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MICROBIAL LOAD MONITOR

Third Interim Report

1 MARCH 1976 **MDC E1461**

Prepared by: J.T. Holen
J.T. Holen
Engineer
Biomedical Engineering

Prepared by: Eugene R. Royer
E.R. Royer
Senior Engineer
Biomedical Engineering

Approved by: S.F. Gibson
S.F. Gibson
Microbiologist
Aerospace Medicine

Approved by: A.V. Montgomery
A.V. Montgomery M.D., Ph.D.
Acting Manager
Aerospace Medicine

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Houston, Texas 77048,
in Response to Contract NAS 9-11877

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY • EAST

Saint Louis, Missouri 63166 (314) 232-0232

MCDONNELL DOUGLAS CORPORATION

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1.0 SUMMARY

This interim report provides the current status of work performed as additional tasks added to Contract NAS 9-11877. Overall activity is to provide a total engineering model flight design. Progress toward this goal is summarized below.

The design of the entire MLM instrument with support equipment is complete. This includes unitized cabinet, incubating reading head, microprocessor controlled electronics, and self-contained operator input/output facilities. The Sample Processing System design included in the unitized cabinet is also complete.

The support equipment includes a Card taper and a media loader capable of loading all 60 channels of the Card simultaneously. The design of this equipment is also complete.

Fabrication of the engineering model flight design has started. The unitized cabinet with one incubating reading head, microprocessor controlled electronics, and molds for the Card and Sample Receiving and Card Loader (SRCLD) portions of the Sample Processing System (SPS) have been fabricated. An alphanumeric display and keyboard have also been fabricated.

Functional testing and software development progresses nicely as the display and keyboard have been added. Limited clinical testing also continues.

2.0 INTRODUCTION

Previous reports catalogued the Microbial Load Monitor (MLM) progress under Contract NAS 9-11877 which continues to direct our work toward an automated microbiological system that detects, enumerates, and identifies medically significant bacteria and fungi. This report covers the work performed on the contract since the Second Interim Report of 25 January 1974.

The effort reported here is a refinement of the previous work. The object of this effort was to develop a new Card configuration which combines the functions of identification, enumeration and antibiotic sensitivity into one Card. A new instrument package was designed around this Card with the objective of integrating the Card filling, incubation, reading, computation and decision making process into one compact unit. Support equipment was also designed to prepare the expendable materials used in the MLM.

3.0 TECHNICAL DISCUSSION

3.1 MLM System Design - The MLM system flight design is a modification of the breadboard static MLM with its clamshell incubation heads. It is designed to be a unitized instrument with both sample loading and detection capability. The sample loading system will have a capacity to load one integrated Card in a null-g environment. The integrated Card performs both screening and antibiotic tests for simultaneous detection and susceptibility capability. The solid state optical detection system, operating at a 665 nm wavelength, is computer driven for maximum reliability, flexibility and ease of maintenance.

3.1.1 MLM Electronic Design - The electronic design encompasses six major areas: first, the MLM head and mainframe electronics; second, the computer or microprocessor; third, the peripheral device interfaces; fourth, the ground station simulator; fifth, the alphanumeric keyboard and display; and sixth, the power supplies, distribution, and regulation.

3.1.1.1 MLM Head and Mainframe Electronics - The MLM mainframe electronics were designed to respond to microprocessor commands given over the input/output bus. All control and data words, which are needed for operation of head and mainframe electronics, pass through this bus interface. Many registers handle these words during the microprocessor directed reading of the detection wells. These are tabulated in Table 1.

The growth electronic circuitry design consists of four parts: (1) control logic and registers, (2) clock, (3) digital to analog (D/A) conversion, and (4) multiplexing and analog to digital (A/D) conversion. Interfacing of these parts is to the microprocessor and to each head. The following describes the use of the growth electronic circuitry design in the system.

TABLE 1

GROWTH ADDRESS CODES

OUTPUT	CODE (HEX)	INPUT
Head or Temperature Channel	070	
Channel Number	071	
Digital to Analog Data Register	072	
Growth CSR*	073	Growth CSR*
	074	Analog to Digital Data Register
Clock CSR*	075	Clock CSR*
	076	Clock Data Register
	077	
*CSR - Control Status Register		

1a. The microprocessor commands a LED current value.

1b. The control logic and D/A send a d.c. analog signal to the head

2a. The microprocessor commands a particular head and channel.

2b. Multiplexors are set up to enable the head and channel.

3a. Microprocessor commands synchronous conversion of detected light value.

3b. Control logic starts modulation of LED current drive signal and enables A/D conversions of detected signal during both light and dark modulation times.

4. Microprocessor reads A/D converted value and averages eight light values and eight dark values. It then computes the difference between light and dark as the useable value for that channel.

5. Microprocessor turns off modulation and repeats steps 1 through 5 for all channels in the head.

The start of each Card reading time is under microprocessor control as time intervals computed from readings of the clock. At initial power-up the microprocessor can initialize the clock to operator input values.

3.1.1.2 Microprocessor - The microprocessor selected to control the MLM flight design is an IMP-16C National Semiconductor Corporation 16 bit parallel processor. The IMP-16C is shown as the topmost printed circuit board in Figure 1. This printed circuit board (8-1/2 x 11 inches) has sockets for semiconductor read-only memory (ROM). The 256 words of semiconductor read/write memory (RAM) are unused since they require the added complexity of a negative 9 volt regulator. Additional RAM memory is held on additional boards similar to the 4K word memory board shown on the left in Figure 1 and memory timing and control board shown on the right.

The microprocessor controls and calibrates the MLM head and mainframe electronics, performs arithmetic processing on the detected signal and comparison of threshold value and data for growth/no growth decisions. Calibration of the emitter detector pairs is accomplished accurately and rapidly by controlled use of the D/A and A/D converters.

3.1.1.3 Device Interfaces - Interfaces for three devices are required in this unit. They are serial interface for a printer (currently a teletype), a parallel interface for a magnetic tape recording device (currently an STR-200 magnetic tape cassette recorder) and a parallel interface for keyboard and alphanumeric display. The serial interface uses one flip-flop, a current loop driver, and addressing logic and logic gates capable of driving signal lines. Some addressing logic is common between serial and parallel devices.

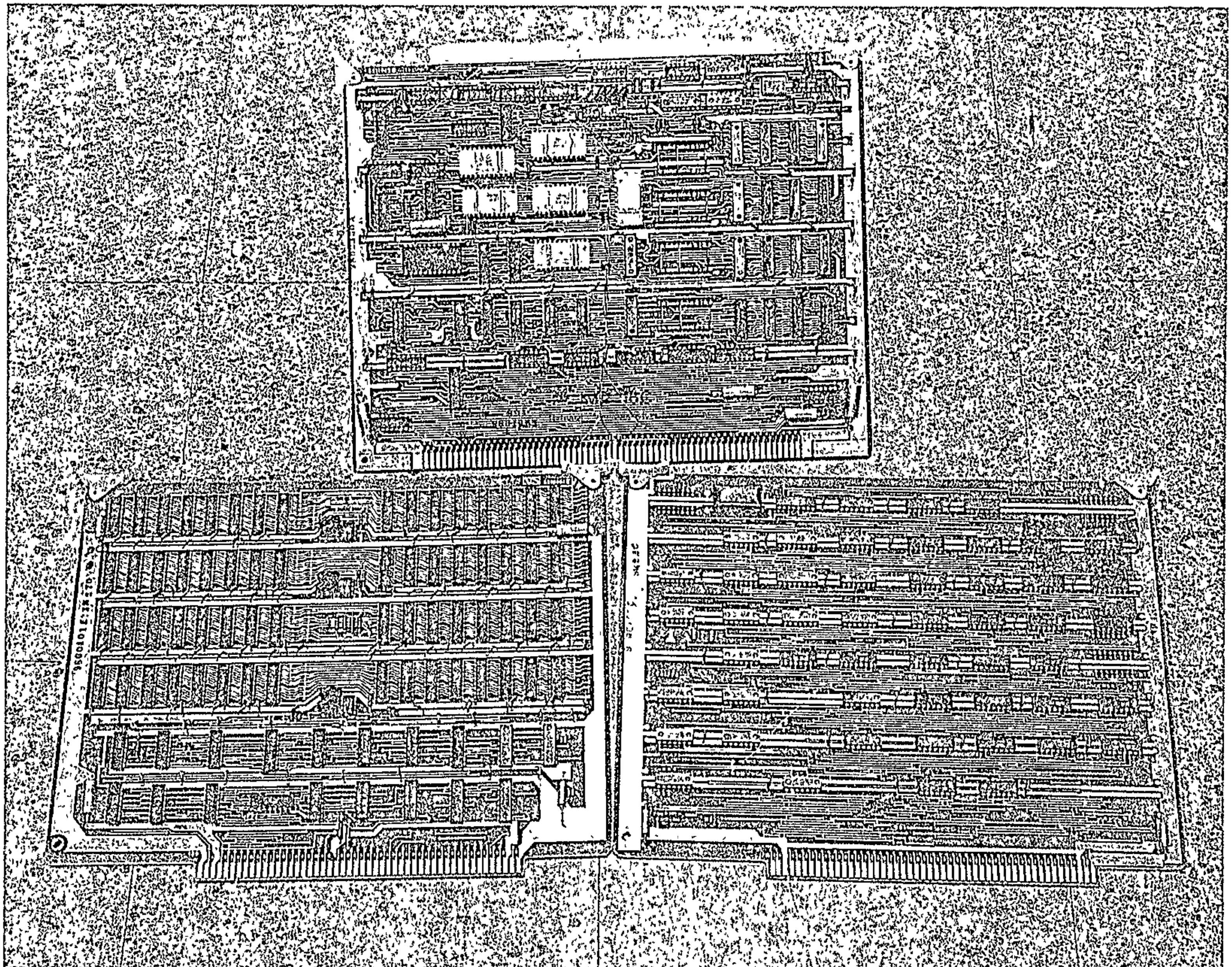


FIGURE 1 IMP-16C MICROPROCESSOR AND MEMORY BOARDS

The teletype interfac e uses a minimum of components while making maximum use of the microprocessors' ability to generate timing functions. All teletype control functions to receive or transmit characters are stored in read only memories. The magnetic tape transport interface consists mainly of addressing, buffering and handshake control signals.

The magnetic tape recording interface is similar to a high speed paper tape parallel interface. Data can be read or written on the STR-200 at a frequency of 125 bytes per second. From a stopped state a tape speed delay of 0.5 seconds is incurred before reading or writing occurs. Information is written or read in block form for maximum density, but block format is variable. When read under microprocessor control the first two bytes define the type of record and the next two bytes define the length of record. The last two bytes written in each block is a computed checksum of all data in the record.

3.1.1.4 Ground Station Simulator - Contact with the ground station can be either serial or parallel transmission at the MLM interfaces. For the purposes of this contract a 20 ma current loop teletype is used to simulate the ground station by remotely interrogating the MLM. With changes in the software the parallel interface could be used for ground station communication. The keyboard and alphanumeric display remains the method of operator control when onboard the spacecraft.

3.1.1.5 Keyboard and Alphanumeric Display - The design of the keyboard and alphanumeric display is complete. The selected keyboard is an ASR-33 type made by Cherry Electrical Products Corporation of Highland Park, Illinois and is a model B70-4753. Alphanumeric displays are from Texas Instruments (5 by 7 dot matrix type TIL305) with cathodes as rows and anodes as columns. Right angle socket connectors (ICN-9008) are from Robinson Nugent.

The heart of the alphanumeric scan circuitry is a bipolar 5 by 7 character generator with row scan. A Monolithic Memories type #MM6055 was selected because of its operation on a single 5 volt power supply and its low power dissipation of only 450 milliwatts. Information is accepted from the MM6055 and stored by a National Semiconductor DM8859 hex LED driver with data latch. Combining the function of data storage with current drivers lowers the complexity of the circuitry.

Displayed information is stored in ASCII format in a small RAM by the microprocessor. Timing circuitry then sequences through the RAM locations. The character generator converts the data based on the display row and presents the conversion to the appropriate LED driver/latch. After 16 memory locations the converted information is displayed. Conversion then begins anew for the next row. The entire display is refreshed continuously at a flicker-free rate.

3.1.1.6 Power Supply Requirements - The power requirements for the major portions of the MLM system are listed in Table 2. As shown, the power use is fairly well distributed between the various portions with the exception of the LED indicators and the incubation heaters. Heaters use filtered but not regulated power. The total current and future power requirements of low voltage DC power is a maximum of 250 Watts.

The negative 12 volt two ampere regulator was designed using the negative 15 volt supply as an input. A low power negative voltage regulator is used with a paralleled current boost transistor. Proportioning of the current between regulator and transistor is accomplished by input resistors, which in addition to

TABLE 2

D. C. POWER REQUIREMENTS 5 HEADS
(All Current Values in Amps)

AREA	+5V	+15V	-15V	-12V	+7.5V	UNREG
EMITTER BD.	1.875	0.030	0.030			
DETECTOR BD.	0.195	0.045	0.045			
GROWTH BD.	1.010	0.075	0.050			
IMP-16C	2.200			0.500		
4K MOS MEMORY	1.700			1.000	0.250	
MEMORY CONTROLLER	1.200					
INTERFACE	0.605			0.200		
HEATER (EMITTER & DET.)		0.110	0.110			10.000
ONE EMITTER	0.100					
INDICATORS	1.500					6.000
KEYBOARD	0.250					
TAPE RECORDER	0.700					

DEVELOPED FROM -15V (-12V column)
DEVELOPED FROM PREREGULATED +5V (+7.5V column)

controlling regulation, invokes the short circuit protection of the basic regu
The circuit as designed holds -11.85 volts from no load to a full load of two

Some secondary regulation is accomplished throughout the system by small
state voltage regulators such as +12 volts or -5 volts. These are voltages us
on the MLM growth board and the detector boards.

Three types of wiring or cabling are necessary in the MLM. These are pow
head signal distribution, and backplane wire wrap. Backplane wire wrap is acc
plished on the card cage and connects all five boards together. Power wiring
distribution from power supplies to the printed wiring board rack and to the h
is by heavy conductor wire. The head signal distribution is accomplished by a
ticonnector combination printed wiring and wire wrap board designed and fabric
to distribute 38 signals to and from the planned fire heads and the MLM growth

electronics board. This board also distributes voltages to each head. A negative five volt regulator is on this board and supplies an analog -5 volts to the heads. Two fabricated cables connect the MLM electronics wire-wrapped backplane to the head signal distribution printed wiring boards.

