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LUNAR SURFACE MAGNETOMETER FAMILIARIZATION MANUAL

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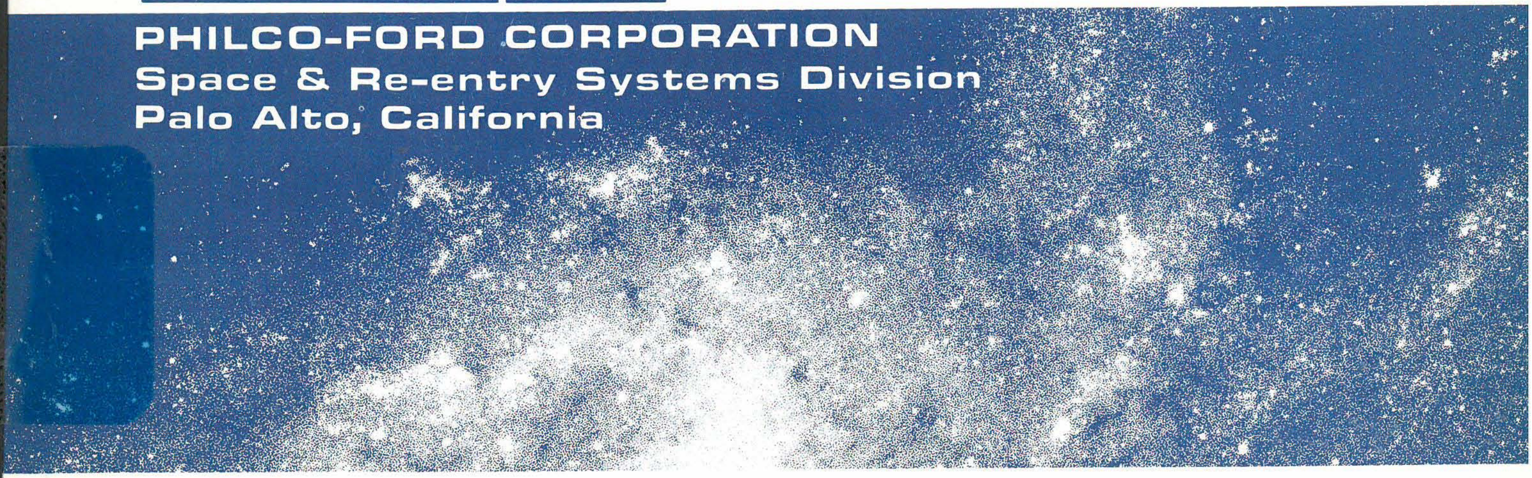

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SECTION 1
INTRODUCTION

1.1 PURPOSE

The two major purposes of this document are: to provide an introduction in depth to the design and design rationale of the Lunar Surface Magnetometer (LSM); and to define certain support requirements relating to instrument transportation, storage, handling, operations, maintenance, and other services that may be needed.

1.2 SCOPE

While a basic familiarity with the instrument is assumed, the level of descriptive information provided is, in general, quite detailed. A discussion of the scientific objectives is included, since these objectives provide the rationale for the entire mission and strongly influence instrument design. On the other hand, the Ground Support Equipment (GSE) for the Magnetometer has little influence on instrument design and it has been assumed that the reader either is completely familiar with this equipment or that he has access to the necessary documentation (e.g., LSM GSE Operations Manual).

The Magnetometer experiment is discussed in Section 2. Scientific requirements are related to instrument design features. The instrument operational plan is presented and the operational (data/command) interface with the Apollo Lunar Surface Experiments Package (ALSEP) is introduced. The physical aspects of LSM design are described in detail in Section 3. Each of the three instrument subsystems (Electromechanical, Processor Electronics, and Thermal Control) is broken down and discussed to the major component level. Design particulars, including basic performance and configuration parameters, are presented. Section 4 also covers the instrument design; in this section the LSM functional aspects are emphasized with the aid of block diagrams.

The remaining three sections are concerned with instrument requirements and specific procedures. Section 5 deals with instrument maintenance. Section 6 defines requirements for transportation and storage of the LSM, as well as detailed handling procedures covering such tasks as instrument installation and removal relating to the shipping container, the ALSEP, and the GSE (flux tanks). Finally, Section 7 treats mission operational requirements and procedures for both the lunar surface (astronaut operations) and the ground (mission control operations).

SECTION 2

THE LUNAR SURFACE MAGNETOMETER EXPERIMENT

2.1 SCIENTIFIC CONSIDERATIONS AND OBJECTIVES

General

The LSM is a magnetometer system for use as a lunar station in conjunction with the ALSEP and using the operational Ames Research Center flux gate instrument. The flux gate is the only magnetometer which can be used in fixed single instrument configuration for the local site survey required on the lunar surface for establishing the level of local field gradients which are due to the background of nickel-iron and/or stony-iron meteoric material.

The purpose of the single station is to examine the topology of the interplanetary field which diffuses through the moon and from this to determine a set of bounds upon the electromagnetic diffusivity of the lunar body, and to examine electromagnetic propagation. The experiment will give some indication of radial and azimuthal inhomogeneities in the lunar interior. The specific purposes of the first single station are as follows:

a. To study the time variation of the field during the lunar month to obtain the diffusive flow of field through the lunar interior.

b. To measure the equatorial surface field due to magnetic flux tubes captured from the solar wind field.

c. To obtain the sunward and antisolar surface hydromagnetic radiation density and spectrum, from which statistically will be given the internal magnetic Reynolds number or the electromagnetic diffusivity.

d. To determine, from interplanetary transients, the lunar response to shock wave and contact discontinuities.

e. To look for the onset of turbulence in the lunar bow shock.

f. To determine the angular extent of the magnetospheric tail by the earth's field at the distance of the moon.

The station is to serve as a prototype for the extension later which will enable a time correlated study of the transit of radiation through the interior to be made, including the ellipticity of the outgoing wave polarization, depending upon the electrical parameters found.

2.2 DESIGN IMPLICATIONS

2.2.1 General

The mission objectives have immediate implications for instrument design. For example, it is clear that both the time variations of the field and the DC level are required. Therefore, the LSM has been designed to provide both types of information. A further design determinant was that the magnetometer must operate throughout the lunar day and night, since the mapping of the field lines to determine the interior configuration requires a complete lunation. The LSM thermal control subsystem therefore has been designed to maintain instrument operating temperatures within an acceptable range at all times. This requires heating the instrument at night while ensuring that the heating technique does not distort the magnetic data.

In addition to the above system constraints, it is necessary to provide internal calibrations from time to time in order to determine that the magnetometer has not drifted, or if it has, to correct the measurements. This requires that each sensor element be rotatable through 180 degrees so that the contribution of sensor offset and lunar field can be separated. Each of the sensors should also have an independent offset capability in order to cancel DC magnetic fields and observe low intensity varying fields. Since the magnitude of the field at the lunar surface is uncertain, it is desirable that the instrument be capable of varying the operating dynamic range.

It is of great importance that a site survey be conducted subsequent to emplacement of the magnetometer. The reason is that local accumulations of nickel-iron or stony-iron meteoric debris cannot be presently ruled out. Such material, having probably passed through the Curie point, would not be expected to have appreciable remnant magnetism. However, even this cannot be stated categorically. Furthermore, in the absence of magnetic material, the induction field can cause serious changes in measured heading and intensity of the field if a sensor element is near such material. The possibility that a larger body of magnetic material lies just beneath the surface or even on the surface disguised by dust and ejecta also cannot be ruled out, although statistically this is less likely.

Self-siting of the system is carried out by a complicated series of rotations of the sensor elements during the Site Survey Mode which forms unidirectional gradiometers as illustrated in Figure 2-1. The directional response of the gradiometer is varied along three mutually orthogonal axes to investigate the gradient in the vicinity of the instrument. This also allows detection of electrical currents in the plasma since the instrument configuration can be used to determine the vertical component of the curl of the magnetic field. A non-zero curl will indicate the presence of currents according to Maxwell's equations. The determination

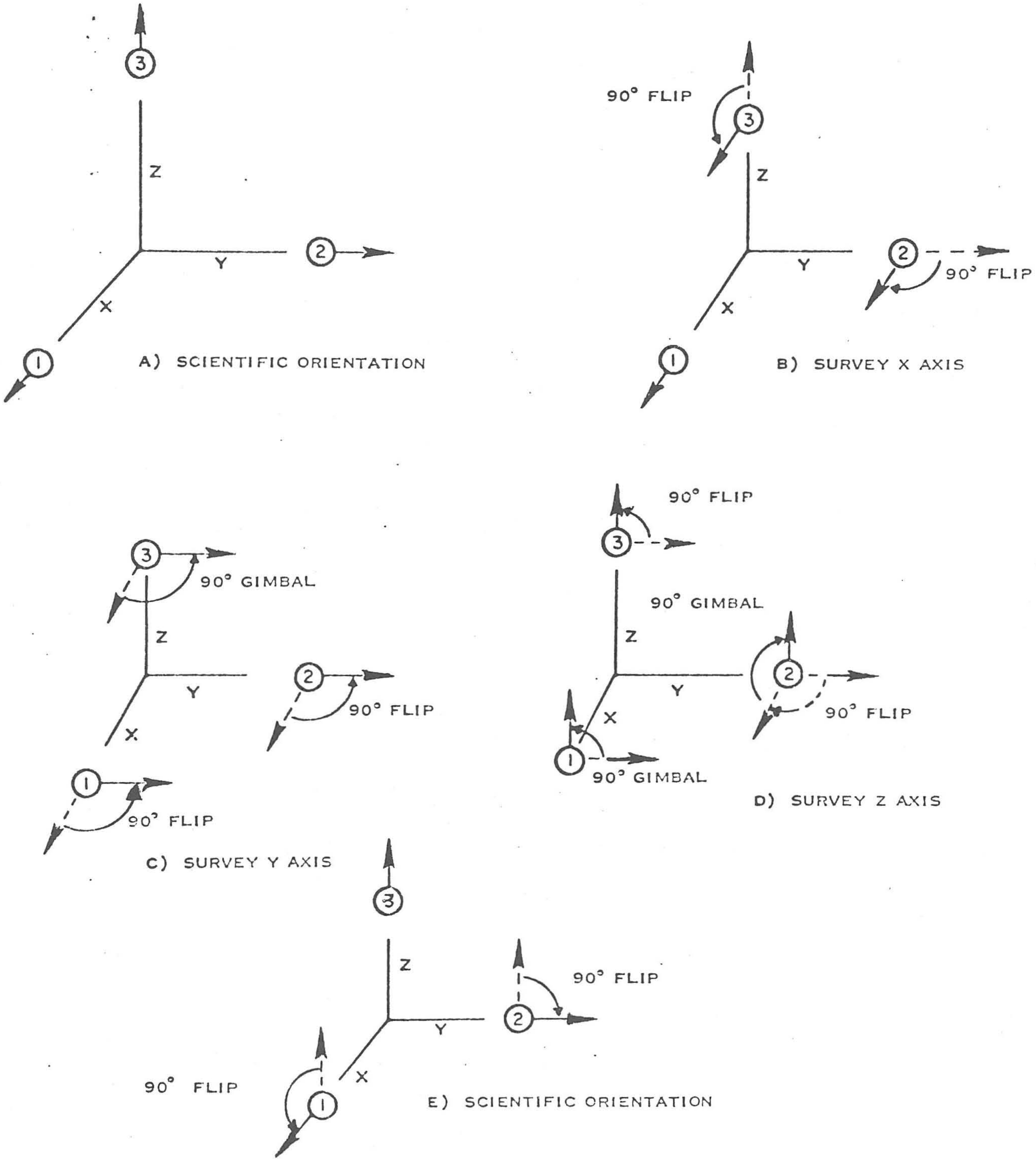


Figure 2-1

Site Survey Mode

of the gradient of the field cannot provide a correction for local ferrous intrusions since only the gradient of the field is observed.

These and other constraints and concommitant instrument requirements are summarized in Table 2-1. The design goal is to achieve a reliability of 0.99 for one year Lunar operation.

To further illustrate the design implications of the constraints and requirements indicated in the table, the physical configuration and operational capability of the instrument are discussed briefly below. This discussion also serves to introduce the more detailed physical and functional description of Sections 3 and 4, respectively.

2.2.2 Physical Configuration

The overall physical configuration of the LSM is shown deployed in Figure 2-2 and stowed (for Lunar transit) in Figure 2-3.

The instrument magnetic sensors consist of three flux-gate magnetometers, each mounted in a sensor head located at the end of a three foot long support arm, as shown in Figure 2-2. These magnetic sensors, in conjunction with the sensor electronics, provide signal outputs proportional to the incident magnetic field components parallel to the respective sensor axes. In the normal scientific operational mode, the sensors are aligned along their respective support arm axes which are arranged to form an orthogonal system. The physical configuration shown in Figure 2-2 provides:

a. Sensor/sensor separation; to permit lunar debris magnetic field gradient detection

b. Sensor/electronics separation; to reduce magnetic field bias caused by the electronics

TABLE 2-1

SUMMARY - LSM SYSTEM CONSTRAINTS AND REQUIREMENTS

Class	Constraint	Requirements
A. Scientific	1. Data Accuracy and Integrity	a. Low Magnetic Bias
		b. Site Survey
		c. Periodic Calibration
		d. Variable Dynamic Range
		e. Range Offset
		f. Logical control of offsets durin calibration and site survey
		g. Thermal Control & Temperature Data
		h. T/M Bandwidth
		i. Scientific Data Processing (Minimum Aliasing Error)
		j. Orientation Determination (Level Sensors & Shadowgraph)
	2. Reliability	a. Ground Support Equipment
		b. Redundancy
		c. Fail-Safe Features
		d. Housekeeping Data
B. ALSEP Interface	1. Mechanical Integration	a. Minimum Weight
		b. Stowed Configuration Form Factor
		c. Hard Point Mounting
	2. Electrical Integration	a. Data Format
		b. Command Linkage
		c. Power Profile
		d. T/M Sampling Rate Compatibility
C. LEM Interface	1. In-Transit Environment	a. Thermal
		b. Magnetic
		c. Dynamic
	2. LEM Ascent Effects	a. Maintenance of Alignment
		b. Maintenance of Sun Shading
		c. Lunar Support Legs
D. Astronaut Interface	1. Astronaut Capability & Work Profile	a. Ease of Removal of ALSEP
		b. Ease of Deployment
		c. Ease of Alignment
E. Lunar	1. System Operational Limits	a. Thermal Control
		b. Temperature Data
		c. Instrument Leveling
	2. Lunar Debris Magnetic Bias	a. Site Survey
		b. Magnetic Sensor/Lunar Surface Separation

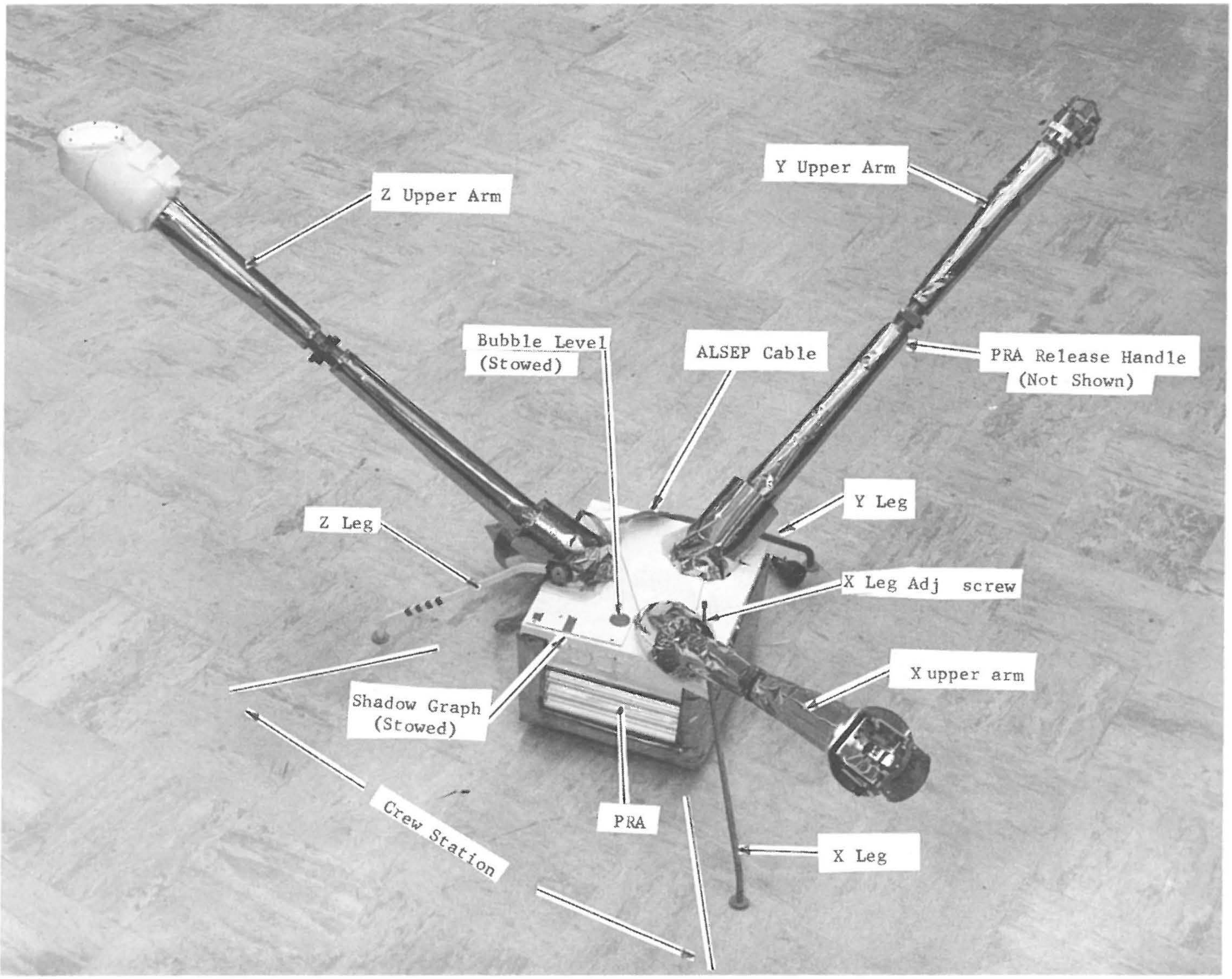
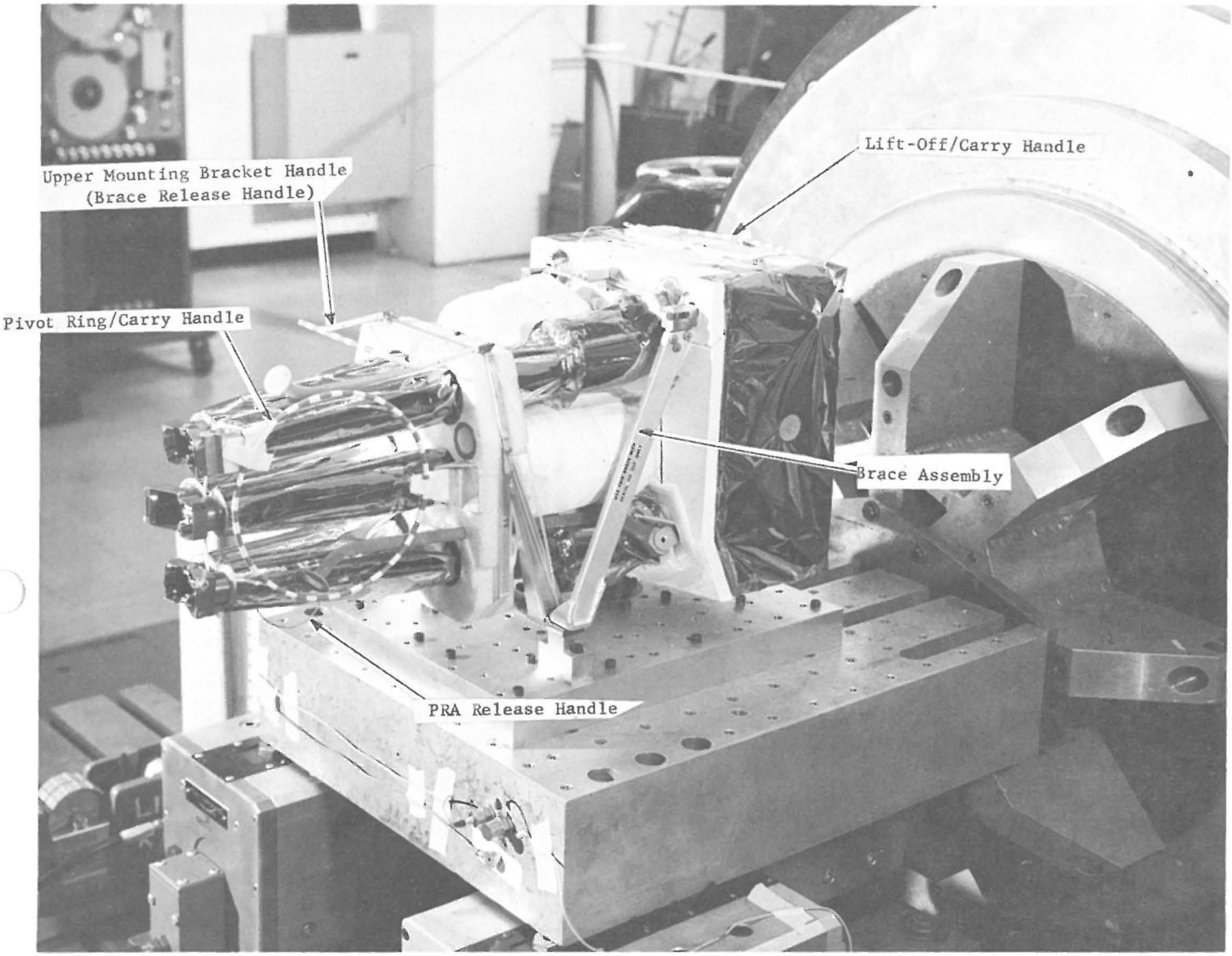

Z Upper Arm
Y Upper Arm
Bubble Level
(Stowed)
ALSEP Cable
PRA Release Handle
(Not Shown)
Z Leg
Y Leg
X Leg Adj screw
X upper arm
Shadow Graph
(Stowed)
Crew Station
PRA
X Leg

Figure 2-2



LSM Stowed

Figure 2-3

c. Sensor/lunar surface separation; to reduce magnetic field bias caused by lunar debris.

The base package commonly referred to as the Electronic/Gimbal Flip Unit (EGFU), from which the three support arms extend, is a rectangular box 9 1/2" x 10 1/2" x 5 1/4" housing the electronics and the electromechanical sensor orientation mechanisms, commonly referred to as the gimbal-flip mechanisms.

Instrument support and stability is achieved via the three lunar support legs shown in Figure 2-2. Each leg is attached to the base package at the base of a sensor support arm and incorporates an independent adjustment to permit instrument leveling by the astronaut.

The sensor support arms are doubly hinged and support legs swing to an upright position to permit stowage of the instrument within the reduced envelope (indicated in Figure 2-3) required by the ALSEP mechanical interface.

The instrument in the stowed configuration is mounted within ALSEP by means of various release fasteners incorporated in the base package and in a support arm restraining clamp. The tie-down method is designed to satisfy the requirements of the launch, translunar, and lunar landing dynamic environments.

2.2.3 Operational Capability

Achievement of the scientific objectives of the experiment requires instrument capability to operate in three modes: scientific (or normal), calibration, and site survey.

In the scientific mode, all three magnetic sensors are aligned parallel to their respective support arm axes, directed either inward (toward the EGFU) or outward. In this mode it is possible to optimize the operational configuration of the instrument (e.g., dynamic range and offset bias) for actual conditions. This is accomplished by means of telemetered commands, as discussed in Sections 4 and 7.

In the calibration mode, signals and control functions are provided which allow the evaluation of scale factors, zero drift, and the combination of permanent fields associated with magnetic sensors and electronic offsets associated with the sensor electronics. The evaluation of the last effect requires flipping the magnetic sensors through 180 degrees. This mode is initiated automatically every 12 hours by ALSEP generated command or as often as required by ground command. Automatic initiation of the mode may be inhibited if required, also by ground command.

In the site survey mode, control functions are provided which permit the detection of the magnetic field gradient in the vicinity of the lunar surface magnetometer. To accomplish the site survey, all magnetic sensors must be aligned parallel to each of the three coordinate axes in turn, as illustrated in Figure 2-1. As shown in this figure, the site survey mode requires both flipping and gimballing the sensors through 90 degrees, as well as 180 degrees flipping for periodic calibration. The outer structural jacket of each sensor head is attached to a sensor arm and remains stationary throughout operation.

The site survey mode is a one-time event, performed shortly after instrument emplacement on the Lunar surface. The survey of each individual axis is initiated by telemetered ground command. Upon completion of each single axis survey, the instrument is effectively in the normal operating mode, in that it is permissable to adjust the operational configuration if required.

Detailed descriptions of the design features and functions which are involved in the above operations are provided in Sections 3 and 4.

