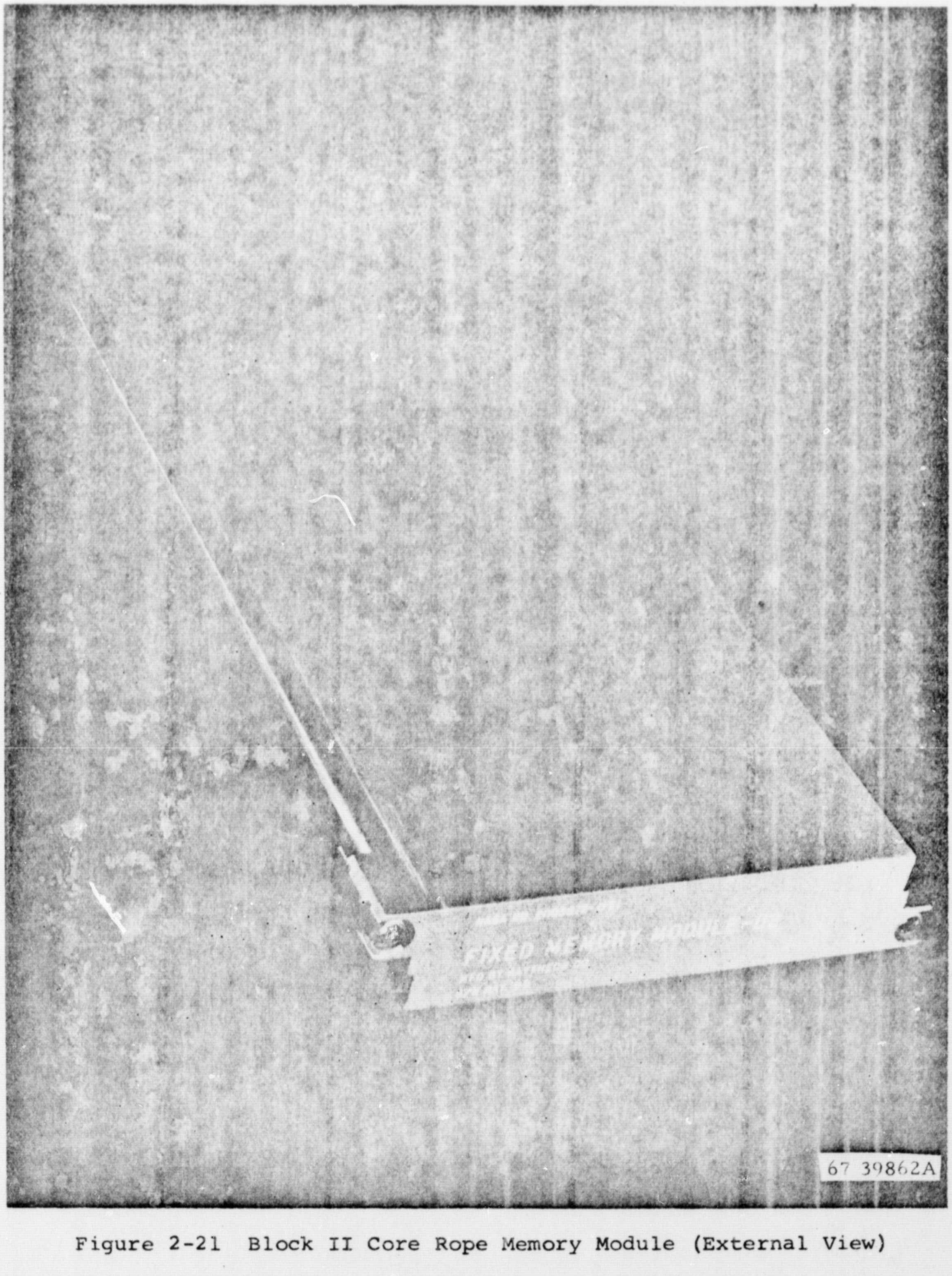

Figure 2-21 Block II Core Rope Memory Module (External View)

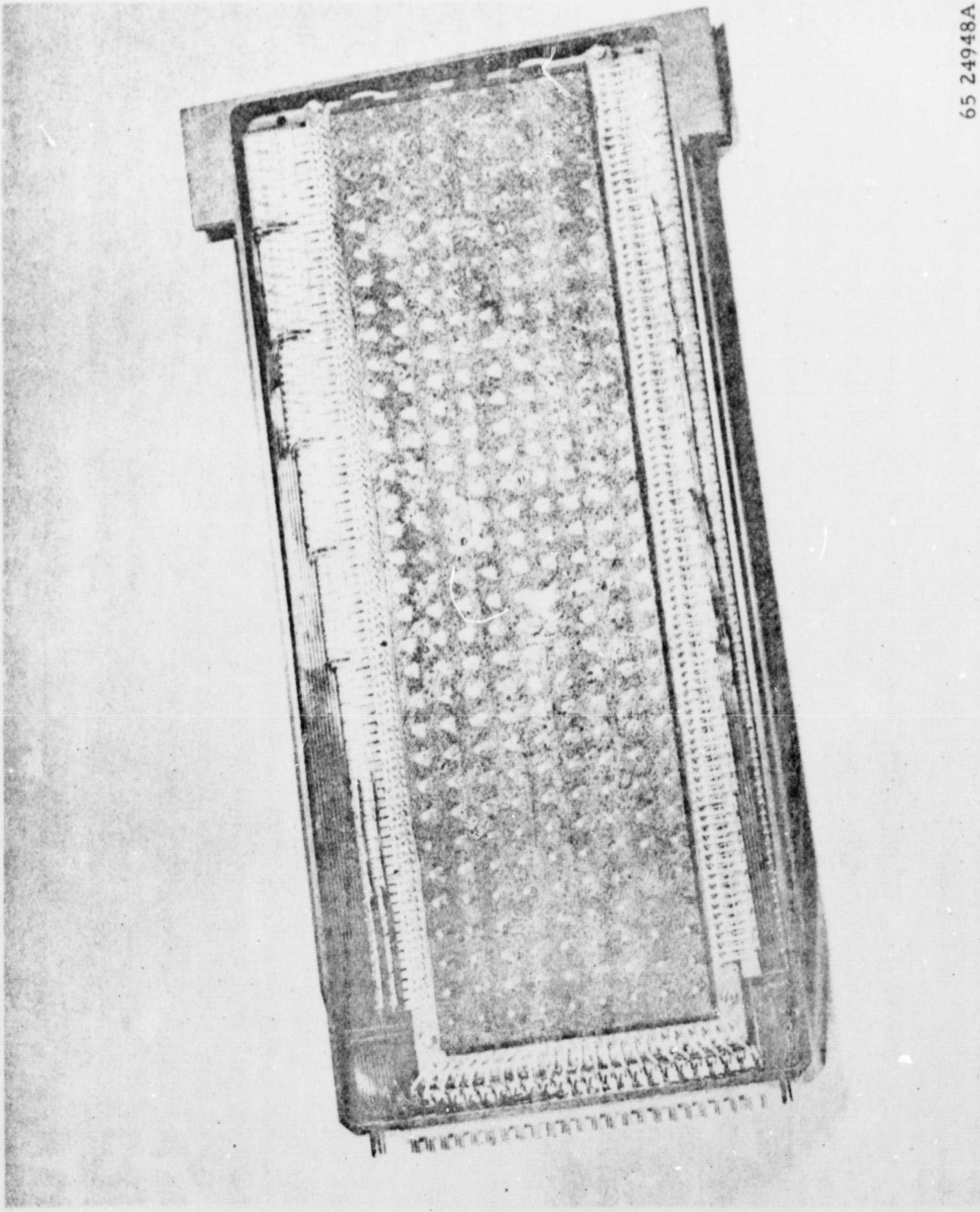

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Figure 2-22 Block II Core Rope Memory Module (Internal View) with the AGC. Examples of computer programs and their specific applications that have been wired into core rope memory modules are listed in Table 2-3.

TABLE 2-3

APOLLO COMPUTER PROGRAMS

LAMESH	diagnostic factory test
SUNDIAL	Command Module system test
AURORA	Lunar Module system test
SOLARIUM	unmanned Earth orbital Command Module flight program
SUNBURST	unmanned Earth orbital Lunar Module flight program
SINDISK	manned Earth orbital Command Module flight program
SUNDISK	manned Earth orbital Lunar Module flight program
COLOSSUS	the flight program for the Command Module for manned flight to the moon
LUMINARY	the flight program for the Lunar Module for manned flight to the moon

2.4.2 JUMPER MODULES

Fixed memory jumper modules are capable of completing the inhibit, set, reset, and clear line paths in fixed memory when an odd number of core rope modules are used. The jumper modules have the same external physical dimensions as the core rope modules and are potted. The jumper modules simulate the resistance of the set, reset, and clear drive lines of the actual core ropes.

2.5 ELECTRONIC COUPLING DATA UNIT

2.5.1 PHYSICAL DESCRIPTION OF TRAYS AND LOGIC MODULES

Raytheon wirewraps the tray and manufactures three types of logic modules for the Block II Electronic Coupling Data Units (ECDUs). Each ECDU contains Trays S and X. However, the trays used for the Command Module ECDU's are wired differently than the trays used for the Lunar Module ECDU's. The versatility designed into the logic and analog modules allows a given set of modules to perform various functions depending on the way in which the modules are interconnected through the tray wiring.

The Command Module and Lunar Module ECDUs each contain one digital mode module, five read counter modules, five error angle counter and logic modules, and several different types of analog modules in varying quantities. Raytheon manufactures the three types of logic modules identified herein. Basically, each module contains four rows of flat-pack micrologic elements (each row being a quadrant), signal layers for each quadrant, and a header having two rows of connector pins (70 pins in each row). Each module has keying pins, jacking screws, and is potted.

The digital mode module contains a clock, pulse generators, and control logic. The timing and phase pulses produced by the digital mode module synchronize most ECDU operations.

The read counter module contains a 16-bit parallel counter (2's complement) capable of counting up and down depending on the polarity of the input control signals. This module also contains special decoding logic which provides signals to the analog-to-digital converters of the ECDU.

The error angle counter and logic module contains a 9-bit parallel counter controlled to saturate at a count of 384. This counter is also capable of counting up and down, but not below a count of zero. The error angle counter and logic module contains decoding logic which provides signals to the digital-to-analog converters and up-down logic which controls the polarity of the read counter module inputs as well as the error angle counter inputs.

2.6 GROUND SUPPORT EQUIPMENT (GSE)

2.6.1 COMPUTER TEST SET

The Computer Test Set (CTS) provides the following functions:

a. monitoring of computer subsystem operation
b. program loading and control
c. data recording of system parameters computer by the AGC
d. display of system parameters as computed by the AGC
e. diagnostic use in troubleshooting system/subsystem problems.

The general capabilities of the CTS are:

a. direct program control including stopping or stepping the program
b. continuous or sampled monitoring of the computer's central register or selected memory locations
c. monitoring of key computer program functions
d. loading of the computer for specific output functions
e. loading programs and/or data into the computer
f. entering signals into the computer to simulate its input
g. monitoring of the system output functions of the computers
h. generating or duplicating paper or mylar tape for use in loading the computer
i. formating and recording computer digital data by tape punch
j. converting digital computer data to analog data for recording on a strip chart recorder (not part of the CTS).

In addition, the CTS provides a self-test capability use for its sale and trouble diagnostics.

The CTS is designed to operate with the computer subsystem during subsystem testing and G&N system testing prior to installation in spacecraft. The Block I(0) CTS (see Figure 2-23) is capable of operating with the Block I(0) AGC, and included those cables now known as the AGC/GSE Interconnection Set, G&N Test. The Block I(100) CTS (see Figure 2-24) is capable of operating with either a Block I(0) or a

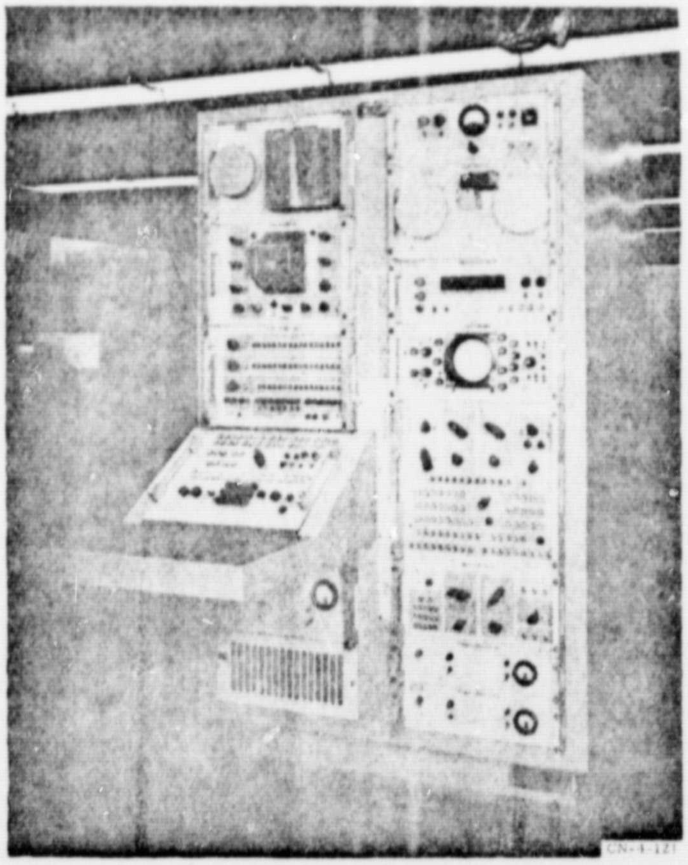

Figure 2-23 Block I(0) Computer Test Set

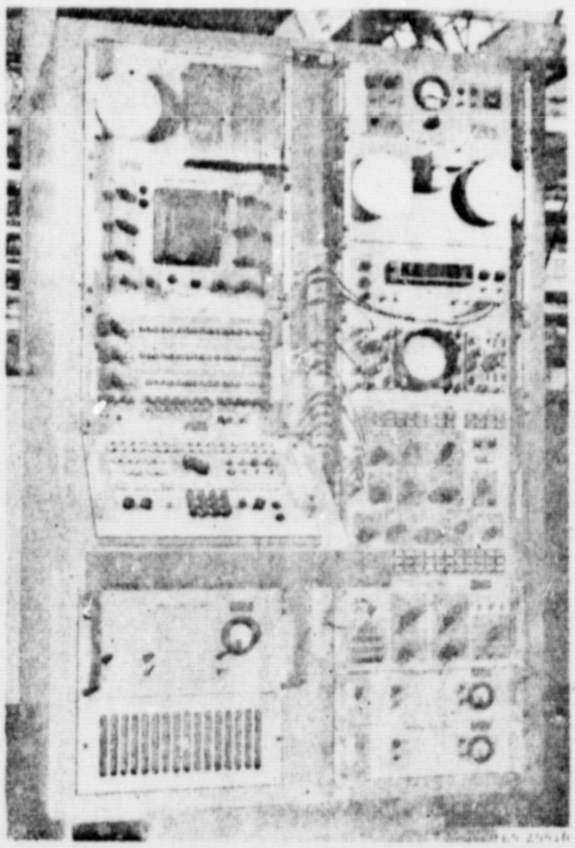

Figure 2-24 Block I(100) Computer Test Set

Block I(100) computer, while the Block II CTS (see Figure 2-25) is capable of operating with the Block I(100) or Block II computer subsystems.

2.6.2 OPERATION CONSOLE

The Operation Console (OC) provides a simulated environment, mounting power, and test connections for the AGC and its DSKYs during subsystem testing. Except for Block I(0) operation, the OC provides for the mounting of the buffer circuit assembly, which is part of the G&N cable set. The DSKYs are mounted in the OC while installed in the appropriate DSKY handling fixtures. The Block I(0) or I(100) AGC is mounted in the OC while installed in its handling fixture. The Block II AGC mounts in the OC directly, without the AGC Handling Fixture.

The Block I(0) OC (see Figure 2-26) is capable of operating with the Block I(0) computer subsystem while the Block I(100) OC (see Figure 2-27) is capable of operating with either the Block I(0) or Block I(100) subsystem. The Block II OC (see Figure 2-28) is capable of operating with the Block I(100) or Block II computer subsystems.