3.1.2 Incubator-Reader Head - The Incubator-Reader Head is designed to receive one 60 hole Card for incubation and reading. The Card is positioned between the emitter and detector mounting blocks, Figure 2. The emitter and detector arrays are mounted in these blocks as are the heating elements and temperature sensors. Each emitter or detector array consists of either twenty light emitting diodes or twenty phototransistors mounted in a glass covered plastic housing. The connector pins from the arrays extend through slots in the array mounting blocks and mate with connectors on the printed wiring boards above or below the mounting blocks. The arrays are screwed to the side of the mounting blocks facing the Card. Thus, replacement of a defective array may be performed in a few minutes. Alignment pins in the array mounting blocks assure accurate positioning of the arrays. The array mounting blocks are machined from aluminum to assure rapid heat flow and a uniform temperature throughout. Each array mounting block has five ceramic heating elements and is electrically isolated from the head housing. The blocks can be aligned with each other with pins which are inserted through both blocks during assembly and then removed.

There are four printed wiring boards in each Incubator Reader Head. The two small boards regulate the temperature of the array mounting blocks. The temperature adjust potentiometers are positioned such that the temperature of each head block can be adjusted without continually opening and closing the head.

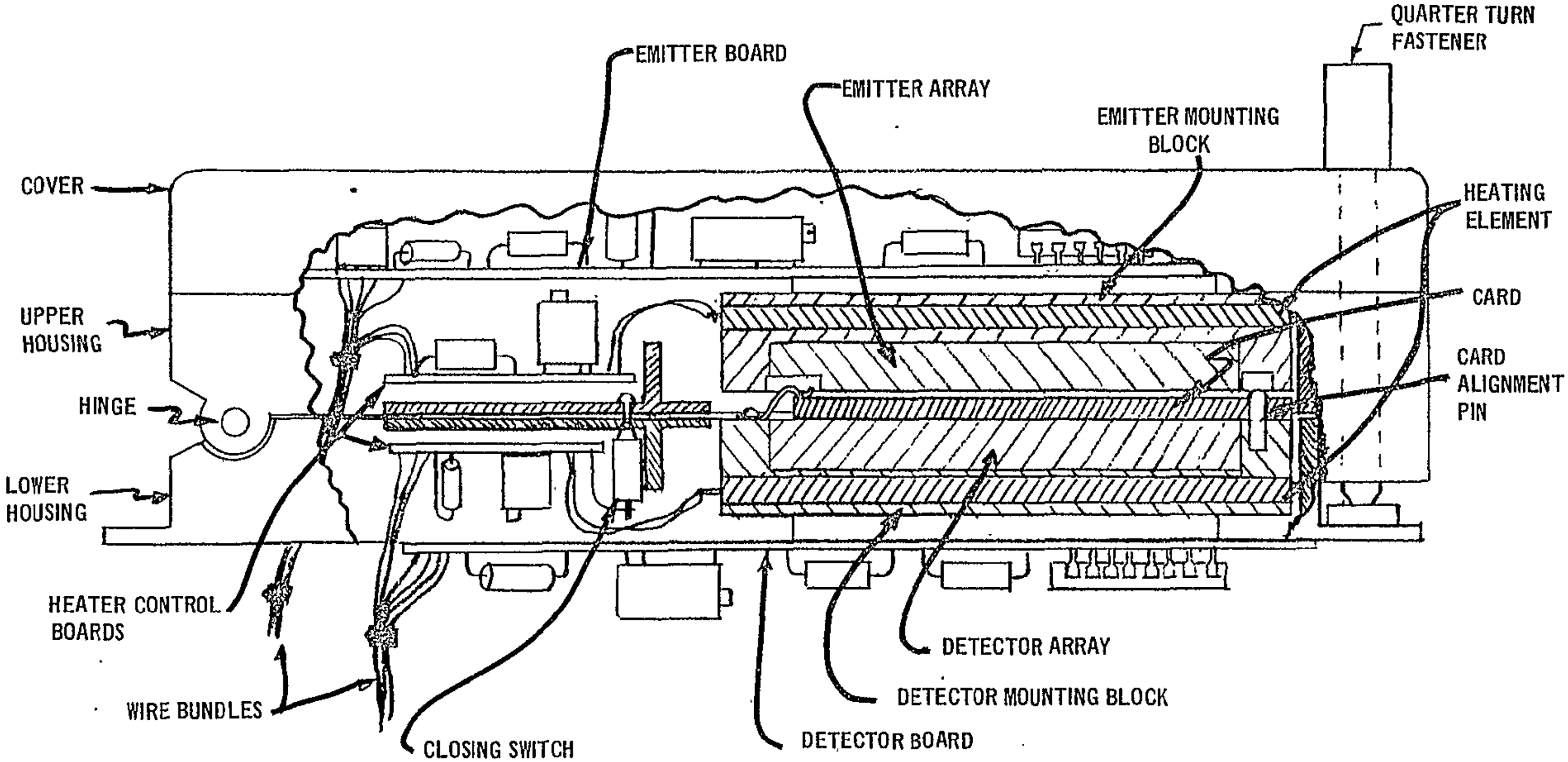


FIGURE 2

INCUBATOR – READER HEAD

Heat is provided for each side of the incubator head by five ceramic tube heaters. Each ceramic heater has an approximate resistance of 50 ohms and, therefore, a combined parallel resistance of approximately 10 ohms. The heater control design makes use of 9 to 11 volt unregulated voltage to power the heaters. Heater input power may, therefore, vary between 8.1 watts and 12.1 watts. Maximum power required during warmup is considered to be 24 watts of 12V power or 2 amps per head (one amp per emitter side and one amp per detector side).

A 723 voltage regulator is used in an unorthodox manner and simplifies the temperature control circuit. The 723 has an internal voltage reference which is used to provide a stable voltage to the temperature sensing bridge. A thermistor is located in one leg. The 723 also has an error amplifier which is used to amplify the voltage difference across the temperature sensing bridge. The amplifier output controls a medium current series pass transistor which in turn controls an external power transistor.

The temperature monitoring circuit uses a separate thermistor bridge with 0.1% resistors which are temperature stable. The bridge output is buffered by two high impedance op-amps and is then fed by multiplexers to the system's analog to digital converter. The microprocessor can, therefore, monitor each head temperature. With straight line voltage to temperature conversion the head temperature can be read to within $\pm$ 0.3°C over a 20 to 50 degree centigrade temperature range.

The two major printed wiring boards in the head contain all circuitry to accept control signals from the growth electronics board and return a buffered, modulated voltage signal representative of each channel. Double multiplexing of the emitters and detectors simplifies the circuitry in the head, Figure 3. This method yields nearly an 8 by 8 array within each 60 channel head. CMOS analog

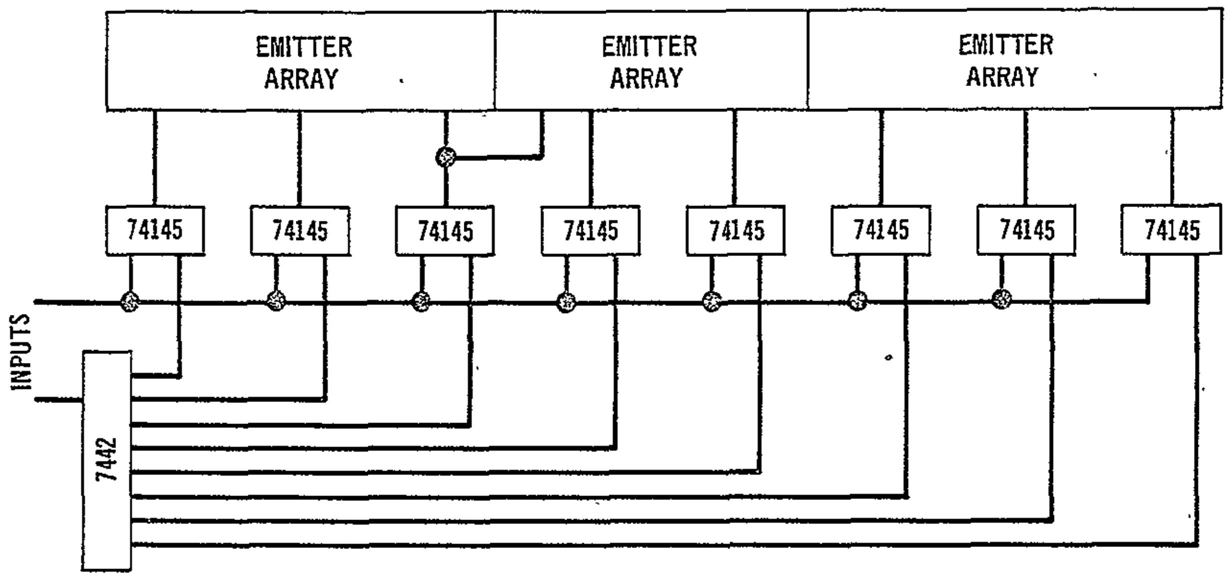


FIGURE 3A

INITIAL MULTIPLEXING

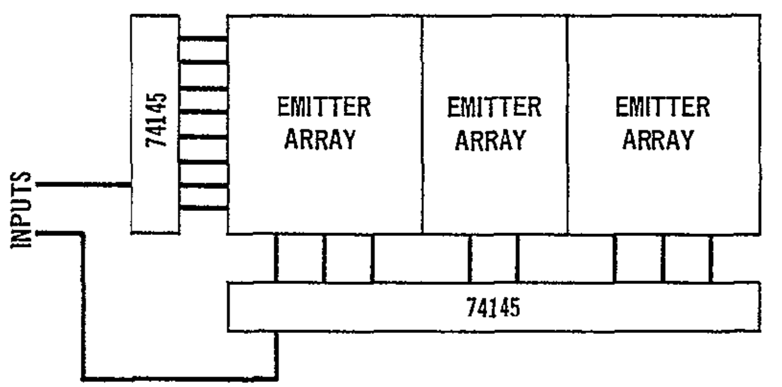


FIGURE 3B

SELECTED DOUBLE MULTIPLEXING

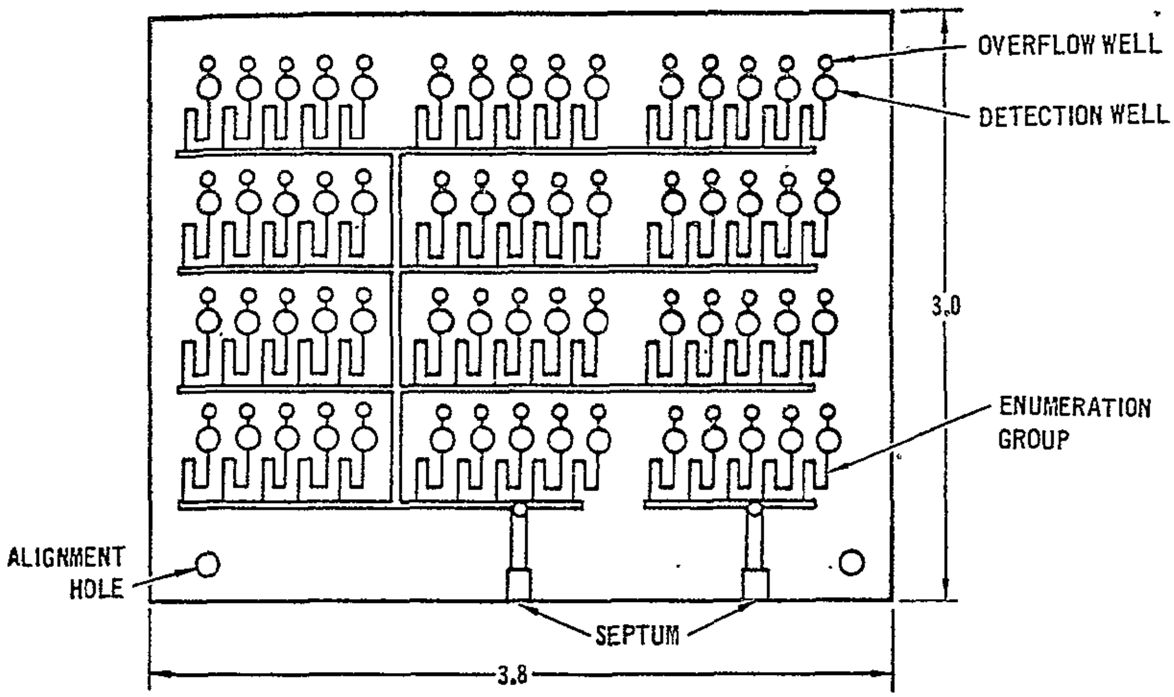
multiplexors are used with the low current detectors, and 74145 drivers and transistors are used with the high current emitters.

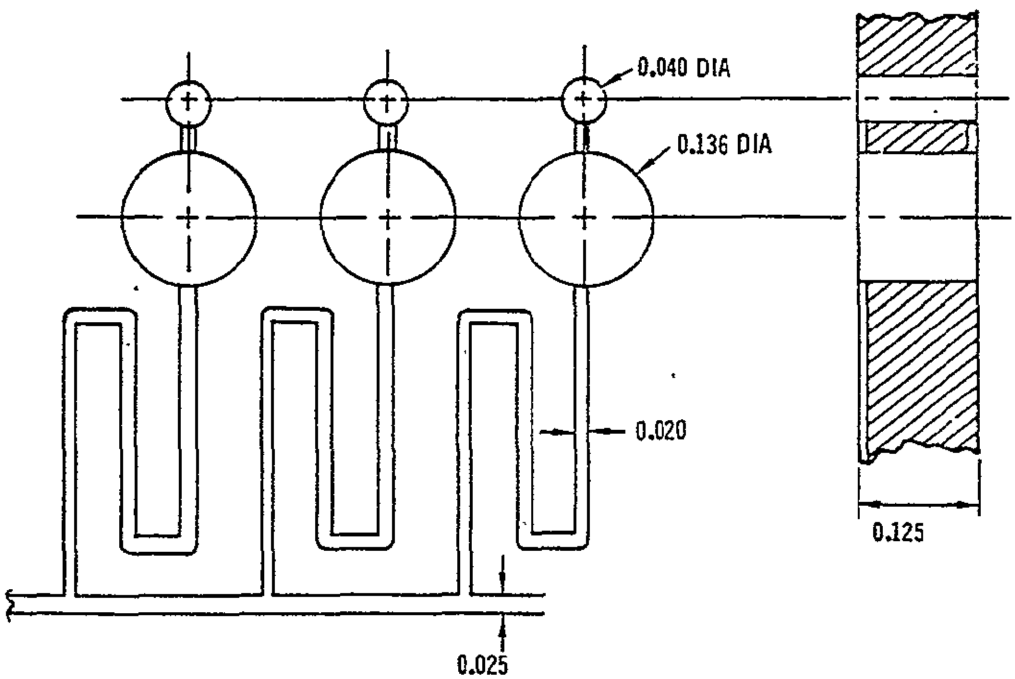
3.1.3 <u>Sample Processing System</u> - The Sample Processing System includes all the equipment that is utilized to take a portion of the specimen to be analyzed and prepare it for incubation and reading by the Incubator-Reader Unit. The three subdivisions are the Cards, Sample Receiving and Card Loading Device (SRCLD), and the Sample Loading System (SLS).