SECTION 3

PHYSICAL DESCRIPTION AND LEADING PARTICULARS

3.1 SUBSYSTEMS GENERAL DESCRIPTION

As discussed in Section 2, the Lunar Surface Magnetometer system design derives primarily from requirements imposed by: (1) the experimental scientific objectives, (2) the various interfaces with ALSEP, the Lunar Excursion Module, the astronaut, and (3) the lunar environment.

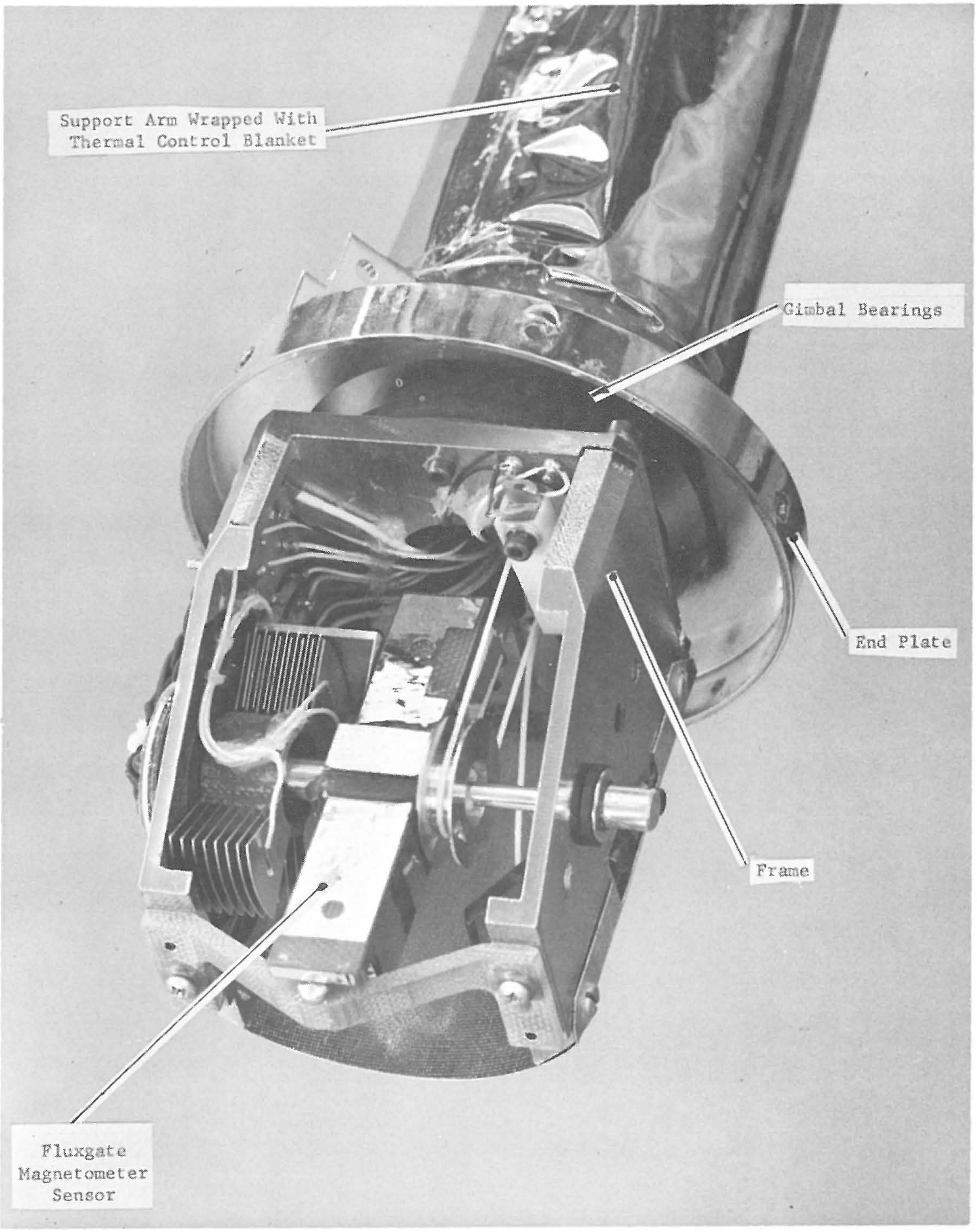
Three primary subsystems comprise the LSM:

1. Electromechanical Subsystem which includes:
   a. Magnetic Sensors
   b. Structural Components and Mounting System
   c. Gimbal-Flip Mechanisms
   d. Orientation and Alignment Monitors

2. Processor Electronics Subsystem

3. Thermal Control Subsystem

The magnetic sensors consist of three fluxgate magnetometers, each mounted within a sensor head located at the end of a 3-foot support arm (Figure 3-1). The axes of the magnetometers normally coincide with the axes of the support arms and form an orthogonal system which is the instrument-based coordinate system.



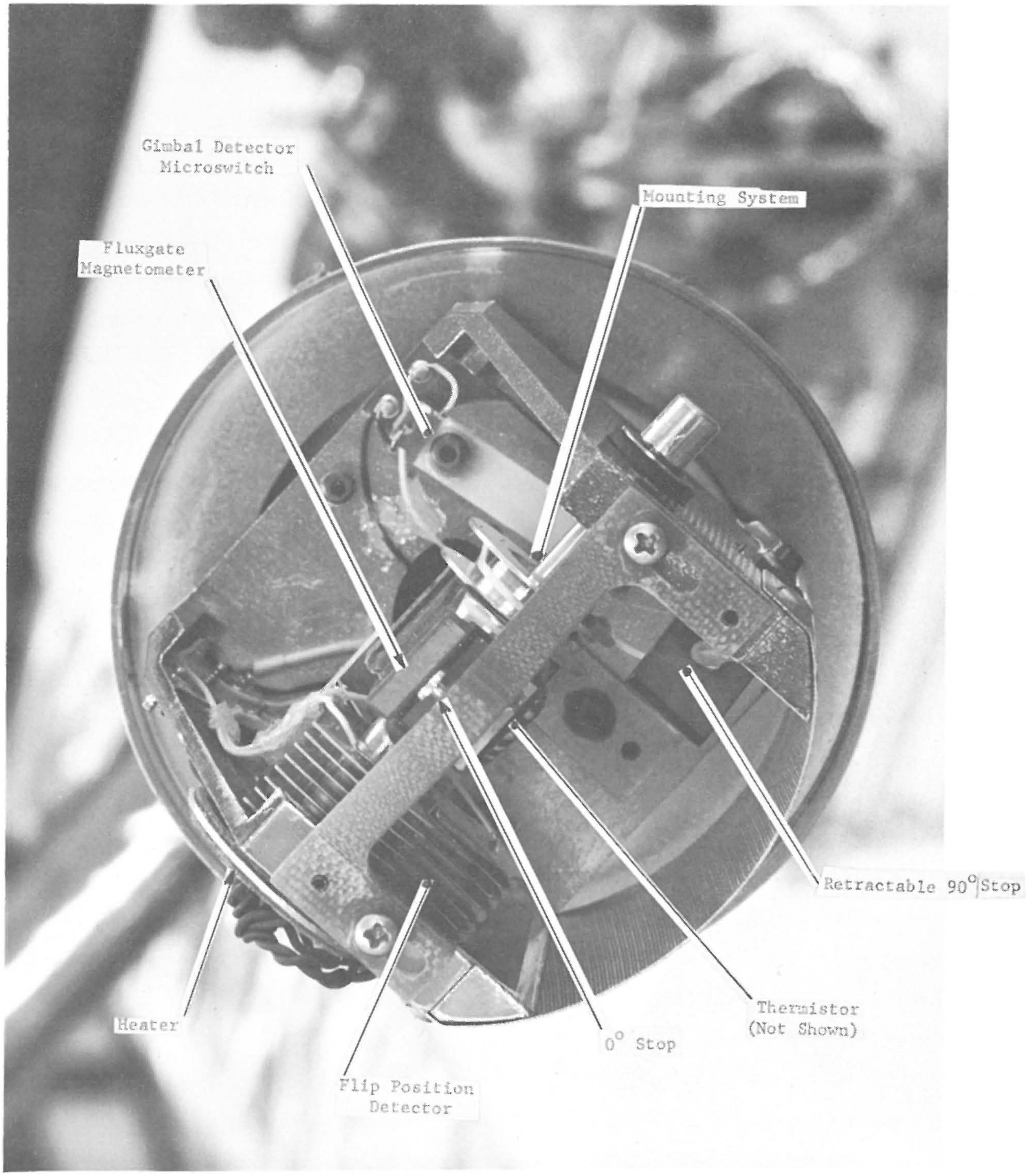
SENSOR HEAD EXPOSED IN ARM

FIGURE 3-1

Within the sensor heads (Figure 3-2), the sensors are mounted on gimbal systems which allow rotation about 2 axes. Rotation about the support arm axis ("gimbal" motion) is accomplished by rotating the entire sensor head internal assembly. Rotation about the sensor's transverse axis ("flip" motion) is accomplished by rotating only the fluxgate sensor on its own transverse bearings within the sensor head assembly. Gimbal rotation for each sensor is through 90° ($\pm$ 15') and occurs only once during the lunar operational life of the instrument. During flip action, each sensor is rotated through 180° ($\pm$ 5') except when a removable 90° ($\pm$ 5') stop is inserted. Flip actions occur over 700 times during the lunar operational life. During two of these flips, the 90° stop is automatically inserted. Incorporated in each sensor head is a multiple-plate capacitance position detector to monitor the flip position of the sensor, a mechanical switch to indicated the gimbal position, electric resistance heaters, and a temperature sensor.

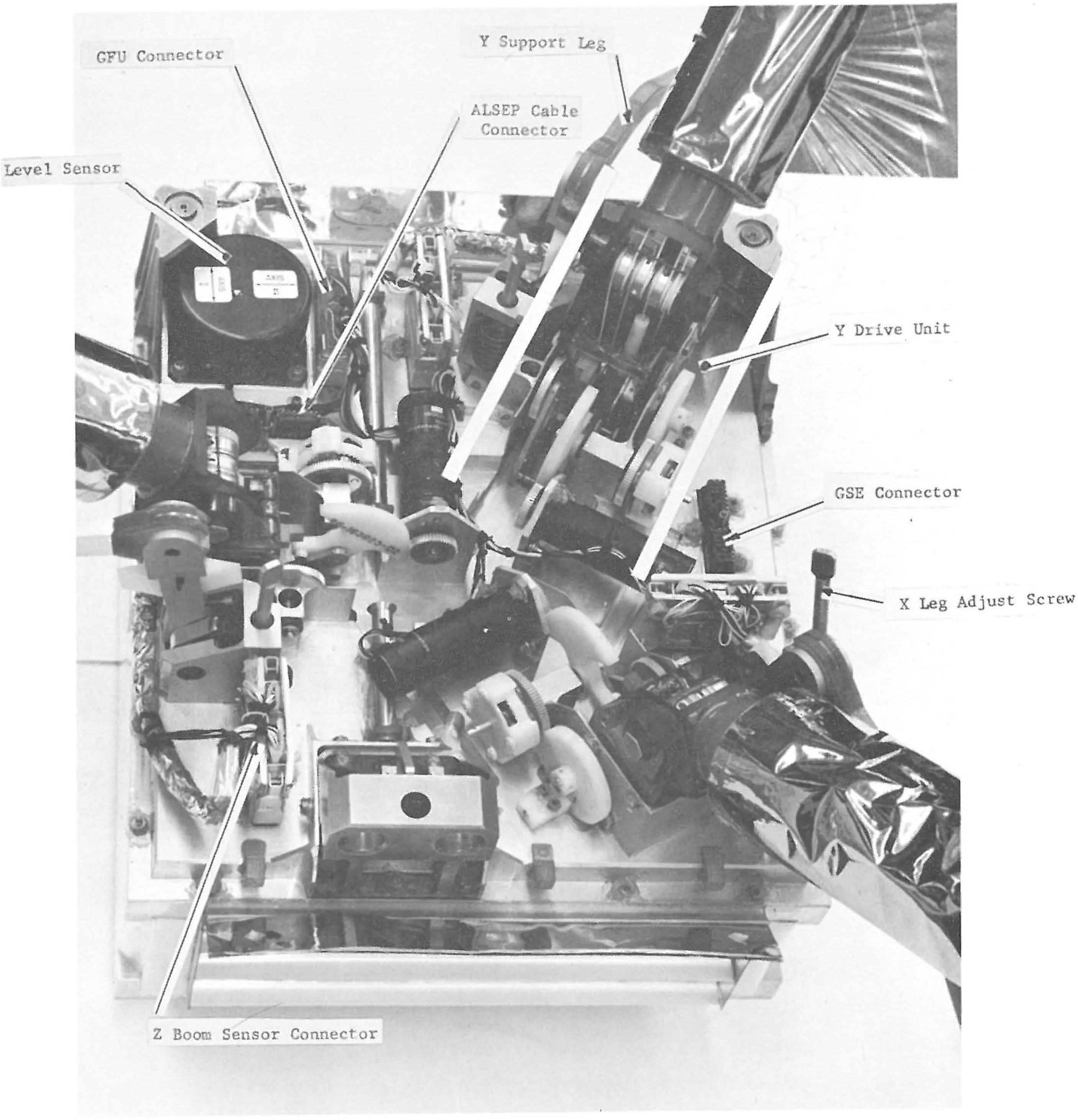
The three sensor booms are each provided with two sets of hinges which permit folding for stowage purposes. The lower hinge is mounted on the Electronics and Gimbal/Flip Unit (EGFU), the upper surface of which constitutes the Gimbal/ Flip Unit (GFU).

The GFU (Figure 3-3) contains drive units for the gimbal/flip actions, a two axis gravity level sensor, and various electrical connectors including those which connect the sensors, the ALSEP cable, and the Ground Support Equipment (GSE) to the EGFU. In addition, the LSM support legs are mounted on the GFU through their adjustment mechanisms. Protruding above the GFU are independent leg-adjusting screws, by means of which the legs may be moved up or down to adjust the horizontal level position of the instrument.



DETAILS OF SENSOR HEAD

FIGURE 3-2



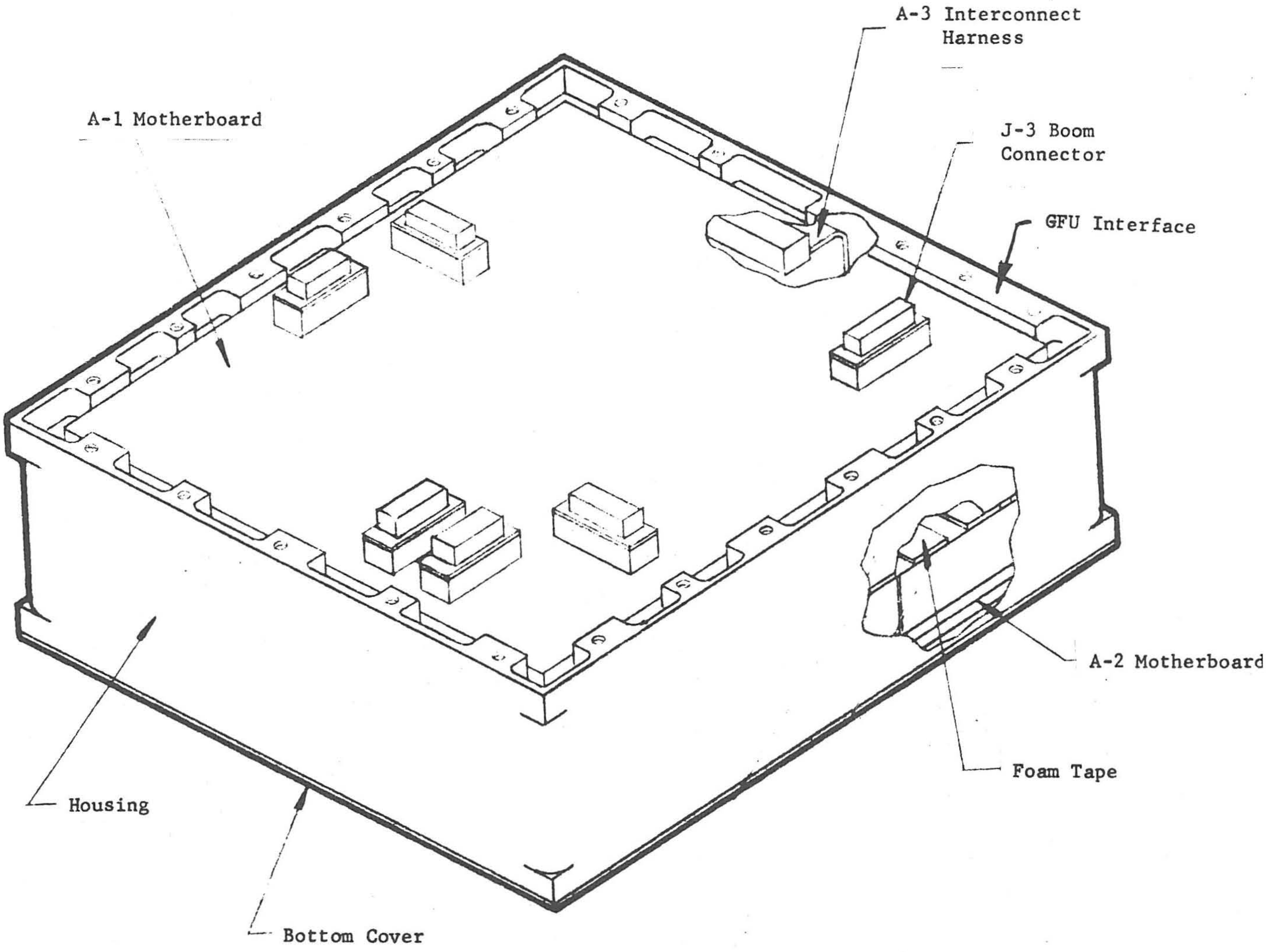
DETAILS OF GFU

FIGURE 3-3

The Processor Electronics Subsystem is housed within the EGFU. This Subsystem is composed of a welded module/interconnection system utilizing both cordwood and formed substrate modules as functional system building blocks (reference Figure 3-4).

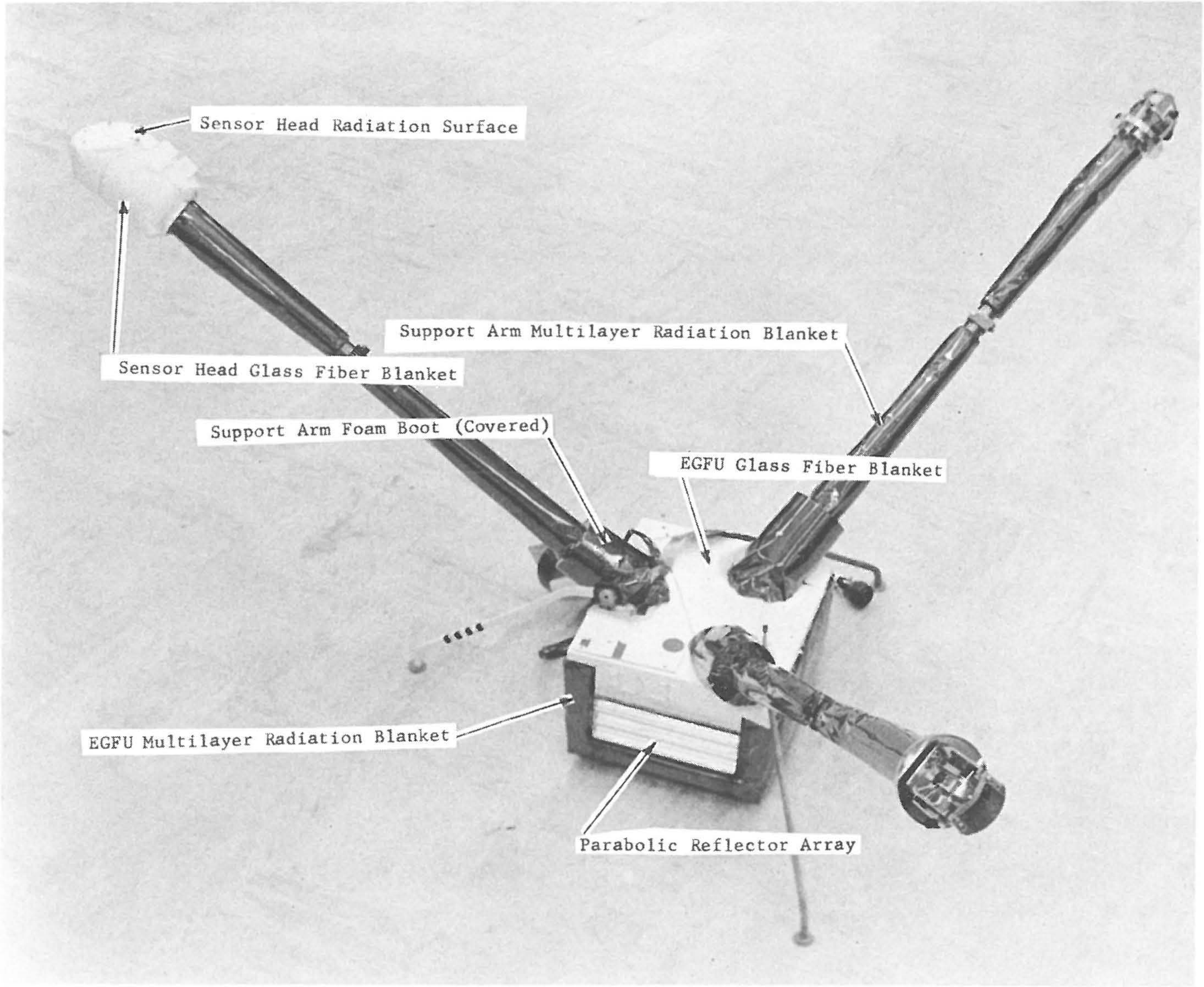
The modules are mounted on two separate interconnect panels with a ribbon cable interconnect system between them. Connector modules are mounted on the top panel and protrude through the GFU to mate with the connectors to the support arms, GSE, and the GFU.

The entire LSM instrument is enclosed within a thermal control subsystem (Figure 3-5). This subsystem is composed of multilayer radiation barrier blankets on the sides and bottom of the EGFU and on the sensor support arms, a glass fiber blanket over a support shroud on top of the EGFU and the sensor heads, foam boots over the lower hinges, and controlled thermal radiation surfaces on the sensor heads. The EGFU also is equipped with Parabolic Reflector Arrays mounted on the sides, which reflect thermal energy emitted from the lunar surface, in addition to providing radiation surfaces.



PROCESSOR ELECTRONICS S/S ARRANGEMENT

FIGURE 3-4



LSM THERMAL CONTROL SUBSYSTEM
FIGURE 3-5

3.2 MAJOR COMPONENTS

3.2.1 Electromechanical Subsystem Components

The following major components are grouped into the electromechanical subsystem:

1. Sensor Heads
2. Sensor Support Arms
3. Gimbal/Flip Drive and Control Mechanism
4. Orientation and Alignment Detectors
5. Support Legs
6. Mounting System

3.2.1.1 Sensor Heads

Each sensor head (Figure 3-2) contains the following items:

1. A fluxgate magnetometer (NASA/ARC-furnished).
2. A mounting system for the magnetometer which includes bearings and a flip drive pulley.
3. A multiplate variable capacitor position detector with a single-segment rotor attached to the magnetometer mount and a three-segment stator attached to the frame.
4. A double-element resistance heater attached to the flip shaft outside the frame.
5. A thermistor attached to the magnetometer mount for monitoring temperature.
6. Fixed stops to accurately locate the 0° ($\pm 5'$) and 180° ($\pm 5'$) flip travel limits.
7. A retractable 90° ($\pm 5'$) stop tab controlled by a cable and redundant return springs.