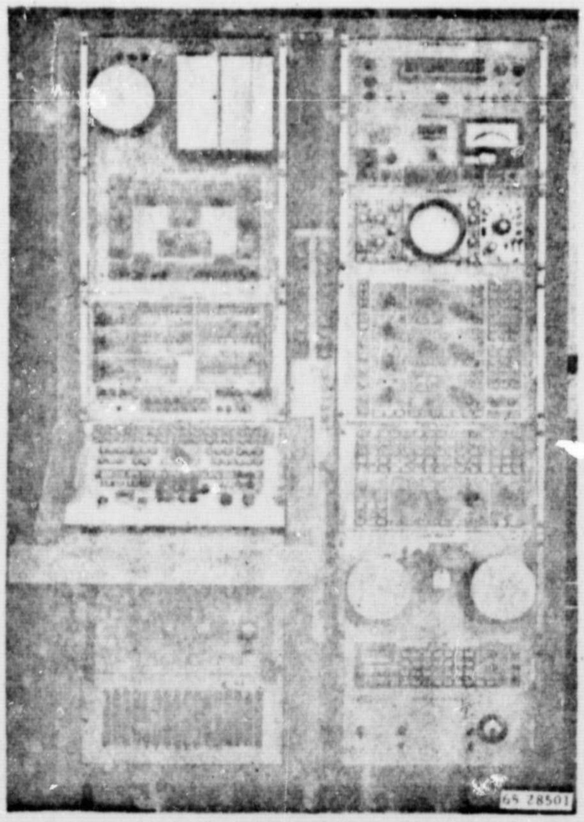

Figure 2-25 Block II Computer Test Set

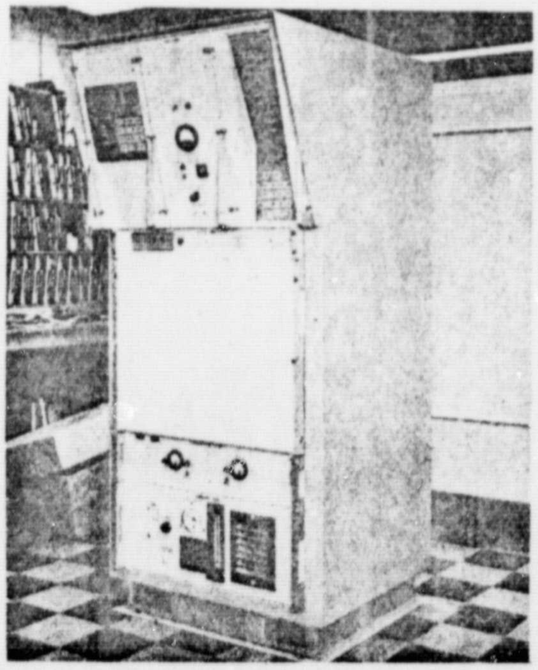

Figure 2-26 Block I(0) Operation Console

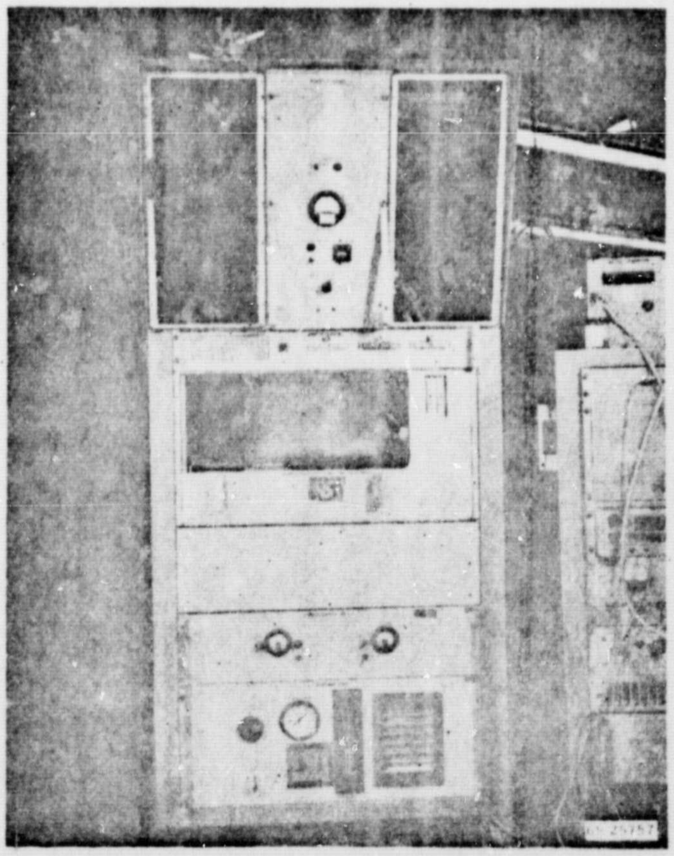

Figure 2-27 Block I(100) Operation Console

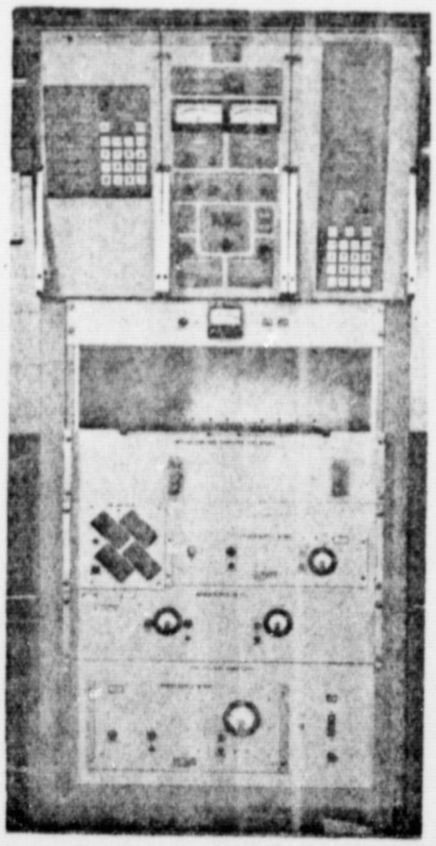

Figure 2-28 Block II Operation Console

The interconnection cables known as the AGC/GSE interconnection set, subsystem test, were a part of the Block I(0) OC. In the Block I(100) and Block II programs, these cables became a separate end item.

2.6.3 CALIBRATION CONSOLE

The Calibration Console (CC) provides the capability of calibrating the AGC oscillator frequency and determining its long-term aging characteristics. A digital ohmmeter provides the capability of monitoring the oscillator temperature. The Block II version added a variable antenna tuning capacitor, the capability of providing a 1 MHz time base reference for up to four Auxiliary Calibration Consoles, and an antenna lighting arrestor. Figure 2-29 shows the Block I(0) version CC.

Functionally, any configuration CC can be used for any configuration computer subsystem with the exception of the oscillator temperature monitoring function provided by the Block I(100) and Block II configuration (see Figure 2-30). The CC can also be used to calibrate the oscillator of the Computer Simulator.

Figure 2-29 Block I(0) Calibration Console

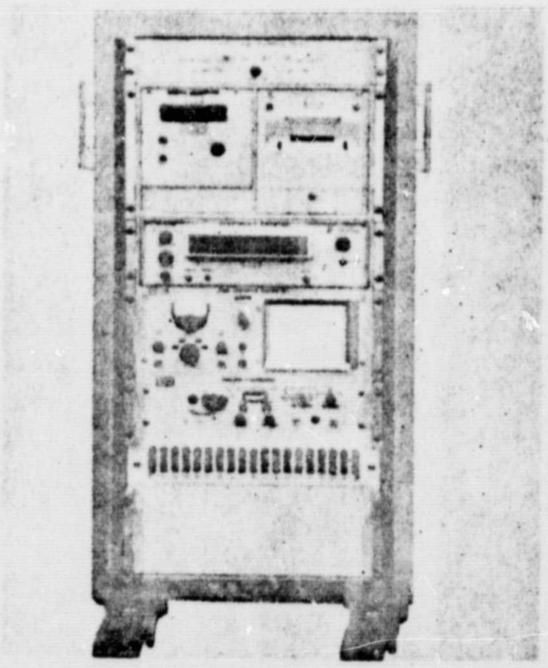

Figure 2-30 Block I(100)/II Calibration Console

2.6.4 AUXILIARY CALIBRATION CONSOLE

The capabilities of the Auxiliary Calibration Console (ACC) are essentially the same as those of the CC. The capabilities are: to calibrate the AGC oscillator frequency, determine the AGC oscillator aging characteristics, and monitor the AGC oscillator temperature. However, the ACC does not have a receiver and must therefore use the 1 MHz time base furnished by a Block II calibration console or other frequency reference.

The ACC (see Figure 2-31) can be utilized with a Block I(0), Block I (100) or Block II computer subsystem or Computer Simulator.

2.6.5 AGC/GSE INTERCONNECTION SET-SUBSYSTEM TEST

The AGC/GSE Interconnection Set, subsystem test, provides the necessary interconnections when used in conjunction with the AGC/GSE Interconnection Set - G&N Test, to perform computer subsystem testing. For Block I(0), this group of interconnecting cables was a part of the Block I(0) Operation Console. The Block I(100) cable set consists of 14 cable

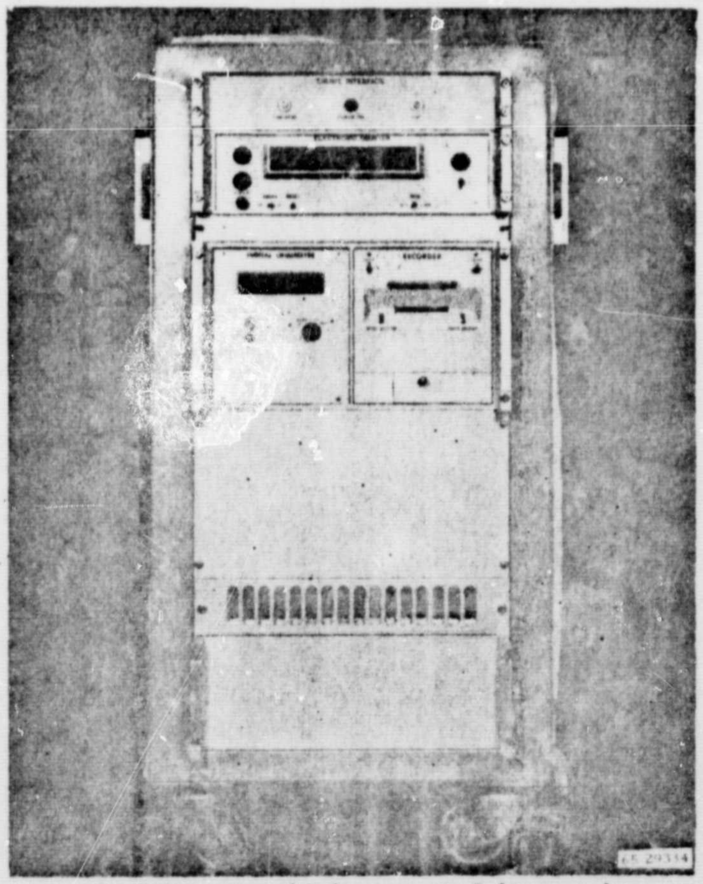

Figure 2-31 Auxiliary Calibration Console

assemblies and a buffer circuit assembly mounting bracket, while the Block II set consists of 21 cable assemblies, a buffer circuit assembly mounting bracket, and a self-test assembly mounting bracket.

The Block I(0) cables (see Figure 2-32), a part of the Block I(0) operation console, provided the interconnections for the Block I(0) computer subsystem in conjunction with the Block I(0) G&N test cable set. The Block I(100) cable set (see Figure 2-33) provided the required interconnections for either the Block I(0) or Block I(100) computer subsystems in conjunction with the Block I(100) G&N test cables (see Figure 2-34). The Block II subsystem test cables (see Figure 2-35) provide the interconnections for the Block I(100) or Block II computer subsystems in conjunction with the Block II G&N test cable set.

2.6.6 AGC/GSE INTERCONNECTION SET - G&N TEST

The AGC/GSE Interconnection Set, G&N Test, provides the necessary hardware to interconnect the computer subsystem with the appropriate GSE during G&N system level tests, and in conjunction with the AGC/GSE Interconnection Set - Subsystem Test, the required interconnection for subsystem testing of the computer subsystem. This set of equipment did not exist as a separate end item in the Block I(0) program, but was a part of the CTS and was capable of providing the necessary interconnections for a Block I(0) computer subsystem (see Figure 2-36).

The Block I(100) G&N cable set (see Figures 2-37 and 2-38) consists of a buffer circuit assembly, nine cables, and an AGC/PSA/SC Adapter Assembly. This cable set is capable of providing the required interconnection for either the Block I(0) or Block I(100) Computer Subsystems.

The Block II cable set (see Figure 2-39) consists of a Buffer-Circuit Assembly, ten cables, an AGC/PSA/SC Adaptor, and a Self-Test Assembly. It is capable of providing the required interconnections for the operations of either the Block I(100) or Block II computer subsystems.

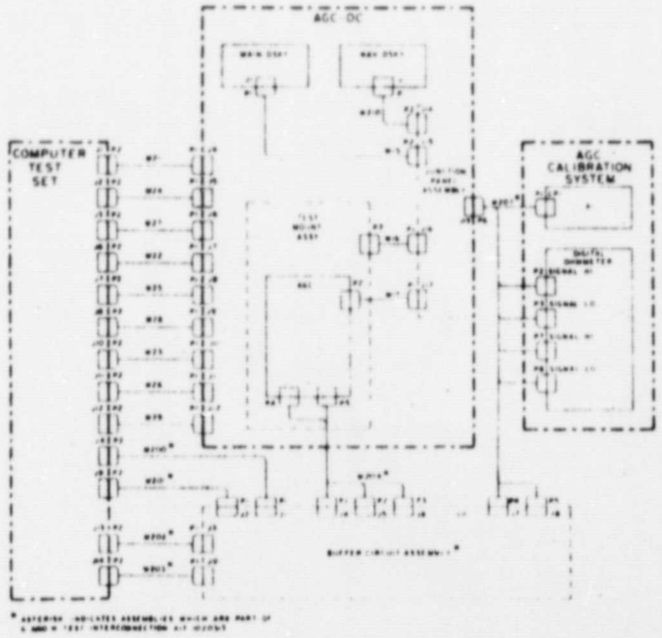

Figure 2-32 Block I(0) Configuration AGC/GSE Interconnection Set - Subsystem Test

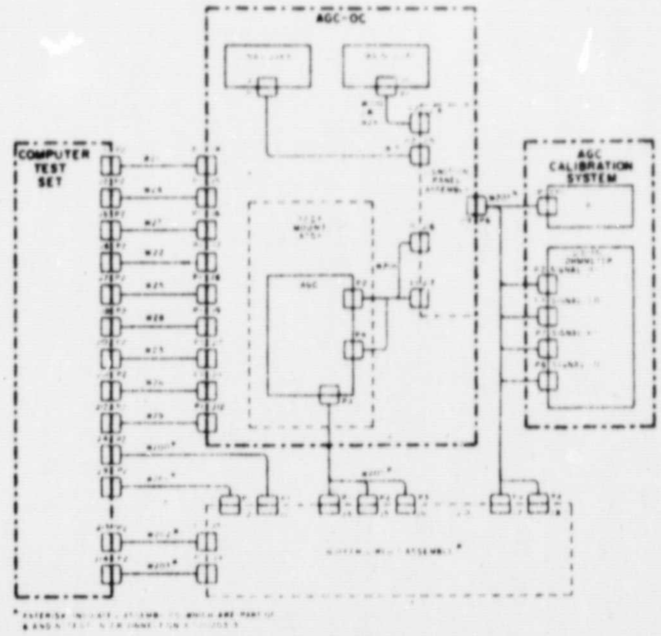

Figure 2-33 Blocks I(0)/I(100) Configuration AGC/GSE Interconnection Set - Subsystem Test

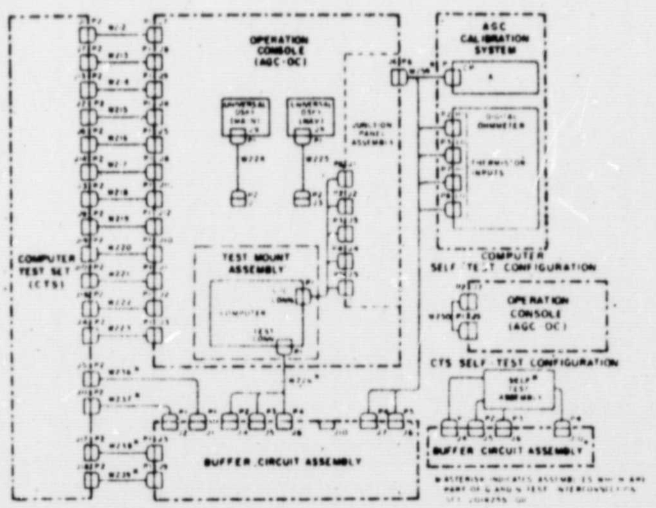

Figure 2-34 Blocks I(100)/II Configuration AGC/GSE Interconnection Set - Subsystem Test

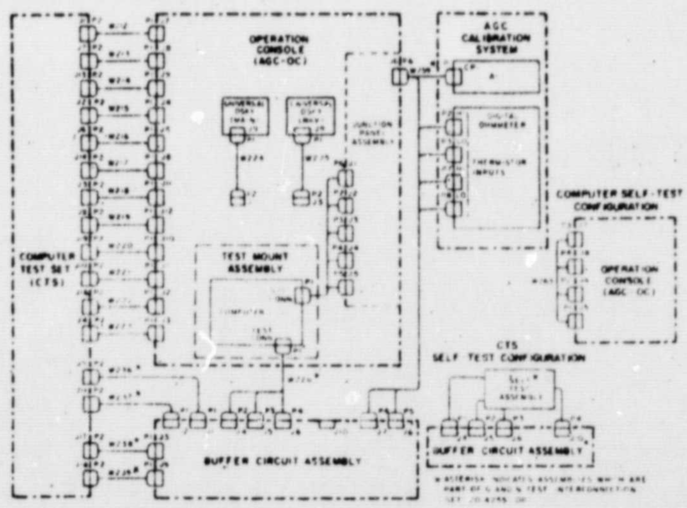

Figure 2-35 Block II Configuration AGC/GSE Interconnection Set - Subsystem Test

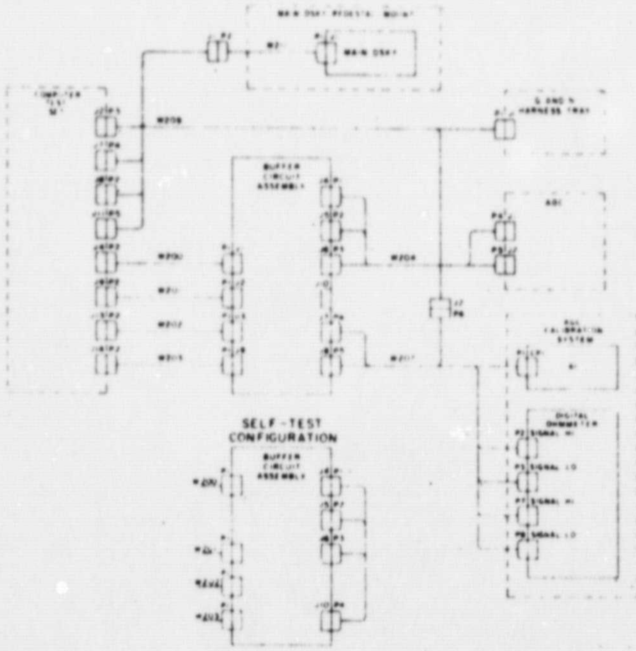

Figure 2-36 Block I(0) Configuration AGC/GSE Interconnection Set - G&N Test

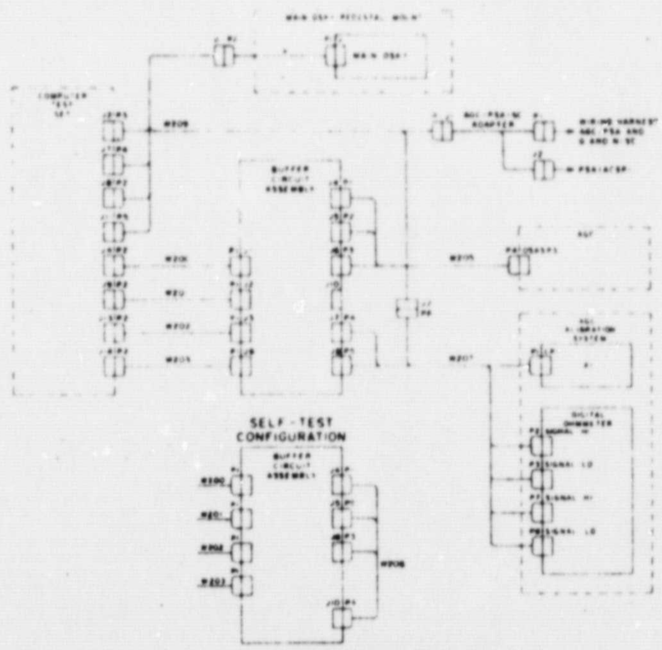

Figure 2-37 Blocks I(0) Configuration (Updated) AGE/GSE Interconnection Set - G&N Test