3.1.3.1 <u>Clinical and Environmental Cards</u> - The Cards are the multiple cuvettes in which the inoculum, diluent and media are combined, incubated, and examined optically for signs of growth. Two 60 detection well Cards have been designed for use in the MLM. The Cards are identical except for the grouping of the detection wells. Both Cards were designed for injection molding.

The Clinical Card has two separate groups of detection wells, Figure 4. The larger group of 55 detection wells is for organism identifications and antibiotic sensitivity tests. The small group of 5 wells receives a diluted inoculum for enumeration. Two SRCLDs are required to load the Clinical Card. The labyrinth like passageway between each detection well and the feeder channels serves to reduce the chance of contaminating diffusion occurring between adjacent detection wells. The overflow hole next to each detection well will receive the residual air remaining in the Card after evacuation. The Card is to be covered on both sides with FEP Teflon adhesive tape. The septum holes are sealed with Silicone rubber.

The Environmental Card is similar except that the detection wells are grouped into three equal sets, Figure 5. This Card will accept diluent from three SRCLDs and perform identification on each specimen. The Card may be used for less than

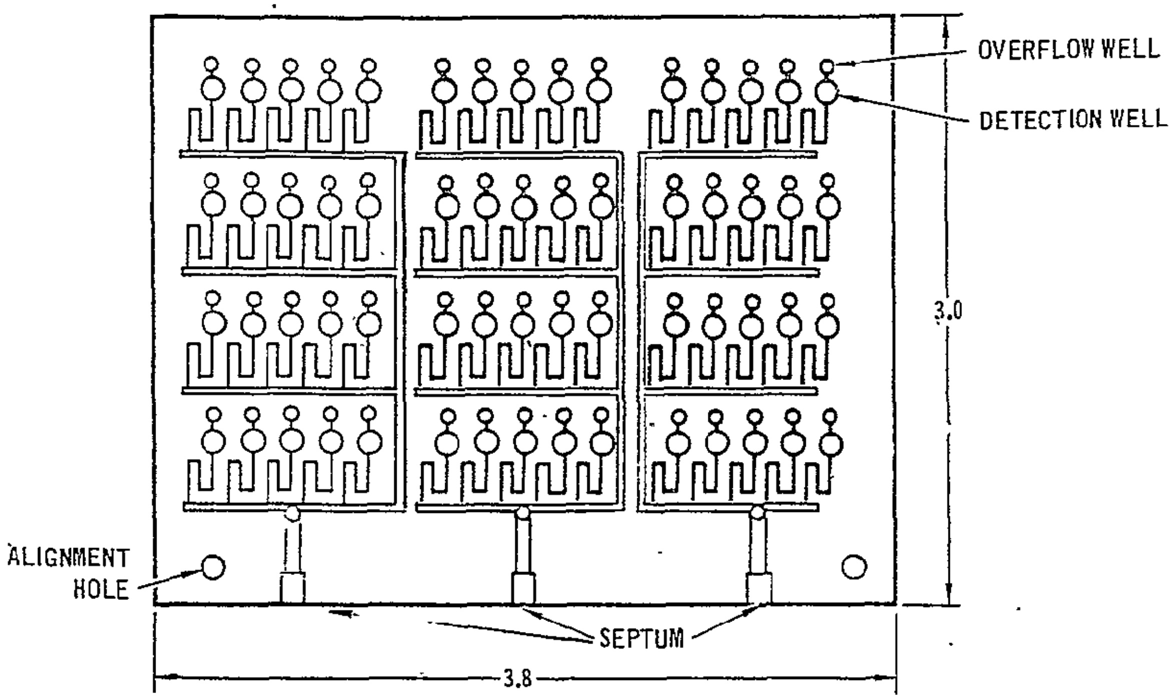


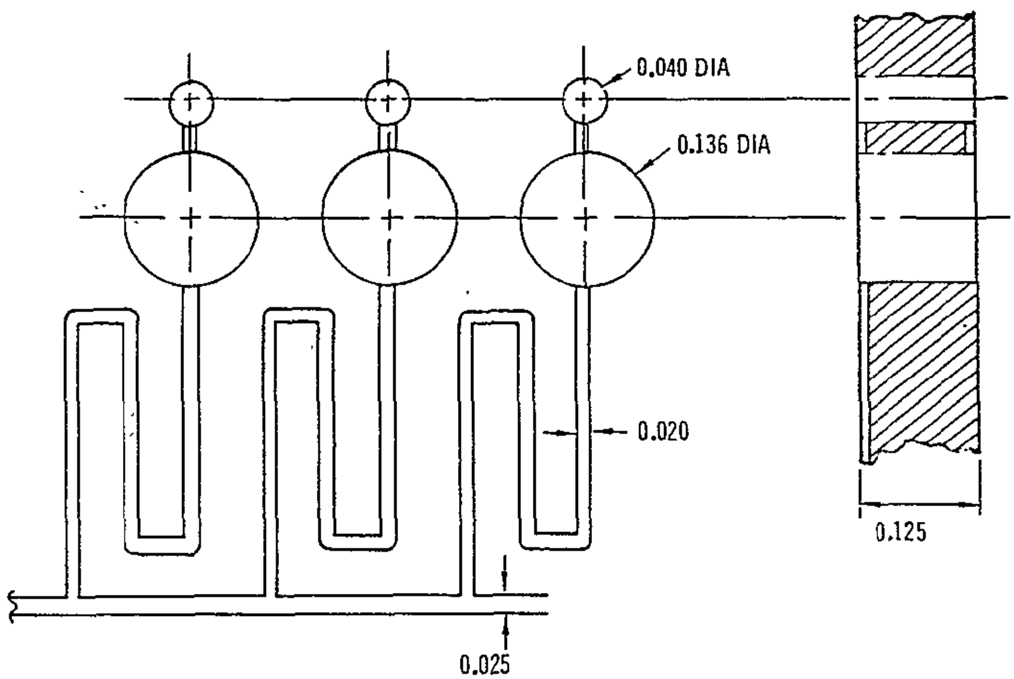


DETECTION WELL VOLUME: 0.032 ML
CARD VOLUME: 2.08 ML
LABYRINTH DISTANCE BETWEEN ADJACENT WELLS: 2.04 IN.

FIGURE 4

CLINICAL CARD





DETECTION WELL VOLUME: 0.032 ML
CARD VOLUME: 2.08 ML
LABYRINTH DISTANCE BETWEEN ADJACENT WELLS: 2.04 IN.

FIGURE 5

ENVIRONMENTAL CARD

three specimens if the cover tape is punctured in each unused segment. If the tape is not punctured in the unused areas, the expansion of the trapped air during evacuation will blow off the tape. Both cards will be prepared with freeze dried media.

3.1.3.2 Sample Receiving and Card Loading Device (SRCLD) - The purpose of the Sample Receiving and Card Loading Device is to interface between the specimen and the Card. For the MLM, that means the SRCLD must suspend the specimen in a diluent and insert it into a Card in a null-gravity environment. Part of this operation requires the separation of the liquid from the gas contents of the specimen so that the gas may be removed, a vacuum created, and gas free liquid inserted into the Card. A significant portion of the SRCLD design effort was devoted to the study of different techniques and devices for separating liquid from gas in a null-gravity environment.

One technique examined was the use of hydrophobic and hydrophilic surfaces. There has been considerable research into this technique to control fuel orientation in rocket fuel tanks during weightless flight. However, it was felt that the bubbling of the diluent in the SRCLD during evacuation would overcome the forces of surface tension and surface adhesion, allowing the diluent to become displaced and lost through the evacuation port.

The other technique studied for fluid orientation was the creation of an artificial gravity through centrifugation. Several different configurations were examined and two were fabricated and evaluated before the present design was developed. One design utilized a turntable upon which the SRCLDs and Card were mounted. However, the Card would be subjected to a varying centrifugal force vector from area to area which would cause poor filling. In another configuration the entire SRCLD was rotated about its axis to position the diluent along the periphery of the main chamber while the Card remained stationary. This configuration was successfully used for filling Cards during the early evaluation of the Card design. The shortcomings of this design are the need for a rotary seal between the Card and SRCLD and the need for a fairly complex bearing assembly to support the SRCLD during rotation.

The final design for the SRCLD is shown in Figure 6. This SRCLD design uses a magnetically driven impeller to establish a preferred fluid orientation in a null-gravity environment. The impeller includes a Teflon covered magnet for coupling to a motor driven magnet external to the Sample Loading System vacuum chamber.

Liquid specimens are injected through the liquid specimen septum, while solid specimens are inserted through the solid specimen port. The solid specimen port is an airlock device with a rubber plug normally sealing its lower end. The specimen on a cotton tip swab is inserted into the solid specimen port. Then the swab handle is broken off and removed. Finally, the plunger is inserted into the port, pressing the swab tip and port plug into the diluent chamber with the plunger sealing the port.

After the impeller is spinning, the diluent chamber is opened for deaeration and evacuation by an SLS actuator which presses on the evacuation needle holder so that the evacuation needle penetrates through the septum into the diluent chamber. The spring prevents premature penetration in addition to withdrawing the needle when the loading operation is complete. A cotton biofilter absorbs any fluid that may have passed through the needle. The Card to be loaded has previously been inserted into the Card slot in the SRCLD so that the filling needle

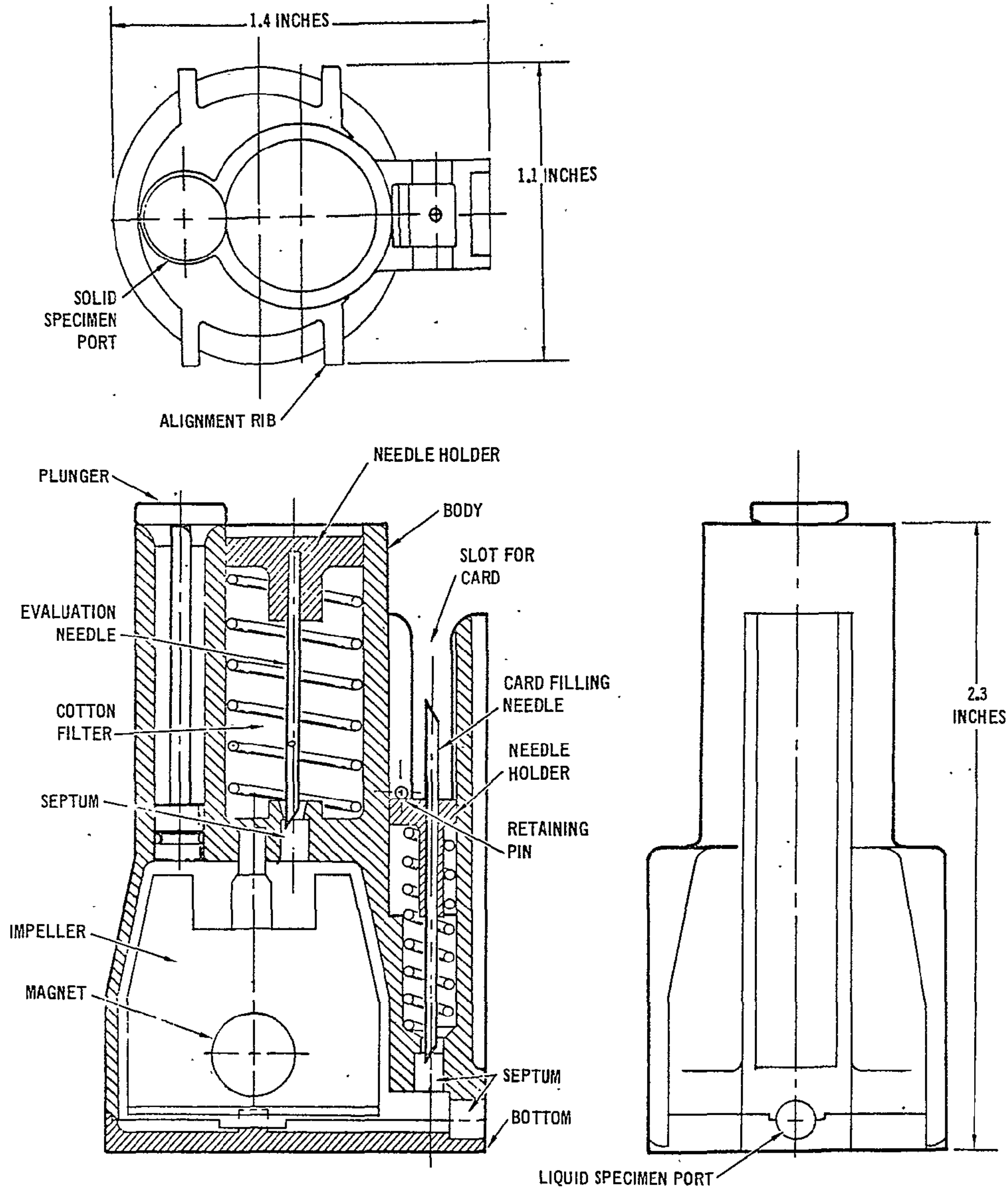


FIGURE 6

SAMPLE RECEIVING AND CARD LOADING DEVICE

Molded Version

penetrates a septum on the Card. The Card is evacuated through this needle by the SLS simultaneously with the diluent chamber evacuation. After sufficient evacuation another SLS actuator pushes the Card further into the slot, pressing the filling needle into the diluent chamber. Then air is introduced from the vacuum chamber of the SLS, through the evacuation needle into the diluent chamber, forcing the diluent with the suspended inoculum through the filling needle into the evacuated Card. Upon completion of the loading operation, the Card is withdrawn, allowing the spring to pull the needle out of the diluent chamber. The diluent chamber has now resealed itself to prevent contamination of the area.