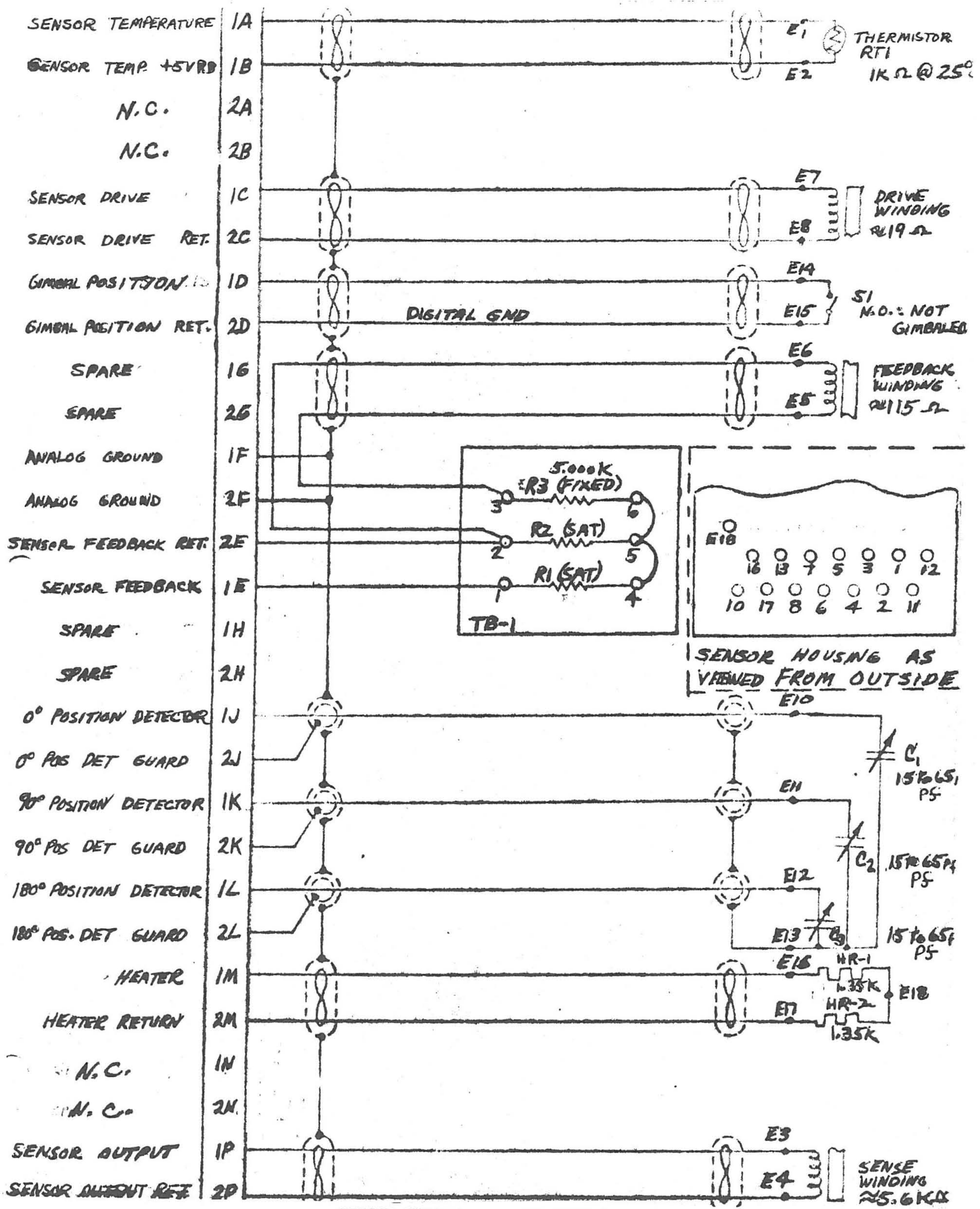
The entire assembly described above is mounted in a frame (Figure 3-1) which is, in turn, mounted on the gimbal bearings located in an end plate fixed to the support arm. Included is the gimbal drive spring and cable operated release pin. A cam-operated microswitch (Figure 3-2) is also included to indicate the pre- and post-gimbal orientations of the head assembly.

Each assembly is covered by a fiberglass shroud (Figure 3-5) which provides support for the sensor head portion of the thermal control subsystem.

3.2.1.2 Sensor Support Arms

The sensor heads are accurately positioned on the sensor support arms. The arms are glass-fiber-reinforced plastic tubes hinged at their base and midpoints to facilitate folding for stowage. Centered within each support arm tube is a smaller tube, also of fiberglass, which contains the electrical harness connecting the sensor head to the EGFU. Appropriately shielded, polyalkene-covered, high-strength copper conductors with outer jackets of cross-linked polyvinylidine fluoride are used, each with its own subminiature crimp-contact, environmental-type connector. Harness details are provided in Figure 3-6. The connector also supports a terminal board to which are mounted Select-at-Test resistors for the sensor electronics.

Four dacron-covered, glass-fiber cables are also contained within the support tubes. These cables are routed around the inner harness tubes by bulkheads with guide holes and pass-over pulleys installed at the lower ends.



SENSOR WIRING HARNESS SCHEMATIC

FIGURE 3-6

3.2.1.3 Gimbal/Flip Drive and Control Mechanism

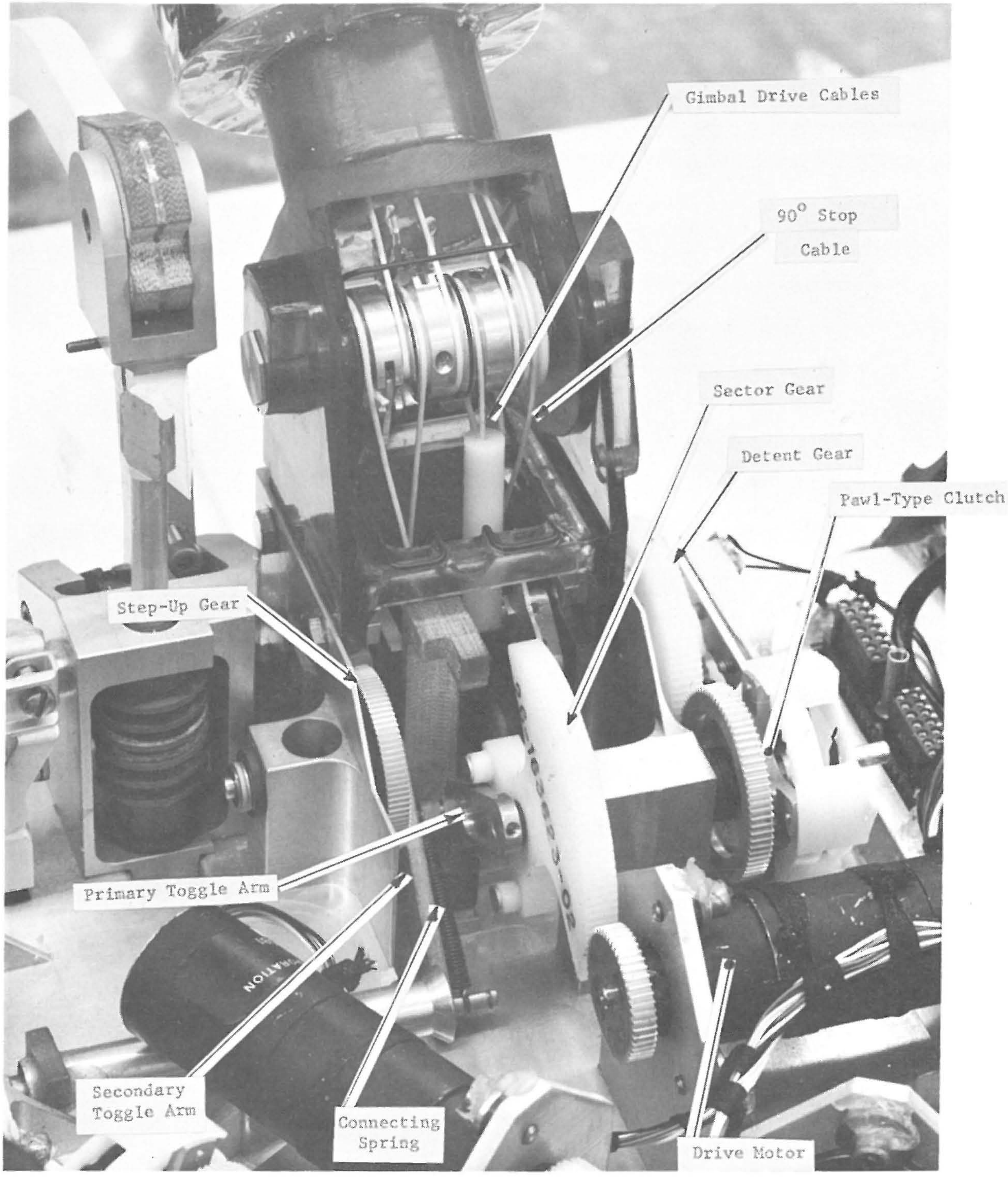
Each sensor support arm terminates in a lower hinge mounted in an associated GFU section. Each section houses an assembly consisting basically of a drive mechanism and a mechanical programmer. The three drive mechanisms provide activating power via the various drive cables to perform the sensor flip and gimbal functions. The three mechanical programmers provide the proper sequence of actuations to carry out the Site Survey Program and to disable the electronic Site Survey Programmer.

The drive power source of the assembly is a two-phase, reversible, 13-volt, 400-cycle, AC motor which drives through an integral 400:1 reduction gear train and a torque limiting clutch (Figure 3-7). Torque is applied to an external gear train which drives both the primary arm of a toggle mechanism and the cam of a mechanical programmer. The latter is driven through a one-way action, pawl-type clutch, since the motor/gear train action is reciprocating. The cam is accurately positioned during its cycle by a series of detents.

The primary toggle arm is connected by a spring to the secondary arm which is, in turn, connected to the flip cable driver pulley through a 3:1 step-up gear train. Toggle action of the assembly, then, causes the appropriate drive cables to rotate the sensor and to hold them against their travel limit stops.

The motor exerts approximately 17 in-ozs of torque. The slip clutch limits the torque to 10 in-oz. The 3-1 step-up gear train applies a maximum of 30 in-oz to the drive cables at the base of the arm. The torque at the top of the arm is approximately 4 in-oz. The restraining torque against each stop is greater than 1 in-oz.

As indicated, the primary arm also drives the one-way clutch, through which is driven the mechanical programmer cam. The reciprocating motion of the primary arm as the sensor is flipped between the 0° and 180°



GIMBAL/FLIP DRIVE AND CONTROL MECHANISM

FIGURE 3-7

positions causes the cam to advance to a new detent position on each 1/2 cycle. A cam follower attached to the sensor 90° stop cable is pulled into position at the proper time. In this condition, the sensor will flip from 180° to 90° instead of from 180° to 0°. In addition, an eccentric crank pin is attached to the cam, to which is fixed the gimbal trigger cable. This cable actuates the gimbal release pin in the sensor head. The cam rotation pulls this cable at the proper time in the Site Survey Program to initiate the sensor gimbal action.

For the Site Survey Program, power to the electronic programmer is shut off by means of a single pole switch. The switch is closed by the movement of the Z axis cam to its final detent position, whereupon a pin protruding from the final cam drive gear closes the switch.

3.2.1.4 Orientation and Alignment Monitors

The following devices are included in the electromechanical subsystem for determination of alignment or index position:

1. Flip Position Detector

Purpose	- Monitors magnetometer sensor orientation relative to the instrument based coordinate system.
Location	- One in each sensor head (See Figure 3-2).
Reading	- Remote through data link (binary data encoded within the engineering subframe).
Design	- The flip position detectors are open-multipleplate, variable capacitors, one for each position; 0°, 90°, 180°. Capacitor construction is of plastic, with gold plating to provide the metallic surfaces. The stator

is fixed to the sensor head housing, and the rotor is attached to the sensor shaft. The rotor is grounded so that when the rotor leaves are meshed with the stator leaves, the capacitance to ground is at a maximum. The capacitor design gives a minimum charge of 40 picofarads (pf). The flip position detector locates the position within ± 10°. This detector is used for a gross measurement, indicating only that the sensor is in either the 0°, 90°, or 180° location. The detector is not used to determine how accurately the sensor is positioned. (The actual position accuracy is ± 5').

2. Gimbal Detector

Purpose	- Differentiates between pre-and post-gimbal orientations of the magnetometer sensor.
Location	- One in each sensor head (See Figure 3-2).
Reading	- Remote through data link (binary data encoded within the engineering data subframe).
Design	- The gimbal detector consists of a microswitch actuated by cam action. The cam has a shim, which is adjustable, to position the cam to allow detection of the gimbal action. As is the case with the flip position detector, the gimbal detector simply indicates the gross position. It does not determine the accuracy of the position.

3. Electronic Level Sensor

Purpose	- Monitors LSM orientation relative to local Lunar vertical.

Location - Mounted on GFU (see Figure 3-3).

Reading - Remote through data link (7 bit words subcommutated within the engineering data subframe).

Design - This detector is a conductive, fluid-type gravity level with a biaxial electrode configuration built by Kearfott Corporation. In conjunction with a bridge-type circuit, the sensor produces two analog outputs proportional to the two angles (in normal planes) between the local vertical and the instrument based vertical within a $\pm 15^{\circ}$ range and with a resolution of $1/4^{\circ}$.

4. Visual-Level Sensor

Purpose - Permits astronaut leveling of the LSM to within $\pm 3^{\circ}$ of local vertical.

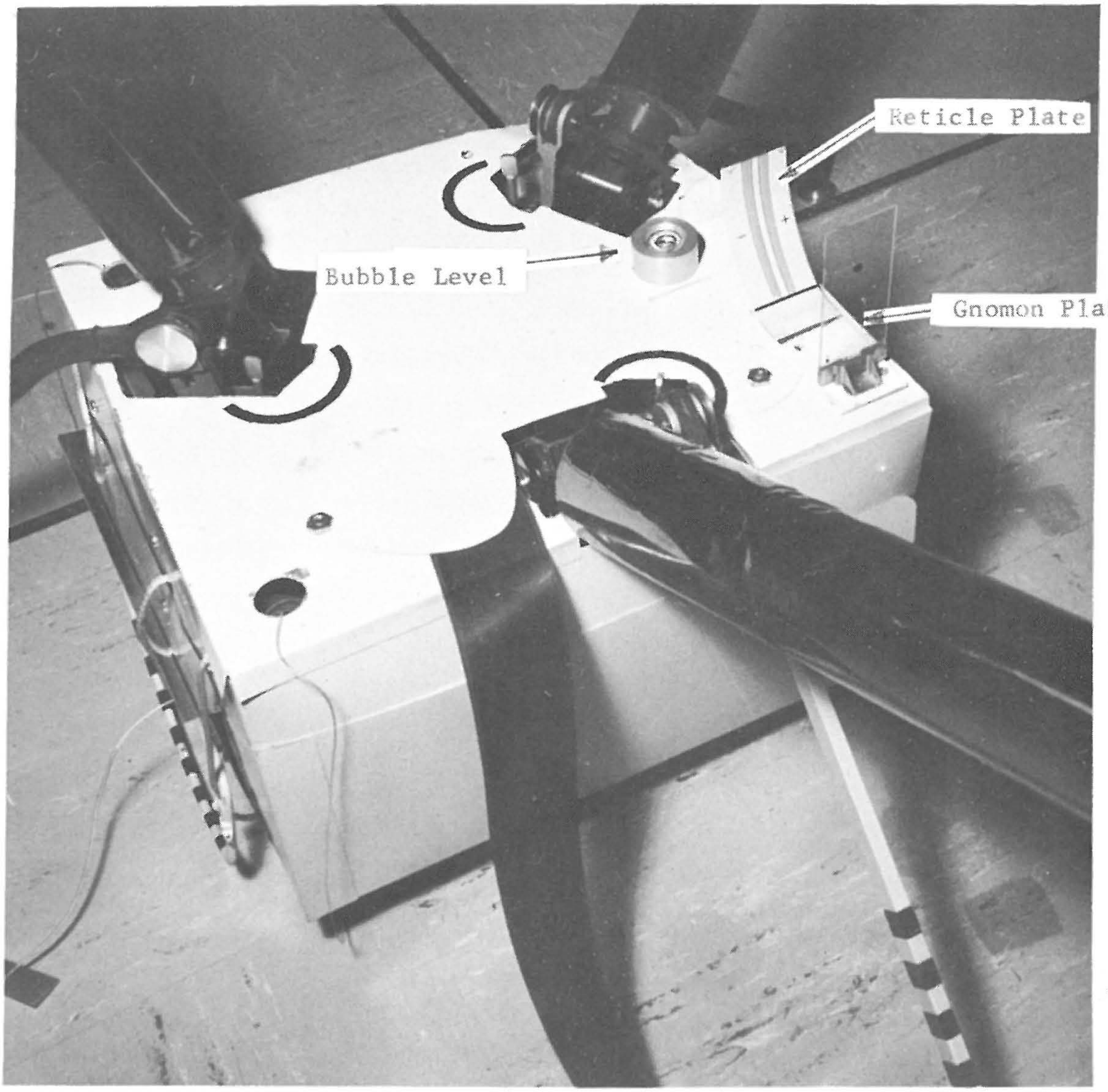
Location - Mounted permanently above the thermal blanket on the GFU (See Figure 3-8).

Reading - Visual only.

Design - This detector is a Geier-Bluhm circular omni-axis bubble level with a $\pm 3^{\circ}$ range and with 1° reticles marked on the glass. At standard conditions the bubble just fills the center reticle.

5. Shadowgraph

Purpose - Permits azimuthal orientation of the LSM by the astronaut and determines the relative angle between the instrument and the East-West (Sun) Line.



Visual Level Sensor and Shadowgraph

Figure 3-8

Location - Mounted above thermal control blanket over GFU between X and Z sensor support arms (Figure 3-8). Fiberglass mounting pylons are anchored to the GFU shroud and penetrate the thermal blanket.

Reading - Visual only.

Design - The shadowgraph consists of a curved reticle plate and a transparent gnomon plate, both mounted on a common base plate such that they will fold flat for stowage. The two plates are spring-loaded to deploy automatically when released. The gnomon and reticle are drawn on the plates with black epoxy ink. The shadowgraph is oriented over the GFU so that the sun casts a shadow of the gnomon on the reticle plate when the Z sensor support arm is oriented towards the sun.

The reticle is marked with two sets of four vertically ruled lines spaced at corresponding one-degree intervals. The two sets of lines are divided by a space equal to the diameter of the image of the gnomon which denotes exact alignment with the sun within the shadowgraph's tolerance. Each successive line of a set indicates an out-of-alignment condition in 1° increments up to the maximum range of $\pm 3^\circ$. The sign of the misalignment is also marked on the reticle. The reticle lines are not parallel but are spaced to maintain a constant accuracy over the range of solar elevation angles from 0° to 45°.

3.2.1.5 Support Legs

The three lunar surface support legs are mounted on the GFU, each in close proximity to a sensor support arm. Each leg consists of two articulated links, an adjusting mechanism, and a foot pad.

The Y and Z axis legs (i.e., the legs neighboring the Y and Z axis sensor arms, respectively) have similar adjustment mechanisms which consist of a worm and worm wheel segment, the latter driving the short link. The worm wheel is turned by the adjustment "screw" which protrudes vertically from the GFU, shroud, and thermal blanket. The short link is connected to the main leg section by a pin and a detent. Retraction of the detent allows the leg to be raised for stowage. The maximum angular excursion of one leg about the line connecting the other legs is 12°.

The X axis leg is similar to the Y and Z legs except that the adjustment mechanism utilizes a traveling nut connected to the short link to provide its adjustment force. The nut travels on a long screw which is canted towards the opposite corner of the GFU and protrudes above the thermal blanket.

3.2.1.6 LSM Mounting System

The LSM mounting system (FIgure 2-3) is used to secure the stowed instrument on the ALSEP pallet,in the LSM shipping container, and on the flux tank pedestals. Two primary attachment points are utilized, one on the GFU and the other on the sensor support arms.

The lower mounting bracket is attached to the GFU and consists of a microsealed aluminum block (Figure 2-3 with two parallel holes of approximately 1/2 diameter. These holdes receive the main mounting pins attached to ALSEP, the shipping containers, and the flux tank pedestals. A double "horseshoe" slide with a locking linkage is included which engages grooves in the ends of the mounting pinds, thereby locking the bracket to the pins. The slide linkage is engaged by the locking tool which is inserted through a guide tube protruding from the side of the GFU opposite to the mounting bracket.

The upper mounting bracket (Figure 2-3) consists of a two-part aluminum frame enclosing a segmented foam block assembled around the folded sensor support arms and legs. The block has six holes (two for each folded arm) and three slots (one for each leg). Two additional large holes are included for use in removal of the bracket. The upper frame section incorporates a folding handle which is used when removing the LSM from ALSEP or from the shipping container. The two ends of this section engage the mating ends of the lower frame section. The lower section includes holes which constitute the other attachment point on ALSEP and within the shipping container. These holes accommodate screw-type locking fasteners which serve to mount the upper bracket. Keyed washers are included beneath the fasteners to which are attached the ends of a continuous cable. This cable is threaded through guides so as to encompass the upper frame. The cable then passes through a hole in a pin in the center of the upper frame. When the pin is rotated, the cable winds on the pin, thereby tightening the two halves together. The pin is provided with a square shoulder which mates with a square hole in the frame for locking purposes.

An additional brace assembly (Figure 2-3) is included in the mounting system which connects the base of the lower frame section of the upper bracket to the GFU. This brace is roughly a large "U"-shaped member, the ends of which mate with the same fasteners which secure the upper bracket to the ALSEP. The closed end of the "U" has holes at the corners which receive retractable pins protruding from two stand-off corner brackets mounted on the GFU. Locking levers attached to the cross member of the brace assembly have hooks which engage slots in these pins to lock the brace to the GFU. A separate locking device is attached to the brace cross member to lock the locking levers in place when stowed. Release cables for the locking device and for each of the levers are attached to these items and are secured to the upper frame half of the upper mounting bracket. Pulling on these cables as the upper frame half is removed releases the lock and disengages the lever hooks and pins. When the hooks are disengaged, the pins automatically retract within their brackets. This is accomplished through the use of a cable attached to each pin through through a guide hole to a common spring between the two brackets in the GFU.

3.2.2 Processor Electronics Subsystem Components

The LSM Processor Electronics Subsystem is housed within the Electronics Gimbal Flip Unit (EGFU). Three separate electronic assemblies plus the chassis and cover make up the subsystem. The electronic assemblies are as follows:

1. A-1 interconnect or motherboard which supports and interconnects all analog function modules.
2. A-2 interconnect or motherboard which supports and interconnects all digital function modules.
3. A-3 interconnect harness which interconnects the A-1 and A-2 boards.

The Processor Electronics Subsystem is arranged as shown in Figure 3-4 with the A-1 board supported above the A-2 board by three spacers in the vicinity of the center of the boards and by the chassis at the board edges. The boards are oriented so the electronics modules are inside and back-to-back, leaving the connector modules external on the uppermost board.

The modules on the A-1 board include the following:

1. Multiplexer and A/D Converter Module
2. Engineering Data Electronics Module
3. Magnetic Sensor Electronics Module
4. Sensor Driver Modules
5. Calibrate/Offset Bias Generator Module
6. Electrical Interface Connector Modules

The digital modules on the A-2 board include:

1. Arithmetic Module
2. Scientific Sequencer Module
3. Engineering Sequencer Module
4. Site Survey/Flip Calibrate Sequencer Module
5. Output Data Buffer Module
6. System Timer Module
7. Power (DC-DC) Converter Module
8. Memory
9. Offset Command Logic Module

The two interconnect boards are 10-layer epoxy laminates with copper circuit traces, a voltage ground, and a heat sink layer. Tubelets (see Figure 3-9) penetrate the board where connections are to be made and are tab-welded to the proper trace.

The two boards are themselves interconnected by means of the A-3 interconnect. This is a group of several independent multiple conductor ribbon cables with flat copper conductors imbedded in mylar. Each cable connects between terminal strips which are part of the A-1 and A-2 boards.