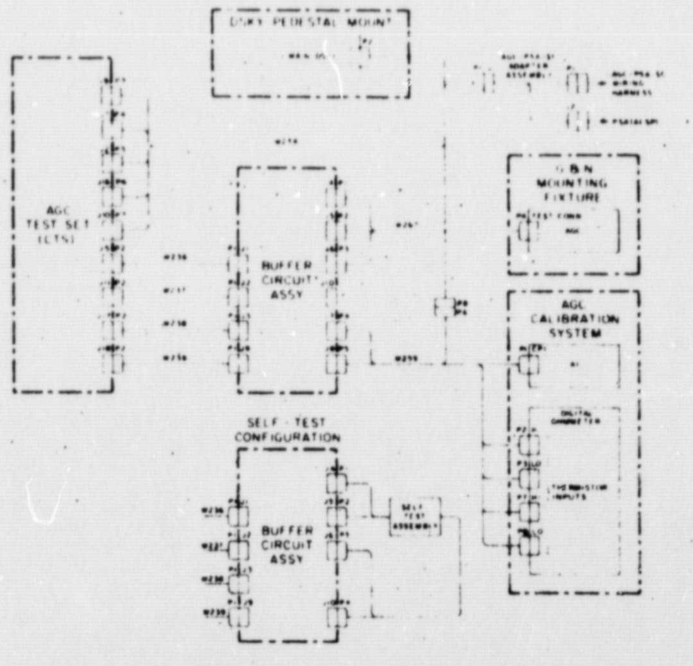

Figure 2-38 Block I(100) Configuration AGE/GSE Interconnection Set - G&N Test

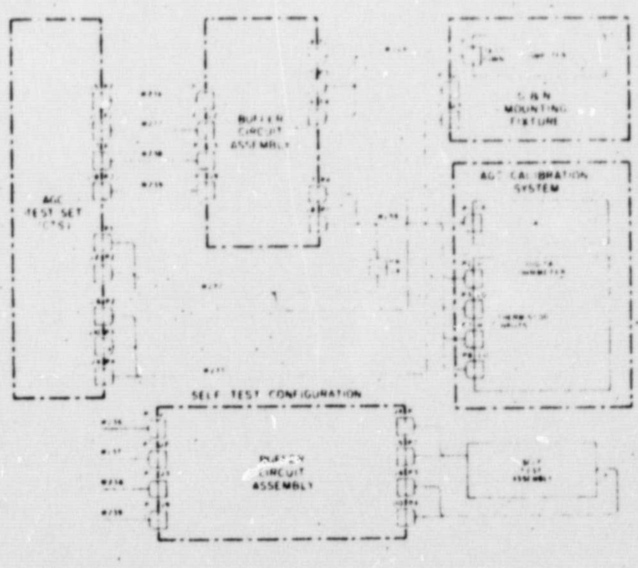

Figure 2-39 Block II Configuration AGE/GSE Interconnection Set - G&N Test

2.6.7 PROGRAM AND MONITOR CABLE SET

The Program and Monitor (P&M) Cable Set (see Figure 2-40) consists of four cables which are identical to four cables of the G&N cable set. These four cables provide the interconnection between the buffer circuit assembly and the CTS. These cable sets are required as a part of a universal test station where both G&N system and computer subsystem tests are conducted. The layout and the dual function of the test station require the duplication of these cables.

The P&M cable set is capable of providing the require interconnection of Block II GSE equipment while testing a Block I(100) Block II computer subsystem and G&N system.

2.6.8 SIMULATION COMPUTER

The Simulation Computer (SC) is a computer subsystem consisting of computer modules mounted in a cabinet with two DSKYs (Main and Navigational) mounted in the cabinet's front doors (see Figure 2-41). The

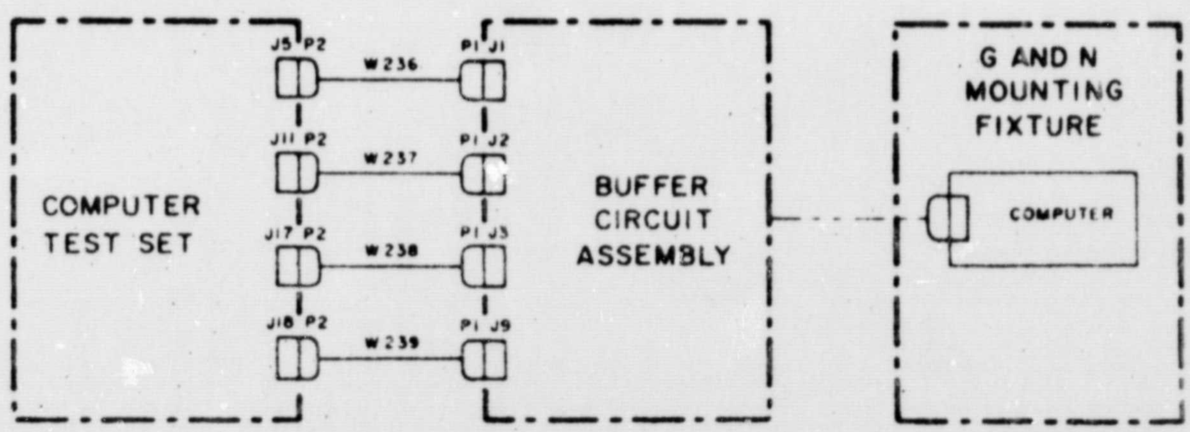

Figure 2-40 Program and Monitor Cable Set

SC presents the same electrical characteristics as a Block I(100) AGC (in its updated configuration) with its DSKYs mounted in an Operation Console. The SC is used to perform engineering experiments and to train computer technicians.

2.6.9 CORE ROPE SIMULATOR

The Core Rope Simulator (CRS) (see Figure 2-42) is an erasable memory device capable of replacing part of a fixed memory of Block I(0) or Block I(100) AGC, or of being used with an SC. Its memory is electrically alterable and can be used for an infinite variety of programs. The CRS also affords the operator the capability of controlling the data being stored and to edit, verify, or review the data in any CRS address. The storage capacity is 4,096 16-bit words.

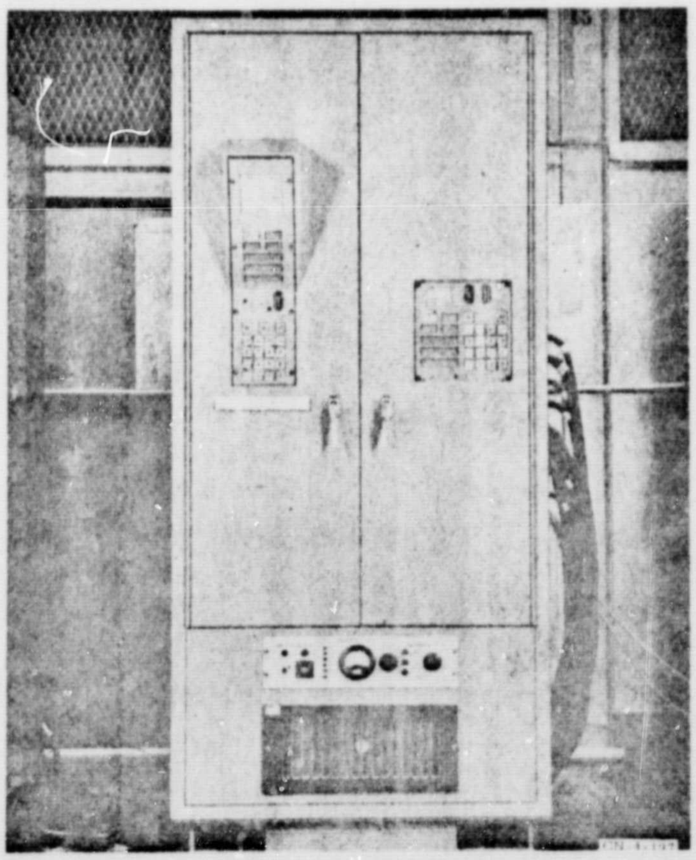

Figure 2-41 Blocks I(0)/I(100) Simulation Computer

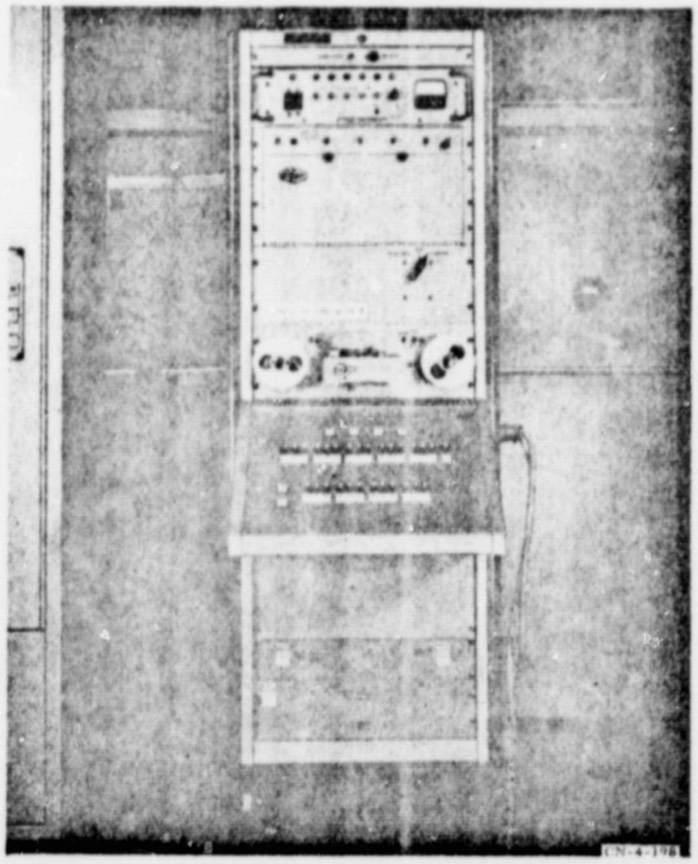

Figure 2-42 Core Rope Simulator

2.6.10 COMPUTER SIMULATOR

The Computer Simulator (CS) produces drive rate outputs identical to those of the AGC for use during Optics-Inertial subsystem tests. The CS is not intended to replace the AGC in these tests. Rather it is used in open-loop tests of various guidance and navigation subsystems, singly or in combination. The CS is part of the Optics-Inertial system analyzer, and is used in Block I, Block I(100) or Block II subsystems.

The AGC simulator (see Figure 2-43) is a self-contained unit designed for installation in a standard 19-inch rack. The unit is fabricated with rack slides to facilitate access to the interior without removing the unit from the rack.

2.6.11 DSKY PEDESTAL MOUNT

The DSKY Pedestal Mount (PM) provides the mounting and necessary electrical connections for the Main DSKY during G & N system tests. The Block I(0) and Block I(100) Main DSKYs mount directly into the PM, while the Block II DSKY is mounted in the PM with its handling fixture (see Figure 2-44).

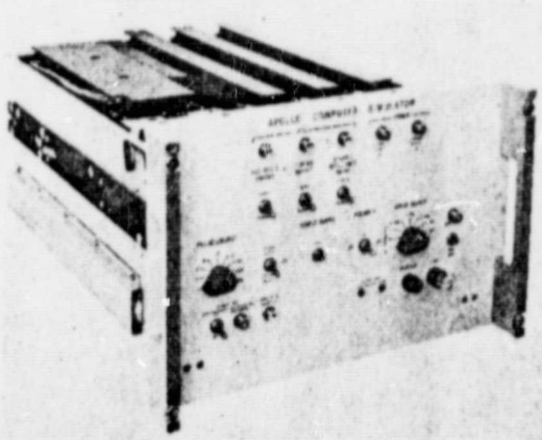

Figure 2-43 Blocks I(0)/I(100)/II Computer Simulator

Figure 2-44 DSKY Pedestal Mount

2.6.12 AGC HANDLING FIXTURE

The Block I(0) and Block I(100) AGC Handling Fixture provides a mounting base and protection for the AGC during transit, storage, and testing. In addition, it provides cooling (in conjunction with an external coolant supply) for the AGC during testing. This handling fixture consists of a phenolic base on which is mounted a liquid-cooled cold plate and a thermal-insulated cover assembly. The Block I(0) and Block I(100) AGC handling fixtures (see Figure 2-45) differ only in materials and incidental mechanical details.

The Block II/LEM AGC handling fixture (see Figure 2-46) consists of a sheet aluminum plate covered with a plastic sheet and two detachable nylon mesh strap handles. The aluminum plate provides protection for the cold-plate mating surface of the AGC and is used only during transit and storage.

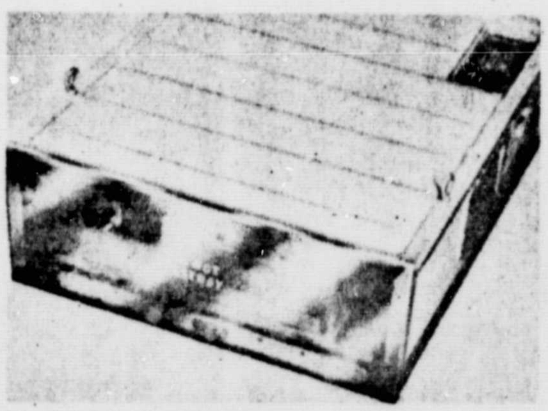

Figure 2-45 Block I(0)/I(100) AGC Handling Fixture

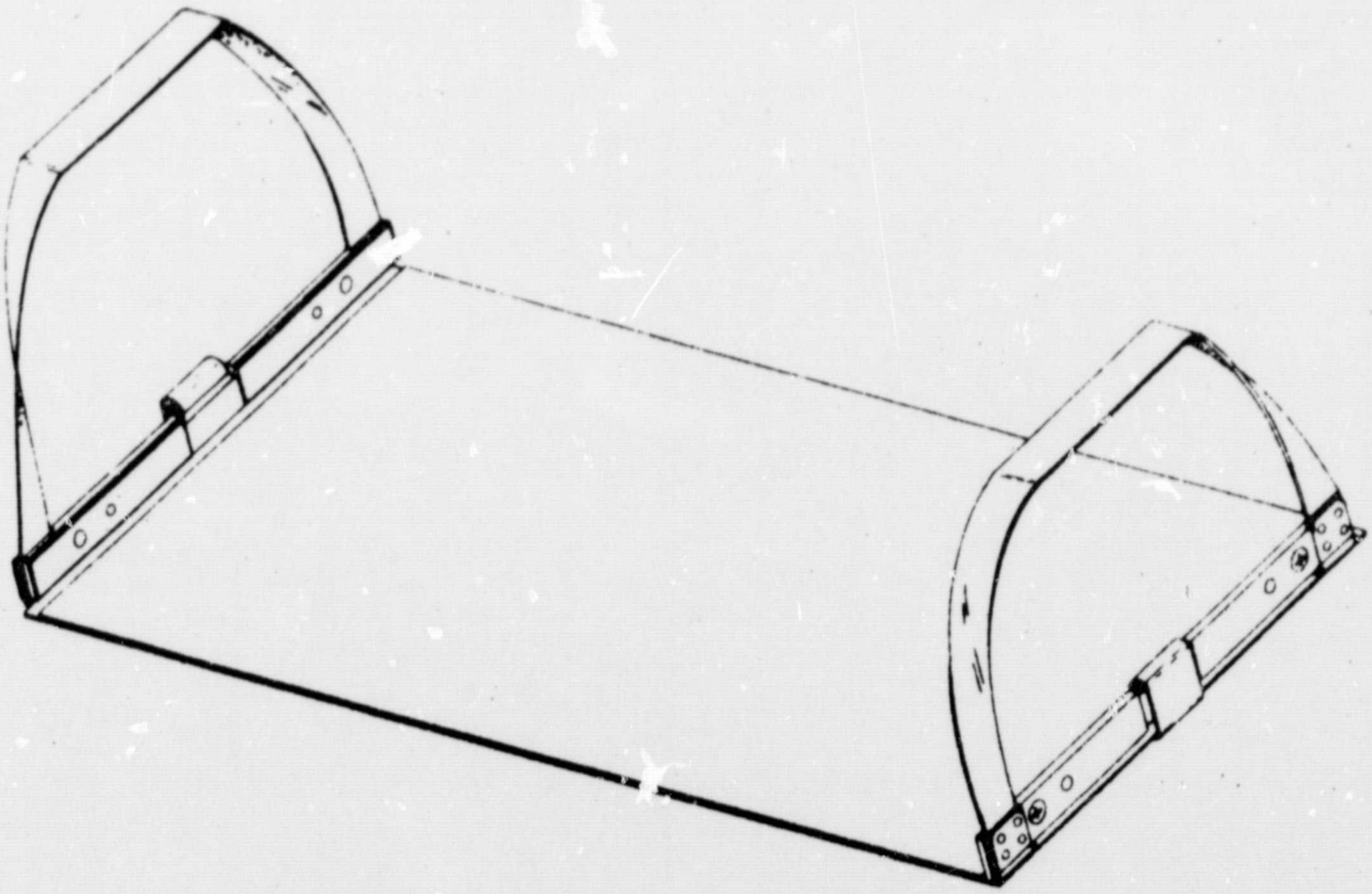

Figure 2-46 Block II AGC Handling Fixture

2.6.13 DSKY HANDLING FIXTURES

2.6.13.1 Blocks I(0)/I(100) Navigational DSKY

The Block I(0) and Block I(100) Navigational DSKY Handling Fixtures (see Figure 2-47) provide protection for either the Block I(0) or Block I (100) Navigational DSKY, during transit, storage or subsystem testing. For subsystem testing, rack slides are provided for mounting of the handling fixture and DSKY in the Block I(0), Block I(100), or Block II Operation Console.