The SRCLD was designed for fabrication by injection molding. Various features of the device were developed with consideration of the limitations of injection molding such as part removal from the mold and the permissible variation in cross section thickness.

3.1.3.3 Sample Loading System (SLS) - The Sample Loading System design is shown in Figure 7. The SLS is designed to load one 60 detection well card using from one to three SRCLDs. The Card and SRCLDs are placed in a swing-up receptacle. The cover of the vacuum chamber is transparent so that the operator may ascertain that all the SRCLDs are functioning. The impeller in each SRCLD is driven by an individual bar magnet located external to the SLS vacuum chamber. All three bar magnets are geared together and driven by a small motor. The vacuum actuators perform two functions. The lower actuator presses the SRCLD evacuation needle into the SRCLD fluid chamber for evacuation. The upper vacuum actuator presses the Card into the SRCLD so that the Card filling needle of each SRCLD enters its respective fluid chamber.

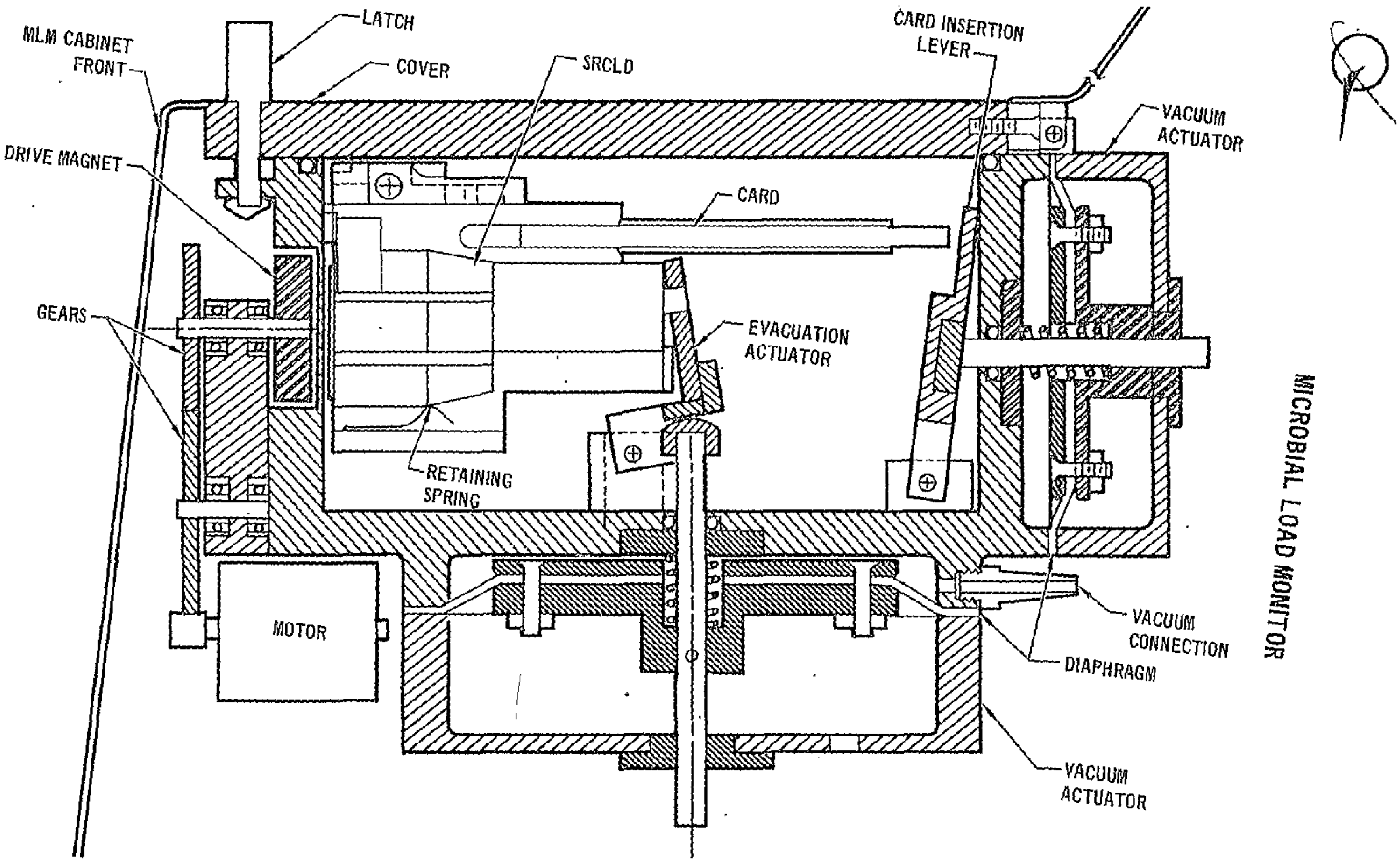


FIGURE 7

SAMPLE LOADING SYSTEM

MDC E1461
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The SLS evacuation system schematic is shown in Figure 8. The SLS is designed to require only vacuum and a small quantity of electrical power. The vacuum actuators operate on the pressure differential between the vacuum source and the cabin atmosphere which can be as low as 10 psig. The sequencing of the vacuum actuators has been planned to avoid compromising the chamber vacuum during the critical portion of the loading cycle. The chamber evacuation valve is a vacuum operated vacuum valve. There are four miniature solenoid valves to control the operation of the SLS. The first solenoid valve is the pilot valve for the chamber evacuation valve. The second solenoid valve permits the fast bleeding of the chamber back to atmospheric pressure. Without it, returning the chamber to atmospheric pressure would take several minutes. The other two solenoid valves control the vacuum actuators. Each solenoid valve requires only .65 watt of power.

The SLS will be mounted in the right front portion of the unitized MLM cabinet and its operation will be controlled by the microprocessor. The microprocessor will also monitor the vacuum level in the SLS chamber through a pressure transducer to insure proper Card loading. Operation of the SLS will be initiated through the keyboard on the MLM.

3.1.4 MLM Unitized Cabinet Design - A sketch of the unitized 300 channel MLM cabinet configuration is shown in Figure 9. Five clamshell type incubating, Card reading stations, similar to the breadboard static MLM, are arranged along the upper back of the unit. Each reading station accepts one 60 hole Card, which can be either clinical or environmental.

A keyboard which has both alphanumeric and special keys is located at the left front of the instrument. This keyboard in the flight prototype operation is

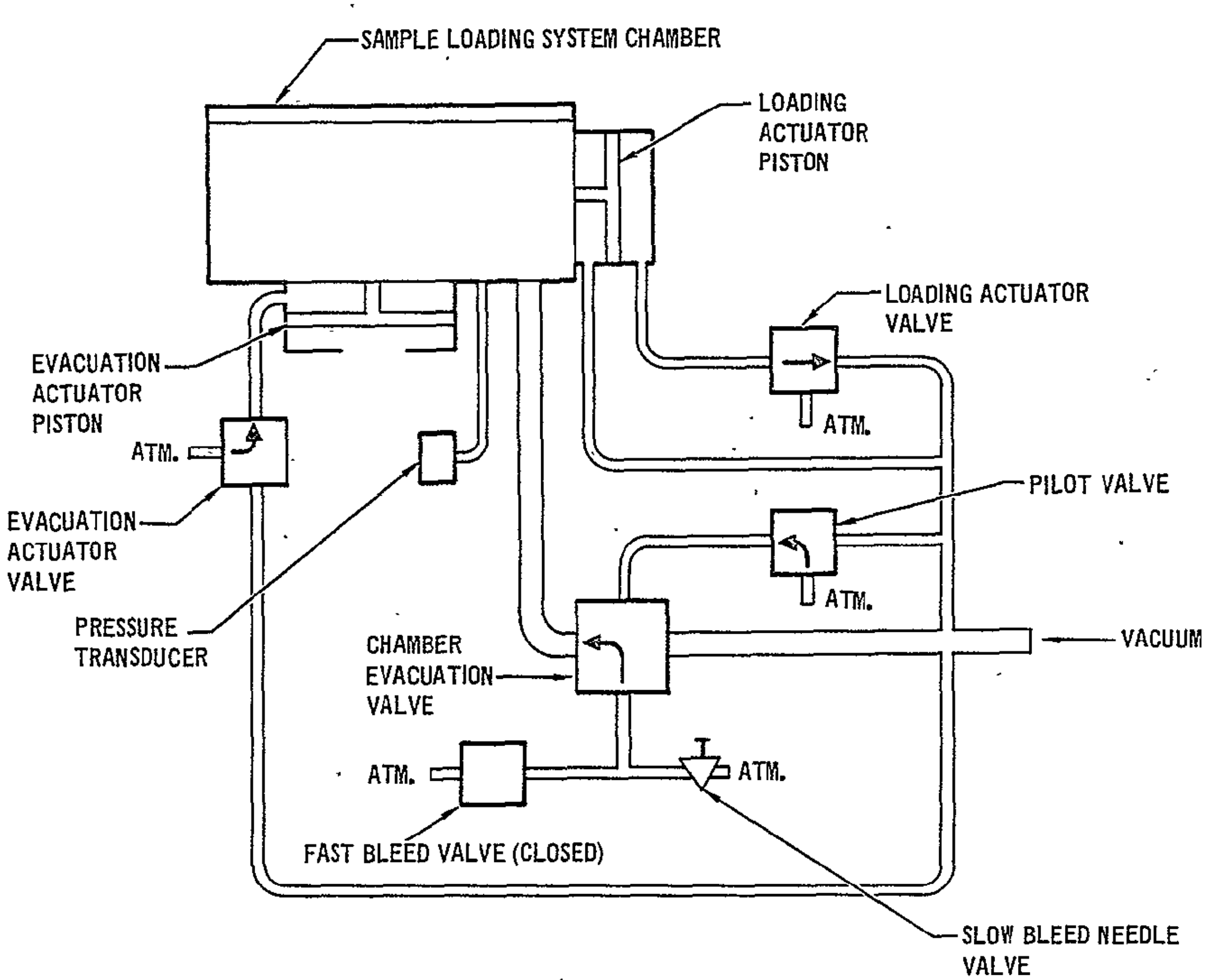

FIGURE 8

SLS EVACUATION AND ACTUATION SYSTEM
(Valves Shown in Deactivated State)

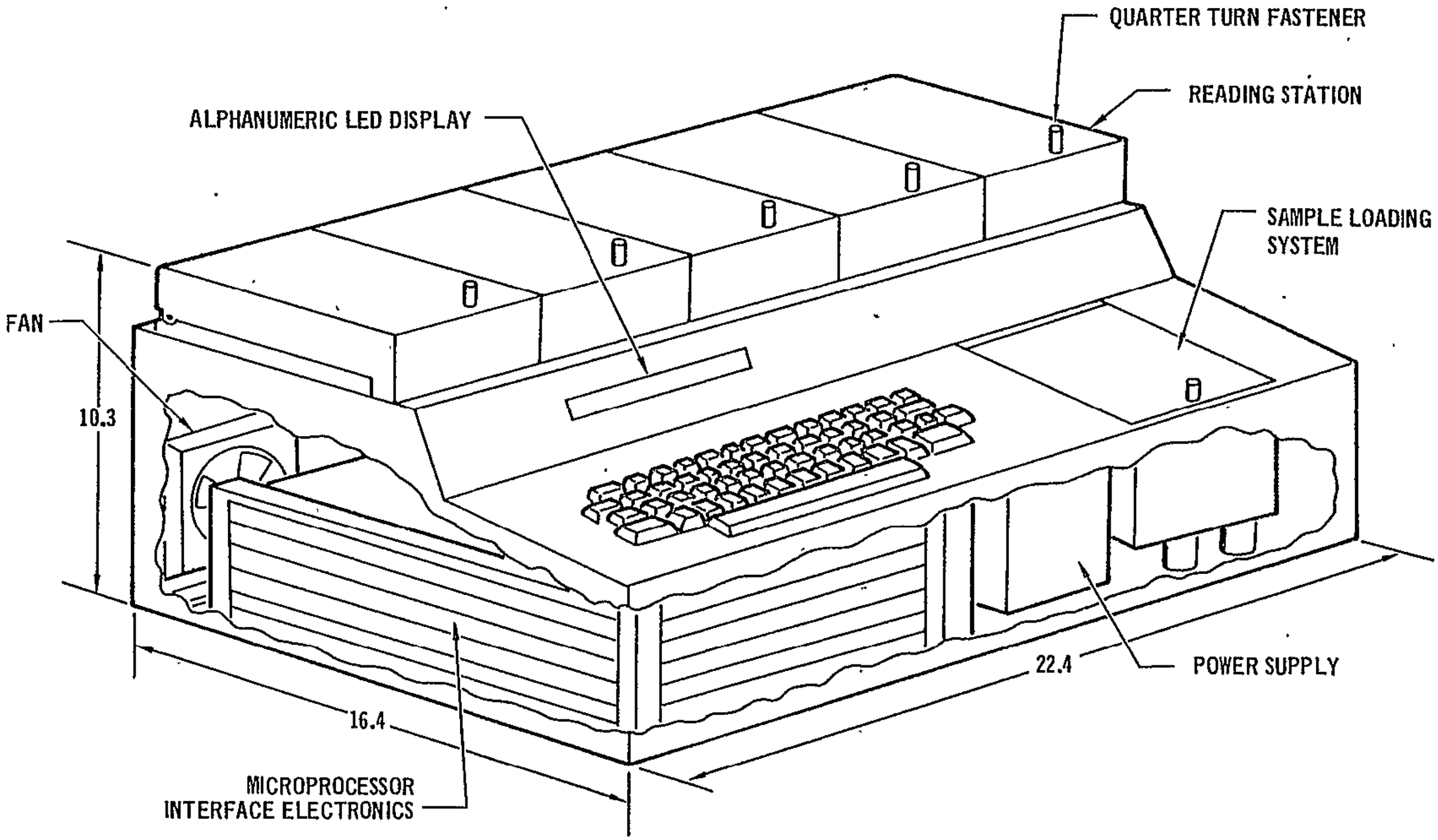

FIGURE 9

MLM UNITIZED CABINET

used for entering information concerning each Card as well as controlling overall MLM operations. A row of alphanumeric LED displays is located above the keyboard for checking each command or data before entry into the microprocessor. It is also used to display information from the Microprocessor when requested from the keyboard.

The sample loading system will be located to the right of the keyboard for easy access to the inside of the vacuum chamber. Operation of the SLS may be controlled either manually or automatically by the microprocessor.