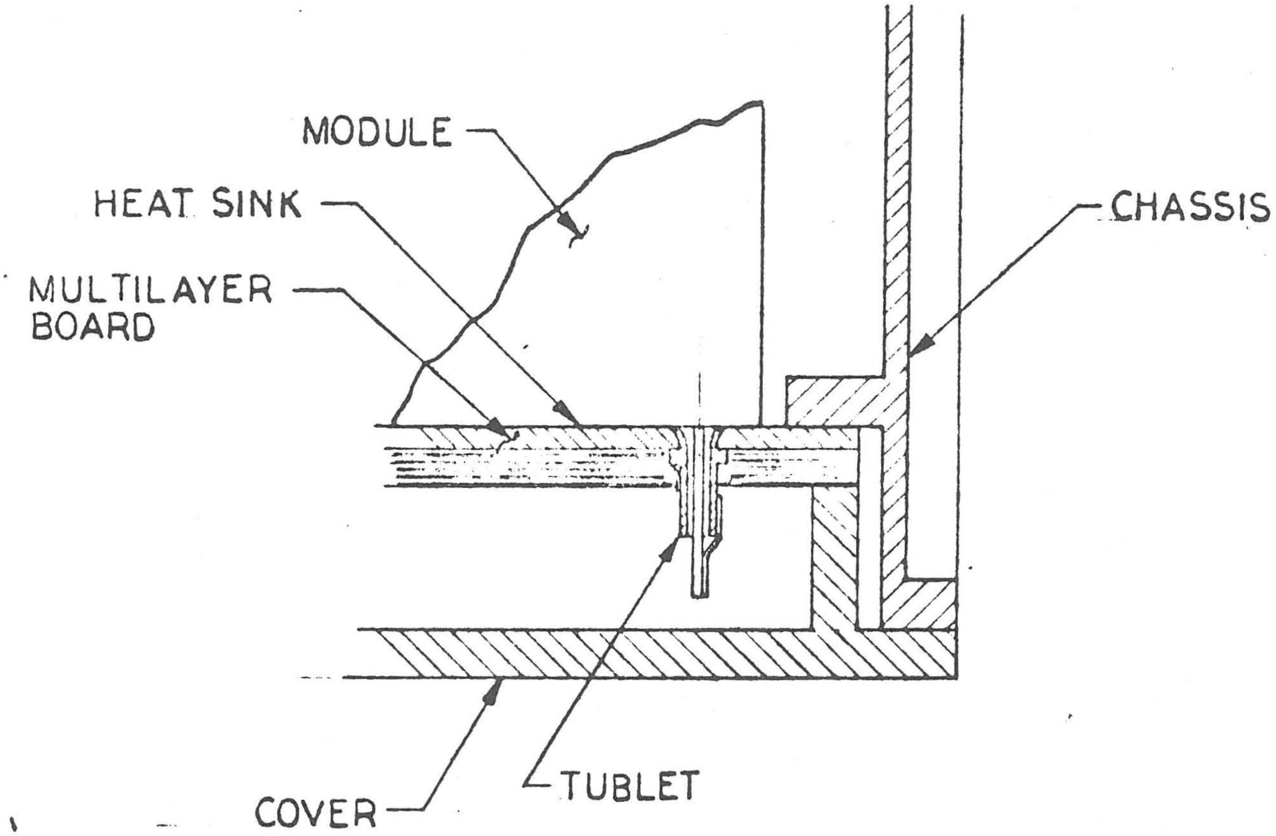


FIGURE 3-9

TUBLET

The modules are of two distinct types:

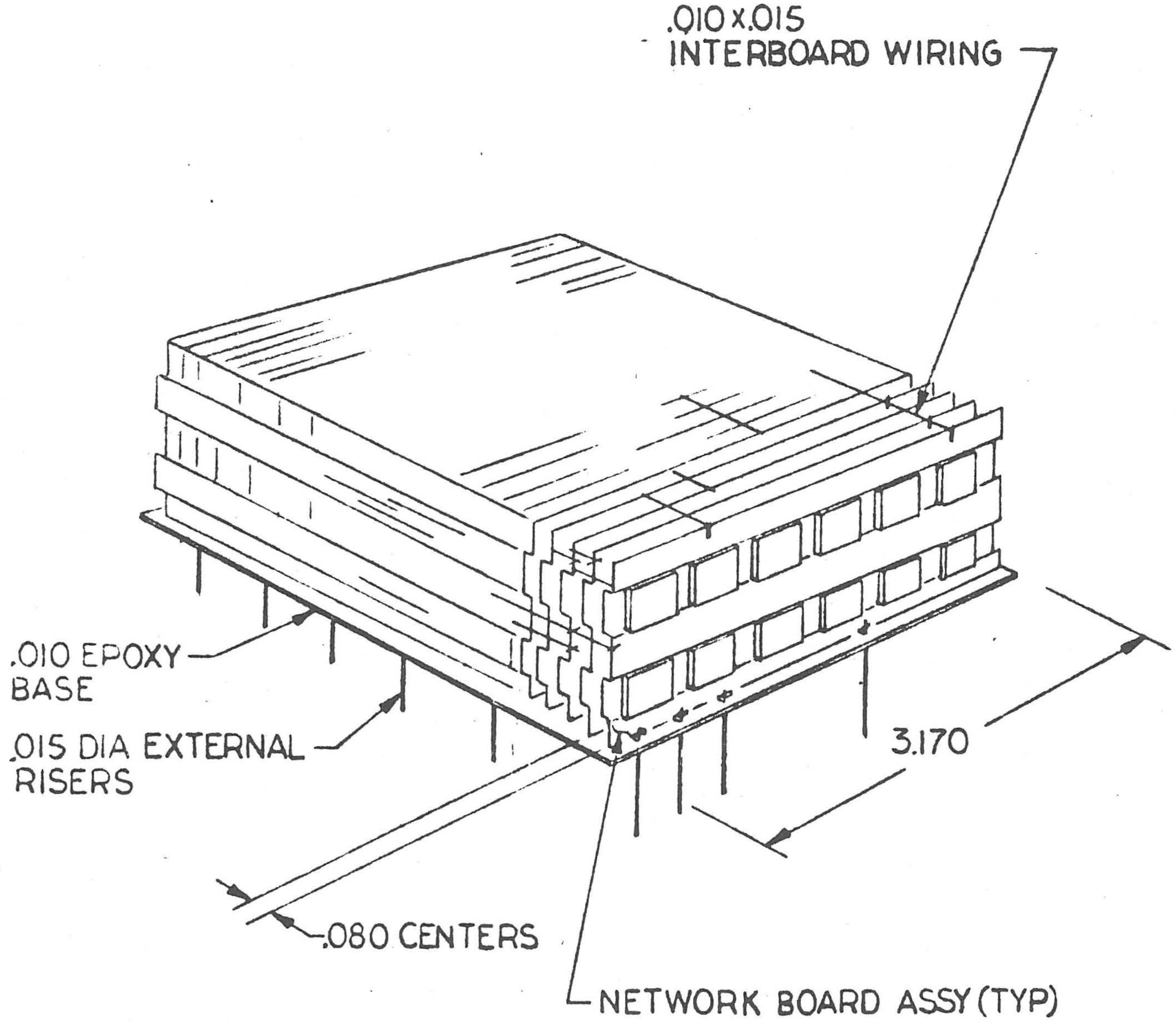
1. Formed substrate modules
2. Cordwood modules

The formed substrate modules (Figure 3-10) are used where the circuitry is composed of a group of micro-electronics integrated circuits. These devices are welded to formed substrates on which the interconnecting circuitry has been printed (Figure 3-11). A voltage ground plane board which surrounds each integrated circuit is then added. The number of integrated circuits per board varies from 4 to 12.

The substrates are interconnected with leads welded to tabs at the edges and dressed along three outside edges of the module. The module connection pins protrude from the fourth edge, or base.

After the completed module is potted with foam, the pins are inserted into the appropriate tubelets in the proper interconnect board. Tabs on the tubelets are then welded to the pins as shown in Figure 3-11.

Cordwood modules (Figure 3-12) are used where the circuitry is composed of discrete electronic components, i.e., resistors, capacitors, transistors, etc. These are "stacked" (as shown in Figure 3-12) with their leads protruding through mylar header boards at each end. Internal interconnect wires are welded to the leads and an additional insulating mylar board is bonded in place. Risers or external leads are then welded to the appropriate points and fed through the base epoxy board which also is bonded in place. The risers form pins which are inserted through the tubelets in the interconnect board and are welded after the module has been potted in foam.



FORMED SUBSTRATE MODULE

FIGURE 3-10

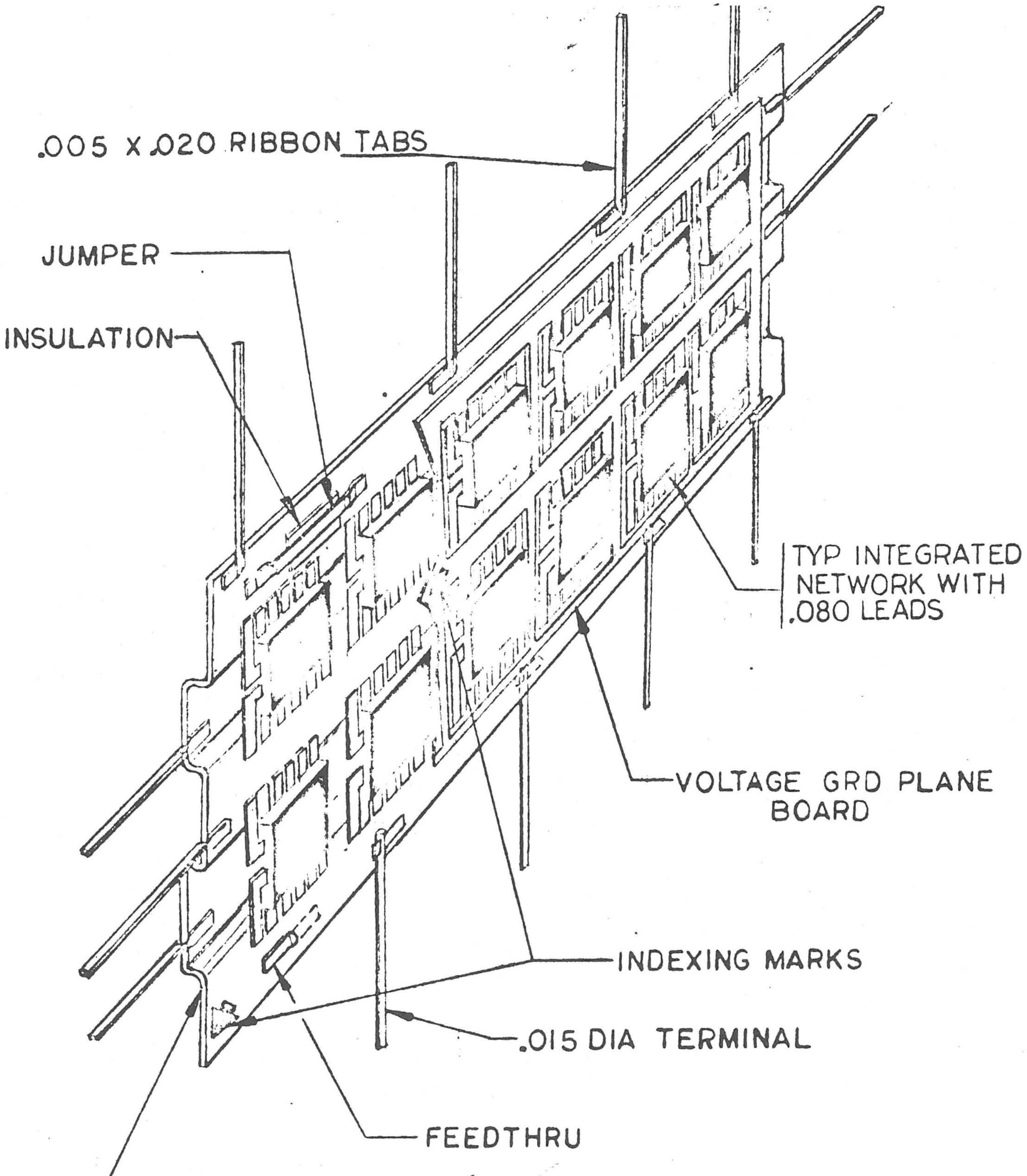


FIGURE 3-11

FORMED SUBSTRATE MODULES (INTERCONNECTS)

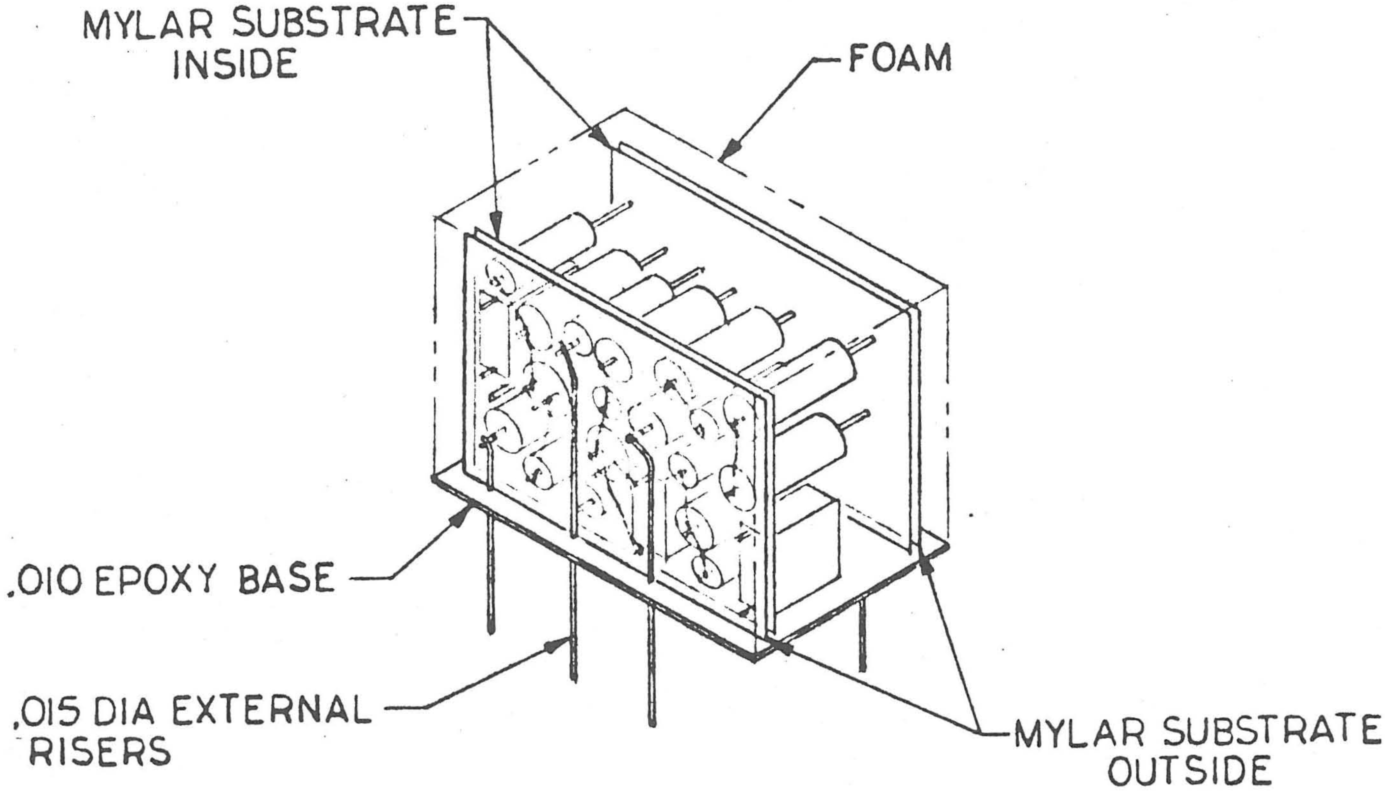


Figure 3-12

Typical Cordwood Module

The memory system utilizes a somewhat more conventional packaging concept in that discrete components are laid in a flat position. This unit is also potted with foam.

3.2.3 Thermal Control Subsystem Components

The LSM Thermal Control Subsystem components may be categorized by the three basic thermal functions which follow:

1. Provide controllable heat flow paths (e.g., surfaces with controlled emittance properties).
2. Provide variable internal heat generation (e.g., resistance heaters).
3. Limit heat flow through non-adjustable paths (e.g., insulation blankets).

Such components provide the means of rejecting internally-generated heat to space. Additionally, they provide a sufficient degree of static or pre-set control to maintain this heat rejection within acceptable limits over the wide excursions of the Lunar thermal environment.

Thermal control components associated with each sensor head consist of a thermal control surface, a fiberglass housing which also provides structural support, glass heat felt insulation, and resistance heaters. The control surface is a three-inch diameter fiberglass cap located on the top surface of the housing. This cap is removable by means of screws and provides physical access to the interior of the sensor assembly. The inner surface of the cap is coated with aluminized mylar bonded with the aluminum side facing out to achieve the required infrared emittance ($\epsilon < 0.1$).

The outer surface of the cap plus the remaining upper surface of the housing is covered with white paint (S13G) having a low solar absorptance to infrared emittance ratio ($\alpha_s/\epsilon \simeq 0.2$). All other housing surfaces are covered with glass heat felt insulation to minimize heat loss. Electronic heaters (Max. Power, 1 W) are mounted within the housing to provide nighttime heating.

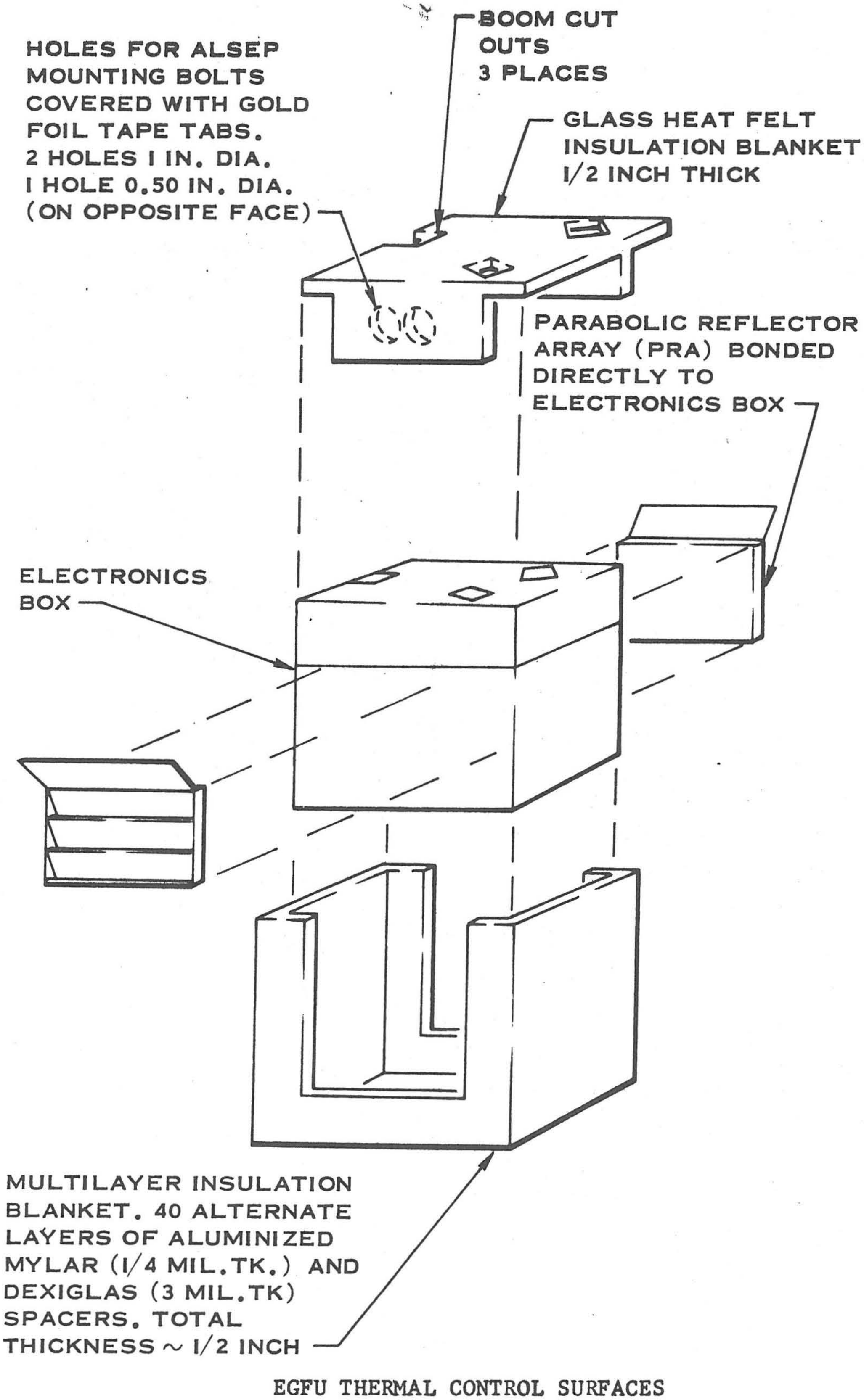
The EGFU thermal control system is composed of the following major items (Reference Figure 3-12).

A. Parabolic Reflector Arrays (PRA), each consisting of:

1. Three thermal control surfaces each composed of an aluminum radiator painted with a high emissivity white paint ($\epsilon \simeq 0.9$). Each radiator is conductively coupled to an aluminum back-up plate.

2. Three parabolic-shaped reflector surfaces each mounted above a corresponding thermal control surface radiator. The reflectors are composed of aluminum-coated, foamed plastic with a parabolic shape and a focal line just off the edge of its mating thermal control surface.

3. A sunshade mounted above the uppermost reflector and aligned to shade the thermal control surface from direct sunlight when the sun is at or near its zenith. The sunshade is hinge-mounted to allow folding over the reflector arrays, and spring-loaded for automatic deployment upon release.



EGFU THERMAL CONTROL SURFACES

FIGURE 3-13

As illustrated in Figure 3-12,a PRA is mounted on each of two opposite sides of the EGFU. The aluminum back-up plate acts as a mounting structure and a conduction path from the EGFU. This plate is bonded directly to the EGFU chassis. All EGFU surfaces except the PRA are covered with thermal insulation. The sides and bottom of the EGFU are blanketed with a multilayer aluminized Mylar-Dexiglas insulation (suitably cut to accommodate the arrays), while the top surface is covered with glass heat felt insulation.*

Various internal electronic heaters are provided to make up the heat lost from the system during the lunar night. Heaters are provided in each sensor head and in the EGFU. The sensor head heaters are wire wound, forming a flat disk 0.87 inches in diameter and approximately 0.025 inches thick. The winding consists of two layers wound in opposite directions to cancel the magnetic fields in each resulting from the 14.7VDC applied voltage. Two of these 0.5 watt heaters are attached to each magnetic sensor support shaft outside of the support frame. Power leads are attached to the terminal strip on the frame.

The heater used in the EGFU is distributed in three elements each consisting of a double wire-wound resistor, and dissipates approximately 2.3 watts of power. This heater is electrically connected to the same power switching circuit as are the sensor heaters and, therefore, is simultaneously controlled.

Heater control is achieved by an internal feedback system consisting of a thermistor sensing element and associated electronic control circuits.

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* Glass heat felt insulation, although characterized in general by a lower thermal resistance than the multilayer insulation, is preferred for applications where numerous penetrations are required (e.g., EGFU top surface) or where complex shaping is needed (e.g., sensor housing).

The controlling thermistor is located in either the X or Y axis sensor head, selection being via ground command. An override to shut all heaters off may be initiated by ground command.

Heat loss through the sensor support arms is reduced by wrapping each arm with multilayer insulation except in the region of the upper hinge where the heat loss is a minimum. Glass heat felt insulation boots are used to cover the lower hinges of each support arm.

3.3 LEADING PARTICULARS

3.3.1 General

The complete instrument weighs approximately 18 pounds, stows within the restricted envelope dictated by the ALSEP design, and requires approximately 5.8 watts of continuous electrical power for normal daytime operation. At night, an additional 5.8 watts of power is available for heating. During calibration, an additional 3.5 watts of power are required for flipping the sensors. A list of primary instrument properties is given in Table 3-2.

TABLE 3-2

1. Sensor Elements	Fluxgates (three)
2. Dynamic Range	0 to ± 400γ (nominal; in three linear ranges of ± 100γ, ± 200γ, ± 400γ
3. Resolution	± 0.2γ
4. Frequency response	DC to 0.6 cps
5. Digital Filter Characteristics	Normalized pole positions -0.65722 ±j0.83016; -0.90476 ±j 0.27091
6. Angular Response	Proportional to cosine of angle between magnetic field and sensor axis
7. Long-term Electronic Stability	Drift less than ± 0.2γ in 24-hour period for constant temperature
8. Bias Offset	0, ± 25%, ± 50%, and ±75% nominal full scale
9. Calibration Raster	+ and -0, 25%, 50%, and 75% of nominal full scale
10. Sensor Geometry	(a) Three orthogonal axes 40 inches long (b) 60 inches between sensors and 26 inches off lunar surface (c) Orientation determination using biaxial level sensor and shadowgraph to within 1 degree in lunar coordinates

11. Vertical Component of Curl $\vec{H}$	1×10^{-8} amp/cm^2 minimum sensitivity
12. Power	3.5 watts average nominal scientific operation. (See section 3.3.4 for further details.)
13. Weight	Less than 18 pounds. (See section 3.3.2 for further details.)
14. Size	Approximately 10" x 11" x 25" in folded ALSEP configuration.
15. Temperature Range	Operating: -30°C to $+65^\circ$C.
16. Life	1 year reliability goal of 0.99
17. Modes of Operation	(a) scientific X, Y, Z orthogonal measurements (b) site survey of magnetic field gradients (c) internal calibration
18. Command Capability	Both internal and ground commands
19. Engineering Readouts	Temperature, voltage, orientation
20. Magnetic cleanliness	$\simeq 2\gamma$ at sensor positions

3.3.2 Weight

The weight distribution for the LSM is given in Table 3-3. These numbers are not absolute since the weight of each model has varied slightly due to minor design changes. The numbers do give a good indication of the weight distribution to each subsystem.

3.3.3 Size/Form Factor

The restricted envelop for the stowed LSM is given in Figure 3-13.

TABLE 3-3

LSM WEIGHT SUMMARY*

MECHANICAL	6.88			
Structure		3.35		
EGFU Cover			0.87	
Support Arms			1.49	
All Hinges				0.41
Harness				0.52
Tubes				0.56
Legs			0.99	
Sensor Hardware Assemblies (3)		0.90		
Head Gimbal (each)			0.08	
Magnetometer Sensor (each)			0.06	
Stops (each)			0.01	
Position Sensor (each)			0.13	
Heater (each)			0.02	
Flip Mechanism		1.10		
Motors (3)			0.45	
Toggle Mechanism			0.55	
Miscellaneous Hardware				
Level Sensor		0.39		
Shadowgraph W/Brackets		0.16		
THERMAL CONTROL	2.78			
Blanket		2.25		
Sunshades		0.20		
Parabolic Array		0.33		
ELECTRONICS	6.91			
ALSEP MOUNTING	1.51			
Upper Mounting Bracket		0.58		
Braces		0.87		
Tool		0.06		
TOTAL LSM ASSEMBLY	17.29 lbs.			