2.6.13.2 Blocks I(0)/I(100) Main DSKY

The Block I(0) and Block I(100) Main DSKY Handling Fixture (see Figure 2-48) provide protection for either the Block I(0) or Block I (100) Main DSKYs during transit, storage and subsystem testing. For subsystem testing, rack slides are provided for mounting of the handling fixture and DSKY in the Block I(0), Block I(100) or Block II Operation Console.

Figure 2-47 Blocks I(0)/I(100) Navigational DSKY Handling Fixture

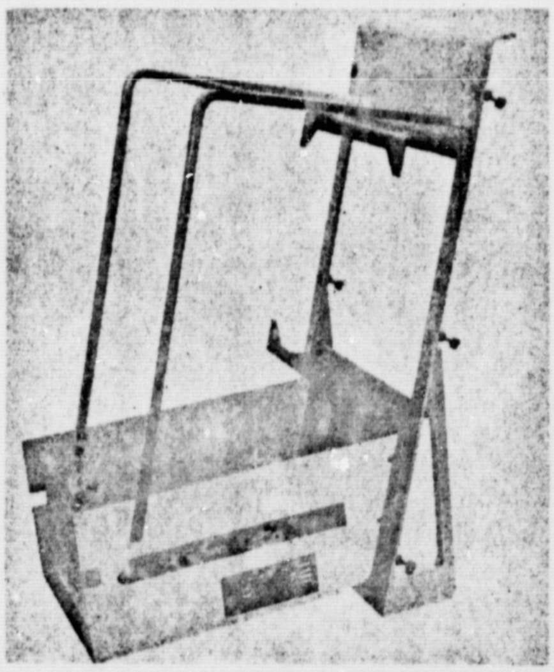

Figure 2-48 Blocks I(0)/I(100) Main DSKY Handling Fixture

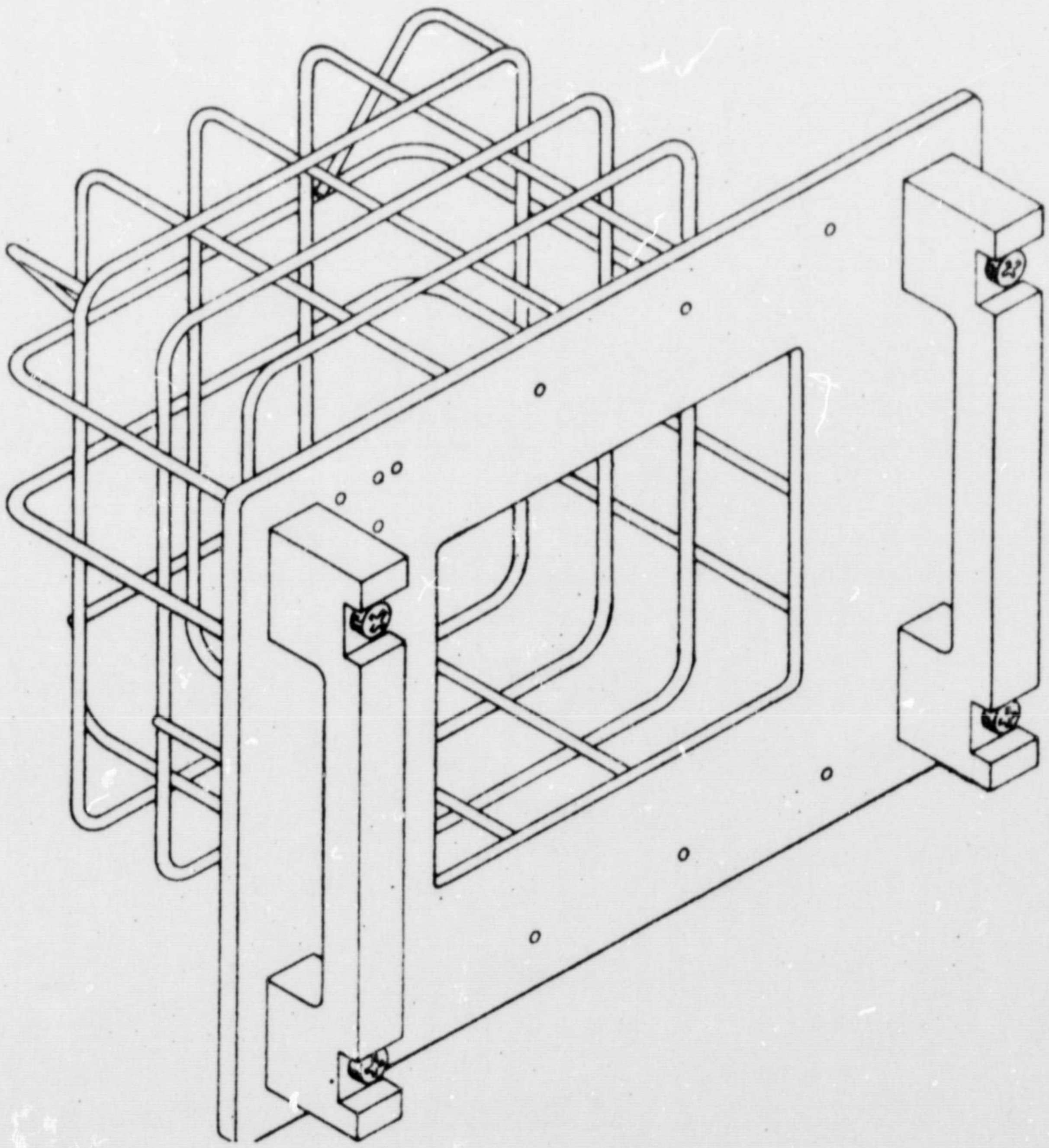

Figure 2-49 Block II DSKY Handling Fixture

2.6.13.3 Block II DSKY

The Block II DSKY Handling Fixture (see Figure 2-49) provides protection for the Navigational Block II Command Module and Lunar Module DSKYs during transit, storage, subsystem test and G & N system test. During subsystem test, the fixture is mounted into the Operations Console, while during G&N system test it is mounted in the DSKY PM.

2.6.14 DSKY ALIGNMENT FIXTURE

The DSKY Alignment Fixture (see Figure 2-50) was used during spacecraft fabrication and provided a means of accurately aligning the spacecraft flange which supports the rear of the Block I(0) and Block I(100) Navigational DSKYs when installed in the spacecraft.

2.6.15 SHIPPING CONTAINERS

2.6.15.1 DSKY

The DSKY shipping container (see Figure 2-51) provides a pressure and humidity controlled environment for the DSKY during shipment and

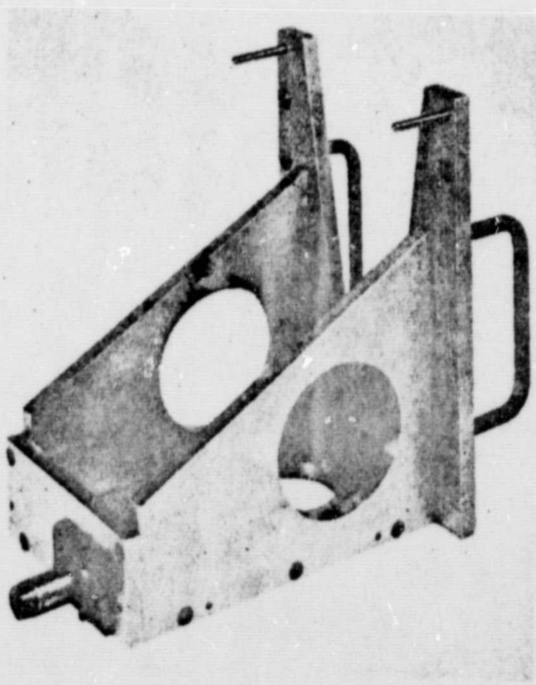

Figure 2-50 DSKY Alignment Fixture

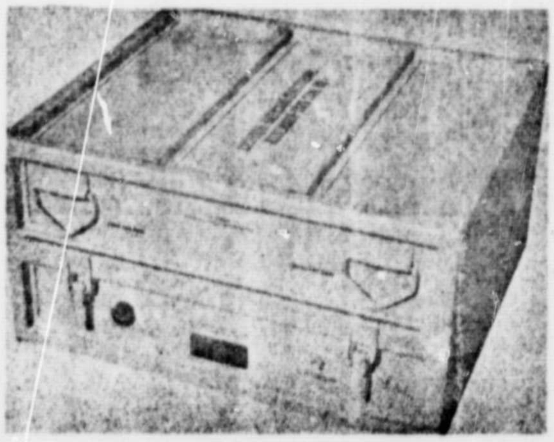

Figure 2-51 DSKY Shipping Container

storage. The Block I(0) and Block I(100) Main and Navigational DSKY containers are capable of providing this environment for either Block I (0) or Block I(100) Main and Navigational DSKYs, respectively. The Block II container is capable of providing the environment for two Block II DSKYs.

The reusable aluminum containers are lined with polyurethane foam contoured to the DSKYs when mounted on their handling fixtures, and thereby provide shock protection for the DSKYs. Pressure regulation is provided by a pressure relief valve. Humidity protection is provided by desiccant containers along with a humidity indicator.

2.6.16.2 AGC

The AGC shipping container (see Figure 2-52) provide a pressure and humidity controlled environment for the AGC during shipment and storage.

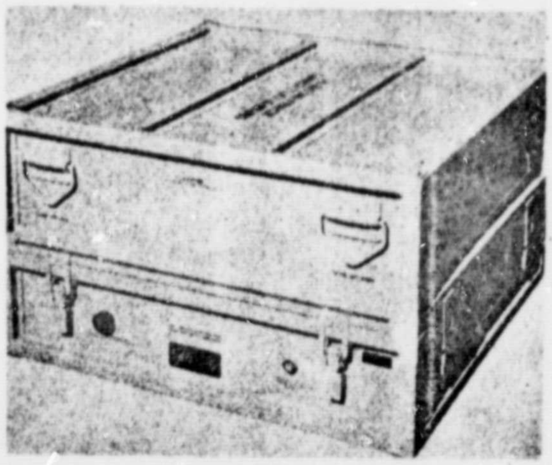

Figure 2-52 AGC Shipping Container

The Block I(0) and Block I(100) containers are identical in construction and are capable of providing this environment for either the Block I(0) or Block I(100) Guidance Computers, while the Block II containers provide the capability for the Block II computer only.

The reusable aluminum containers are lined with polyurethane foam contoured to the computer when mounted to its handling fixture, and thereby provides shock protection for the computer. Pressure regulation is provided by a pressure relief valve. Humidity contol is provided by desiccant containers along with a humidity indicator.

2.6.16 PROGRAM ANALYZER CONSOLE

The Program Analyzer Console (PAC) (see Figure 2-53) is an erasable memory device which can replace all or part of the fixed memory of an AGC 16-bit 36,864 word capacity. The PAC memory can be used and reused with an almost infinite variety of programs, unlike the fixed core ropes of the computer which are not electrically alterable. The operator has

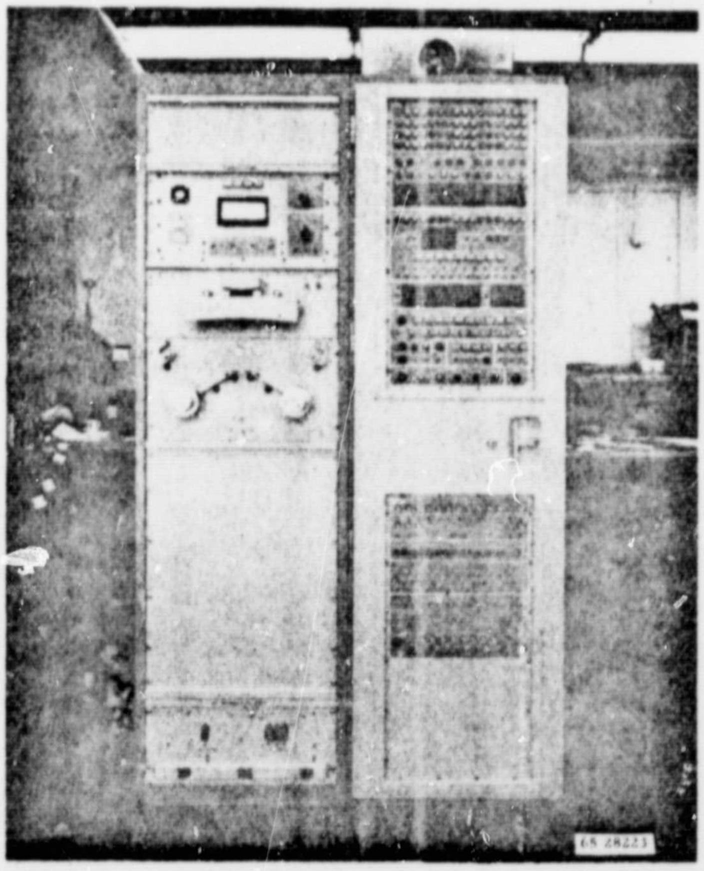

Figure 2-53 Program Analyzer Console

complete control over the data being stored and can review, verify, or edit data at any address in the PAC, and any erasable address of the computer. Also, the operator has complete control over the starting, stopping, or stepping of the computer program. The PAC has no capability of exercising the computer's input/output interface.

The PAC is capable of operating with the Simulation Computers and Blocks I(100)/II AGCs.

2.7 EQUIPMENT SUMMARY

Table 2-4 is a listing of Block I/I(100)/II Apollo hardware quantities.

TABLE 2-4

APOLLO HARDWARE LISTING

Nomenclature	Block I	Block I/100	Block II	Cumulative
Computers	6	12	57	75
DSKY	12	24	102	138
PSA Harness	--	13	---	13
Core Ropes	92	94	378	564
Connector Cover	--	12	52	64
Rope Jumpers	--	35	60	95
CDU	--	--	122	122
Installation Kit, AGC	--	---	19	19
Installation Kit, LM	--	--	19	19
Computer Test Set	16	3	7	26
Interconn. Kit, G & N Set	13	4	7	24
Operation Console	8	1	4	13
Interconn. Kit, Subsystem Test	8	1	4	13
Program and Monitor Kit	--	--	6	6
Computer Simulator	11	4	12	27
Calibration Console	6	--	3	9
Auxiliary Calibration Console	--	--	9	9
Core Rope Simulator	5	--	--	5
Simulation Computer	3	--	--	3
Program Analyzer	--	--	5	5
Shipping Container, AGC	6	14	--	20
Shipping Container, MDSKY	4	16	--	20
Shipping Container, NDSKY	4	16	--	20
Shipping Container, UDSKY	--	--	10	10
Handling Fixture, AGC	7	12	32	51
Handling Fixture, MDSKY	8	14	--	22
Handling Fixture, NDSKY	9	13	--	22
Handling Fixture, UDSKY	--	--	44	44
Pedestal Mount, MDSKY	9	2	2	13
Alignment Fixture, DSKY	-	4	-	4

SECTION 3

ENGINEERING

An Engineering staff was maintained throughout the program. This staff included residents at MIT/IL who were assigned to the design and development of both hardware and software. Field Engineering personnel were assigned at Apollo field sites for the testing and analysis of hardware/software, beginning with acceptance testing and continuing through the launch of vehicles. Field sites supported are AC Electronics, Milwaukee, Wisconsin; North American Rockwell, Downey, California; Grumman Aerospace Corporation, Long Island, New York; Manned Spacecraft Center, Houston, Texas; Kennedy Space Center, Florida.

This section contains a summation of major problems, solutions, and contributions of the Raytheon engineering support effort during the program.

Since the Block I(0) phase of the program was basically a development stage, the emphasis in this section will be devoted to Block I(100) and primarily Block II.

3.1 AIRBORNE HARDWARE

In May 1964, Raytheon was directed to provide engineering support to MIT/IL for the design and development of the Block I(100) AGC and DSKYs. The primary design goals identified were:

a. humidity and moisture proofing of the subsystem

b. correct AGC cooling problems

c. change AGC Input/Output (as required).

Effort to accomplish the tasks identified above had been initiated when Raytheon became a subcontractor to AC Electronics in July 1964. The design effort associated with the above goals was more extensive than originally envisioned, and continued until early 1965. In spite of numerous design changes, Raytheon delivered the first Block I(100) AGC subsystem in late February 1965, and the design goals were met.

3.1.1 BLOCK I(100)

3.1.1.1 Guidance Group Engineering Changes

The following descriptions of changes summarize the major improvements and solutions to problems detected during qualification, factory, and field testing. Detailed descriptions of specific changes in Block I(100) are outlined in the applicable ECP/ERP listed in Table 3-1. Qualification testing of Block I(100) was performed on AGC 110A; the test sequence is shown in Figure 3-1.

The purpose of this qualification test program was to demonstrate the design integrity of the AGC group when exposed to one operational cycle at the design limit environmental conditions. These conditions are those that may be encountered during equipment life, including emergency and abort flight phases. In addition to the design limit tests, overstress vibration tests were conducted to determine the design margin of safety.

3.1.1.2 Mechanical Differences

Some of the retrofits made caused the outward physical appearance of the subsystem to change. Other retrofits replaced and added parts to the internal structure of the equipment. The mechanical changes that are not related to the electronics of the hardware are described in the following paragraphs.

a. Computer - Five mechanical changes were made to the computer as specified in ECPs 147, 114, 187, 212, 185.

1. Replacement of standby power switch - At the time of production of certain computers the standby power switches with part number 1006296 were not available for installation. As a result, switches with part number MS24524-22 were used as permitted by Waiver No.'s RAY 00204 and 00237. Although the substitute switch was physically interchangable it did not meet the reliability specifications. This retrofit installed the switch with part number 1006296.