The MLM mainframe electronics, IMP-16C microprocessor, memory, device interfaces and power supplies are all contained underneath and behind the front keyboard and SLS. The cabinet has been designed for quick access to all areas for ease of fabrication and service. The Incubating-Reading Heads are easily removed and replaced. A filtered intake fan has been included to provide cooling and to reduce dust collection in the cabinet. The electrical and vacuum connections are made at the right rear portion of the cabinet.

3.2 <u>Card Preparation Equipment</u> - The two major pieces of equipment needed to prepare the Cards in volume are the Media Loading Machine and Taping Unit. These two machines will improve the consistency of the Cards as well as save preparation time.

3.2.1 <u>Media Loading Machine</u> - A 60-channel machine has been designed for the simultaneous loading of the media into the 60 detection wells in the Card. It consists of 60 Hamilton Microliter syringes mounted about the periphery of a 16 inch diameter disc, Figure 10. All of the syringes are operated by a single gear motor and crank mechanism. However, the stroke of each syringe may be set separately simply by adjusting a screw adjacent to the syringe. Each syringe is

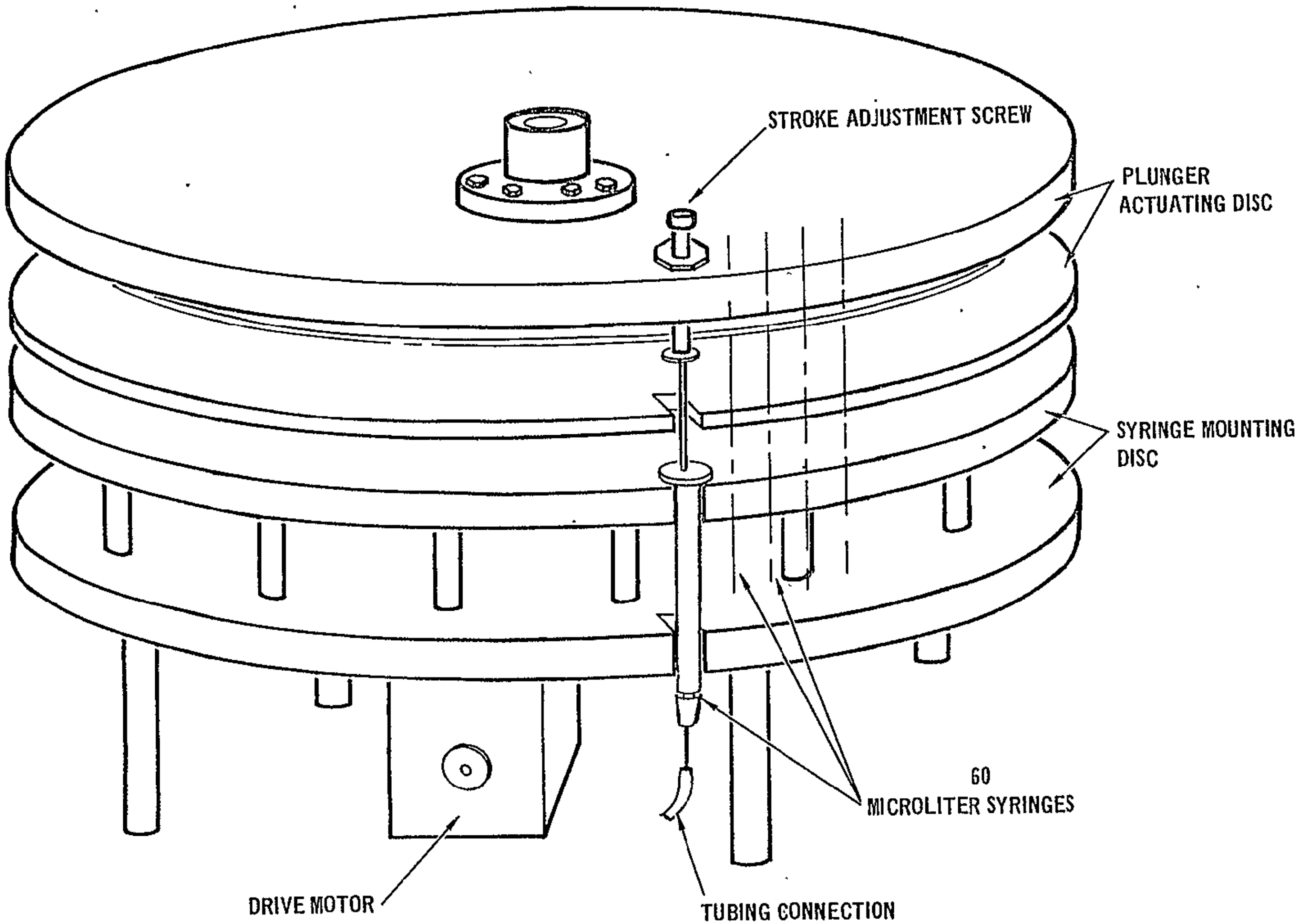

FIGURE 10

MLM MEDIA PUMP

connected by disposable polyethylene tubing to a hollow stainless steel needle in the dispenser, Figure 11. The dispenser is alternately dipped into the media cuvettes and then into the Card. Aspiration and ejection is controlled automatically by the position of the dispenser. With this machine, 300 60-channel Cards can be filled with media per hour. Approximately 40 Cards can be filled before the cuvettes will need to be refilled. Adjustment or cleaning is readily performed due to the arrangement of the syringes and the dispensing needles. In addition to quickly loading the media into the Cards, the Media Loading System eliminates the error-prone repetitive hand loading.

3.2.2 Taping Unit - The Taping Unit was designed to reduce taping operation time and to ensure consistency in tape tension and application pressure. The Cards are fed into the machine from a hopper while the operator pushes a lever to force the Cards through the machine, Figure 12. At the first station the Teflon tape is laid lightly onto the Card. At the second station the tape is rolled under high pressure. At the third station the operator cuts the tape with a knife through guides. With this machine, one person will be able to tape one side of 300 Cards per hour. The machine will also save a considerable amount of tape compared to the manual hand taping device and improve the consistency of the tape bond to the Card.

3.3 System Fabrication - The Engineering Model Microbial Load Monitor fabrication consists of turning the individual component descriptive designs into concrete working items and then mating them into a working system. The results of this process is discussed below.

3.3.1 MLM System - A Unitized Cabinet concept was used since the Engineering Model MLM was conceived to be a self-contained system except for disposables and

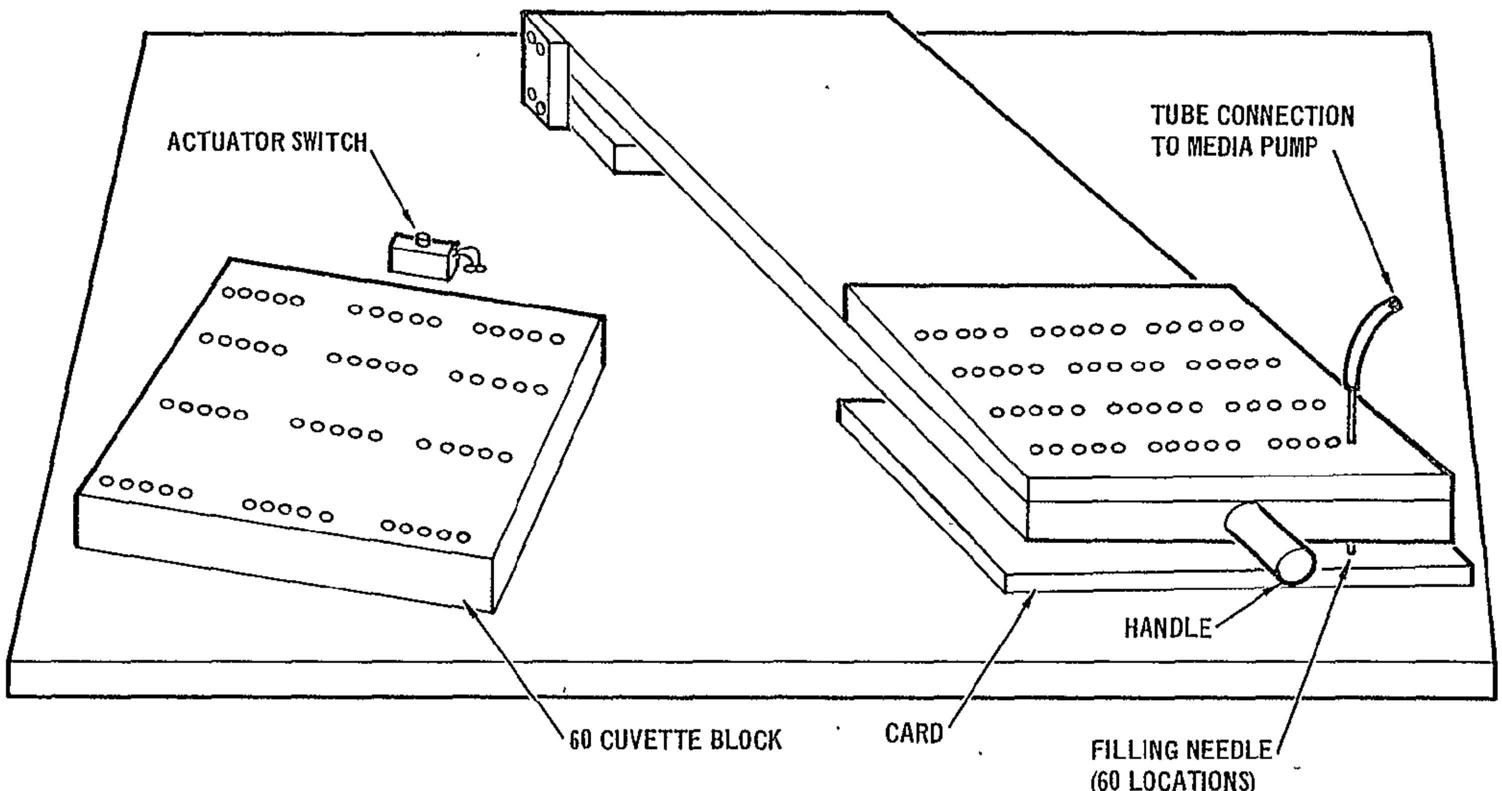

FIGURE 11

MLM MEDIA DISPENSER

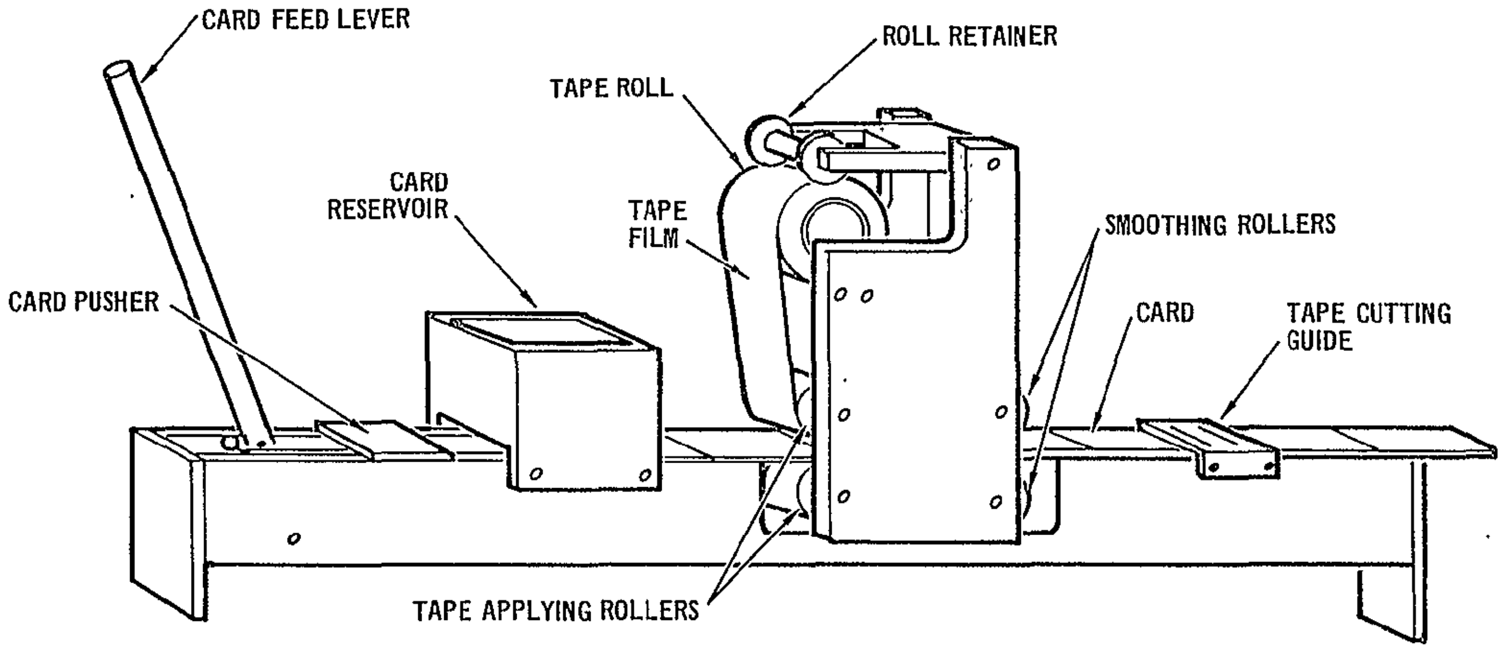

FIGURE 12

MLM CARD TAPING MACHINE

input power (including vacuum). Within this framework will reside: incubating heads, controlling and detecting electronics, power supplies, the Sample Loading System (SLS), and operator interfaces. Tying them all together are the signal and power distribution wiring.

3.3.1.1 Incubating Reading Head - The design of the incubating reading head, as previously described, was fabricated and assembled as follows. Emitter and detector arrays are fabricated in groups of 20 (5 columns by 4 rows). Alignment of individual light emitting diodes (LEDs) and phototransistors is very critical so placement of them on the ceramic substrate is accomplished under a microscope, and the substrate is likewise aligned in the plastic housing. Three pairs of these units are assembled in one head. The completed head is shown in Figure 13.

A printed wiring (p.w.) board was designed and etched to hold the driving and demultiplexing circuitry for the LEDs. A similar board was made to hold the multiplexing and preamplification circuitry for the phototransistors. A redesign of the emitter p.w. board was patched in when it became apparent during testing that the anodes and cathodes of the LEDs were reversed. After redesign the system worked correctly. Subsequent heads will include a redesigned p.w. emitter board.