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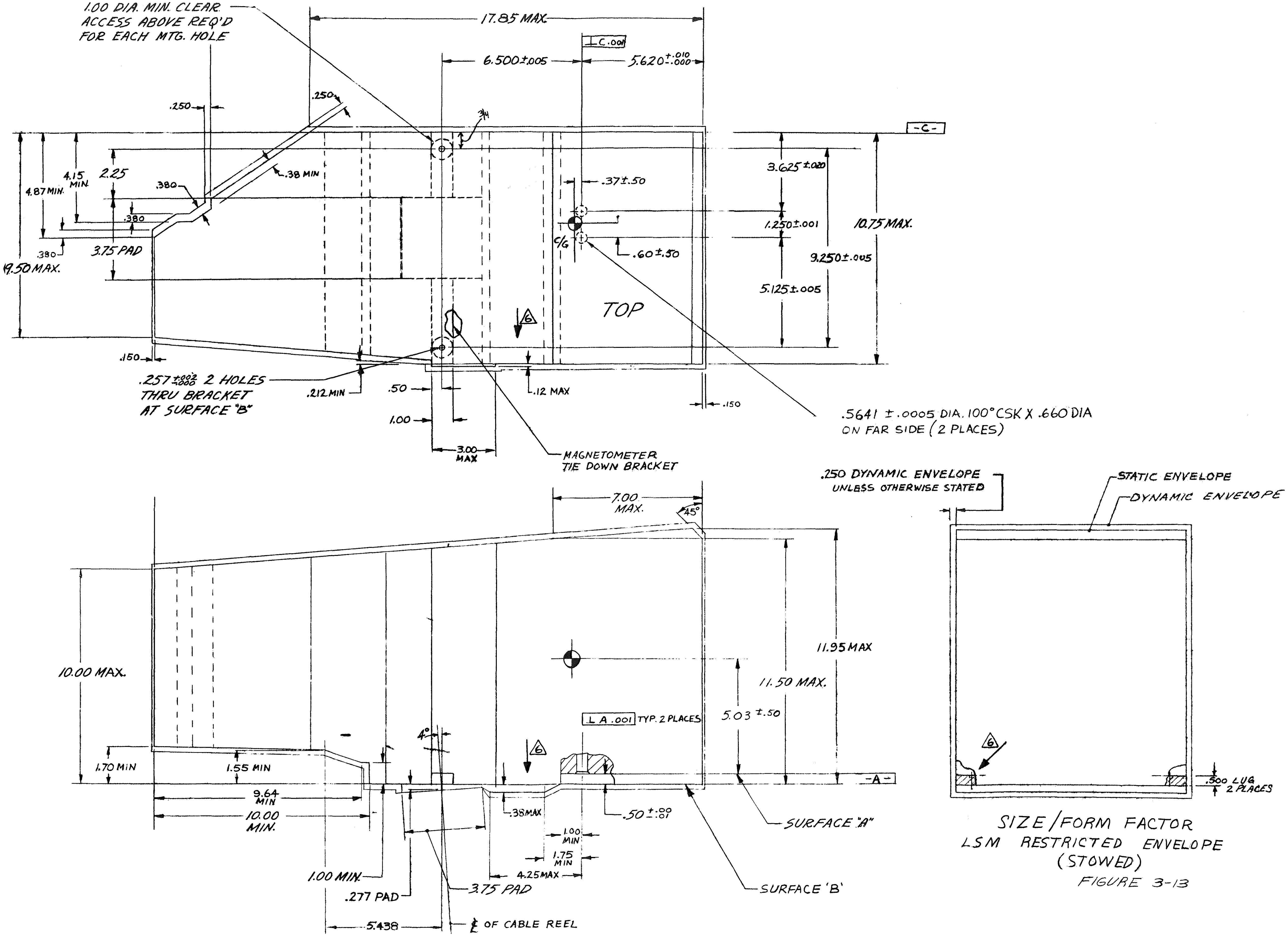
* Based on weighings and estimates of LSM #2. The approximate weight of LSM #3 is 18.5 lbs.



SIZE/FORM FACTOR
LSM RESTRICTED ENVELOPE
(STOWED)
FIGURE 3-13

3.3.4 Power Requirements

The power profile for the LSM is given in Table 3-4.

TABLE 3-4

LSM POWER PROFILE

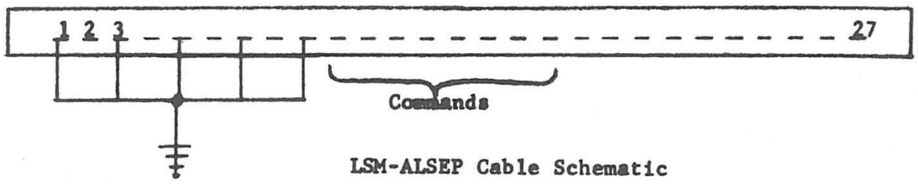
Operating Mode	Average Power	Instantaneous Power
Scientific - Day	3.95 watts	5.8 watts
- Night	9.1	10.85
Flip/Cal		
Motor Off - Day	4.95	6.9
- Night		11.9
Motor On	7.2	9.2
Site Survey	5.6	
Motor Off	5.2	
Motor On	7.45	9.4
Turn On		10.2

3.3.5 ALSEP Cable

The wire assignments for the ALSEP Cable are given in Table 3-5.

TABLE 3-5

CONDUCTOR	SIGNAL	LSM CONNECTOR (P6)	
1	Shield	N.C.	
2	Data	2A	
3	Shield	N.C.	
4	Frame Mark	2B	
5	Shield	N.C.	
6	Shift Pulse	2C	
7	Shield	N.C.	
8	Demand Pulse	2D	
9	Shield	N.C.	
10	CM-1 Range Select	2E	
11	CM-2 Steady Field Offset	1F	
12	CM-3 Offset Address	2F	
13	CM-4 Flip-Cal Inhibit	1G	
14	CM-5 Flip-Cal Initiate	2G	
15	CM-6 Filter Bypass	1H	
16	CM-7 Site Survey	2H	
17	CM-8 Temperature Control	1J	
18	Data Return	2J	
19	Chassis Return	Chassis	
20	Power Return	1L	
21	Operating Power	2L	
22	Power Return	2M	
23	Operating Power	1M	
24	Power Return	1N	
25	Operating Power	2N	
26	Power Return	2P	
27	Operating Power	1P	
		1A	Spare Contacts
		1B	
		1C	
		1D	
		1E	
		1K	
		2K	



LSM-ALSEP Cable Schematic

SECTION 4

FUNCTIONAL DESCRIPTION

As discussed in previous sections, the LSM comprises a complex system designed to operate on the lunar surface for one year. The system is self-contained except for ALSEP-supplied main bus power and telemetry, timing, and command links.

Normal acquisition and processing of data, both scientific and engineering/diagnostic, proceeds continuously in any of the operational configurations (e.g., measurement range, range offset, etc.) selectable by ground command. Calibration of the scientific data is initiated periodically by automatic ALSEP-supplied command or on an "as required" basis by ground command. In a similar manner, the complex series of operations required to perform site survey is carried out by ground commands triggering internally-programmed sequences. Electronic operational sequences are converted to the required magnetic sensor orientations by the electromechanical subsystem. The instrument provides its own power and thermal control.

A functional block diagram for the LSM electronics is shown in Figure 4-1. While this diagram is adequate to indicate the operation of the LSM electronics and to introduce the LSM/ALSEP electrical interface, a complete description of instrument operation requires a broader view. As illustrated by the brief introduction in the preceding paragraph, the overall operation of the LSM can be categorized functionally as follows:

1. Electromagnetic Measurement and Housekeeping
2. Data Processing
3. Calibration and Sequencing

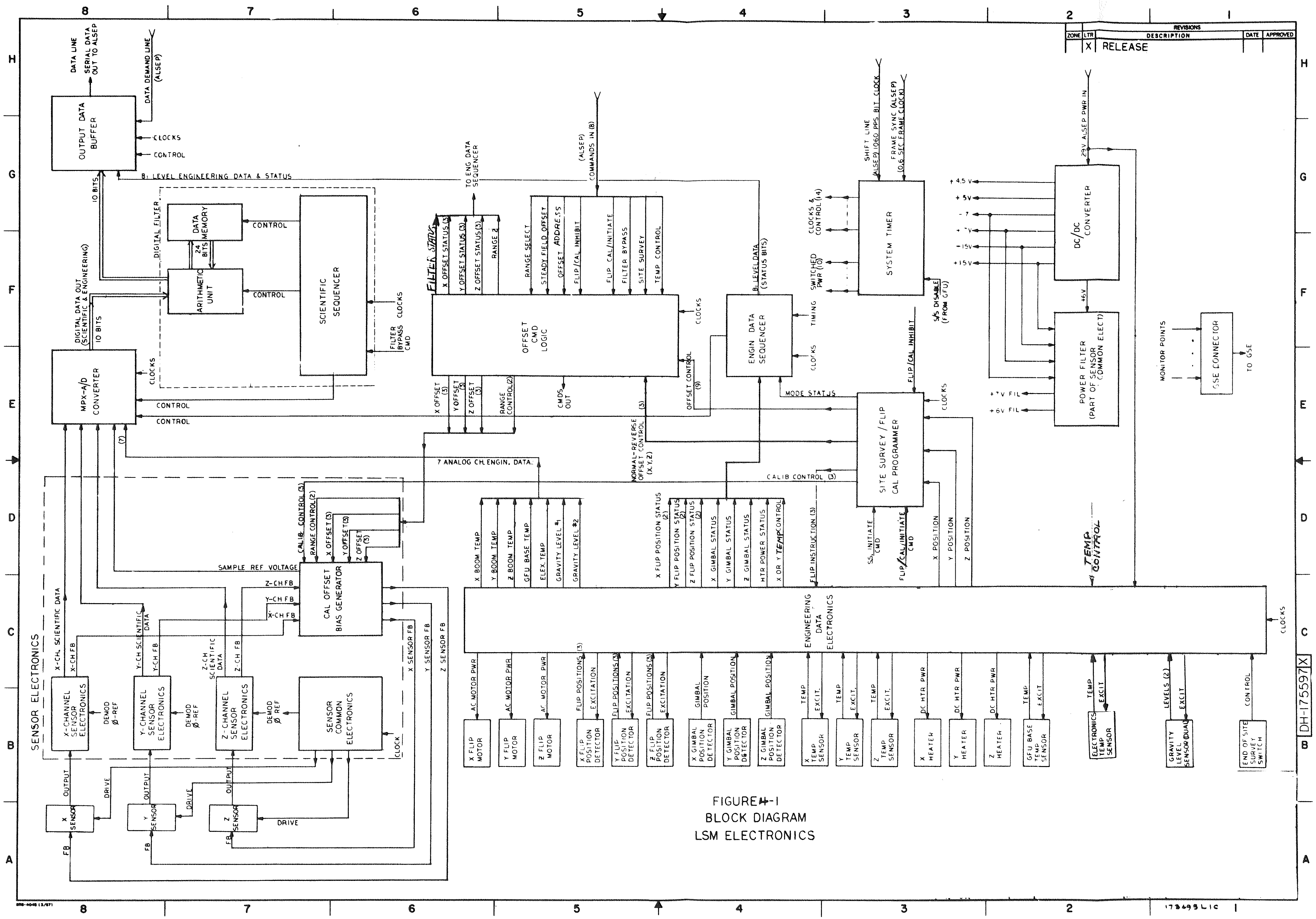


FIGURE 4-1
BLOCK DIAGRAM
LSM ELECTRONICS

4. Sensor Orientation
5. Power Control
6. Thermal Control

Housekeeping

The following housekeeping data is provided by the LSM:

Temperature. - 5 channels (X, Y, Z sensors, Electronics, and Gimbal-Flip Unit)

Tilt. - 2 Axes

Voltage. - +5 V Ref Supply

Fluxgate Sensor Orientation. - X, Y, Z Sensor Flip Position (Nominal)

0°
90°
180°

X, Y, Z Sensor Gimbal Position (Nominal)

Pre-Gimbal (0°)
Post-Gimbal (90°)

Range (Nominal). - ±100γ, 200γ, ±400γ

Mode. - Calibrate or Scientific

Offset. -

Offset Address	Steady Field Offset (Nominal)
X	0, ±25%, ±50%, ±75%
Y	0, ±25%, ±50%, ±75%
Z	0, ±25%, ±50%, ±75%

Heater Power. - On, Off

Temperature Control. - X axis thermistor, Y axis thermistor, or OFF

Calibration Inhibited. - In, Out

Digital Filtering. - In, Out

The greatest portion of the housekeeping function is provided by the Engineering Data Electronics subsystem. The Sensor Electronics and Offset Command Logic have internal monitor points to provide housekeeping information. The Engineering Data Sequencer accepts bi-level (state) data and processes the data to the Output Data Buffer in the proper sequence. The DC/DC converter provides output voltage as required and the System Timer provides clock signals and switched power to the other subsystems.

Each of the above listed LSM functions is diagrammatically illustrated and discussed in detail in Section 4.2. Throughout the discussion, considerable attention has been given to internal interfaces.

4.2 DETAILED FUNCTIONAL DESCRIPTIONS

4.2.1 Electromagnetic Measurement and Housekeeping Function

4.2.1.1 Block Diagram Description

Figure 4-2 shows a block diagram of those portions of the LSM which function to provide the electromagnetic measurement and the housekeeping data. The electromagnetic measurement function provides an analog voltage which is directly proportional to the incident magnetic field intensity at the fluxgate sensor. The housekeeping function provides: (1) data describing the "health" of the instrument, (2) status data defining the operational state of the instrument to permit proper interpretation of the scientific data, (3) instrument orientation data to permit referencing the vector magnetic field data to lunar coordinates, (4) monitoring of instrument temperature by five sensors, and (5) monitoring of the +5V reference supply for the magnetic field measurement calibration check.

The electromagnetic measurement function is accomplished primarily by the fluxgate magnetic sensors and the subsystem denoted Sensor Electronics. Supporting roles are played by the Offset Command Logic, the Site Survey/Flip Cal Programmer, the System Timer, and the DC/DC Converter.

Elements of the electromagnetic measurement function are introduced below and discussed in detail in Section 4.2.1.2. Elements of the housekeeping function are introduced below and discussed in Section 4.2.1.3.

Fluxgate Sensor (X, Y, Z)

The fluxgate sensor consists of a saturable core with three separate sets of windings: the Output winding, the Drive winding, the Feedback winding. The drive winding is used to stimulate the core. The second

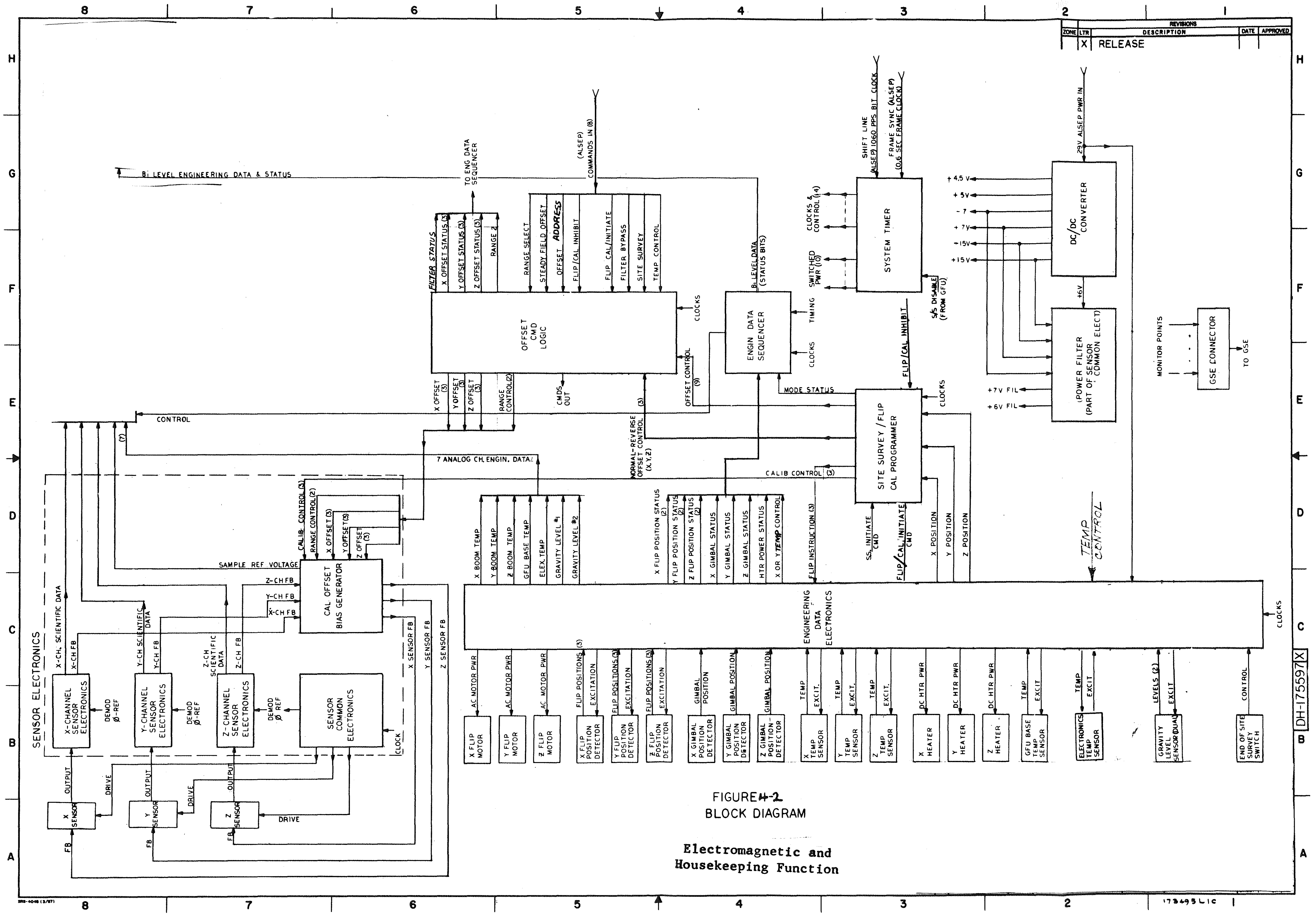


FIGURE 4-2
BLOCK DIAGRAM

Electromagnetic and Housekeeping Function

harmonic voltage induced in the output winding is supplied to the Sensor Electronics and is a function of the ambient magnetic field. The feedback winding is used to apply a signal which produces a magnetic field that cancels the ambient magnetic field. This allows the sensor to work in a linear (zero field) region at all times when the instrument is on scale.

Sensor Electronics

The Sensor Electronics is comprised of the X, Y, Z Channel Electronics, the Sensor Common Electronics, the Cal-Offset Bias Generator, and as a part of the Common Electronics, the Power Filter.

The function of the sensor electronics is to interface with the fluxgate sensor and provide an output voltage to the analog-to-digital converter. The output voltage is directly proportional to the incident magnetic field at the sensors. The Sensor Electronics provides the drive signal for the fluxgate sensor; accepts the sensor output signal, and drives the feedback winding. The Sensor Electronics requires power from the DC/DC Converter and timing signals from the System Timer to generate the sensor drive frequency and the demodulation signals in the Channel Electronics.

The parameters of the sensor electronics which have a command interface are:

1. Range: full scale value of either ±100 γ, 200γ, or 400γ may be selected.

2. Offset: a DC offset field (compensation) of ±(0, 25%, 50%, 75%) may be applied to each sensor independently. This percentage is referenced to the selected full scale range value.

The interface between the commands and the Sensor Electronics is provided by the Offset Command Logic.

Offset Command Logic

The purpose of the Offset Command Logic Subsystem in the electromagnetic measurement function is to provide range and offset control information to the Sensor Electronics.

Received commands are synchronized to an interval LSM clock. Static storage is provided by flip-flop in this subsystem for the Range Select, Offset Address, and the Steady Field Offset commands.

The range control information is applied to the Sensor Electronics in the form of a 2-bit binary code; i.e., all 3 channels (X, Y, Z) are on the same range. The offset control information is a 3-bit binary code for each sensor channel. By means of the Offset Address command, each channel may be selected independently and a unique offset is applied to that channel via the Steady Offset Command.

A three-state counter for range and three seven-state counters for offset retain memory of these conditions as long as power is applied, or until commanded to advance.

Site Survey/Flip Cal Programmer

The purpose of this Programmer in the electromatnetic measurement function is to accept the fluxgate sensor position monitor data and to provide a normal-reverse signal to the Offset-Command Logic. Normal-reverse control is necessary to maintain the desired offset field polarity when the sensor is flipped from the normal (0^o) to the reverse (180^o) orientation, or vice versa.

System Timer

The System Timer provides the clock signal required by the other subsystems. These signals are provided from a voltage-controlled oscillator-that is synchronized with the ALSEP 1060 Hz shift pulse signal.

DC/DC Converter

The DC/DC Converter accepts 29V primary power from ALSEP and provides regulated, filtered voltages as required.

4.2.1.2 Electromagnetic Measurement Detailed Description

4.2.1.2.1 Fluxgate Magnetic Sensor

The operation of the sensor is summarized by Figure 4-3. When driven by a sine wave at a frequency f_o, the output signal from the sense winding will contain a second harmonic signal component at $2f_o$, whose amplitude is proportional to the input magnetic field and whose phase relative to the drive waveform is determined by the polarity of the magnetic field. Basically, the Sensor Electronics then amplifies and filters the $2f_o$ signal and synchronously demodulates it to derive a voltage proportional to the magnetic field. After demodulation (and low pass filtering to remove the demodulation harmonics), the resulting signal is further amplified and fed back to the sensor feedback coil to null out the ambient field. The Sensor Electronics is thus a modulated carrier servo system. Because of the high loop gain, the fluxgate sensor operates essentially at null, and the resulting output voltage is that voltage required by the feedback network and feedback coil to generate a magnetic field which completely cancels the input field.

The output signal of the sense winding is not as clean as the idealized waveform shown in Figure 4-3. In practice, the output contains large

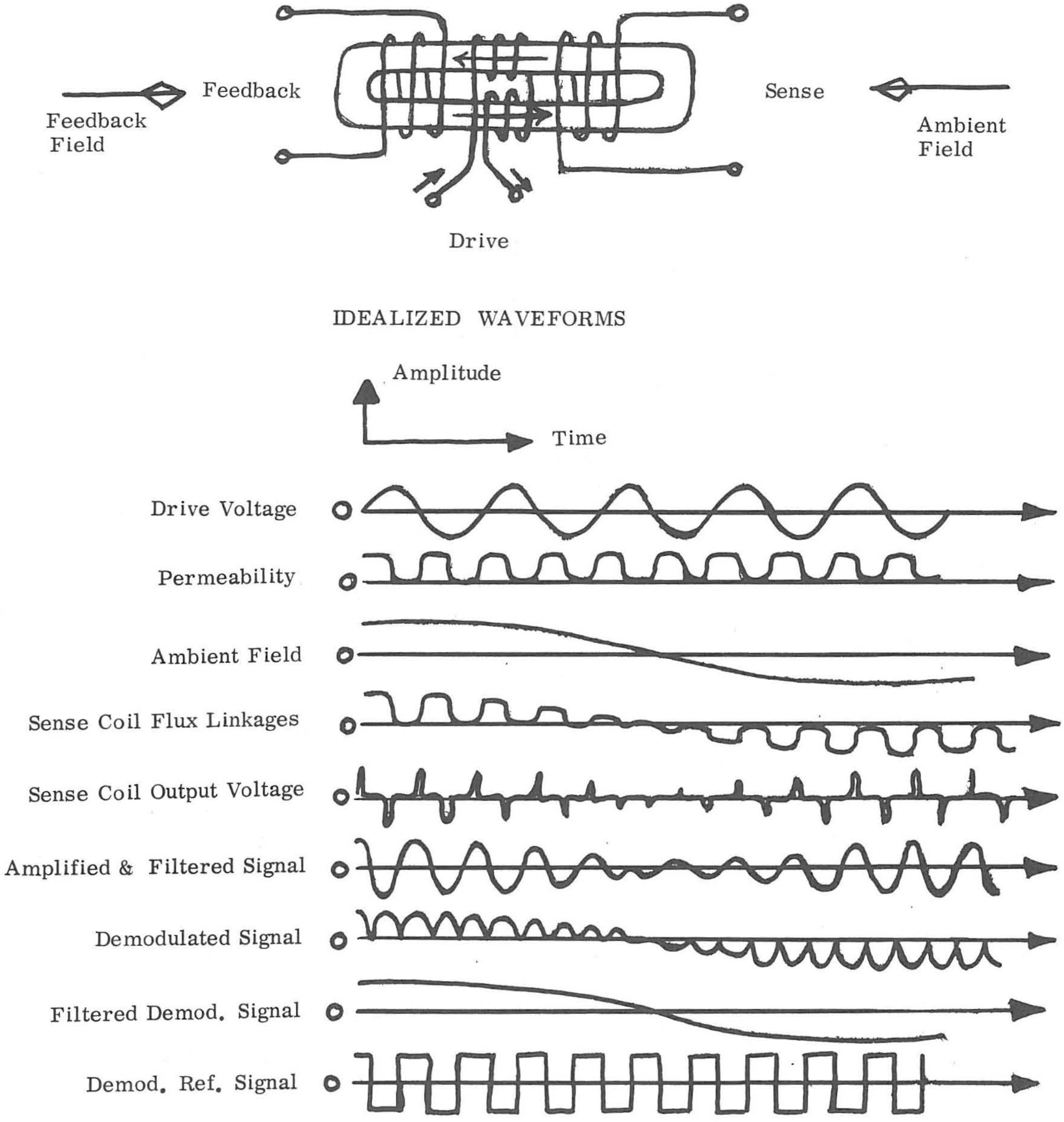


Figure 4-3 Fluxgate Sensor Representation

odd-harmonic signals due to imbalance and stray coupling. A typical null signal spectrum is indicated in Table 4-1. The amplifiers and filters must provide sufficient amplification of the desired second harmonic carrier signal while rejecting other harmonics so as to prevent saturation and harmonic distortion which can cause offsets. Harmonic distortion can cause offset by two mechanisms:

a. Second harmonic distortion of the fundamental can cause a second harmonic signal which acts exactly like a DC offset to the system.

b. Mixing of odd harmonics can generate a second harmonic signal which also acts like a DC offset to the system.