TABLE 3-1

ELECTRICAL AND MECHANICAL CHANGES

ECP	ERP	DESCRIPTION
		Kit No. 8104119 (Computer)
147	R-10009	Replaces standby power switch
111	R-10023	Redesign trap circuit in module A37
114	R-10035	Vibration dampening
187	R-10048	Replaces front closeout panel
188	R-10051	Adds resistor to tray A
189	R-10052	Grounds 0 V to AGC tray
212	R-10053	Adds potting to modules B2, B3, and B4
185	R-10058	Adds moisture sealing gaskets to modules
		Kit No. 8104118 (Main DSKY)
111	R-10023	Adds capacitor to key reset filter
175	R-10033	Adds G&N failure detect module to main DSKY
186	R-10043	Replaces DSKY decode modules
182	R-10055	Reworks DSKY
184	R-10057	Vibration dampening of keyboards
195	R-10065	Removes keyboard button travel interference
		Kit No. 8104121 (Navigational DSKY)
111	R-10023	Adds capacitor to key reset filter
186	R-10043	Replaces DSKY decode modules
182	R-10055	Reworks DSKY and relieves interference
183	R-10056	Replaces guide pins
184	R-10057	Vibration dampening of keyboards
195	R-10065	Removes keyboard button travel interference
		Kit No. 8104122 (G&N Harness)
109	R-10020	Reworks AGC to PSA and G&N to spacecraft harness
208	R-10067	Modifies harness for night watchman

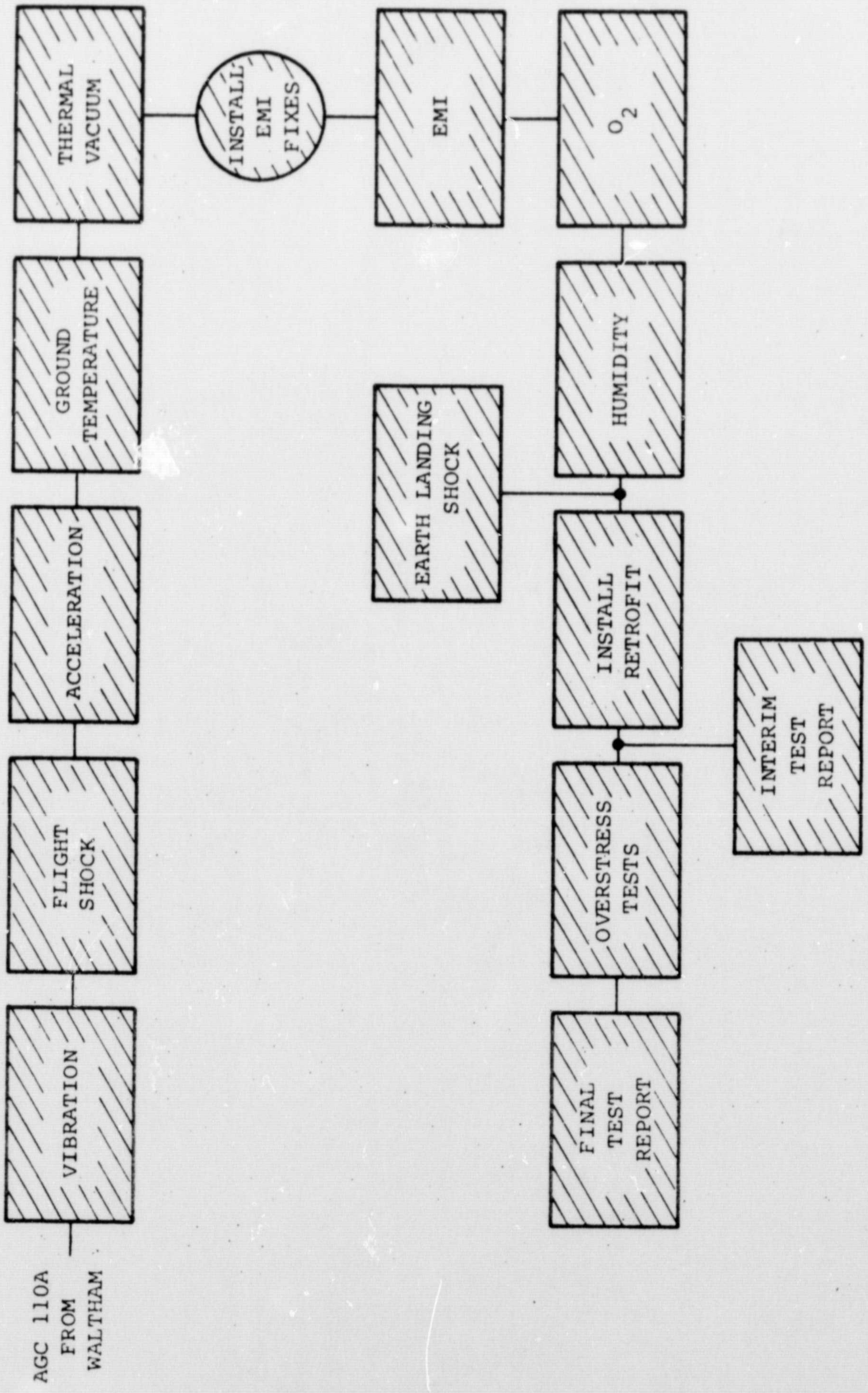

Figure 3-1 Block I(100) AGC 110A Qualification Test Sequence

2. Vibration dampening of computer - Vibration tests on the computer revealed excessive amplification in the central areas of trays A and B. To dampen the vibration, foam rubber cushions were placed between the modules and the covers on trays A and B and the area between the trays. These foam cushions are in compression and place a small preload on the modules and covers. In addition, new brackets were added to the rear of each cover and two new screws were added, securing the tray B cover to the tray B midplate. The commulative result of these modifications reduced the vibration amplitude to approximately one third of its original value.

3. Replacement of front closeout panel - Vibration tests on the computer revealed a resonance in the front closeout panel. As a result a new front closeout panel was fabricated and installed with proper material to dampen the vibration noise.

4. Potting of power switch modules B2, B3, and B4 - The original design of these modules did not require potting in several areas. These areas were potted to preclude the possibility of moisture entering and contaminating the module.

5. Addition of moisture sealing gasket - NASA elected to accept the moisture sealed configuration which renders the computers more readily reparable and provides some measure of added shock isolation to the individual modules. This retrofit added the moisture sealing gaskets to the Malco pins to improve the moisture resistance of the computer.

b. Main DSKY - Four mechanical changes were made to the Main DSKY as specified in ECPs 175, 182, 184, and 195.

1. Installation of G&N failure detect module - The G&N failure detect module (night watchman) is a separate module which bolts onto the back of the Main DSKY, as shown in Figure 3-2. The module is plugged into the 244 pin connector on the back of the Main DSKY. Another 244 pin connector on the bottom of the module accepts the spacecraft harness that

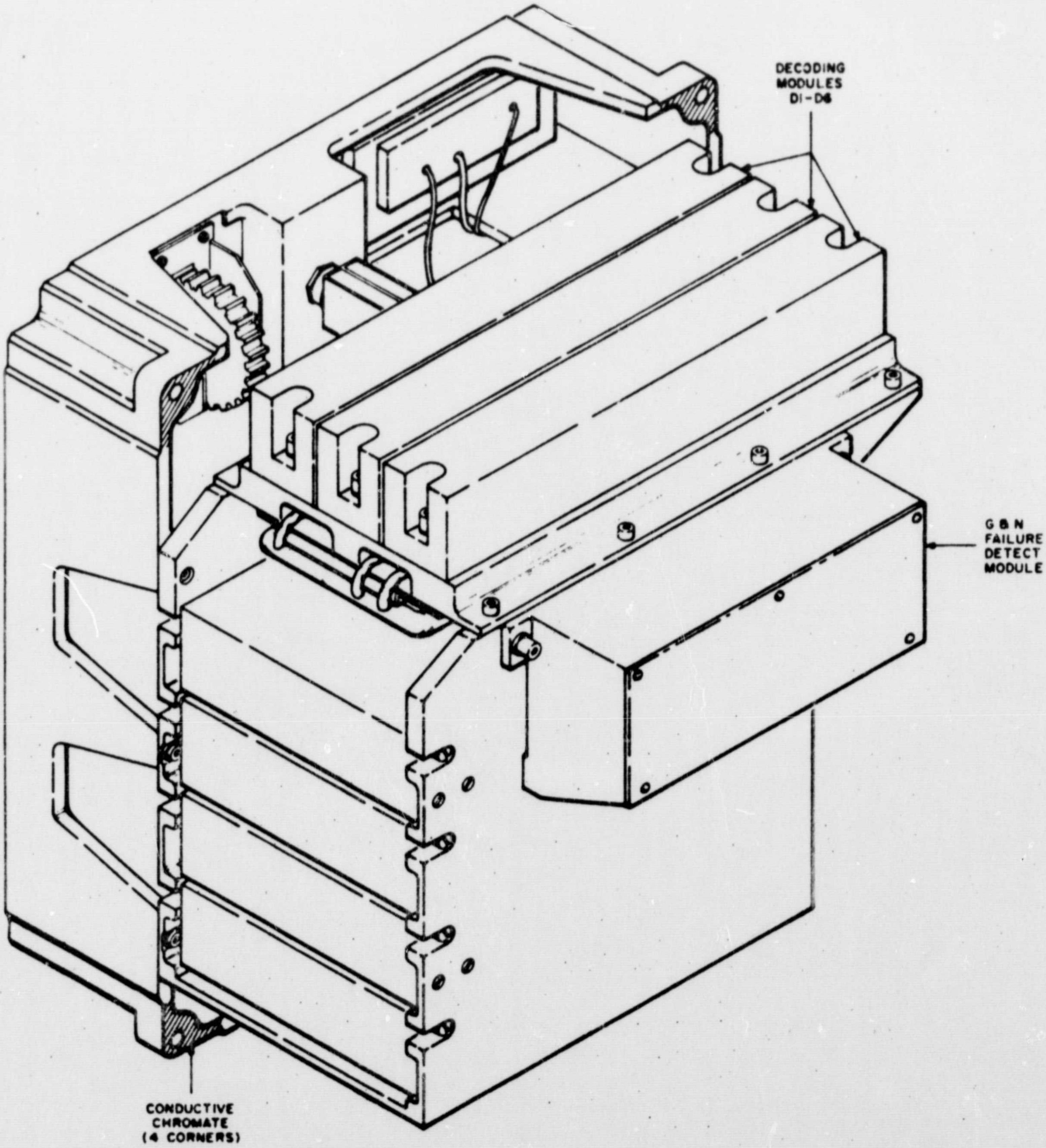

Figure 3-2 Main DSKY (Rear View)

formerly plugged into the Main DSKY. The G&N failure detect module provides a feed-through capability for signal lines entering the DSKY and detect circuitry which produces an alarm if the input signal is not within required specifications.

2. Reworking the Main DSKY - The mounting holes were enlarged to allow NR to replace the present hardware with strengthened noncaptive hardware to improve structural shock performance when installed in the spacecraft. The protective finish on all mounting surfaces was changed from non-conductive anodize to conductive chromate to provide improved electrical bonding. The surfaces that have conductive chromate are shown on Figure 3-2.

3. Vibration dampening of keyboard - When the DSKY was subjected to 3 dB and 6 dB overstress conditions, actuation of the normally closed switch contacts was noted. The pulses resulting from switch actuations did not constitute system failure or have adverse affect on circuit operation due to the RC filter network in the keyboard circuit. However, the switch actuations had a severe degradation effect on switch contact reliability. As a result, rubber strips and vibration pads were installed to increase vibration dampening, provide a safety factor for overstress conditions, and improve the reliability of switch contacts under such conditions.

4. Removal of keyboard button interference - Depression of keyboard buttons with a twisting motion resulted in some buttons "hanging-up" on the back of the front panel and housing. Also, some buttons caught in the crack formed by the junction of the panel and housing. As a result, the surfaces on the rear of the front panel and housing were built-up so that the buttons are fully guided to the limit of travel. The button guides were also chamfered to ensure smooth travel in both directions.

c. Navigational DSKY - Four mechanical changes were made to the Navigational DSKY as specified in ECPs 182, 183, 184, and

195. ECPs 184 and 195 apply to both DSKYs and are described in 3. and 4. above.

1. Reworking the Navigational DSKY - The protective finish on all mounting surfaces was changed from nonconductive anodize to conductive chromate and 0.125 inch was machined off the top of the Navigational DSKY front panel to relieve mechanical interference.

2. Replacement of guide pins - The Navigational DSKY guide pins have exhibited a tendency to fall out and/or become bent as a result of normal handling and installation. As a result, the old guide pins were removed, their holes enlarged, and new guide pins with a larger shank diameter were installed. These pins, being press-fitted into the housing, will provide more positive retention and increase shear strength. The addition of a shoulder to the pin will provide more positive alignment and relieve bending.

3.1.2 BLOCK II

3.1.2.1 Design Changes and Improvements

Block II development began with the fabrication of preproduction equipment including prototypes and engineering models which were used in various simulation, test, and development programs.

The following descriptions of changes summarize the major improvements and solutions to problems detected during qualification, factory, and field testing. Detailed descriptions of specific changes are outlined in the applicable ECPs listed in Tables 3-2 and 3-3. Qualification testing of the Block II system was performed on AGC C-1 and DSKY S/N RAY 30; the test sequences are shown on Figure 3-3 and 3-4 respectively.

a. Potting erasable memory modules with sylgard - Over several months, it was determined that based upon production line and field performance, the reliability of the Erasable Memory (EM) modules was identified as one of wire fatigue brought about by large excursions of the RCA core stack imbedded in the RTV-11 encapsulant material. The erasable

TABLE 3-2

DSKY ENGINEERING CHANGES

ECP	Description
176	In-process vibration and thermal cycle of AGC modules Breakin C1
291	Alarm lights Breakin C1
367	Addition of light diffusing paint Breakin C1
419	IDM relay replacement in DSKY Breakin D1
470	Random workmanship vibration Block II AGC and DSKY Breakin C1
476	Painting of alarm indicator face Breakin D9 Retrofit D1 through D8
479	DSKY teflon coated pushbutton shaft Breakin D1
493	Y-line feedback of base resistor Breakin D1
494	DSKY wiring improvement Breakin D1
501	Implementation of flight processing specification Breakin D1
505	Implementation of flight processing spec and new diode Breakin D1
641	Nonmetallic materials modification for DSKY Breakin D30 Retrofit D3, D4, D7 through D29, S/Ns 13, 28, 30
673	DSKY pushbutton cap housing assembly leaf spring Breakin D30 Retrofit D3, D4, D7 through S/Ns 13, 28, 30
735	Addition of safety glass to cover DSKY EL and IL indicators Breakin D55 Retrofit D1, D3, D5, D7 through D16, D19 through D30, D32 through D54, S/Ns 13, 28, and 30
739	14 legend IL, indicator, status/caution
768	Thermal vacuum of EL and cover assembly

TABLE 3-3

AGC ENGINEERING CHANGES

ECP	Description	ECP	Description
176	Computer module vibration Breakin C1	402	Clear circuit driver modification Breakin C1
226	Aluminum to magnesium conversion of AGC trays Breakin C1	403	Strobe adjustment Breakin C1
254	Computer multilayer board (MLB) layout Breakin C1	440	"Clear rope" driver circuit modification Breakin C3 Retrofit C1 and C2
257	Redesign of rope and erasable drivers Breakin C1	443	Replacement of short screws Breakin C3 Retrofit C1 and C2
258	Redesign power supply module Breakin C1	447	Incorporation of plastic pads under trays A and B covers Breakin C3 Retrofit C1 and C2
259	Redesign of erasable memory Breakin C1		
301	Thermal instrumentation 602 only	452	Wiring change to accommodate auxiliary memory unit Breakin C8
322	Computer wiring changes Breakin 601	460	Addition of jumper wires in tray A Breakin C3 Retrofit C1 and C2
324	Sense amplifier threshold voltage stability change Breakin C1	470	Random workmanship vibration Breakin C1
351	Alarm module temperature stabilization of warning integrator and improved oscillator fail alarm Breakin C1	474	Manufacture test connector jumpers to ground certain gate inputs Breakin C8
368	Improved power supply module relays Breakin C1	478	Paint exposed surfaces on mid-tray spacer Breakin C3 Retrofit C1 and C2

TABLE 3-3 (Continued)

AGC ENGINEERING CHANGES

ECP	Description	ECP	Description
485	Redesign power supply to remove 28 Vdc regulator Breakin C6	564	Implementation of flatpack specifications ND 1002359A and ND 1002358B Breakin C13
486	Cut pins on AGC power supply to remove 28 Vdc regulator Breakin C6 Retrofit Cl through C5	604	Incorporation of erasable memory vibration pads Breakin C13 Retrofit Cl through C12
501	Implementation of flight processing spec Breakin C8	631	Replace RTV-102 with RTV-109. ECP 631 should be incorporated in PN 2003993-031 and above. ECP 631 does not affect part number change. It may be included in other part number assemblies.
505	Implementation of flight processing spec ND 1002341 and new diode		
511	Correction of computer noise SCAFAL problem	719	28 V failure detection (V-fail). Alarm module.
518	Standby change on computer Breakin C12 Retrofit Cl through Cll		

memory module was exposed to vibration at the encapsulated subassembly level at RCA, in the completed module level at Raytheon and at the computer level. There was a real question as to the extent of the problem induced by excessive vibration time and levels because of the poor damping characteristics of the RTV-11 potting material.