The novel incubation heater circuit was fabricated, assembled into the head and tested. During testing of the MLM head it was determined that a loss of the negative five volt power could result in excessive and uncontrolled head temperature. Shutdown can be accomplished by the central processor (when running) but not during manual testing. A modification to the heater drive circuit added two resistors and one transistor which have the effect of shunting the power transistor's base current whenever negative five volts is absent.

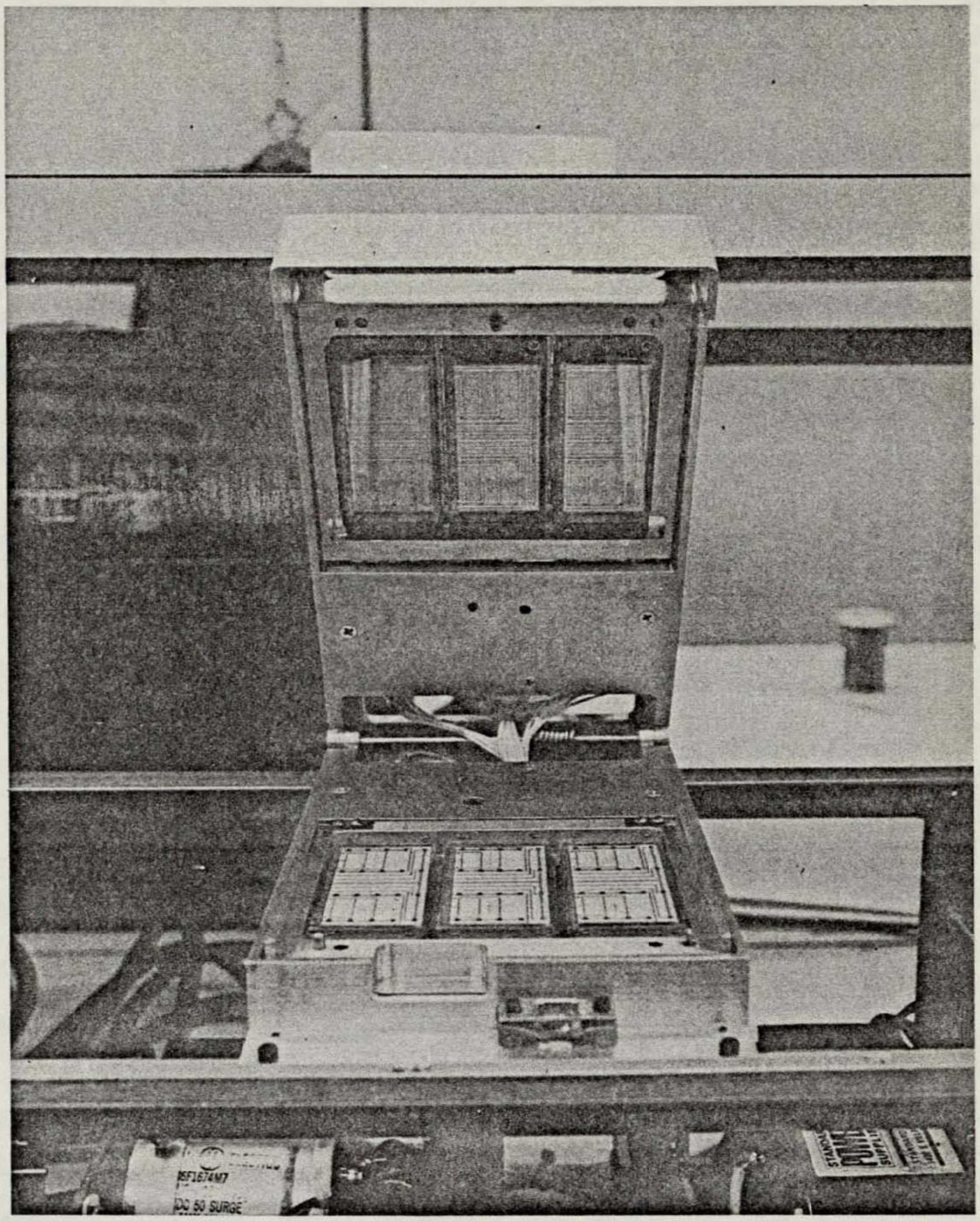

FIGURE 13

ASSEMBLED MLM INCUBATING READING HEAD

3.3.1.2 MLM Electronics - The majority of the MLM electronics is housed in a National Semiconductor Corp. IMP-OOH/800 six slot card cage with six 144 pin wire wrap connectors. Other circuitry is distributed in each head, as previously described, or near the alphanumeric display and keyboard. The three boards associated with the IMP-16C/300 microprocessor and memory were shown previously in Figure 1. The other two card cage boards are described below.

The Growth Electronics board shown in Figure 14 is an 8-1/2 inch by 11 inch double sided printed wiring board. The electronics can be subdivided into four major areas. The first is circuitry related to functions of analog to digital conversion. These are located on the right of Figure 14. The largest module is the A/D convertor. The second area is that circuitry related to the digital to analog conversion. These integrated circuits are located on the left hand side of the board. The third is the clock circuitry and is located in the upper left and upper center of Figure 14, except for the oscillator which is located in the extreme lower right corner. The fourth area is the device address decode and control logic which is located in the middle to low central area.

The Interface Electronics board is an 8-1/2 inch by 11 inch double side printed wiring board (IMP-OOH/891) which, with proper sockets, is interconnected by wire-wrapping. This allowed a flexible and reliable method of initially fabricating the interface circuitry and allowed for fabrication of the alphanumeric display and keyboard without redesign and refabrication of the whole interface board. The wire wrap pins do prevent the use of a sixth board in the Card cage.

3.3.1.3 Power Supplies - Two mainframe power supplies were purchased and mounted in the unitized cabinet. The main supply is a triple output SPS250T with

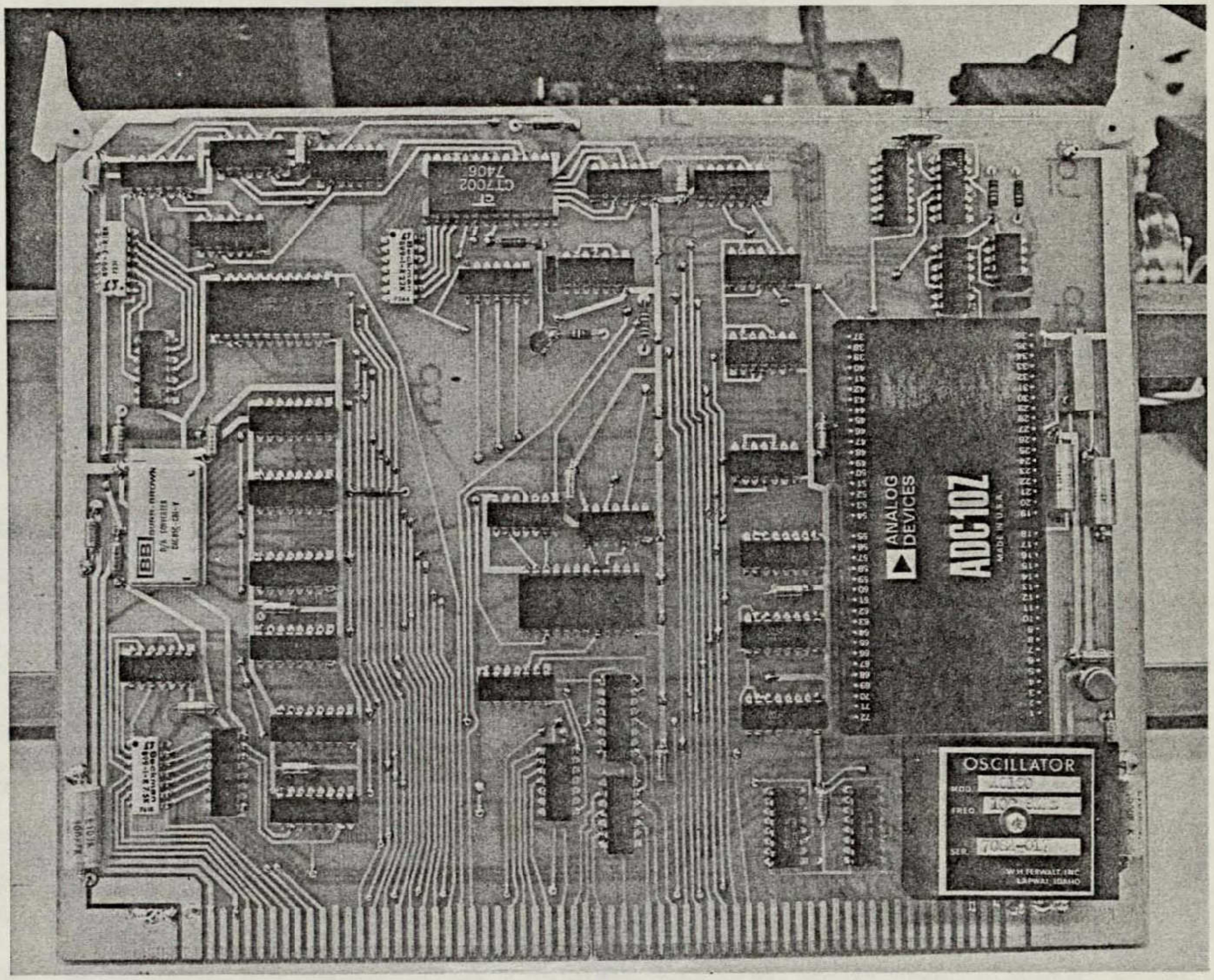

FIGURE 14
MLM GROWTH ELECTRONICS BOARD

12 amps at +5 volts and 3 amps at $\pm$ 15 volts. Another unregulated supply with 8 to 11 vdc at a full load of 20 amps to no load.

3.3.1.4 Operator Controls - During the majority of the fabrication phase, operator commands were input through the ASR-33 teletype and responses output through the same. Fabrication of the alphanumeric display and keyboard brings a transition phase where either can be used. Normal use is considered to be just keyboard and display. The only limits are lack of hard copy and length of message restricted by the 16 character display.

3.3.2 Sample Processing System Fabircation - The Sample Processing System fabrication during the preceding twenty month period consisted primarily of securing molded Cards and SRCLDs, and assembling them as needed for testing and evaluation.

3.3.2.1 Card Fabrication - Initially, several cards were machined from polycarbonate sheet stock to evaluate the Card design and to satisfy testing requirements. When the contract extension began, bids were solicited for fabricating an injection mold for both the Clinical and the Environmental Cards and for molding 700 Clinical Cards from styrene. Precise Metals and Plastics was the low bidder. We have received the molded Cards and have prepared them for testing as required. Figure 15 shows the Clinical Card and Figure 16 shows the Environmental Card. The taping is done with a manual taping device which can do one Card at a time.

3.3.2.2 Sample Receiving and Card Loading Device Fabrication - One SRCLD was machined from polycarbonate stock for design evaluation, Figure 17. Bids were requested to fabricate an injection mold for the plastic parts of the SRCLD and to mold 1400 units from styrene. Precise Metals and Plastics was