TABLE 4-1

TYPICAL LSM SENSOR OUTPUT SIGNAL SPECTRUM AT NULL

Harmonic	Amplitude
f_o	13 mv rms
$3\ f_o$	30 mv rms
$5\ f_o$	10 mv rms
$7\ f_o$	15 mv rms

Notes:

1. f_o = drive frequency (5.9625 KHz)
2. Even harmonics insignificant at null

4.2.1.2.2 Sensor Electronics

The Sensor Electronics is the heart of the scientific measurement function of the experiment and, as such, is worthy of a more detailed treatment. The basic configuration is a closed loop servo system, as shown in Figure 4-4, with a closed loop response given by:

$$G_{T(s)} = \frac{G(s)}{1 + G(s)\ H(s)}\text{, in volts per gamma.}$$

The Sensor Electronics is diagrammed in Figure 4-5.

The LSM Sensor Electronics design provides loop gain sufficiently high that system accuracy is essentially established by the feedback function H(s); e.g., in

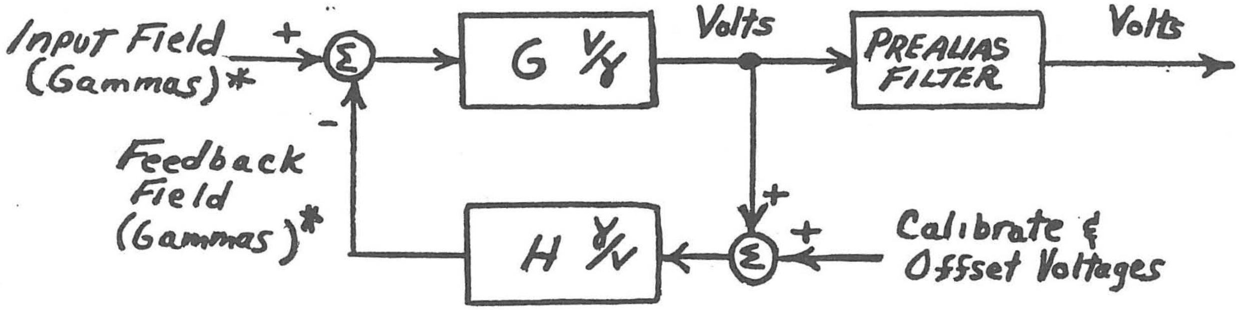
$$G_{T(s)} = \frac{G(s)}{1 + G(s)\ H(s)}$$

let $\frac{1}{G(s)}$ be much less than H(s). Then

$$G_{T(s)} = \frac{1}{\frac{1}{G(s)} + H(s)} \cong \frac{1}{H(s)}$$

Thus, the overall system (static) accuracy can be made to be essentially equal to 1/H(s). Also, range switching is readily implemented by simply altering the value of H(s). Precision wire wound resistors ($\pm 0.03\%$ and 3 ppm/°C) are used in the feedback networks, and the minimum static loop gain G(s) H(s) (which occurs on the 100 gamma range) is greater than 10^5, while H(s) (for the 100 gamma range) is 40 gammas per volt. The importance of having the design insensitive to the forward loop gain function G(s) will become more apparent in the subsequent detailed discussion of the implementation and the error analysis.

The calibrate and offset fields are generated by causing precisely known currents to flow through the sensor feedback winding. These currents in turn produce the required magnetic fields. The basic configuration of the Cal/Offset Bias generator is a network of precision summing resistors



*(1 Oersted = 1 Gamma in free space)

γ = Gamma

$$G \doteq 0.25\times10^{4}\ V/\gamma\ @DC$$

$$H = \left\{\begin{array}{l} 40\ \gamma/V \text{ on } 100\gamma \text{ Range} \\ 80\ \gamma/V \text{ on } 200\gamma \text{ Range} \\ 160\ \gamma/V \text{ on } 400\gamma \text{ Range} \end{array}\right\} \begin{array}{l} \text{for } \pm 2.5 \text{ Volts} \\ = \pm \text{ Full Scale Out} \end{array}$$

$$\text{Loop Gain, } GH = \left\{\begin{array}{l} 1.0\times10^{5} \text{ on } 100\gamma \text{ Range} \\ 2.0\times10^{5} \text{ on } 200\gamma \text{ Range} \\ 4.0\times10^{5} \text{ on } 400\gamma \text{ Range} \end{array}\right.$$

Figure 4-4 Sensor Electronics Basic Configuration

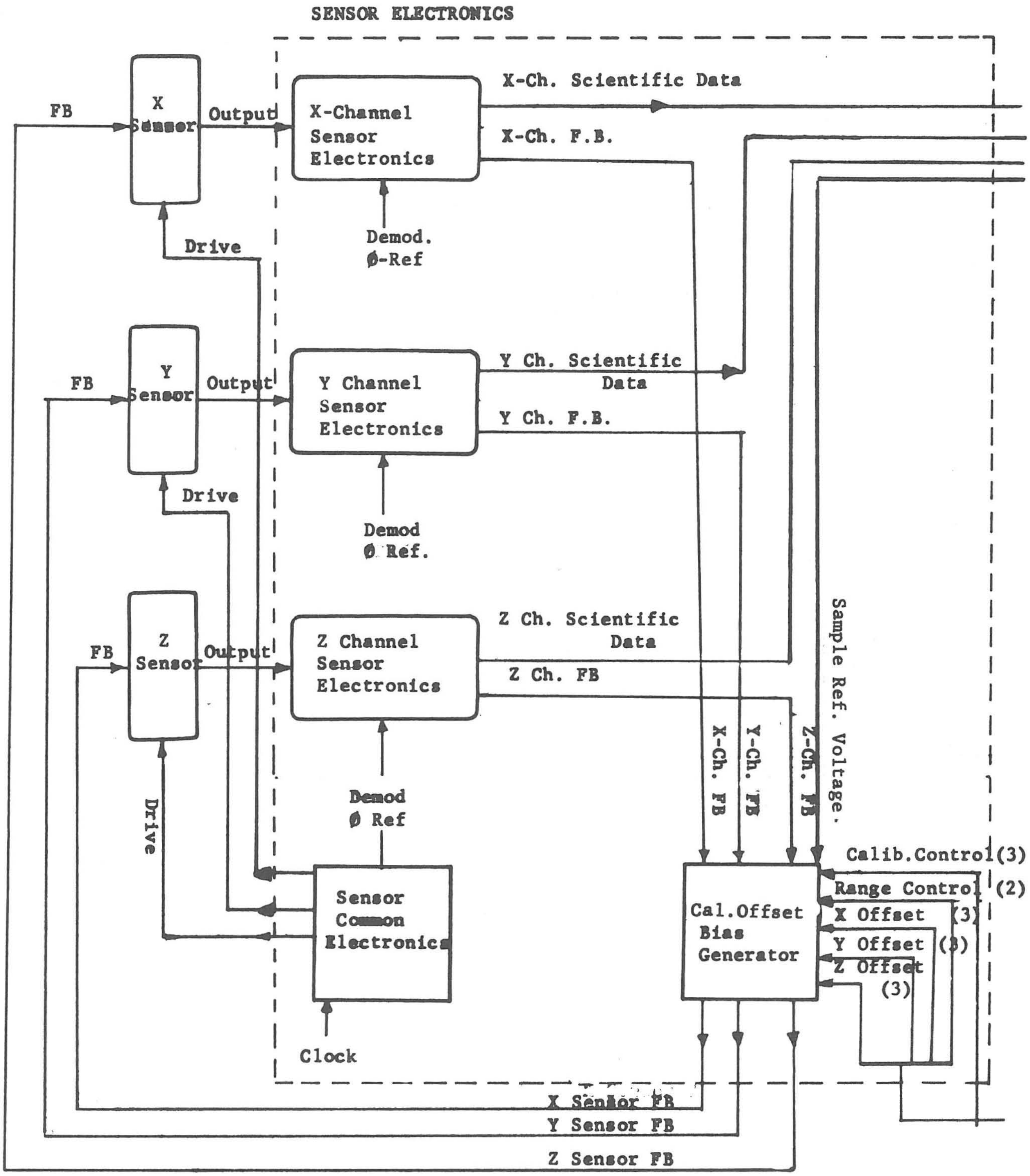


Figure 4-5 Sensor Electronics Block Diagram

(±0.03%, 3 ppm/°C, wire wound) switched to a precision reference supply by FET switches.

4.2.1.2.2.1 Sensor Channel Electronics

Figure 4-6 presents a functional block diagram of the sensor channel electronics.

Forward Loop. The Sensor Channel electronics forward loop consists of Input Amplifiers, a Buffer Amplifier, and the Demodulator/Integrator. The considerations which constrain the forward loop design are as follows:

1. Gains. In order to adequately suppress DC offset and low-frequency noise of the demodulator and the post-demodulator amplifier, a minimum loop gain of 10 (exclusive of the post-demodulator amplifier) is provided. (The demodulator stage has approximately unity gain.) From the sensor feedback and sense coil scale factors, the required gain of the carrier amplifier-filter section calculates to be 1.25×10^4 volts per volt, or about 80 db.

   The post-demodulator gain required to obtain the desired minimum overall loop gain is 10^3, or 60 db.

2. Loop Stabilization. To stabilize the loop, which is difficult because of the high open loop gain and the complex filter networks in the carrier domain, a dominant first order real pole was chosen. To implement this chance, the post-demodulator amplifier has been configured as an integrator with a minimum DC gain in excess of 60 db. (The demodulator, post-demodulator amplifier, and filter hereafter will be called simple "demodulator-integrator").

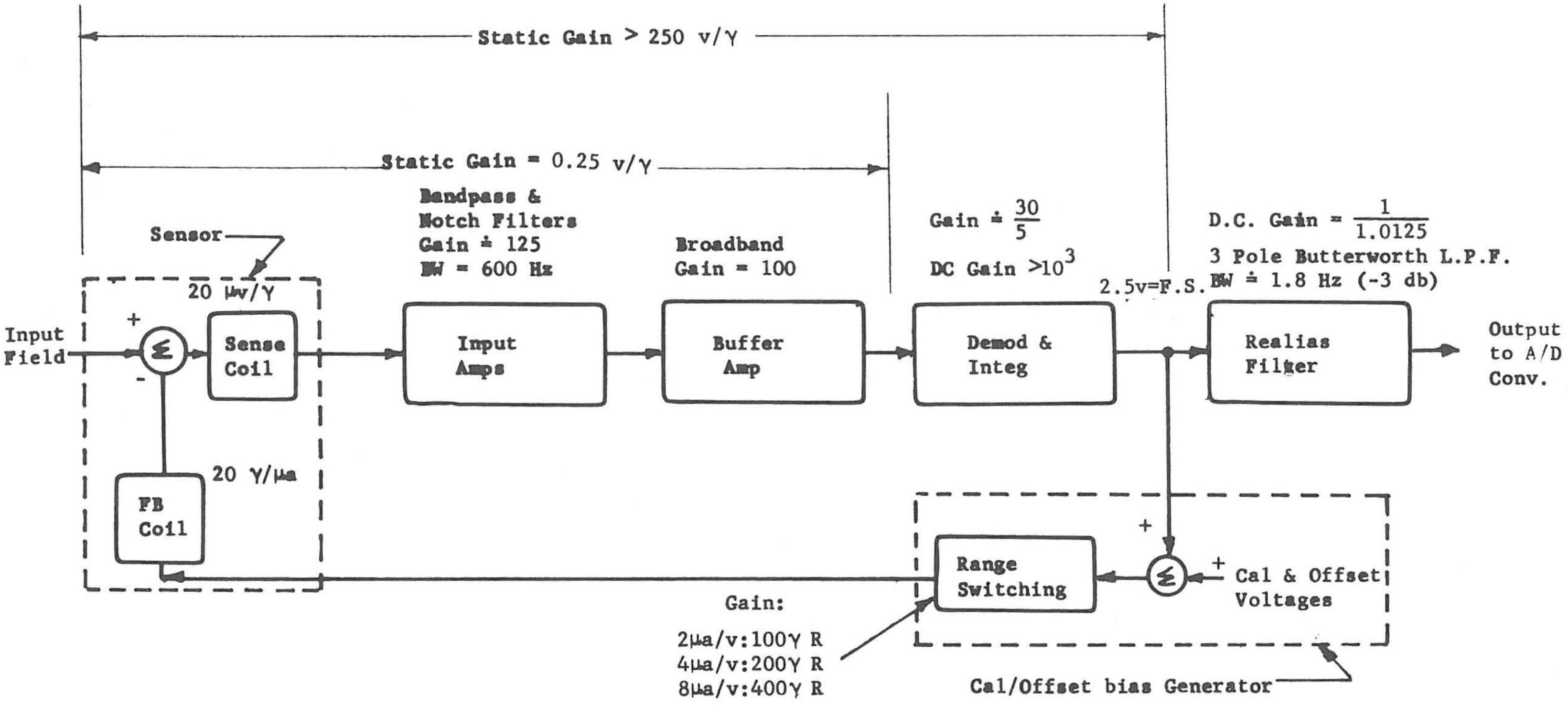


Figure 4-6 Sensor Channel Electronics

3. Carrier Filter Requirements. The configuration used previously with the Ames fluxgate sensor and also chosen for LSM consists of a push-pull emitter-follower input stage (for high input impedance and low even-harmonic distortion), followed by a notch filter at the drive frequency, a notch filter at the third harmonic, and a bandpass filter at the second harmonic (signal carrier) frequency. This is followed by a bandpass amplifier at the second harmonic frequency, and then by a buffer amplifier which drives the demodulator. Considering the gains, the sensor output spectrum, and the buffer amplifier dynamic range (about 2 volts rms), the filters should provide about 80 db of attenuation at the fundamental and the third harmonic, and about 60 to 70 db attenuation at higher harmonics. The bandpass characteristics of the filters are optimized for maximum rejection of the undesired signals, minimum phase shift change over temperature, loop stability, and immunity from saturation by magnetic signals in the 60-300 Hz range.

Prealias Filter. The prealias filter, located outside of the sensor servo loop, serves to band limit the sensor electronics output signal. This is required to reduce aliasing errors at the A/D converter sample rate of 26.5 samples per second. A three-pole Butterworth configuration with a cutoff frequency of about 2 Hz is utilized for this purpose. The measured response of one filter is given in Figure 4-7. The prealias filter is implemented by an R-C configuration around a high-gain, low drift DC amplifier.

4.2.1.2.2.2 Cal-Offset Bias Generator

The Cal-Offset Bias Generator consists of a positive and negative precision reference supply, field effect transistor (FET) ladder switches, drivers, and precision resistor summing networks. Figure 4-8 presents

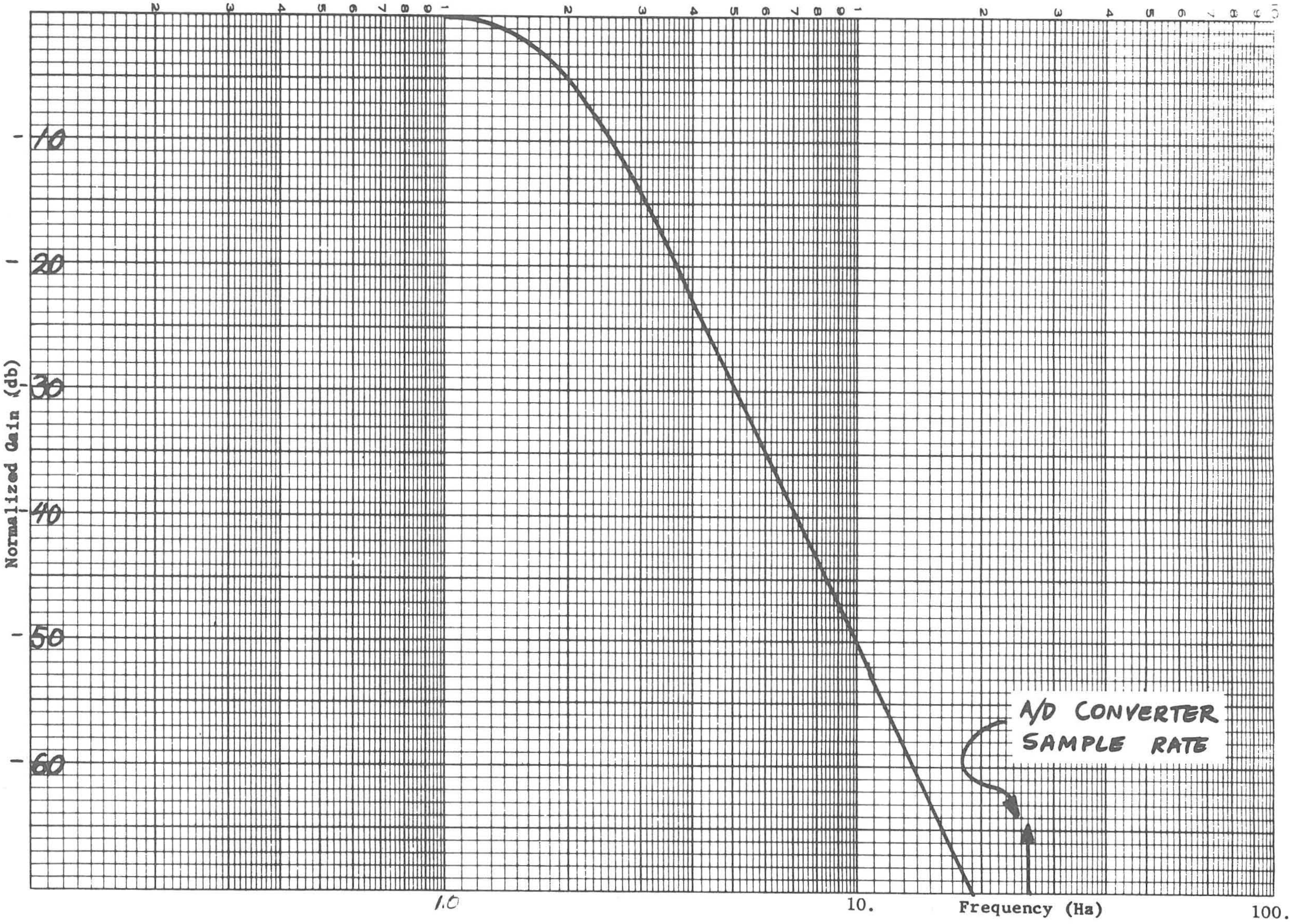
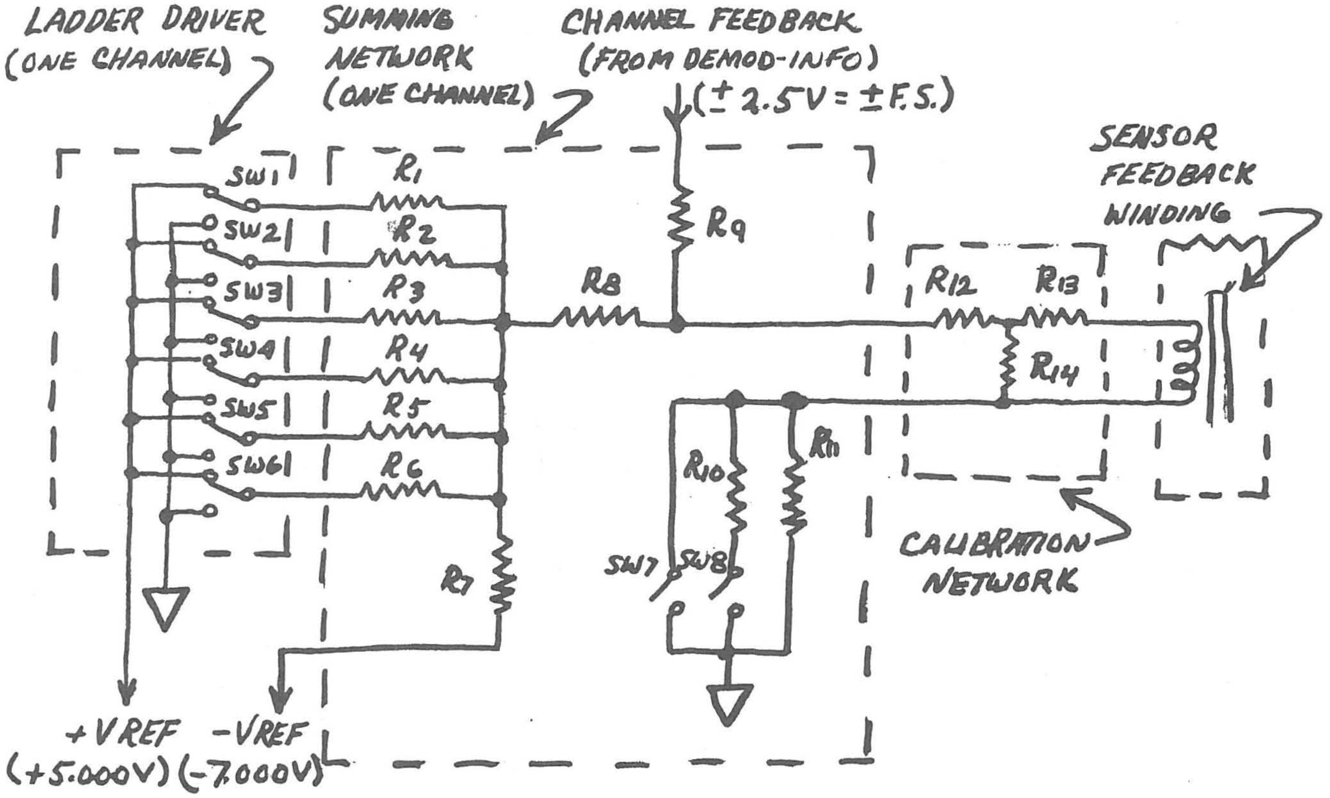


Figure 4-7 Sensor Electronics Prealias Filter Measured Response



R1 = CAL MSB RES. = 125K, WW
R2 = CAL BIT2 RES. = 250K, WW
R3 = CAL LSB RES. = 500K, WW
R4 = OFFSET MSB RES. = 125K, WW
R5 = OFFSET BIT2 RES = 250K, WW
R6 = OFFSET LSB RES = 500K, WW
R7 = REF BIAS RES., WW
R8 }
R9 } = SCALING RES., WW
R10 = 200γ RANGE RES., WW
R11 = 100γ RANGE RES., WW
R12 = SAT, IMPEDANCE EQUALIZER, MF
R13 = IMPEDANCE SET, WW
R14 = SAT, GAIN ADJUST., MF

SW1 = CAL MSB LADDER SWITCH
SW2 = CAL BIT2 LADDER SWITCH
SW3 = CAL LSB LADDER SWITCH
SW4 = OFFSET MSB LADDER SWITCH
SW5 = OFFSET BIT2 LADDER SWITCH
SW6 = OFFSET LSB LADDER SWITCH
SW7 = 400γ RANGE SWITCH
SW8 = 200γ RANGE SWITCH

Figure 4-8 Implementation of Cal/Offset Bias Step Generation, Range Switching, and Calibration (Identical for X, Y, & Z Channels) a functional block diagram of the Cal-Offset Bias Generator. A binary ladder network is used to generate the constant increments selected for the calibrate and offset steps.

4.2.1.2.2.3 Sensor Common Electronics

A functional block diagram of the Sensor Common Electronics is shown in Figure 4-9.