Based upon a series of tests conducted by MIL/IL, Raytheon, and AC Electronics, it was determined that the basic problem of the motion of the core stack in the encapsulant material was one which could be resolved by:

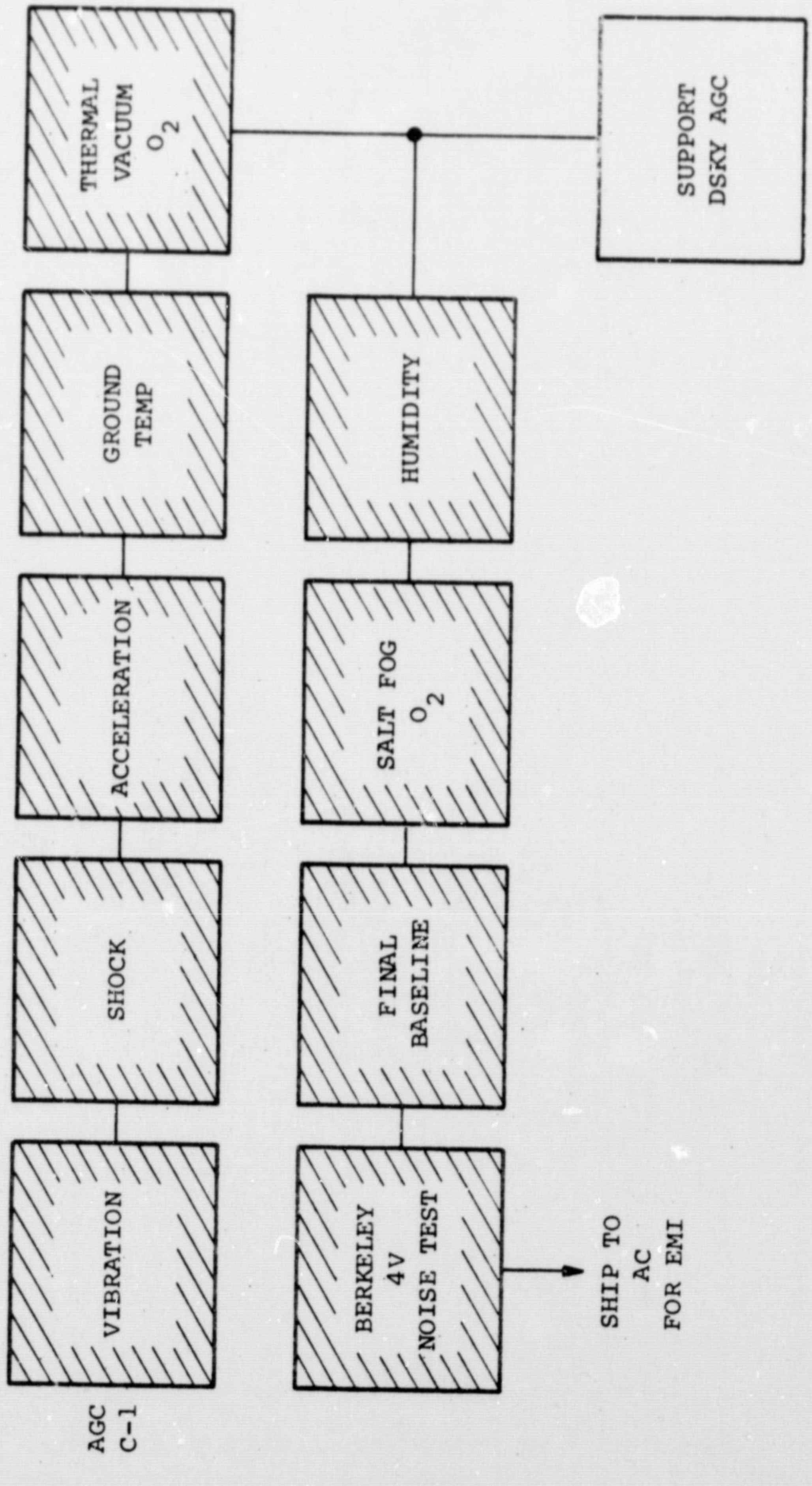

Figure 3-3 Block II AGC Qualification Test Program

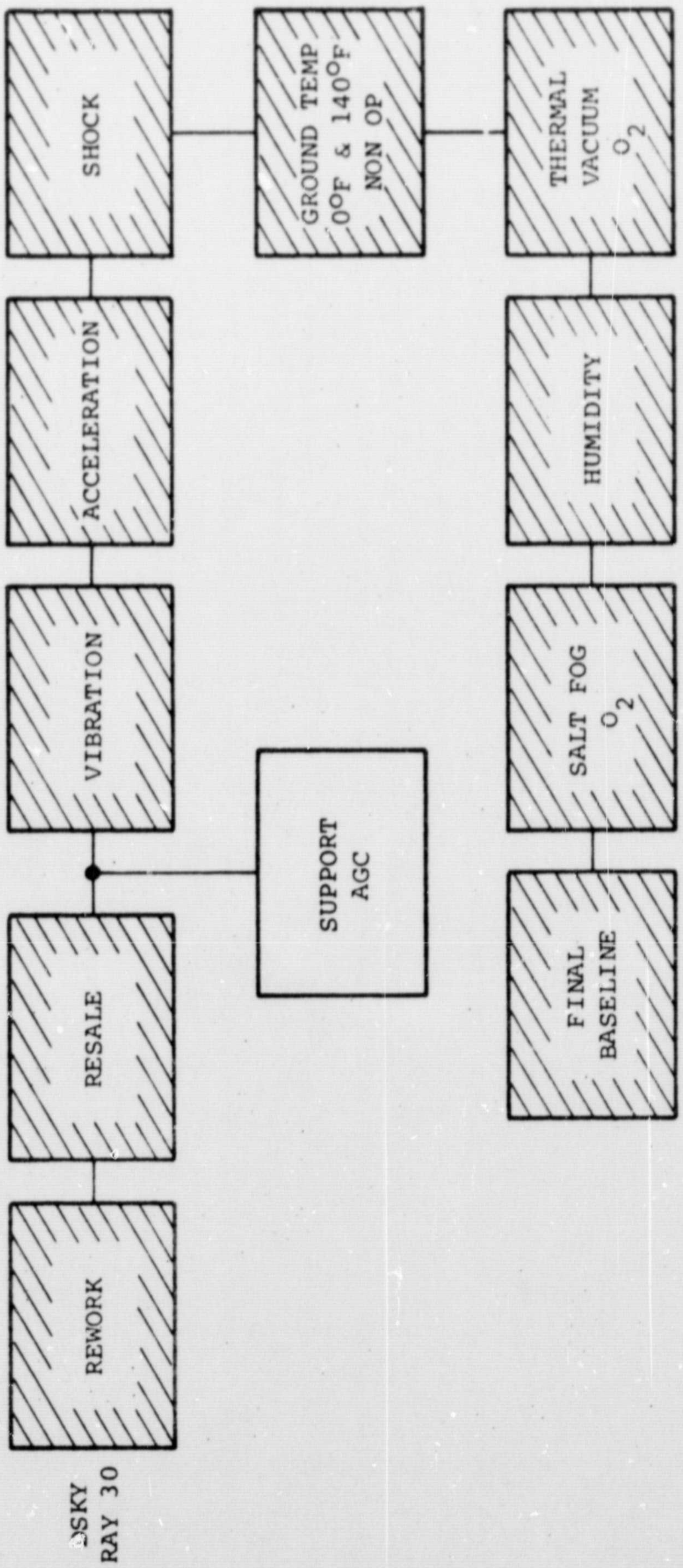

Figure 3-4 Block II DSKY Qualification Test Program

1. reducing the vibration exposure

2. selection of a new encapsulant material which would provide the damping characteristics needed while not introducing a new family of problems associated with compatibility with core material, dielectric coefficient, adhesion, aging and chemical characteristics.

The EM module vibration exposure time and levels were reduced at RCA and Raytheon. Vibration testing proved that a new and more rigid header design was not the solution to the problem. However, MIT/IL and AC Electronics conducted an encapsulant material evaluation program by identifying the desired encapsulant characteristics as measured against those available in the open market for the replacement of RTV-11 used in potting the core stack in the EM module. The most attractive encapsulant materials on the market to suit the needs of the EM module application and environment were the following:

1.	Scotchcast	221
2.	Eccogel	1265
3.	Sylgard	182
4.	Sylgard	184
5.	Kalex	70
6.	Marasett	AC4

The evaluation test included but was not limited to the following:

1. MIT/IL

   Dielectric
   Moisture
   Aging

2. AC

   Stress evaluation
   Brittle point
   Adhesion
   Vibration
   Chemical

As a result of the evaluation performed above, Sylgard 184 was selected as the new encapsulant material and was incorporated by Raytheon and RCA as directed by Change Order 365, Directive R-1720.

b. Sense Amplifier stability - The change resulted in two Sense Amplifier Modules which are mechanically identical, but not interchangeable because the thresholds are set to approximately 30 mV for Rope Sense Amplifiers and approximately 20 mV for Erasable Sense Amplifiers. The reason for the proposed change is to optimize setting for both memory systems. Currently a typical rope "1" is 80 mV, and a typical rope "0" is 20 mV, while for the erasable memory a typical "1" is 60 mV and a typical "0" is 10 mV under nominal conditions at room temperature.

The threshold setting of 25 mV means that with worst case variations of parameters, a rope "0" could possible be read out as a "1" or an erasable "1" could be read out as a "0". Reducing the erasable threshold and increasing the rope threshold provides more adequate margins for worst case conditions.

The proposed change was implemented by changing the procedure for selection of the resistor which adjusts the threshold. This change was necessary to assure operation of the AGC over the required temperature range considering the worst case combination of module parameters.

Analysis of the original design indicated that the Vy voltage within the Sense Amplifier modules did not properly regulate at the lower temperature extreme. Since Vy is used to establish the sense amplifier threshold, the result was an increase in the threshold at low temperature which resulted in a decrease in the memory system margins. The change added a resistor and diode to the circuit.

This change provided stable current through the diode regardless of Q7 base current. This guaranteed that the operating points of the diodes would be beyond the knee of the curve and into a region of operation which is stable with temperature variations.

c. Block II restart problems and solutions - Computer Restarts during testing became a concern which resulted in a very extensive investigation.

1. functions which generate restarts:

   Interrupt Alarm (too many of too few)
   Counter Alarm (too many or too few)
   TC Trap Alarm (too many or too few)
   Night watchman Alarm (too few)
   Parity Alarm (erasable or fixed)
   Voltage Alarm (VFAIL)
   Oscillator Alarm (STRT2)
   CTS Fresh Start (pushbutton)
   Standby

2. causes of restarts:

   failure within computer
   excessive internal noise
   excessive external noise
   crosscoupling of signal lines

3. corrective action taken:

   test connector cover (shorting plug to terminate test lines

   removal of ALGA, Start 1 and Start 2 lines (C-12)

   improved power supply supplying grounding and rerouting (C-12)

   improved Newspeak test ropes

   modifications to Block II CTS to improve monitoring of alarm lines

   video tape used during DSKY vibration.

d. Trays A and B cover vibration pads

1. tips of Malco pins are not completely covered by potting material for possible trouble shooting aids

2. the covers may deflect under vibration and short to the exposed pin tips

3. foam plastic vibration pads were placed between the tray covers and the exposed pin tips.

e. False SCALFAL signals

1. false indications of scalar failure were observed during preliminary testing of AGC C8

2. cross-coupling was occurring because of the close proximity of the SCALFAL wire to 16 rope inhibit wires

3. measured cross-coupling voltages

Computer	Cross-coupling
603	400 - 600 mV
200R	200 - 400 mV
C8	900 - 1100 mV #1 Tray B
C8	600 - 800 mV #2 Tray B
PC-4	400 - 500 mV
c7	500 - 600 mV

4. cross-coupling was reduced to 50 - 70 mV by rerouting the SCALFAL wire in 200R

5. C8 and above used rerouted wiring

f. Erasable memory vibration - to minimize environmental levels seen during the AGC and flight environments, a damping pad (see Figure 3-5) was added to the top of the module.

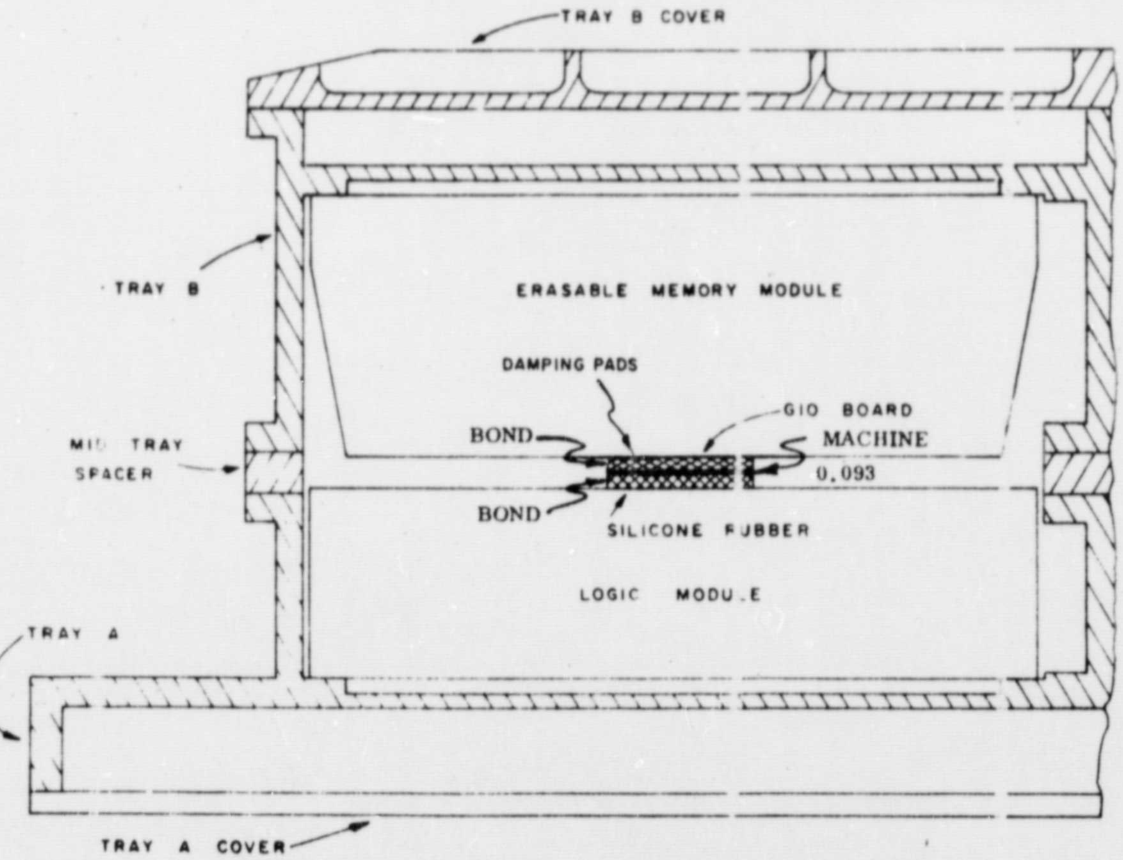

Figure 3-5 AGC Cutaway Showing Damping Pads Between Modules

1. moved resonance point of module to a higher frequency (away from common module/AGC resonance)
2. provided a lowering in the worst-case axis amplification levels by a factor of three.

g. Blue Nose gates - A redesign of the logic section of the Block II computer was required due to a potential problem caused by application of Fan IN Interface Gates (called Blue Nose). The internal design of the dual flatpack integrated circuit inadvertently provides diode sneak paths between the resistors of the circuit. When the B+ connection is made to a circuit (as is the case when used as a Fan IN Interface) the diodes become forward biased and cause cross coupling between the two circuits within the package.

A change of flatpack components for those circuits being used as Blue Noses was required. This approach involved the development of a modified dual integrated circuit which does not have the collector resistors connected to the collector. However, since the resistors and the extraneous diodes would still exist within the package, it was necessary to connect the B+ lead to +4 V to back bias the diodes. This approach also caused a redesign of the MLBs in 24 logic modules (21 types) and the development, procurement and screening and burnin of a resistorless flatpack unit (333 required per system).

h. DSKY pushbutton switch spring - Due to failures of the DSKY pushbutton switch spring (shown in Figure 3-6) a failure analysis and design review of the spring was performed. The failure analysis and design review indicated that in normal use the spring could crack at points of stress concentration. As a result, a new spring was designed.

As shown in the drawing, the new spring replaces the present spring in form, fit, and function with tighter geometric constraints. The wraparound design of the new spring lengthens the spring arm to reduce stress and allows the new spring to be incorporated in the existing pushbutton switch design. The thickness of the spring was changed from 0.010 to 0.018 inch to retain the same spring rate. The material of the new spring is the same as that for the present spring but is specially hardened to a minimum of 270,000 lbf/in^2 U.T.S. to increase the fatigue strength of the spring.

i. DSKY fire fix - As a result of the flammability study performed as authorized by CCA 497-0428, the DSKY alarm indicator (P/N 1006387-003) and DSKY pushbutton caps (P/N 1006353) required material changes as follows (see Figure 3-7):

1. alarm indicator - affix nonflammable nonreflective glass cover with an aluminum frame as an integral part of the indicator panel
2. DSKY pushbutton caps - replace the acrylic cap with one of aluminum having etched and acrylic filled characters.