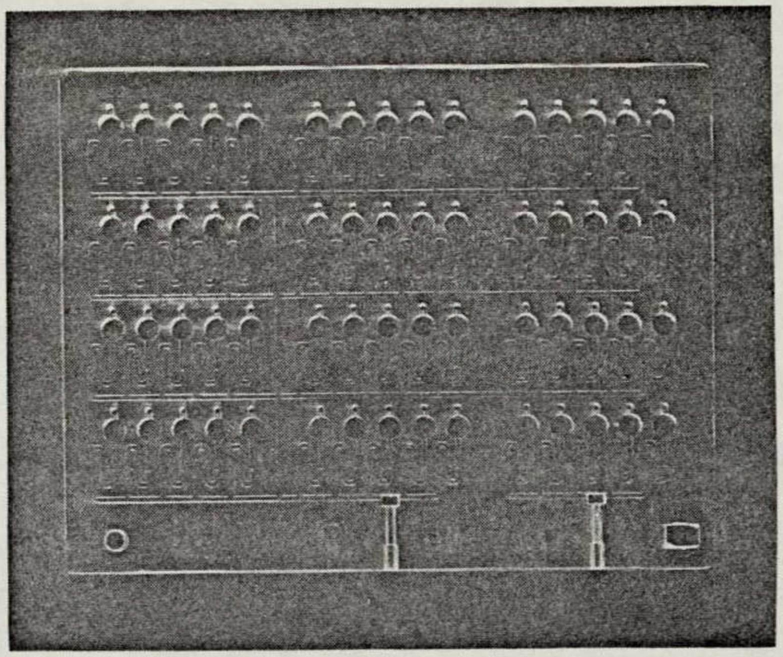

FIGURE 15

MOLDED CLINICAL CARD

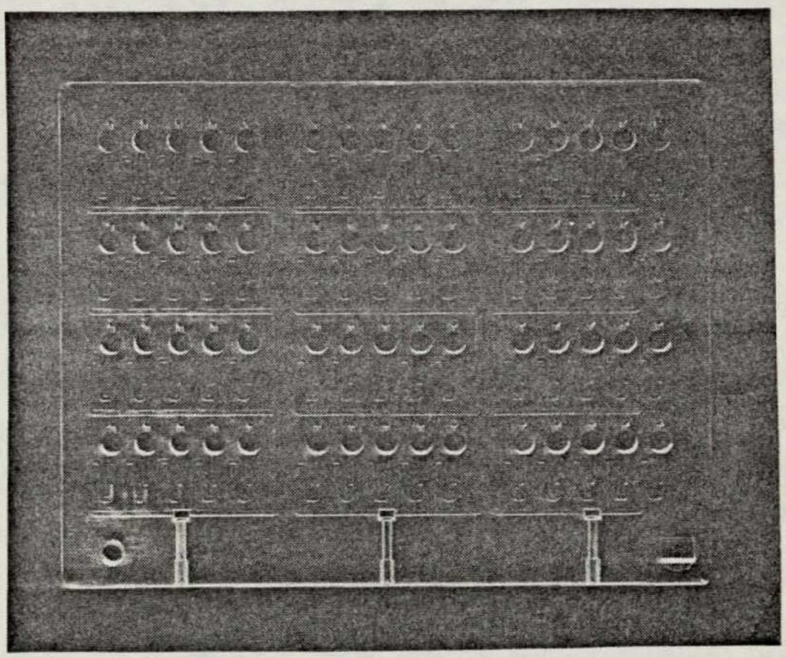

FIGURE 16

MOLDED ENVIRONMENTAL CARD

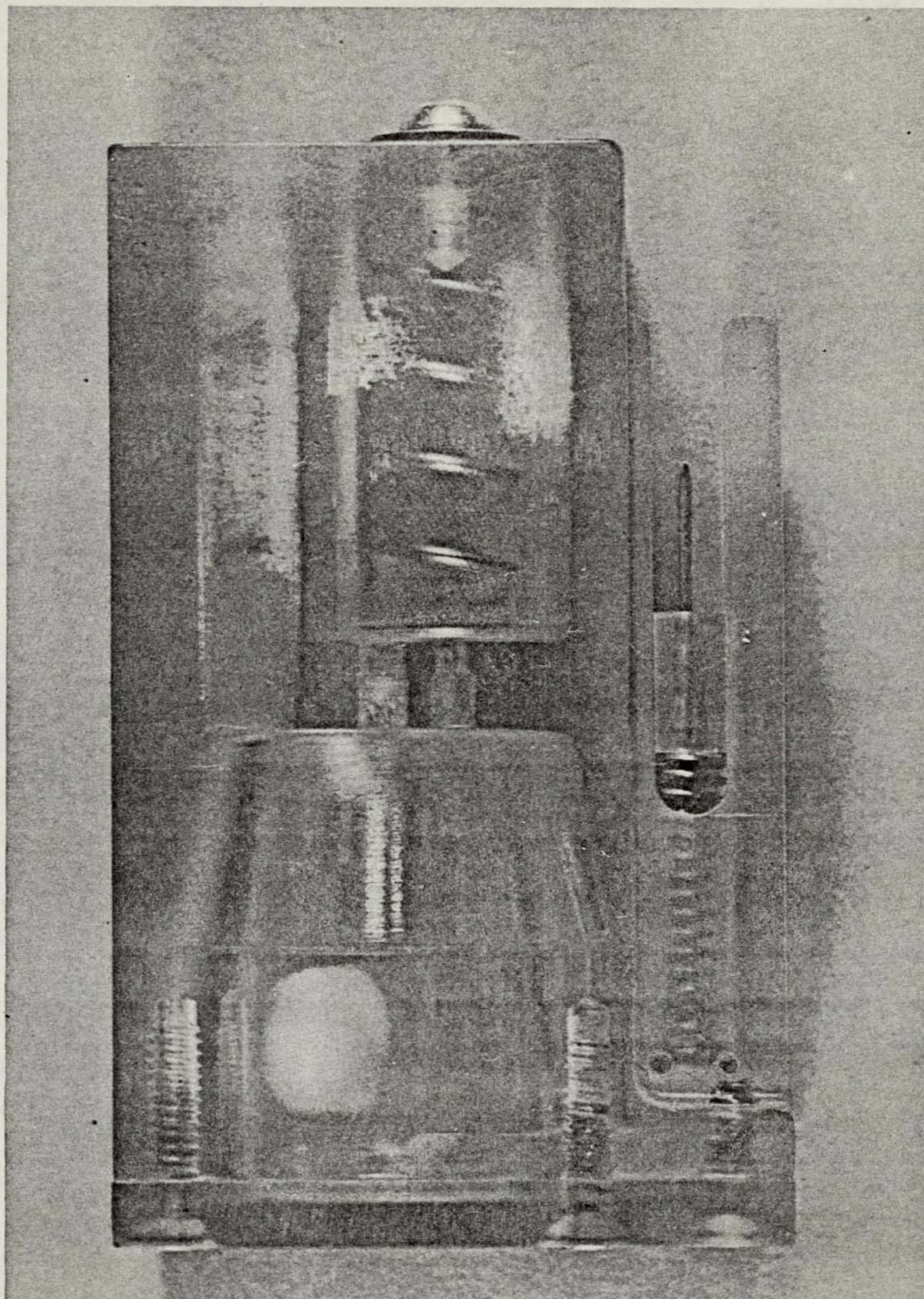

FIGURE 17

SRCLD TEST UNIT

again the low bidder. The other parts were also procured for SRCLD fabrication, Figure 18. The custom fabricated parts purchased were both needles and the large spring. The Teflon covered magnet is a standard stirring bar for laboratory usage. Custom magnet designs were investigated, but the cost for 1400 pieces was found to greatly exceed the cost of the stirring bars. Teflon covering is required to prevent contamination of diluent by corrosion of the magnet. Several simple tools were fabricated to assist the assembly of the SRCLDs. SRCLDs were assembled as needed for testing and evaluation, Figure 19. The arrangement of the SRCLDs for loading a Clinical Card is shown in Figure 20. Until the Sample Loading System is fabricated, most of the Cards will be loaded from a simple laboratory earth gravity system.

3.4 MLM Software - The software for the MLM is produced in assembly language format on the IMP-16P microcomputer shown in Figure 21. Software is split into modules for ease of assembly and use. Many modules such as the monitor are placed in PROMs (programmable read only memories); the excess is placed in RAM (common term for read/write memory).

3.4.1 Assembly Language - Assembly language programming is accomplished on the IMP-16P with 8K words of read/write memory (RAM). Many system programs are available to support the programming. In the order of their use they are: CEDIT, GENLRD, DEBUG, and PRMSFTB. CEDIT is the conversational editor and assembler which allows the basic start of programming from the keyboard, line changes, deletions, etc., and then the assembly of the program with checks made for logical programming errors such as duplicate names, invalid addressing and illegal commands.

A logical error free program can be loaded by GENLRD, the general loader program. DEBUG is usually loaded also. DEBUG allows checking the operation of