Flip-Flop. A demodulator reference frequency at twice the drive frequency and with a certain fixed phase relation is required. Flip-flop and delay circuits are used to provide the necessary frequency division and phasing. In order to avoid the problem of transmitting the critical second harmonic demodulator signal among other LSM subsystems, a second flip-flop is used to divide a fourth-harmonic repetition rate (clock 12 from the timer) down to obtain the desired frequency. The flip-flop must present low output impedance in both states, and have good symmetry for low even harmonic content of the outputs. The time delay must be stable over temperature to avoid excessive demodulator phase error. To meet these requirements, complementary flip-flops and a differential amplifier comparator phase-shifter circuit (similar to those used on the AIMP magnetometer) have been utilized.

Sensor Driver. The Sensor Driver generates the excitation signal for the fluxgate sensor drive coils. This excitation acts to modulate the input magnetic field being measured. Design requirements of this circuit, however, are quite stringent. A spectrally pure sine wave drive is required in order to minimize the existence of undesired harmonics on the sense coil output. The second harmonic content of the sensor drive signal is most critical, and must be low compared to the fundamental level to prevent DC offsets due to second harmonic feedthrough. In addition, the sensor presents a highly non-linear load to the driver, appearing as a very high impedance for the first quarter cycle until the core saturates,

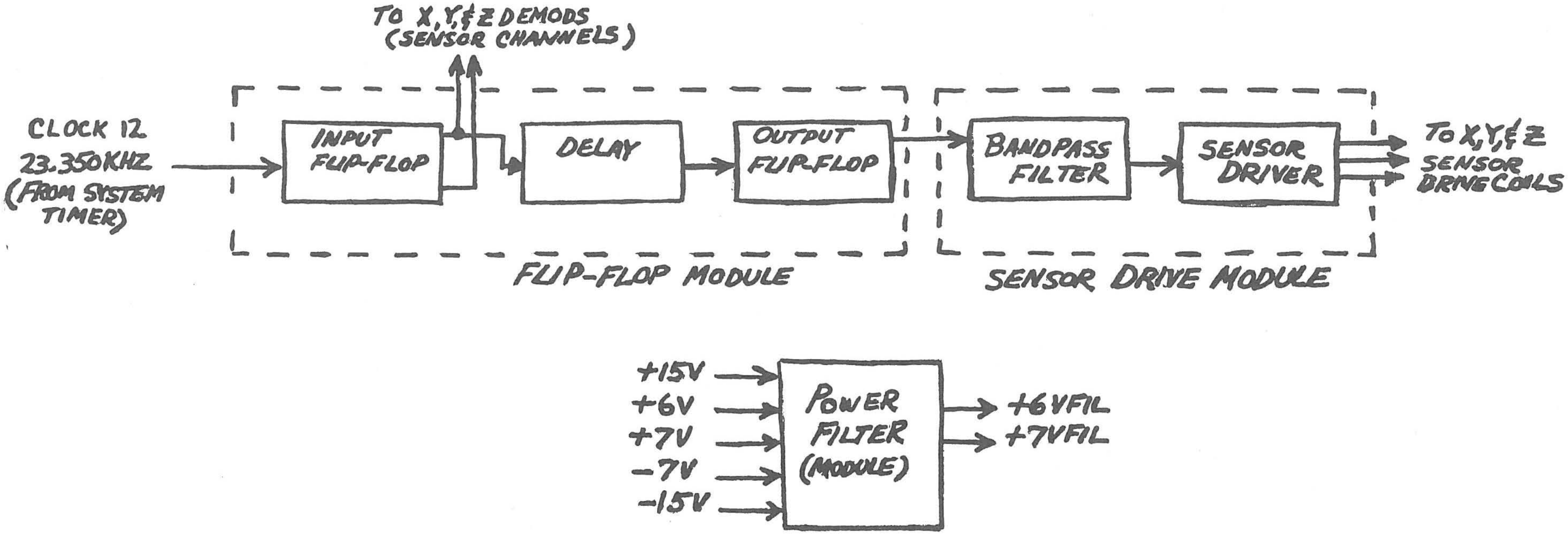


Figure 4-9 Sensor Common Electronics

and then as a very low impedance (drawing about 60 ma peak) for the next quarter cycle. This loading repeats for each half cycle of the drive waveform.

Because of the high power consumption of the Sensor Drive, a single driver is utilized in LSM to operate all 3 sensors. A drive filter network removes harmonics from the square wave output of the flip-flop. It consists of two coupled L-C bandpass sections tuned to the fundamental (drive) frequency. The filter is followed by a drive amplifier. The drive amplifier is a high-gain feedback amplifier designed for low output impedance, low second harmonic distortion, and low power consumption at the drive signal requirements.

Power Filter. To provide the necessary additional filtering of DC power for the Sensor Electronics and to provide low source impedance, a Power Filter is employed. Active filtering provides the best design compromise between weight and power efficiency.

4.2.1.3 Housekeeping Detailed Description

4.2.1.3.1 Engineering Data Electronics

The Engineering Data Electronics (EDE) performs the following housekeeping functions:

> Indicates the nominal flip position (0°, 90°, 180°) of each fluxgate sensor by exciting the flip position sensors and outputting the resultant data in the form of three 2-bit status words.
>
> Provides three position sensor capacitors in each sensor head assembly, one for each nominal position (0°, 90°, 180°). Their outputs are encoded into a two-bit status word containing the position information for a given scientific channel.

Indicates the nominal gimbal position (pre or post-gimbal) of each fluxgate sensor by exciting the gimbal position switching and outputting the resultant data in the form of three 1-bit status words.

Provides the five temperatures monitored within the instrument by exciting the thermistors with a reference voltage and outputting the resultant five analog voltages.

Indicates the orientation of the instrument relative to the local lunar vertical by exciting the two axis gravity level sensor and outputting the resultant two analog voltages.

Provides heater power status and temperature control status.

Provides +5V reference voltage analog data.

Flip Position Detector Electronics

This element consists of nine identical circuits, each of which detects a change of capacitance indicative of the relative position (0°, 90°, or 180°) of a fluxgate sensor.

The detector operates by supplying, from a high impedance source, a 90 kHz square wave excitation to a position-sensor variable capacitor. This excitation is monitored, and an appropriate digital output ("1" or "0") signal is produced as a function of the capacitance presented to the 95 kHz excitation.

Three position sensor capacitors are provided in each Sensor Head Assembly, one for each required position (0°, 90°, or 180°). Their outputs are encoded into a two-bit status word containing the position information for a given scientific channel.

The functional block diagram of the flip position detector electronics is given in Figure 4-10.

Gimbal Position Electronics

This element consists of three status indicator circuits to detect the gimbal positions and produce status flag outputs. Inputs are switch closures from switches located in the GFU. Outputs are either a digital "1" indicative of "pre-gimbal" (switch open) or a digital "0" indicative of "post-gimbal" (switch closed).

Temperature Monitoring Electronics

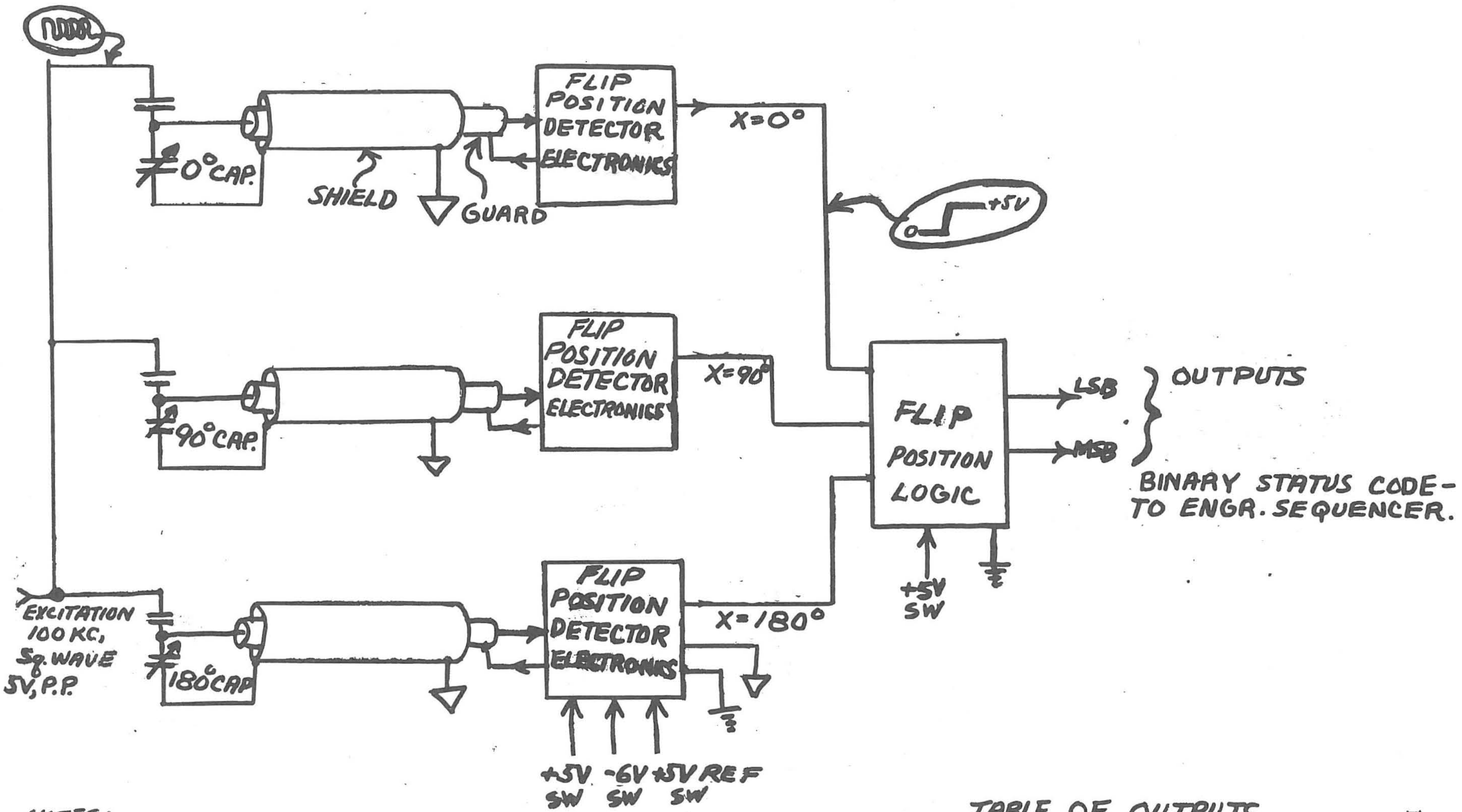
Five identical temperature monitoring circuits are provided to measure temperatures at various locations in the LSM. Each circuit consists of a thermistor-resistor network. A precision 5 volt, DC pulse signal is applied across the network, and a properly scaled output voltage is transmitted to the MPX-A/D converter for encoding. The functional block diagram of the Temperature Monitoring Electronics is given in Figure 4-11. A typical Temperature Sensor calibration curve is given in Figure 4-12.

Gravity Level Sensor Electronics

This section consists of two identical channels, each of which converts to a DC voltage the output of a 95 kHz precision-amplitude square wave voltage from a gravity level sensor. The functional block diagram of the gravity level sensor electronics is given in Figure 4-13. A typical Level Sensor calibration curve is given in Figure 4-14.

4.2.1.3.2 Sensor Electronics

The sensor electronics provides the +5V reference monitor. Signal conditioning is by resistive divider or the +5V reference. This test point provides a gross (7 bit) check on the validity of the interval calibration



NOTES:

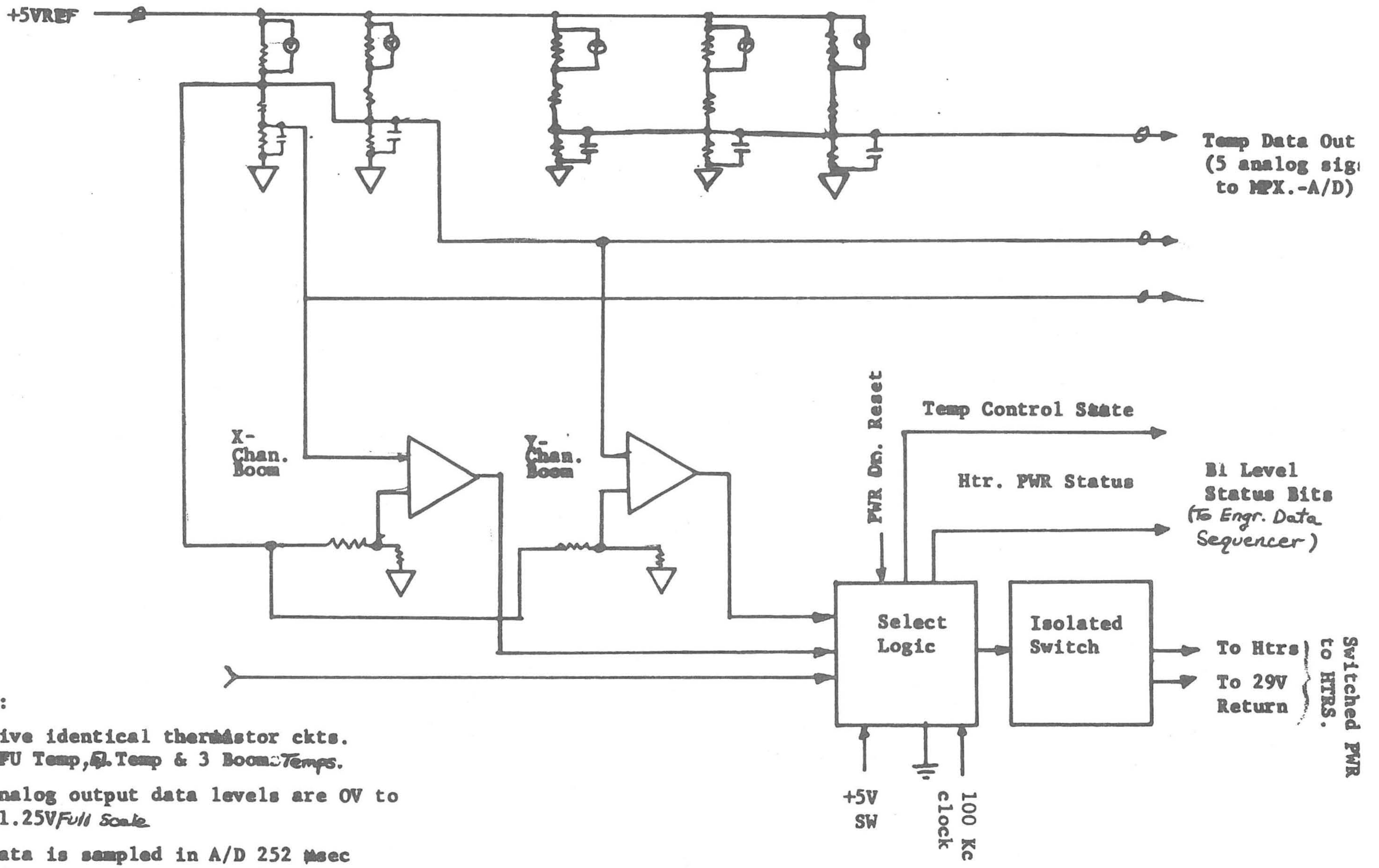
1. WHEN MAGNETOMETER IS ON THE POSITION, THE OUTPUT OF THE DETECTOR ELECTRONICS IS +5V (= "1")
2. THE SYMBOL ⏚ IS DIGITAL GROUND; ▽ IS ANALOG GROUND
3. ALL VOLTAGES ARE ON FOR 1MSEC, ONCE PER TLM FRAME

TABLE OF OUTPUTS

POSITION	MSB	LSB
X=0°	0	1
X=90°	1	0
X=180°	1	1
NEITHER	0	0

Figure 4-10 Flip Position Detector & Logic - Functional Block Diagram

MT-DA1609



NOTES:

1. Five identical thermistor ckts. GFU Temp, El. Temp & 3 Boom Temps.
2. Analog output data levels are 0V to +1.25V Full Scale
3. Data is sampled in A/D 252 µsec after the start of the 1 ms interval.

Figure 4-11 Temperature & Heater Control Functional Block Diagram

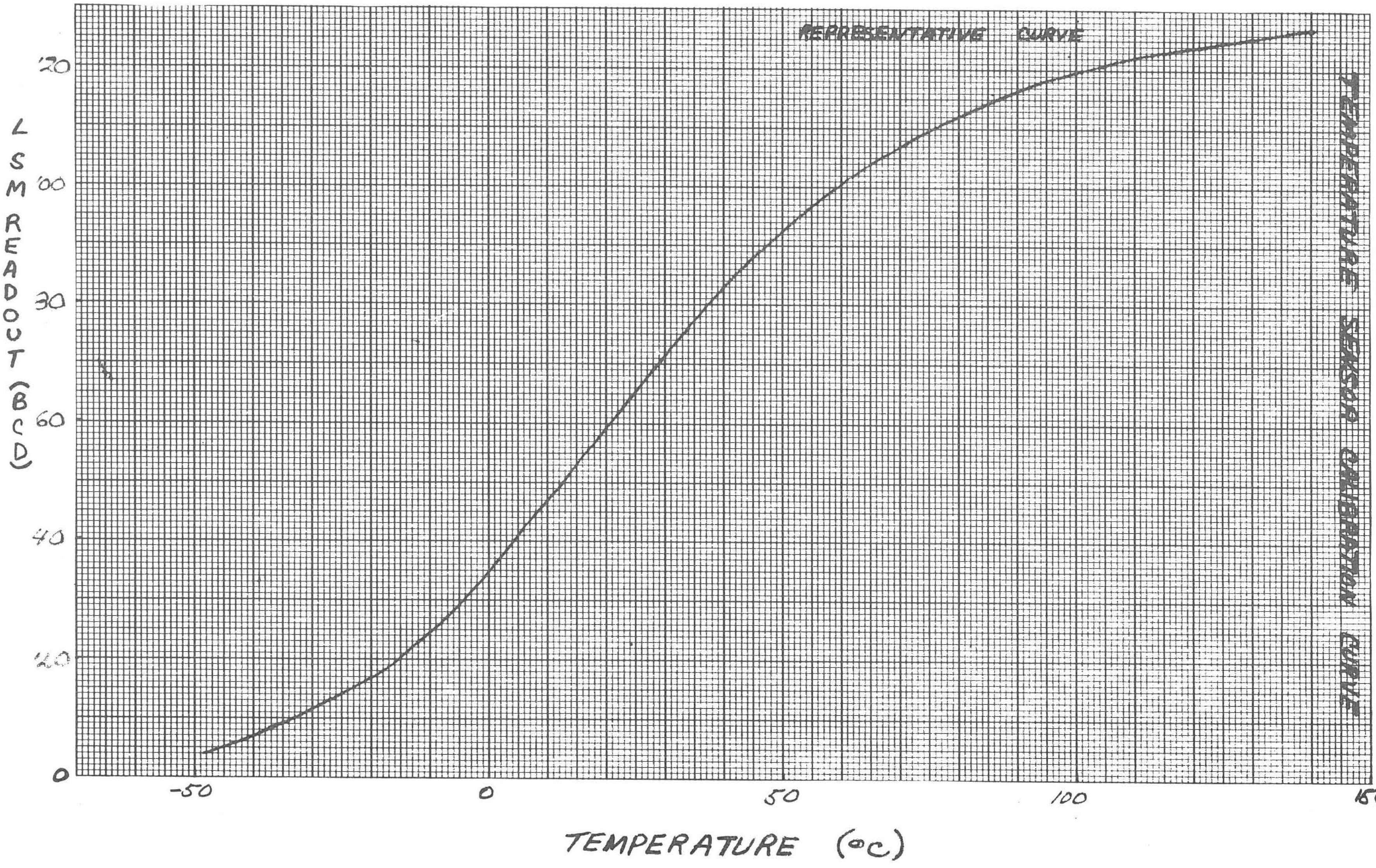
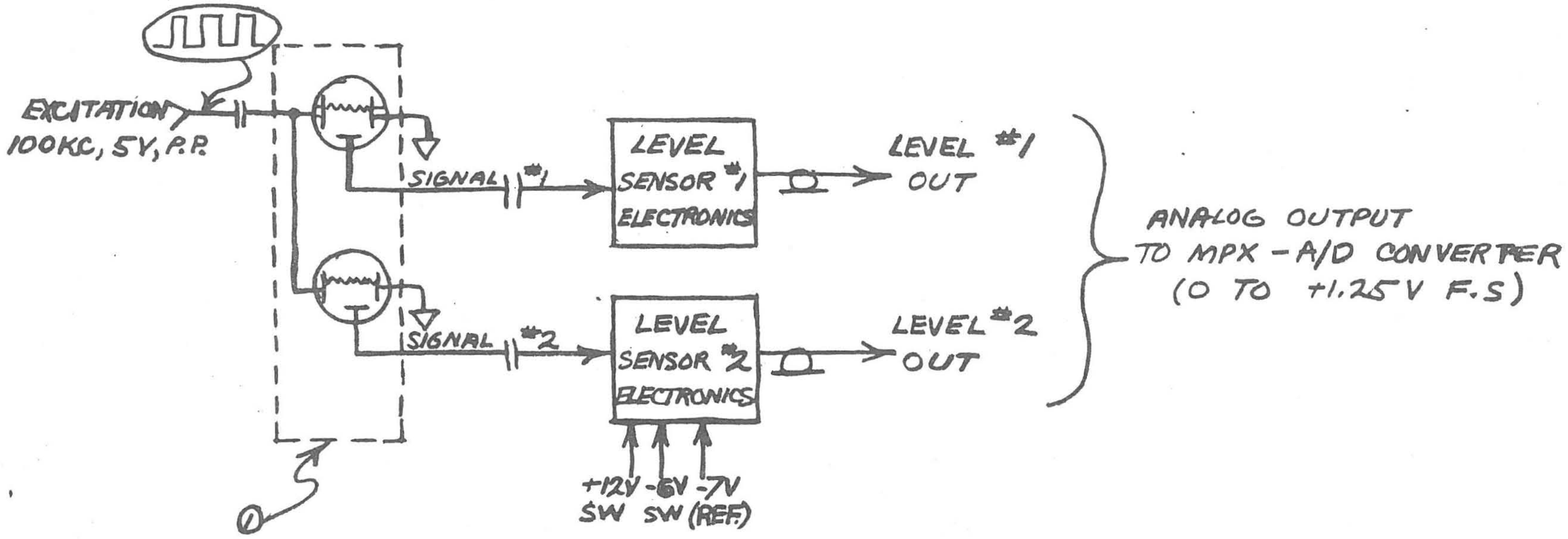


FIGURE 4-12

TEMPERATURE SENSOR CALIBRATION CURVE



NOTES:

① 2-AXIS GRAVITY LEVEL SENSOR

② SENSOR IS LOCATED IN GFU

③ CONNECTIONS INTERNAL TO LEVEL SENSOR, TWISTED LEADS OUT—(4)

④ 4 INTERNAL RESISTORS NOT USED.