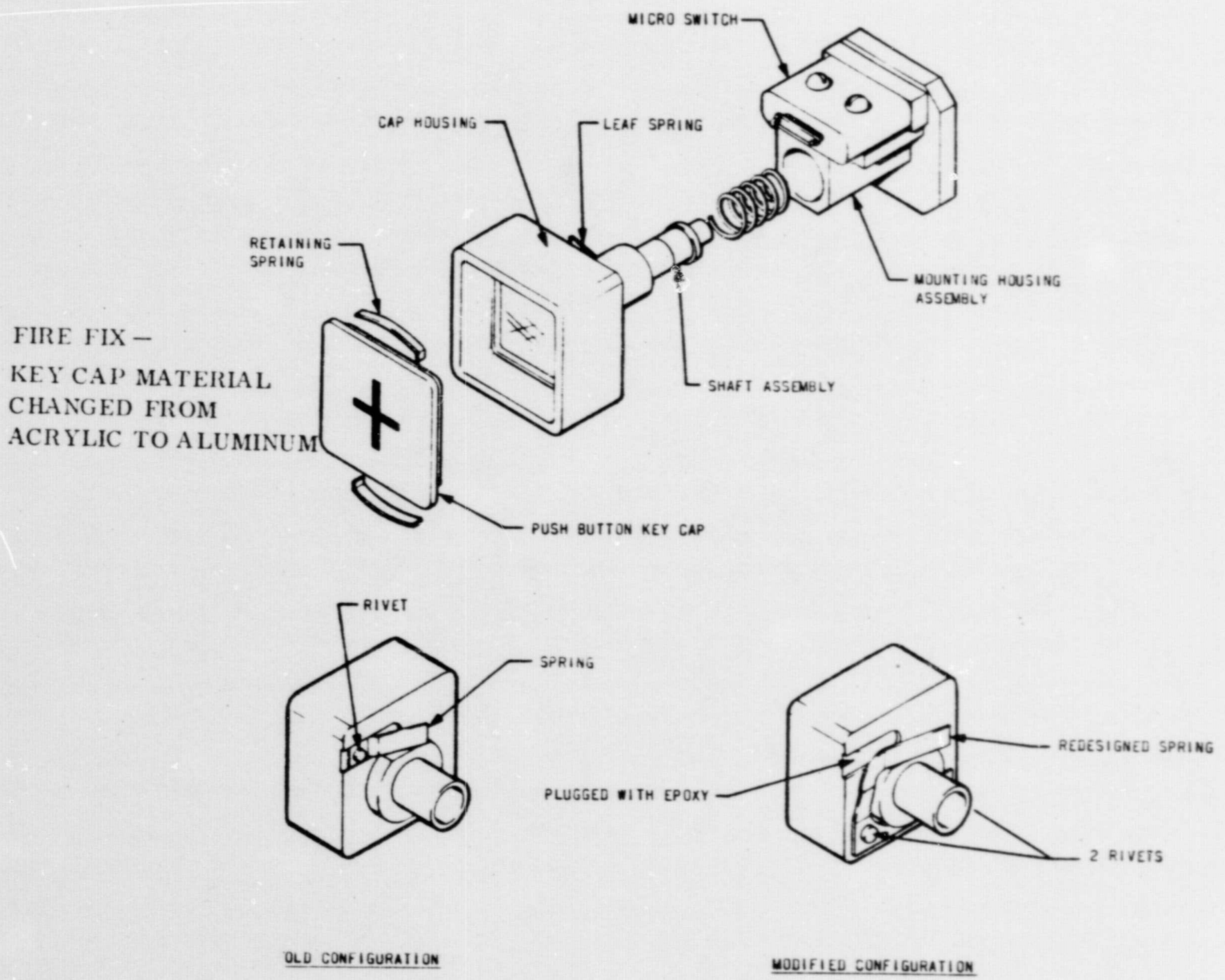

Figure 3-6 DSKY Key Cap and Leaf Spring Fix

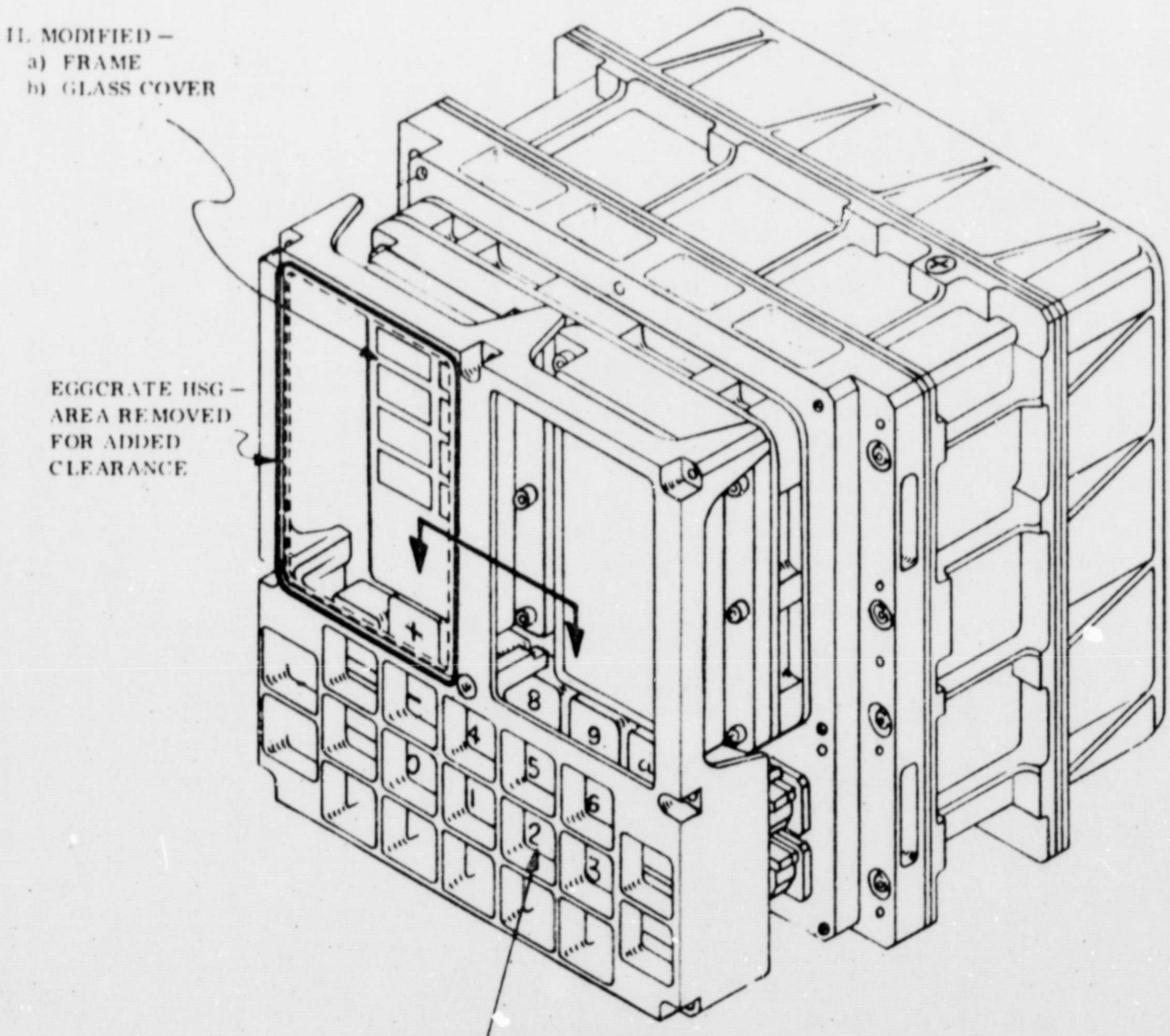

Figure 3-7 DSKY Fire Fix Changes

j. Teflon coated shafts for DSKY pushbutton switch assemblies - After the fabrication of the first Block II DSKYs, it was found that the production pushbutton switch assemblies exhibited rough operation. A decision was made to change the surface of the cap housing to a 32 finish. This change eliminated most of the roughness in the operation of the switch assembly.

However, it was found later that the smooth operation that resulted from the improved finish became rough after a long period of operation and a high force was required to operate the switches. This appeared more pronounced on the verb, noun and enter switches as they received the most use.

An investigation was conducted by Raytheon Engineering and several possible solutions were tested. Shaft assemblies of the existing design were cycled and rough operation was verified at the end of a 10,000 cycle test. Other shaft assemblies with various coatings and combinations were tested and the best all around design proved to be a teflon coating of the shaft assembly. Extended tests had been run on this design and no failure or indication of failure had been observed after cycling 50,000 times. The change to Teflon coated shaft assemblies was approved and incorporated in DSKY D1 and subsequent DSKYs.

k. Fixed memory module strand coupling elimination - Noise problems developed in the AGC during system test. Through testing and investigation it was found that excessive capacitance between strand lines of the fixed memory module.

Electrical Engineering decided that the addition of 12 diodes between twelve Malco pins and corresponding strand line resistors would resolve this problem. Layouts were made to install 12 diodes in a diode block which is then assembled into the existing fixed memory module by reworking the header. This change, which created a complete new configuration, was processed and solved the capacitance problem.

1. Fixed memory strand shift analysis - Under worst case conditions, the strand currents can become additive and significantly add to or subtract from the reset current. This can cause undesired changes in core output amplitudes and peaking times. This was a problem in several rope programs, especially Newspeak.

A program was written and checked out which will predict the problem areas. After analysis of a rope program by this computer program, it is possible in conjunction with the core rope map to select wires for reverse direction to minimize the effect. This analysis was completed and implemented first on the new Lamesh B-1 program, and the Sundisk program backup ropes. This technique was adaopted for subsequent flight rope modules. Reduction of net sense lines reduced the core output voltage requirements; reduction of + sense lines reduced "0" noise.

Two additional fixed memory problems which were significant are: Block II core rope "Low 1" and rope diode dynamic impedance. A detailed discussion of these problems was submitted in Apollo Engineering Report GPT-68-50 dated 29 February 1968, and ERP 10211 dated 20 February, 1969.

3.2 GROUND SUPPORT EQUIPMENT

At the time Raytheon became a subcontractor to AC Electronics in July 1964, delivery of Block I GSE was in progress; and Raytheon had initiated the following design effort:

a. design retrofit kits to modify all GSE to work with both the Block I and the Block I (100 series) AGC

b. design additional retrofit kits to modify all GSE to work with Block I, Block I (100 series) and Block II Apollo Guidance Computers.

The first retrofit program proceeded smoothly, and additional GSE was delivered to meet the needs of the program.

Detailed design of the necessary GSE to test the Block II AGC was delayed by the finalization of the computer design, and the necessity of incorporating additional features, such as rfi shielding on cables. A maximum effort was exerted to provide equipment at all sites to support the computer program.

The problems encountered in fabrication and test of this equipment were further complicated by incompatibilities discovered between the AGC and GSE. Updating Block II engineering models in use during the GSE production cycle necessitated constant changes. Once the design change requirement cycle was minimized, deliveries were maintained on a constant flow.

Significant changes that were implemented are as follows:

a. CTS Diagnostic Compatibility I - elimination of false stop condition and erroneous alarm displays

b. CTS Diagnostic Compatibility II - elmininination of race condition in record mode, false stop command in RS agreement mode, and erroneous S-sample and G-stop pulses

c. CTS Diagnostic Compatibility III - eliminated erroneous stop condition resulting from a new DSKY program which was generated for the testing of the C1 computer subsystem

d. Noise Reduction, CTS and PAC Buffer Box - new grounding and improved noise rejection circuits and reduced noise coupling and shield currents which were observed during an extensive noise analysis study.

3.2.1 GSE NOISE SUMMARY

The GSE noise analysis study was performed at Raytheon on the AGC-PAC and AGC-CTS combinations. The G&N configuration was evaluated in Milwaukee by Raytheon and AC Electronics personnel.

The study revealed that noise resulted from coupling in the buffer box and cabling between the noise rejection circuit output and the AGC input (see Figure 3-8).

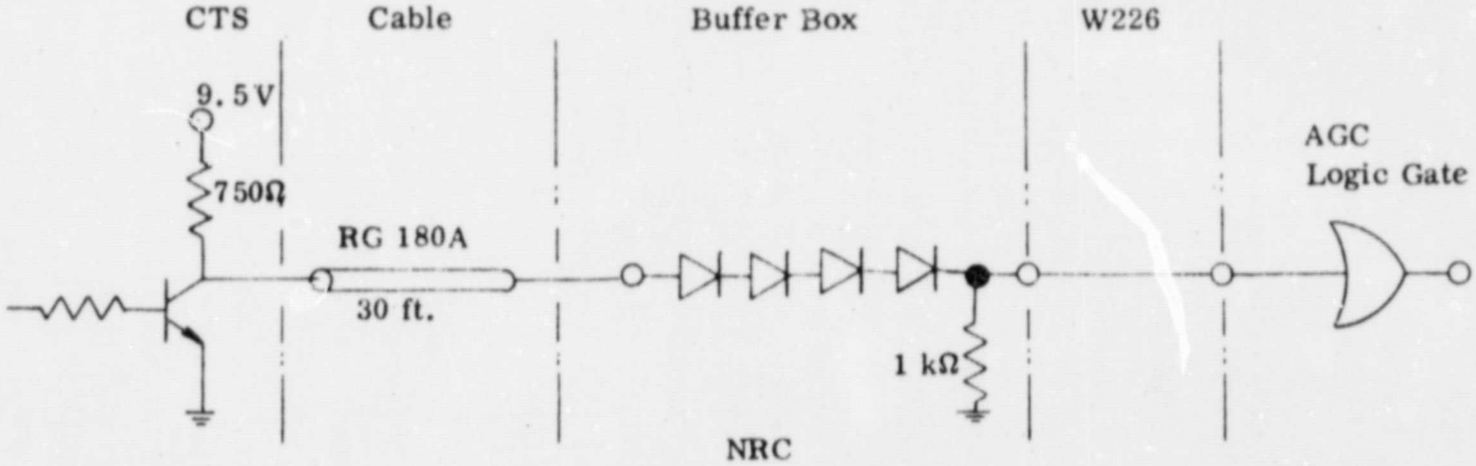

Figure 3-8 AGC Input and Noise Reduction Circuit Output Schematic

In the worst case noise conditions, 450 mV was measured across the 1 kΩ resistor. This condition was improved by reducing the value of the 1 kΩ resistor to 220 Ω. This lowers the impedance to ground during the zero state, making it more difficult to couple a voltage to the line. The circuit modification reduced the noise level to 100 mV.

The decreased drive is adequate for the AGC but marginal in CTS self-test. This condition requires the addition of 16 pairs of integrated circuits to the CTS self-test box.

At the G&N test level, the noise study revealed high shield currents in the W226 cable. These were reduced by establishing a buffer box ground bus, referenced to the buffer box case. A ground strap was added from the buffer box case to the AGC case, as shown in Figure 3-9.

The success of the noise analysis study at Raytheon and AC Electronics eliminated the need for its continuation at the field sites. The study and resultant change are described in detail in ECP 674.

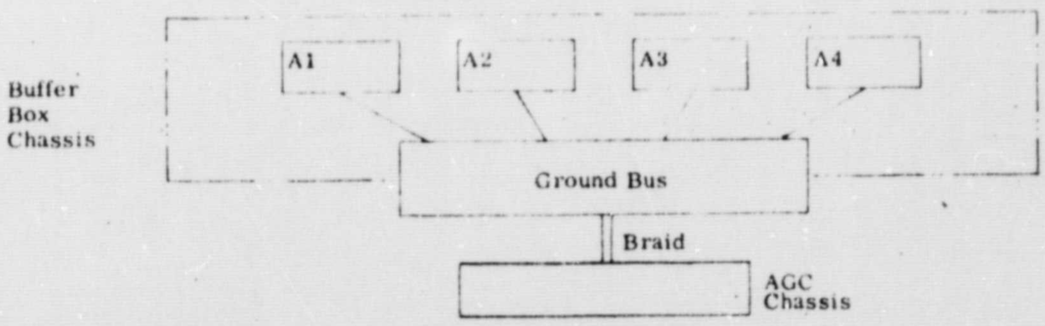

Figure 3-9 Buffer Box and AGC Case with Connecting Strap

3.3 FACTORY TEST EQUIPMENT

As the Block II program progressed the needs for improved Factory Test Equipment (FTE) for the timely analysis and isolation of intermittent and non recurring failures became evident.

Three significant steps were taken resulting in improved data collection techniques and constant monitoring capabilities.

3.3.1 DSKY MONITOR

A closed circuit television camera, monitor, and video tape recorder were installed to maintain constant surveillance of the DSKY displays during factory testing.

3.3.2 DIAGNOSTIC CAPABILITY IMPROVEMENT

In order to provide the required information to improve failure diagnostic capabilities, the following was accomplished:

a. The subsystem checkout program (Newspeak) was revised. This revision is known as Lamesh.

b. The CTS was modified to provide a more definitized alarm display and to provide for data and alarm retention upon the occurrence of a failure condition. This capability can be utilized in either subsystem or system modes of operation.

The added features provided by factory test program Lamesh to improve the diagnostic capabilities were as follows:

a. Capability of analyzing the data and to indicate on the DSKY the probable cause of a "Go Jam."

b. Many routines were modified to add the capability of storing failure data for single and multiple failures.

c. An added routine provides for improved counter generated interrupt testing by assuring that the counter is being incremented prior to entering an idle loop to wait for the resultant interrupt caused by the counter overflow.

d. The interrupt priority test was modified so that the relative priorities of the T3, T4, T5, and T6 interrupts are tested.

e. The T6 RUPT routine was modified to detect faulty addressing upon the generation of the T6 RUPT.

f. A new routine was added, which allows any special routines loaded into erasable memory to be run as a part of the automatic cycling test.

g. A new routine was added to provide for recording of the contents of erasable memory on paper tape when the operator deems it necessary.

h. Program controlled resetting of CTS alarms is provided by the alarm test routines. This eliminates the problem of the normally on condition of the CTS alarms with the present Newspeak program.

CTS modifications are as follows.

a. Additional alarm indications and CTS for Go Jam and erasable memory parity failures.

b. A lockout of CTS registers upon the recognition of an alarm condition to prevent further updates, thereby retaining the AGC central processor data at the time of the failure.

c. A lockout of any additional alarm indications on the CTS after the first failure condition is detected. This allows only the actual failure condition alarm to be displayed and not additional resultant alarm conditions.

d. Provide for the AGC controlled reset of the alarm circuitry of the CTS. This function is utilized during intentionally generated alarm tests of program Lamesh. Also, the lockout functions of the CTS registers and alarms can be reset under AGC program control.

e. The lockout of the CTS registers and alarm circuitry is optional so that troubleshooting with continuous AGC alarms present can be accomplished.

f. The features described above can be utilized when the CTS is used in either the AGC subsystem or G&N system level test configurations.

3.3.3 APOLLO DATA ACCUMULATION MEMORY SYSTEM

The purpose of the Apollo Data Accumulation Memory System (ADAMS) is to provide a record of the computer events immediately prior to detection of a computer failure. The data assists in failure analysis and substantially reduces the time to isolate the failure mechanism. This is particularly true for intermittent failures that require long periods of test to reproduce a failure.

ADAMS stores data from 72 critical signals available at the AGC test connector. These signals are routed from the AGC to a special buffer box which provides the drive necessary for both the CTS and ADAMS. Only output signals from the computer are supplied to ADAMS. All computer control is from the CTS. The storage medium is a 4,096 location, 72-bit, random access memory. The storage is in the form of an endless list which loads the newest data into the location containing the oldest information.

The last ADAMS memory location accessed is displayed and is the address of the last set of data to be printed. ADAMS interfaces with a teletype model ASR-33 line printer whose function is to print-out, in octal, all (or selected parts) of the stored data. Normally, all of the 4,096, 72-bit, data lines are not needed for complete analysis of the computer failure. The 4,096 lines represent 4,096 ms or approximately 4 μs of computer operating time. The operator controls the starting address of the data to be printed. This is determined by estimating the number of microseconds of computer history needed for complete analysis of a failure.

3.4 SUMMARY

Continuous engineering support was provided throughout the program. All required changes to the GSE were processed and implemented. The development of all Airborne Hardware was completed and the design goals were achieved.

SECTION 4

MANUFACTURING

4.1 INTRODUCTION

The Manufacturing effort was primarily the fabrication, assembly and testing of Airborne and Ground Support Equipment. This task involved the development of factory test, assembly and inspection plans, and equipment which ultimately led to the delivery of hardware. This section describes significant events, problems which affected deliveries, action taken, and achievements attained in manufacturing throughout the program.