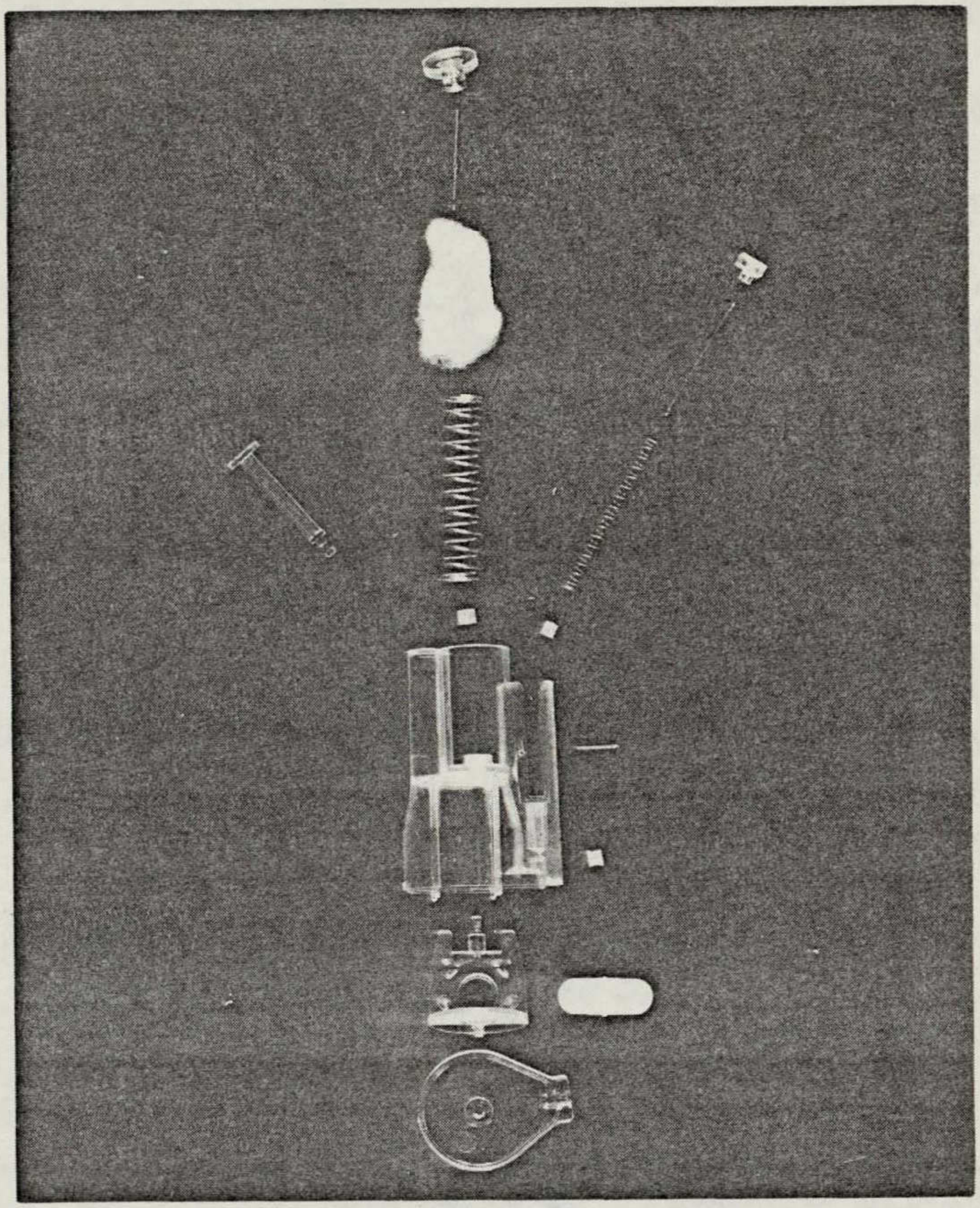

FIGURE 18

SRCLD COMPONENTS

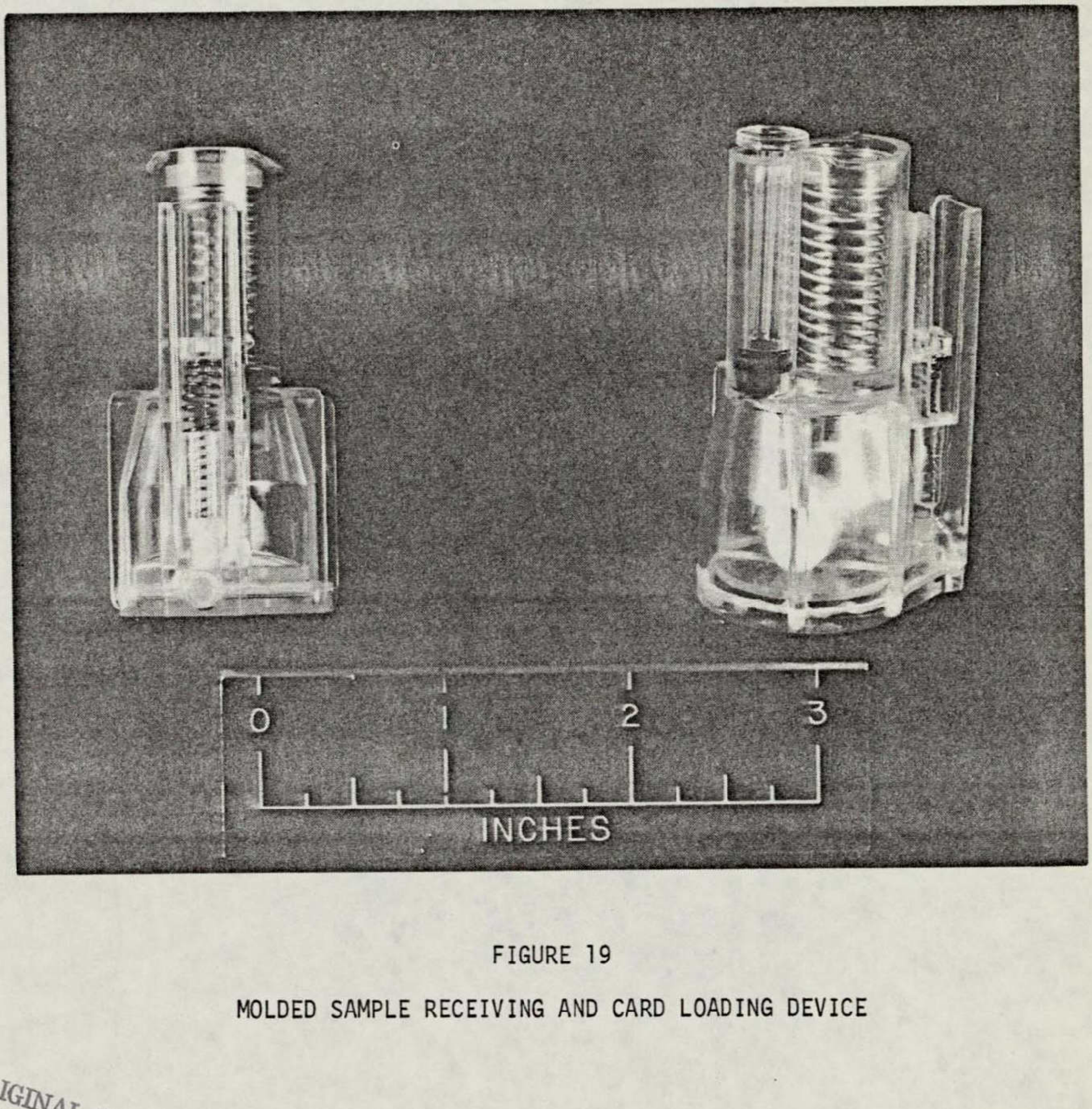

FIGURE 19

MOLDED SAMPLE RECEIVING AND CARD LOADING DEVICE

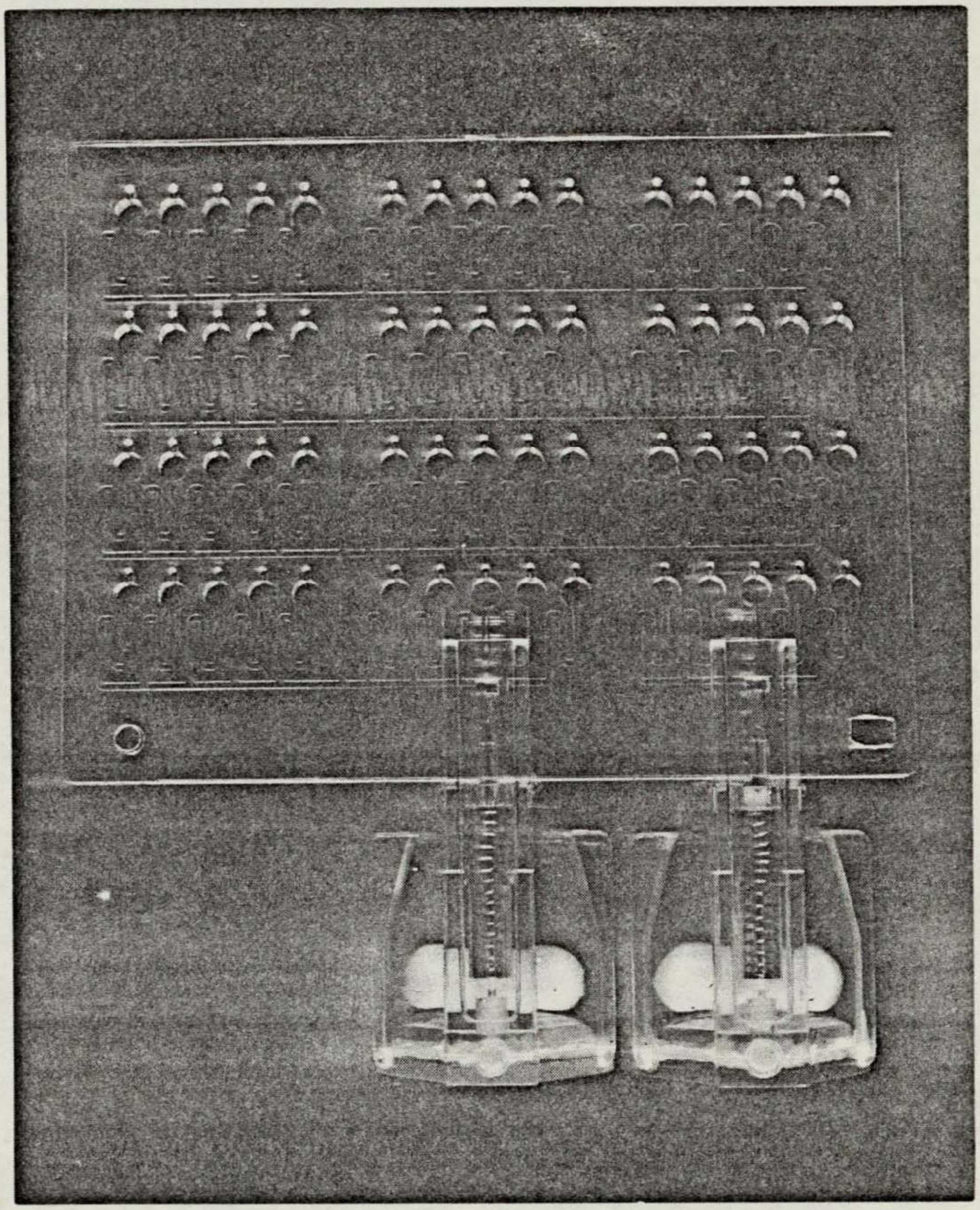

FIGURE 20

CARD WITH SRCLDs

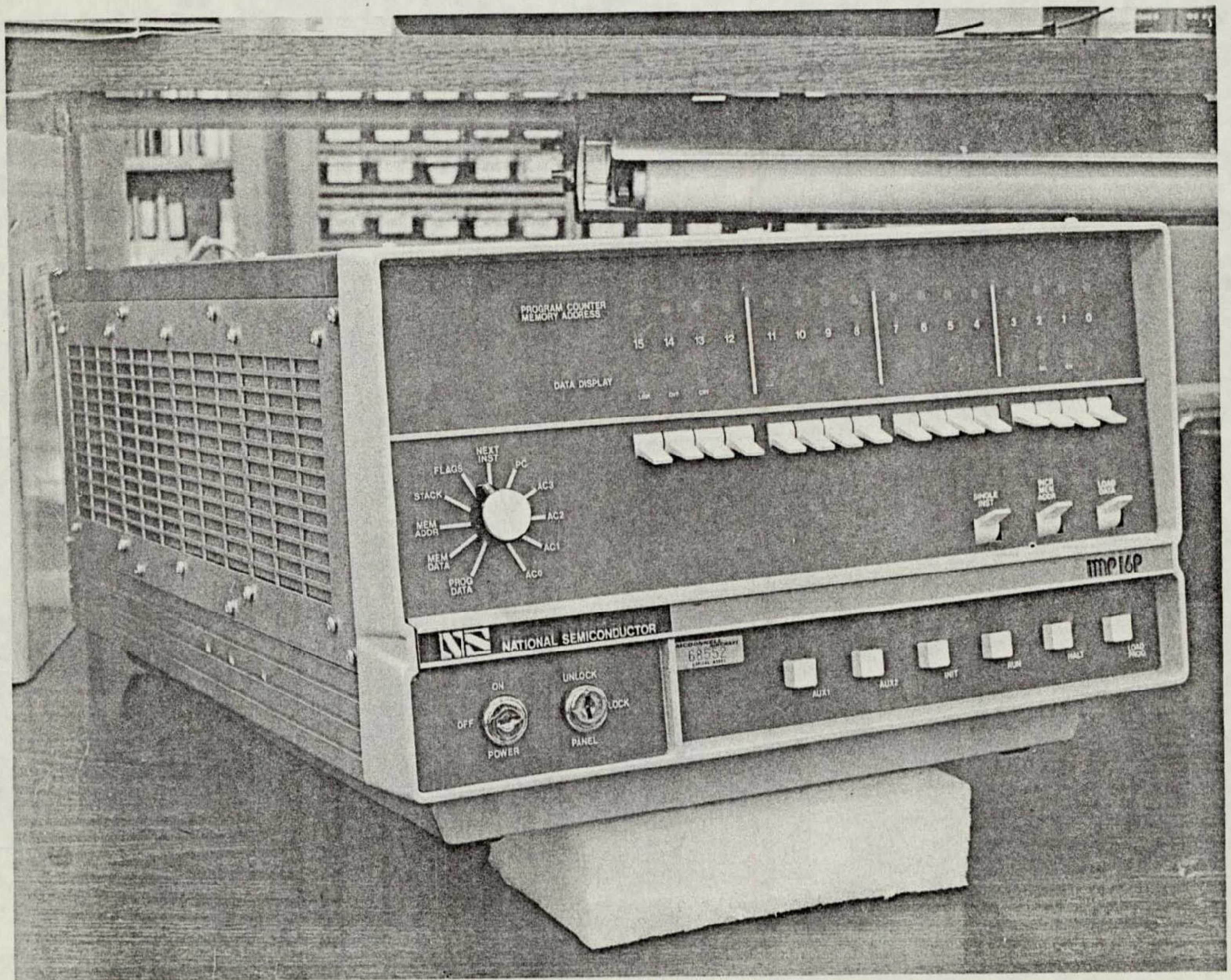

FIGURE 21 IMP-16P MICROCOMPUTER

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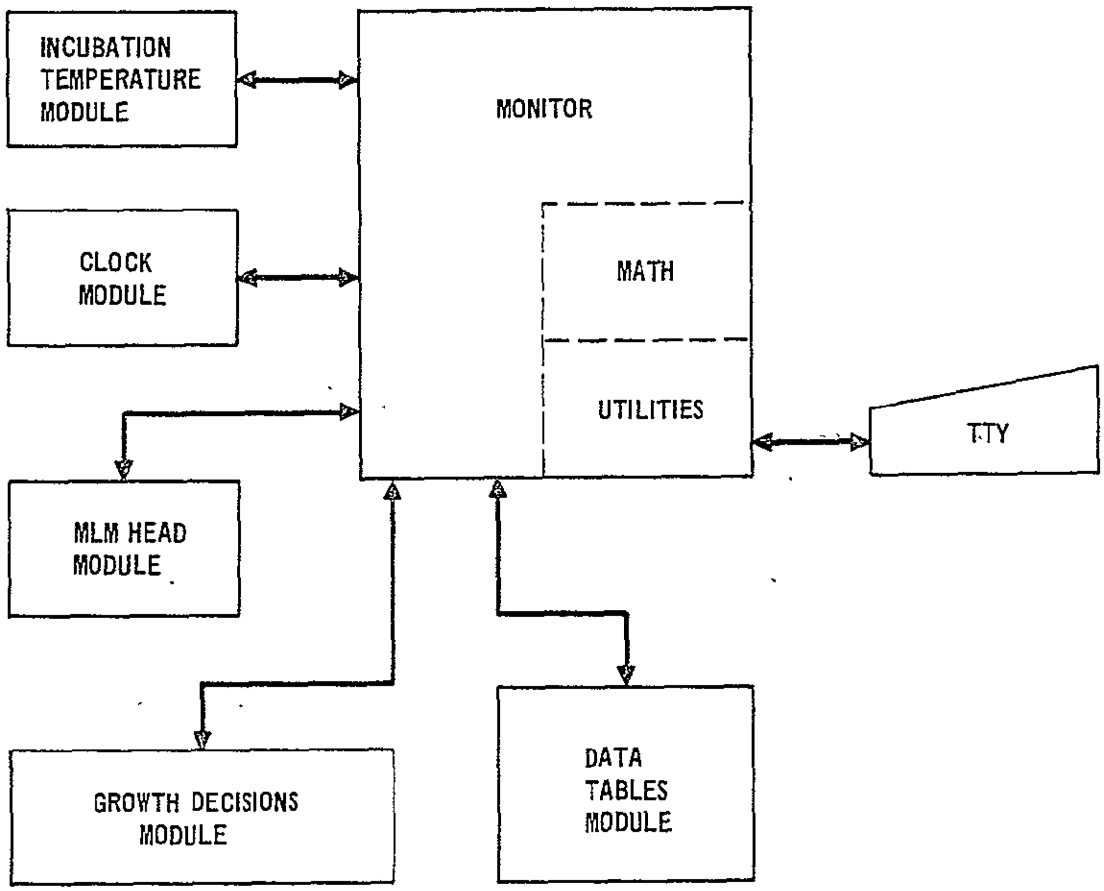

FIGURE 22

MLM SOFTWARE ORGANIZATION

is located in the upper 512 words of memory with an entrance address of FFFE. Teletype routines are located in the lower 256 words of the upper 512 (i.e., FEØØ to FEFF).

The clock module has the purpose of controlling and reading the clock integrated circuit. Upon power up, this module initializes the clock (month, day, hour and minute) with values input by the operator. The time read can be used by the monitor module to compute elapsed time for each head and decide whether to read or not to read based on predetermined time intervals. The clock is configured to generate a 24 hour clock. This module is also located in PROM within locations FCØØ to FDFF, except for variable time locations in lower RAM memory. The remaining modules are located in the 4K of RAM memory until all four heads are fabricated and operational.

The incubation temperature module is used by the monitor to check head incubation temperature of each side of the head. If it is within limits - fine, if not then notification is given the operator. If the temperature becomes too high the heater control can be shut down by the monitor through the use of the incubation temperature module.

The MLM head module has the purpose of addressing each head and reading the detected light level of each channel. The raw data is sequentially stored in the data tables module. One section of the MLM head module has the capability to calibrate the light emitting diodes' drive currents when the monitor is commanded to do so by the operator.

The data tables module is the largest of all the modules since all data resides here. A complete MLM system will need data room for 300 initial values, 300 current values, 300 different light emitting diode current drive values, 5 starting times, 51 threshold values, and space for all alphanumeric characters used in formatting a communication with the operator, such as organism names, fault notification and operator commands.

The growth decisions module has the purpose of computing the percentage change of the present channel data from the initial data taken when the Card was first entered into the head. These percentage changes are then compared with preset threshold values for determination of growth detection. Notification is given when the threshold is exceeded on two consecutive readings.

3.5 System-Functional Testing - Testing started with the power supplies and progressed to other items as they were assembled. The power supplies were tested for conformation to manufacturer's specifications and were excellent with the exception of ± 15V load regulation. Some of the difference may be attributed to difference in testing procedures. Table 3 lists the results.

Emitters and detectors were then checked in the incubating reading head with d.c. input drive to the emitters. Functional check showed cathode and anodes of the emitters reversed. The emitter board was rewired and the resulting check was good.

The heater circuit was checked with a full head but no Card. The test results are:

a. Warmup time from a cold start is less than 15 minutes.
b. Due to thermal lag in the circuit the 35°C controlled temperature varies ± 0.15°C.
c. Maximum power is delivered during warmup from a cold start and is 12.1 watts.

TABLE 3

POWER SUPPLY TEST RESULTS

MANUFACTURER'S SPECIFICATIONS	MEASURED VALUES			
LINE REGULATION	Vin	Vout	Load	Lost Regulation
±0.1%	115 VAC ± 10%	+15	3 AMP	96.0 VAC
	104 to 126 VAC	-15	3 AMP	96.0 VAC
		+ 5	10 AMP	95.5 VAC

Load Regulation	+15		-15		+5	
	NL	FL	NL	FL	NL	FL
	15.18v	15.13v	15.18v	15.13v	5.09v	5.08v
±0.1%	± 0.16%		± 0.19%		± 0.1%	—

Noise & Ripple	+15	-15	+5
	4mv PP*	4mv PP*	3mv PP*
TYP 0.5 to 2 mv rms	1.42 mv rms	1.42 mv rms	1.06 mv rms
0.1%	0.03%	0.03%	0.06%

*Ambient noise on scope was 3 mv P/P with outputs loaded and A/C power off

d. After stabilization the average power input is 2.4 watts at 20°C ambient with a cycling full on to full off power input.

Maximum power delivered during warmup from a cold start will vary due to the unregulated voltage. Both maximum power and warmup time will be rechecked as additional heads are added.

Checking then progressed to operation verification of the IMP-16/C and interfaces associated with the teletype. A simplified monitor was used in PROM to check startup. EX and FL commands (EXam and FilL) were used to check and debug the dynamic RAM memory. Problems were found which were either related to missing or miswired wires. These problems were solved and testing of the growth board started. After the growth board, testing progressed to the addition of the incubating reading head; printout of raw data; to a long term test with blank card for stability. The results of all testing to date has been excellent once initial problems were overcome.

4.0 PROGRAM STATUS

The MLM system engineering model design reached the following levels at the end of this contractual period. Mechanical and electronic design is complete. The Sample Processor System design is complete.

Fabrication of the MLM system engineering model reached the following levels. Fabrication of the unitized instrument is complete up to one head and excluding the Sample Loading System. Four additional heads and the Sample Loading System are left to be fabricated in some future period.

Limited testing of the system with one head has begun with molded Cards which were delivered late during the sixth contractual quarter. Testing was delayed approximately two months due to failure of both memory boards in the IMP-16P microcomputer used to develop software for MLM use. A two month no-cost extension was requested and granted.

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