4.2 SCHEDULES

The scheduling of hardware fabrication and deliveries was a monumental task throughout the program. The untimely availability of flight qualified components to meet the stringent requirements of Apollo, and the incorporation of hardware changes were contributing factors affecting schedules. Many problems impacting cost and schedule were introduced into the Block II program because parts which had been purchased prior to the release of the Flight Process Specifications (FPSs) failed under the lot rejection criteria of the FPSs - a criteria which had been purposely established to insure that industry would produce substantially better parts.

In order to minimize schedule delays, action was initiated in the areas of purchasing, work-around schedules and failure analysis expediting. Examples of action taken was the assignment of resident subcontract personnel at major vendors, increasing of the planning and scheduling staff to accommodate the additional effort required, and a buildup of the Quality Assurance and Reliability Analysis Laboratory personnel staffs assigned to the program.

As the program progressed there were increasing demands in achieving a high confidence level of the flight hardware. These demands necessitated the implementation of additional in-process inspection requirements and higher skilled production personnel.

Late releases of Block II designs caused major program schedule problems. Raytheon, concerned about potential program impact, initiated action to assist MIT/IL in its effort to complete the design of the Block II AGC. This action took the form of additional liaison between the Apollo program office and Engineering department personnel and an increase in the design review effort within Raytheon.

During the summer of 1965, MIT/IL discovered serious design problems in the first Block II AGC breadboard (AGC 200M). These problems were attributed to the distributed capacitance exhibited in "signal layer" design (tall headers); MIT/IL decided at this time that the solution to this problem was to convert to multilayer boards (MLBs).

Raytheon, on direction from AC Electronics, initiated the procurement of MLBs and took a management risk in initiating the development of logic test tapes, DITMCO test tapes, DITMCO fixtures, etc. This action minimized the schedule impact to the program for introduction of MLBs.

A decision was then made to modify MLBs to accommodate a design requirement initiated by MIT/IL. This change was to provide a second voltage source, commonly referred to as "FAP". Subsequently, redirection was given to modify MLBs to incorporate the "expander gate". Significant effort was required to verify the artwork changes and modify logic test tapes. Realizing the necessity of a logic test tape verification program, the modification of the AGC-200C (breadboard) logic modules to C-1 configuration was authorized. This action minimized the impact on the C-1 schedule.

During February 1965, the Block II initial Class "A" release began. Schematics with parts lists, followed by mechanical assembly drawings, were released calling for these parts. Some time later, revisions of assembly drawings began to call out the conversion part numbers for those parts which were to be covered by FPSs. The conversion number was to be assigned to those parts which had completed processing to the FPSs. However, the associated processing specifications were not released until September 1965.

There were a number of problems associated with this activity including:

a. lack of test equipment for new tests required by the FPSs

b. lack of computer programs to perform the variables data comparisons required by the FPSs

c. rejection of entire lots of parts under the lot rejection criteria of the FPSs.

Additional problems arose because of pressing schedule requirements. In attempts to process and release parts to the production floor early enough to meet AGC delivery schedules, Raytheon found it necessary to permit, and in some cases direct, vendors to deliver material in small lots. This action added to Raytheon's planned workload in the Screen and Burnin facility, the Reliability Analysis Laboratory and in Component Engineering.

In order to implement the FPSs Raytheon took the following actions:

a. replanned test sequences and test levels were required

b. installed new test equipment as required by FPSs

c. recycled much of the material on hand, at the time of the FPS release, through parts of the test sequences in order to achieve closer conformance to FPS requirements

d. developed computer programs for variables data requirements

e. increased the number of personnel performing parts analysis

f. negotiated FPSs with vendors for future procurements.

The major problems associated with the application of FPSs were resolved. The parts received under FPS provisions were superior in quality to what they would have been, had the FPSs not been imposed; and the FPSs have thus served a useful purpose in elevating the state of the art of semiconductor manufacturing.

As the program evolved, it was necessary to design the GSE equipment in parallel with a changing AGC design and yet supply a testing capability concurrent with AGC deliveries. The lead times required to alter existing designs or implement new design approaches were severely curtailed by late AGC design releases and changes. On several occasions, late GSE design changes were implemented on the test floor, minimizing the effect on schedule, although complicating the configuration and documentation requirements.

A serious problem imposed on the Block II GSE design was the requirement for rfi shielding. Raytheon initiated the incorporation of these changes into the drawings, but in accordance with later direction, the rfi shielding was deferred. This decision necessitated a change in the drawings, resulting in a delay in Change Control Board action for all GSE drawings. As a result of the above problem, special procedures were established to minimize the impact of these problems on the performance and schedule of the GSE.

Raytheon initiated recommendations to change certain GSE from Block I(100) configuration to Block II, thereby resulting in earlier availability of Block II GSE to support the needs of the overall program. This was particularly true of the Computer Simulators. The retrofit of certain GSE items directly from the Block I(100) to the Block II configuration provided the Engineering department with early "learner" models of the ultimate Block II GSE.

The Block II GSE field retrofit effort was necessitated by the program need for equipment in the field to support the computers being delivered. In view of the late identification of certain GSE design changes, Raytheon chose to implement a field retrofit program, rather than delay delivery with an inline breakin.

4.3 MANUFACTURING IMPROVEMENTS

Beginning with the production and delivery of Block I(100) AGCs, action was required to improve the flow of the product. Considerable improvements and achievements were made in the areas of test, assembly, processes, and tooling.

4.3.1 TEST AND ASSEMBLY

a. The subsystem test area was developed into specialized test bays with maximum cabling protection via elevated flooring. Diagnostic capabilities were extended with the implementation of the Apollo Data Accumulation Memory System (ADAMS). Fault isolation techniques were advanced and additional vibration facilities were installed.

b. Improvements made in assembly areas include construction of a controlled environmental encapsulation area and the installation of a substores on the assembly floor.

c. Test and inspection quality assurance procedures were generated and continually maintained by Configuration and Quality Control Engineering in accordance with NPC 200-2.

d. A training program was implemented in the areas of assembly, inspection, welding, soldering and wirewrap to assure the high reliability requirements of the program.

4.3.2 TOOLING AND PROCESSES

a. An automatic foam mixing and dispensing machine with some major modifications was perfected. Significant advantages were improved environmental storage of materials, a more homogeneous mix and reliable control of a more accurate mix ratio.

b. Semi-automatic matrix welders were developed to weld crosswires through pattern holes of matrix insulators. Operators are required for loading, initiating, and unloading only. The welding and indexing is completely automatic, eliminating human error and increasing output.

c. The AGC program is largely tape-oriented, with tapes used in test and checkout of AGC logic and CDU modules; weaving and testing of wirewrapped trays and wiring harnesses. In an effort to improve response time in the preparation of tapes, Raytheon installed an IBM 1401 computer and tape punch unit.

d. Induction soldering process - Special process controls were conceived to meet critical ND requirements. These process controls involved the use of infrared detection devices with automatic shutoff controls for sensing solder temperatures.

e. Detailed Instruction Routing Cards and Process Sheets were developed. These contained flow cards, traceability records and highly detailed assembly procedures, drawings and visual aids, and were under constant change control of Industrial Engineering.

f. Manufacturing continuously evaluated and implemented the latest approved handling and packaging materials and techniques. This resulted in continually improved protection for computer hardware.

g. A highly successful configuration and traceability plan was developed.

h. Computerized waiver application controls to assist inspection verification were initiated.

i. Screen and Burnin technology was advanced.

j. Innovations in materials storage and inventory control techniques were improved.

4.4 SUMMARY

The manufacturing of all Block I(0), Block I(100), and Block II hardware has been completed.

SECTION 5

RELIABILITY AND QUALITY ASSURANCE

5.1 INTRODUCTION

Throughout the life of the Apollo program a Reliability and Quality Assurance plan was maintained in accordance with NASA standards to assure the delivered equipment met the reliability levels of its intended design.

The increasing demands for high reliability resulted in a continuing effort to obtain components and materials to meet the stringent requirements. To achieve the reliability goals prescribed for the program within the schedule, it became necessary to provide constant assistance to manufacturers of materials and components. Also effective screening techniques and advanced failure detection devices were required.

Early in the program, in order to improve the quality of supplied material, a substantial number of quality assurance representatives were assigned to vendors' plants that supplied critical parts. In addition, parts' managers were assigned to other critical part suppliers. This action established close communications and motivated the vendors in supplying a higher quality product.

A good example was the considerable difficulty experienced with TO-47 micrologic in the Block I(100) program. Based on that experience at the beginning of the Block II program, Raytheon negotiated a separate production line for flatpacks. Also, a full-time program manager was assigned to the vendor. As a result of this early effort and close subsequent liaison between the vendor and Raytheon, flatpack micrologic, the most commonly used part in the computer, passed the stringent flight processing requirements and were available in quantity to production.

With the increasing volume of production, needs arose for additional support especially in the area of failure analysis. Additions to the staff of specialists who worked closely with design and manufacturing personnel and vendors led to an effective closed loop for corrective action. Because of the intensive studies conducted, extremely proficient analysis techniques evolved especially in the areas of semiconductors, integrated circuits and relays.

A factor that is worthy of mention is that personnel involved with Apollo were made aware of the importance of perfection.

In recognizing that one of the prime requirements for high quality and reliability is a well motivated work force, Raytheon began a Product Excellence Program (PEP), Raytheon's version of Zero Defects, in early 1965, both at Sudbury and Waltham. Along motivational lines many persons including the manager of Reliability Education from AC Electronics presented a series of Apollo oriented lectures to Raytheon personnel. The motivational and orientation efforts were enthusiastically received by Raytheon employes.

The reliability effort during the program was intensive, but a complete documentation of the activities and achievements are too lengthy for discussion in this report. Specific events which are considered to be significant are discussed in the following paragraphs.

5.2 FLATPACK CONTAMINATION

Failures due to shorts were experienced at the module and higher level assemblies which were attributed to the presence of conducting particles within the flatpack micrologic. The supplier of micrologic units implemented new process changes, cleaning operations, and numerous courses of corrective action. Specifications for computer vibration testing were amended, particularly in the Y axis, to optimize the orientation of the flatpacks to detect contamination. Later a test was devised to perform vibration testing on individual logic modules to provide an improved screen.

5.3 FLATPACK CORROSION

A time dependent failure mode due to corrosion of chip elements was detected following early leak test methods. The hermetic integrity of integrated circuits is essential for maximum reliability. The assurance of this integrity is dependent on the effectiveness of the leak tests.

The initial findings of a study program resulted in the development of a freon/glycerine test. This test showed that it was an effective screen; however, the yield rate was less than 50 percent, since it rejected a percentage of good devices as well as rejecting leakers. Due to the uneconomical yield rate, the development effort was continued in order to further the state of the art of leak testing to provide a reliable and nondestructive test which at the same time would provide an acceptable yield rate. Raytheon developed the FC-75 leak test and weight test specified in ND 1002358, Rev. B, and ND 1002359, Rev. A. For the weighing procedure, all devices are accurately weighed before and after pressurization. During pressurization the devices are immersed in FC-75, an inert fluorocarbon liquid. Leakers whose weight is increased by the weight of the liquid which enters the package are rejected after weighing.

This method of conditioning of flatpacks affords the following advantages:

a. Corrosive liquids are eliminated.

b. Very few good devices are rejected; therefore, a higher yield in production is realized.

c. The criteria for failure is a change in specimen weight and a decision by the test observer is not necessary.

d. Specimen weights are recorded and can be easily rechecked.

e. Backfilling fluid can become trapped within a specimen and detection can still be accomplished.

f. It contains a weighing failsafe by requiring unit rejection on both increasing or decreasing weight indications.

g. Allows storage of specimens under FC-75 for as long as four hours prior to the final weighing.

The test is further audited whereby calibrated leakers and nonleakers are inserted in each lot. This provides constant monitoring of the effectiveness of the new test and capabilities of the operators.

The revised leak test procedure, described herein, represents an advance in the state of the art and appears to be the most effective production technique in use to detect gross leaks in small volume integrated circuit packages.

5.4 IMPLEMENTATION OF NEW DIODE 1006399

The diode, P/N 1006751, which was used in the Block II AGC subsystem, experienced channeling and surface instabilities during in-process flight qualification testing. The 1006751 diode, which uitlized "mesa" construction was replaced with a new diode, P/N 1006399, which uses planar construction.

5.5 RELAY CONTAMINATION

The early Block I DSKYs were continually plagued with an inherent relay contamination problem. This indicated a definite need for tightened acceptance criteria and additional environmental requirements. With the development of the Block II DSKY, new relay vendors were selected, who also had difficulty with contamination (see Figure 5-1). The Block II DSKY qualification test resulted in the implementation of flight processing specifications. Raytheon residents and the vendors also introduced extensive cleaning, handling, processing, and tooling changes to lessen contaminants during the manufacturing process. This action resulted in low yields. Along with the flight processing specifications and suppliers improvements, additional efforts to separate acceptable relays produced vibration screens at the relay, indicator driver module, and DSKY levels. These screens were designed to eliminate

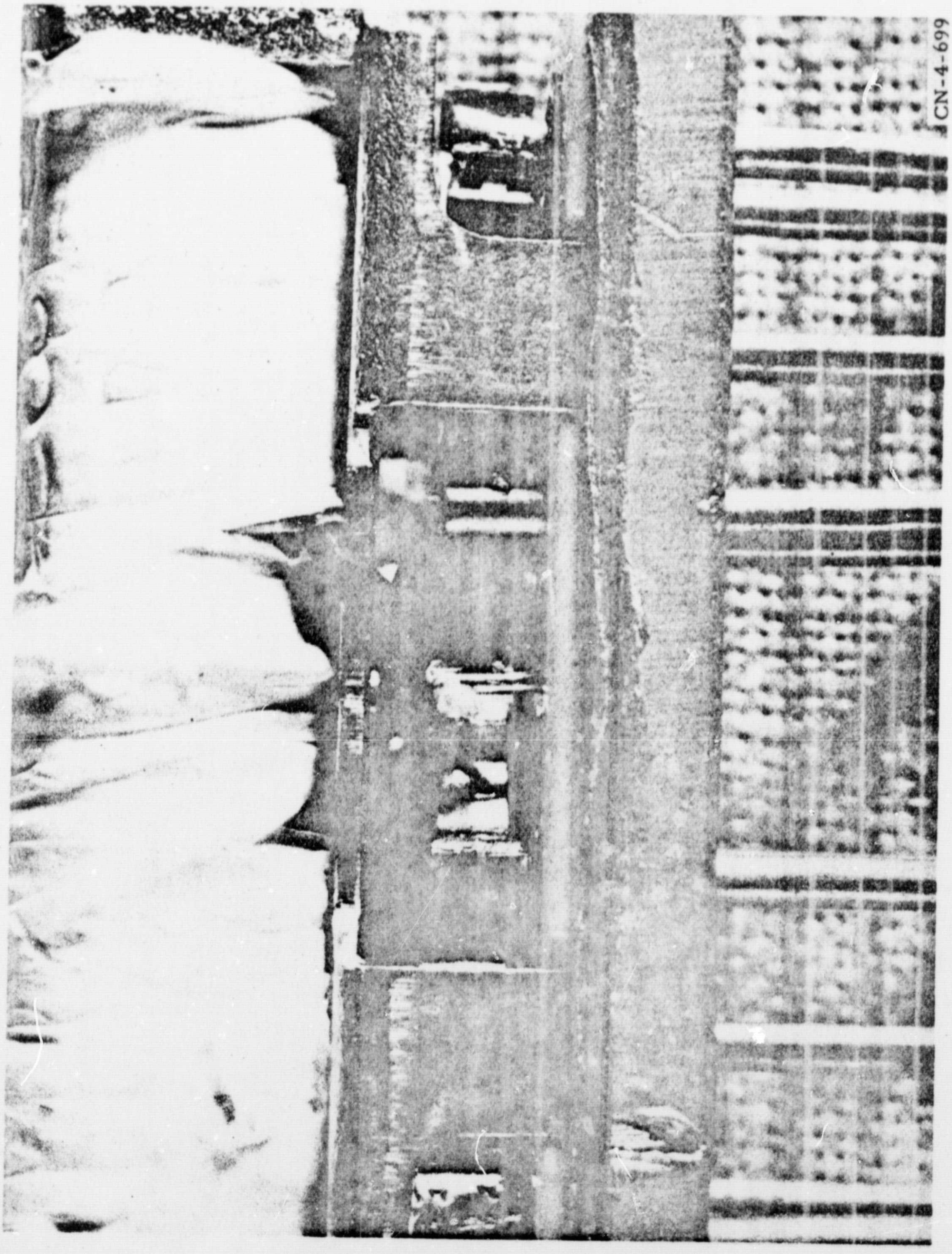

Figure 5-1 Apollo Relay Contamination

contaminated relays through the detection of contact shorts and opens during relay operation. Resultant data analysis indicated these vibration tests provided an overall effective screen.

5.6 DSKY ELECTROLUMINESCENT DISPLAY SAFETY GLASS

Electroluminescent glass (EL) failures were experienced during spacecraft altitude testing at the Manned Spacecraft Center and at Kennedy Space Center. A very intensive study of this problem was conducted which indicated that the integrity of some display panels were marginal. The investigations resulted in a modification which included a bonded glass panel to provide additional protection for the EL displays. Also, improved environmental screening techniques were implemented.

5.7 SUMMARY

The imposed controls placed upon suppliers of materials, the rigorous testing, screening, and analysis performed at vendors plants and at Raytheon ultimately made it possible to obtain components and materials to meet the requirements for Apollo. The constant surveillance of critical materials, testing and manufacturing processes, the development of effective failure analysis techniques, and the closed loop corrective action system were all responsible for attaining the objective of high reliability goals.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The fabrication of all Airborne and Ground Support Equipment has been completed. The original design goals were met and the necessary modifications and refinements to meet the increasing requirements throughout the program were accomplished. The manufacturing of the complex and sophisticated Apollo equipment in production quantities was the result of scientific advancements in the handling and testing of parts, the progressive development of fabrication and assembly methods, and controlled facilities.

The technological advancements in the art of producing materials and components as a result of the program have been a benefit to space and military programs as well as commercial applications The integrity of the total computer subsystem has been proven by the successful performance during the Block I(100) and Block II missions.

The Apollo Guidance Computer has proven its capabilities and future deep space flights will certainly require a similar design.

In the development of future designs requiring additional sophistication, consideration should be focused upon the modernization of displays, the use of nonmechanical devices, the latest memory design, for example, the braid and plated wire types, and the utilization of higher levels of integration in logic circuitry.