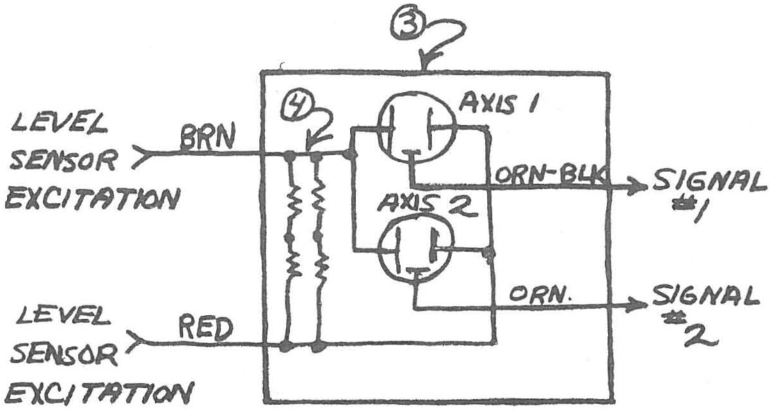


Figure 4-13 Gravity Level Electronics Functional Diagram

LEVEL SENSOR CALIBRATION CURVE

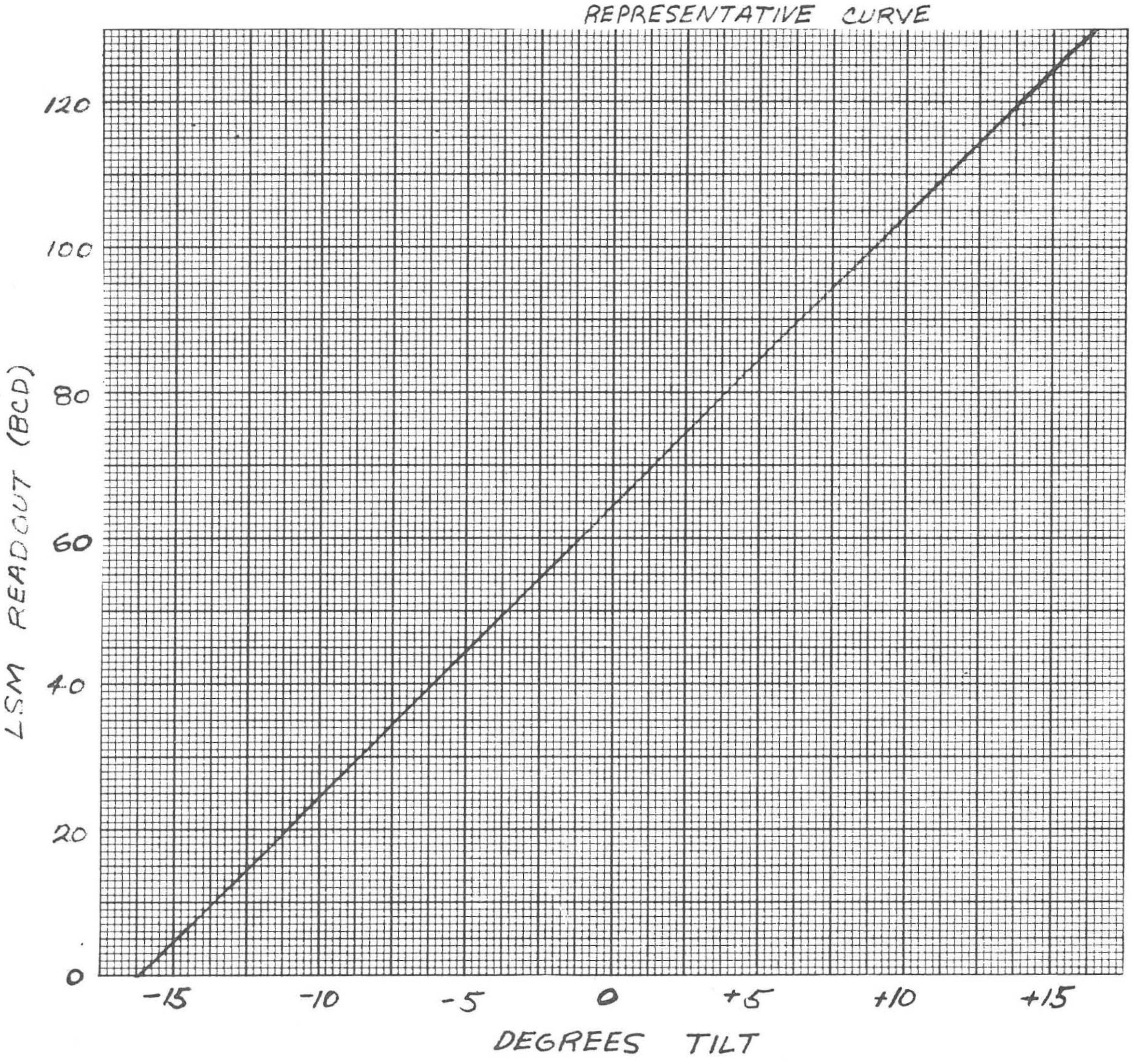


Figure 4-14

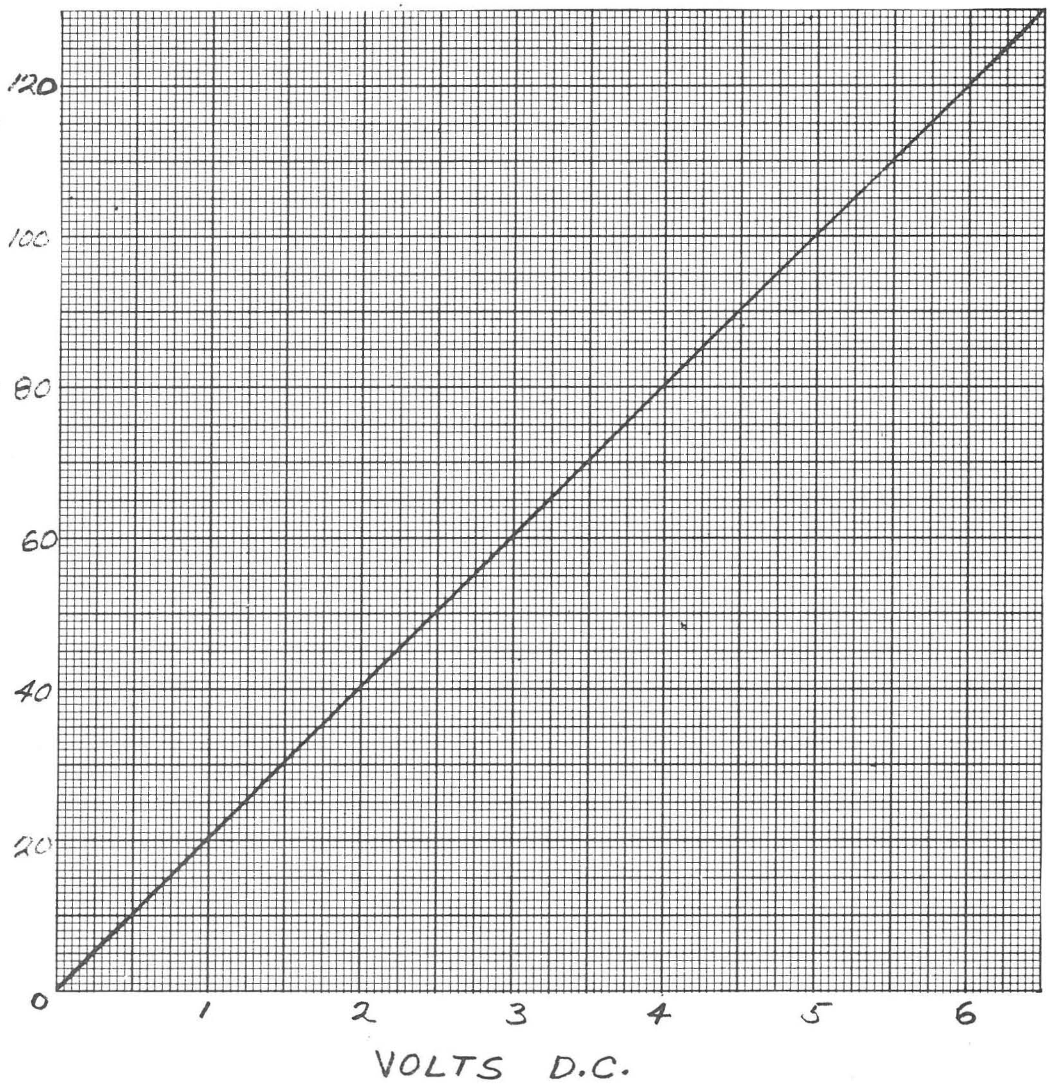
since the calibration rasters are generated using this voltage. A typical reference voltage calibration curve is given in Figure 4-15.

4.2.1.3.3 Offset Command Logic

The Offset Command Logic provides the majority of the information concerning the (command) operational state of the instrument. Operational state data provided includes the following:

Range
Mode
Offset (Offset Address and Steady Field Offset)
Cal Inhibit Status
Filter Status

REFERENCE VOLTAGE CALIBRATION CURVE



+5 VOLTS REFERENCE

Figure 4-15

4.2.2 Data Processing Function

4.2.2.1 Block Diagram Description

The functional block diagram of the subsystems which comprise the data processing function is given in Figure 4-16.

The analog data is converted to digital form by the MPX-A/D converter. The data is then filtered in the digital domain by the digital filter and transferred to the output data buffer. The Offset Command Logic Subsystem serves to process the filter bypass command. The engineering data sequencer formats the engineering data, and the system timer provides clock and control signals for the entire function.

4.2.2.2 Data Processing Detailed Description

The LSM provides internal data processing for two reasons. First, since the LSM data is not read out continuously, the data must be manipulated (in time) to provide a maximum amount of data in the time available. Secondly, since the LSM data is sampled, it must be sampled in a synchronous manner and the LSM scientific data must be processed (i.e., band-limited) in order that minimum error is introduced into the data by the sampling process.

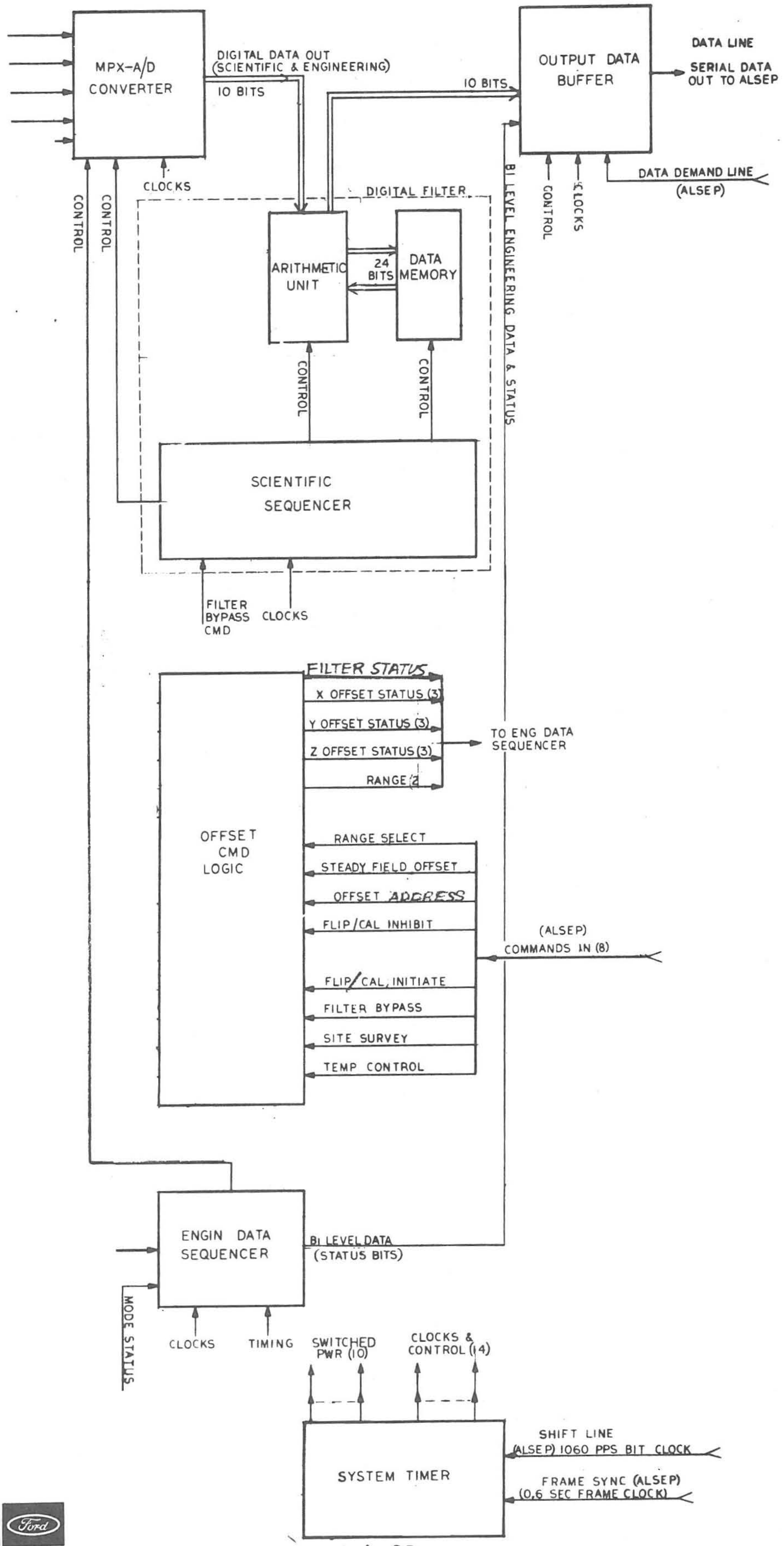


Figure 4-16

Data Processing Functional Block Diagram

The principle which dictates the band-limiting is the Nyquist sampling theorem which states that in order for a bandwidth limited signal to be sampled by a perfect (zero transition time) switch without error (loss of information), the sampling rate must be at least twice the bandwidth of the signal. In actual practice, the filter bandwidth which limits the signal spectrum is not an ideal function, nor is the switch perfect. For these reasons, the bandwidth is generally limited to much less than ½ the sampling rate. The LSM has two such samplers: the A/D Converter and the ALSEP system. The A/D Converter samples the continuous analog information and the ALSEP system samples the LSM output. In order to minimize aliasing error the prealias filter has a 3 db bandwidth of about 2 Hz for a sampling rate of 26.5 samples per second. Likewise, to accommodate the ALSEP sampling rate of 3.3 Hz, the LSM data is processed by a digital filter which limits the 3 db bandwidth to 0.27 Hz.

In order to sample the LSM data in a synchronous manner, the LSM scientific data is read out in the ALSEP frame as shown in Figure 4-17. Housekeeping data is transmitted in Frame word 5. Each word is 10 bits in length.

	1	2	3	4	5	6	7	8
1								
2								
3	17 LSM		19 LSM		21 LSM			
4								
5								
6								
7	49 LSM		51 LSM		53 LSM			
8								

17, 49	X Axis
19, 51	Y Axis
21, 53	Z Axis

Figure 4- 17 LSM Word Assignment in Data Frame (Scientific Data)

The engineering, or housekeeping word is shared between 8 analog signals and the status bits discussed in Section 4.2.1. The engineering subcommutation format is given in Figures 4-18 and 4-19. The timing relations of the ALSEP-LSM signals are shown in Figures 4-20 and 4-21.

4.2.2.1 MPX-A/D Converter

This subsystem is composed of an 11-channel analog multiplexer and a 10-bit successive approximation voltage-to-digital converter. It performs the functions of selecting and digitizing scientific data and engineering data. Three scientific channel inputs are received from the Sensor Electronics Subsystem, and eight engineering channel inputs are received from the Engineering Data Electronics Subsystem.

The multiplexer analog-to-digital converter is power-switched during its interval of operation. It features automatic zero correction, which essentially eliminates zero offset and zero drift.

The full-scale input voltage range of the three scientific channels is -2.5 to +2.5 volts. The input range of the eight engineering channels is 0 to +1.25 volts.

The scientific data output code is a 10-bit binary, in sign and magnitude representation. Truncation is provided at 31/32 of full scale, as follows:

+ truncated full scale: (+) 111110000

- truncated full scale: (-) 111110000

SUB-FRAME CHANNEL	ENGINEERING ANALOG DATA (7 BITS; 3 BCD, TO 127)	STATUS FLAGS	
		BIT 1	BIT 2
1	X SENSOR TEMPERATURE	X FLIP POSITION	X FLIP POSITION
2	Y SENSOR TEMPERATURE	Y FLIP POSITION	Y FLIP POSITION
3	Z SENSOR TEMPERATURE	Z FLIP POSITION	Z FLIP POSITION
4	CFU SENSOR TEMPERATURE	X GIMBAL POSITION	Y GIMBAL POSITION
5	ELECTRONICS SENSOR TEMPERATURE	Z GIMBAL POSITION	TEMP. CONT. STATE
6	LEVEL DETECTOR #1	SPARE = 1	HEATER STATE
7	LEVEL DETECTOR #2	MEAS. RANGE	MEAS. RANGE
8	REF. SUPPLY VOLTAGE (5 vdc)	SPARE = 1	SPARE = 1
9	SAME AS 1	X FIELD OFFSET B_1	X FIELD OFFSET B_2
10	SAME AS 2	X FIELD OFFSET B_3	Y FIELD OFFSET B_1
11	SAME AS 3	Y FIELD OFFSET B_2	Y FIELD OFFSET B_3
12	SAME AS 4	Z FIELD OFFSET B_1	Z FIELD OFFSET B_2
13	SAME AS 5	Z FIELD OFFSET B_3	OPER. MODE STATE
14	SAME AS 6	OFFSET ADDRESS STATE	OFFSET ADDRESS STATE
15	SAME AS 7	FILTER STATUS	FLIP/CAL INHIBIT STATUS
16	SAME AS 8	SPARE = 0	SPARE = 0

Figure 4-18 Summary LSM Engineering Data

SUB-FRAME CHANNEL	FUNCTION B_1 (2')	FUNCTION B_2 (2°)	STATUS B_1 (2')	STATUS B_2 (2°)
1	X FLIP POSITION		0 0 1 1	0 = FALSE 1 = 0° 0 = 90° 1 = 180°
2	Y FLIP POSITION			
3	Z FLIP POSITION			
4	X GIMBAL POSITION	Y GIMBAL POSITION	0° = 1 90° = 0	1 = 0°(PRE) 0 = 90°(POST)
5	Z GIMBAL POSITION	TEMP. CONTROL	0° = 1 90° = 0	0 = Y OR OFF 1 = X
6	SPARE	HEATER STATE	1	1 = ON 0 = OFF
7	RANGE		0 1 1 0	0 = 100 0 = 200 1 = 400 1 = ERROR
8	SPARE		1	1
9	X_1 FIELD OFFSET	X_2	X_1 X_2 X_3 (OR Y OR Z) 0 1 1 = 0% 0 1 0 = 25% 0 0 1 = 50% 0 0 0 = 75% 1 1 0 = -75% 1 0 1 = -50% 1 0 0 = -25%	
10	X_3	Y_1		
11	FIELD OFFSET Y_2	Y_3		
12	Z_1 FIELD OFFSET	Z_2		
13	Z_3	OPERATIONAL MODE		SCIENTIFIC 1 CALIBRATE 0
14	OFFSET ADDRESS STATE		0 1 0 1	0 = NEUTRAL 0 = X 1 = Y 1 = Z
15	FILTER STATUS	FLIP/CAL INHIBIT	FILTER BYPASSED 1 NOT BYPASSED 0	1 INHIBITED 0 NOT INHIBITED
16	SPARE		0	0

Figure 4-19 Summary LSM Engineering Data

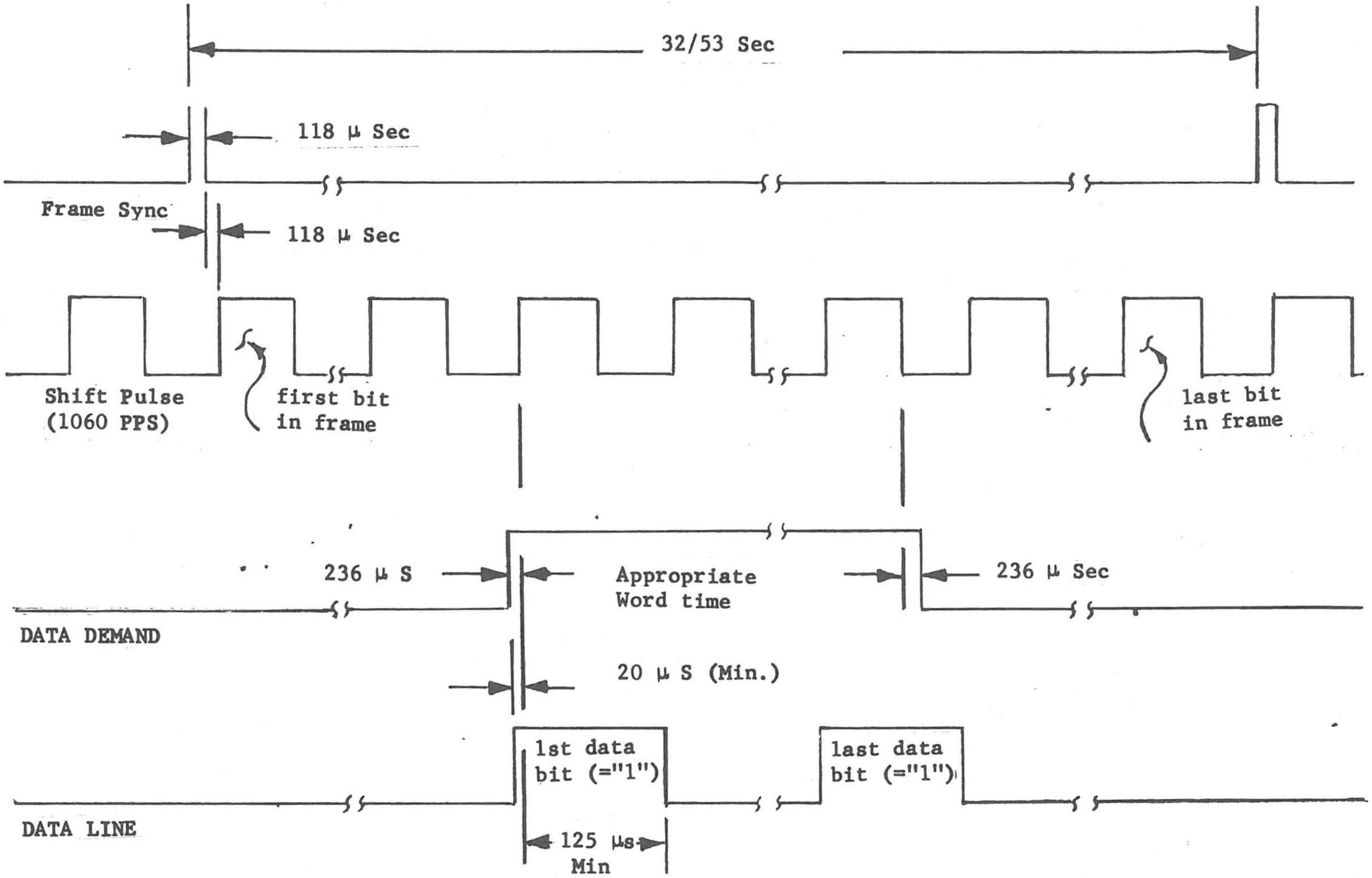
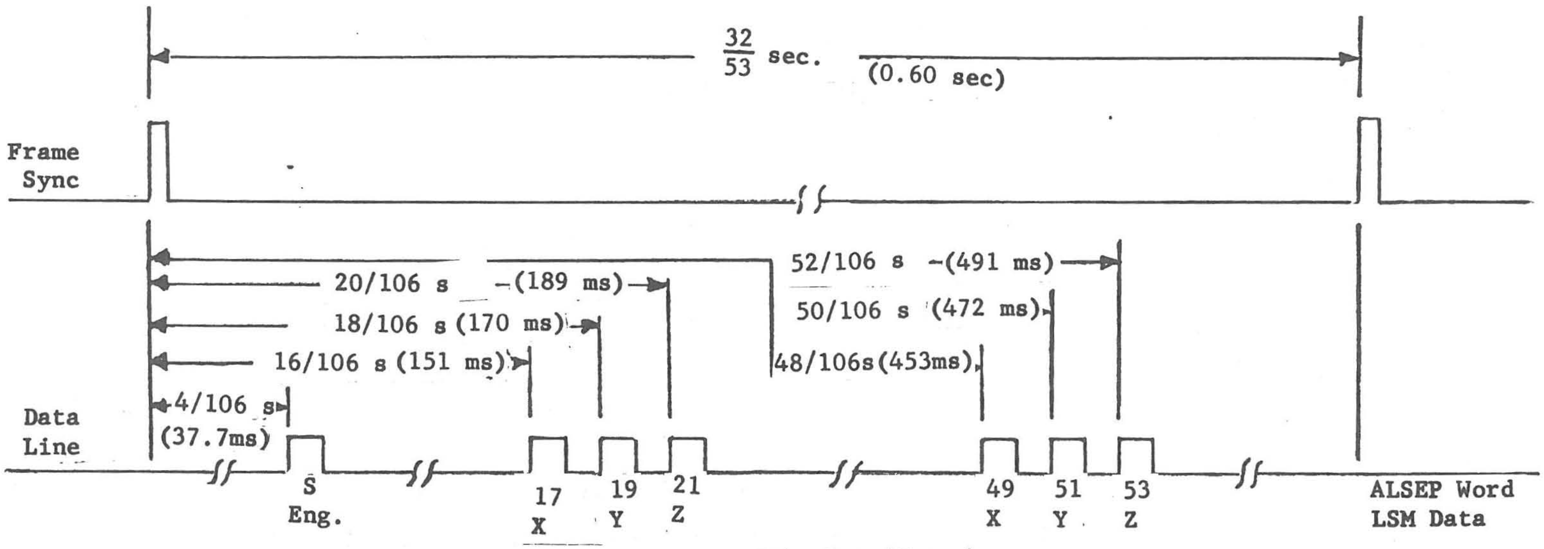


Figure 4-20 LSM - ALSEP Timing Relations



Remarks: (64 words/frame) (10 bits/word) = (640 bits/frame)
(640 bits/frame) ÷ (1060 bits/sec) = (32/53 sec./frame)

1 Bit ≈ 1 ms.

1 Word ≈ 10 ms.

*Most Significant Bit Read Out First

* 2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Sub Frame Mark Bit	Data							Status Bits	

Engineering Data Word Format

* 2^9 (512)	2^8 (256)	2^7 (128)	2^6 (64)	2^5 (32)	2^4 (16)	2^3 (8)	2^2 (4)	2^1 (2)	2^0 (1)
Polarity Bit	Data			(1 111 110 110 = -Sat. Data) (0 000 000 000 = + 0 Gamma)					

Scientific Data Word Format

Figure 4-21 LSM-ALSEP Timing Relations

The engineering data output code is seven-bit unipolar binary. This code is derived by deleting the sign bit, the two most significant bits and the least significant bit from the 10-line A/D output.

Resolution (least significant) of the scientific data is 4.88 millivolts; for engineering data it is 9.77 millivolts.

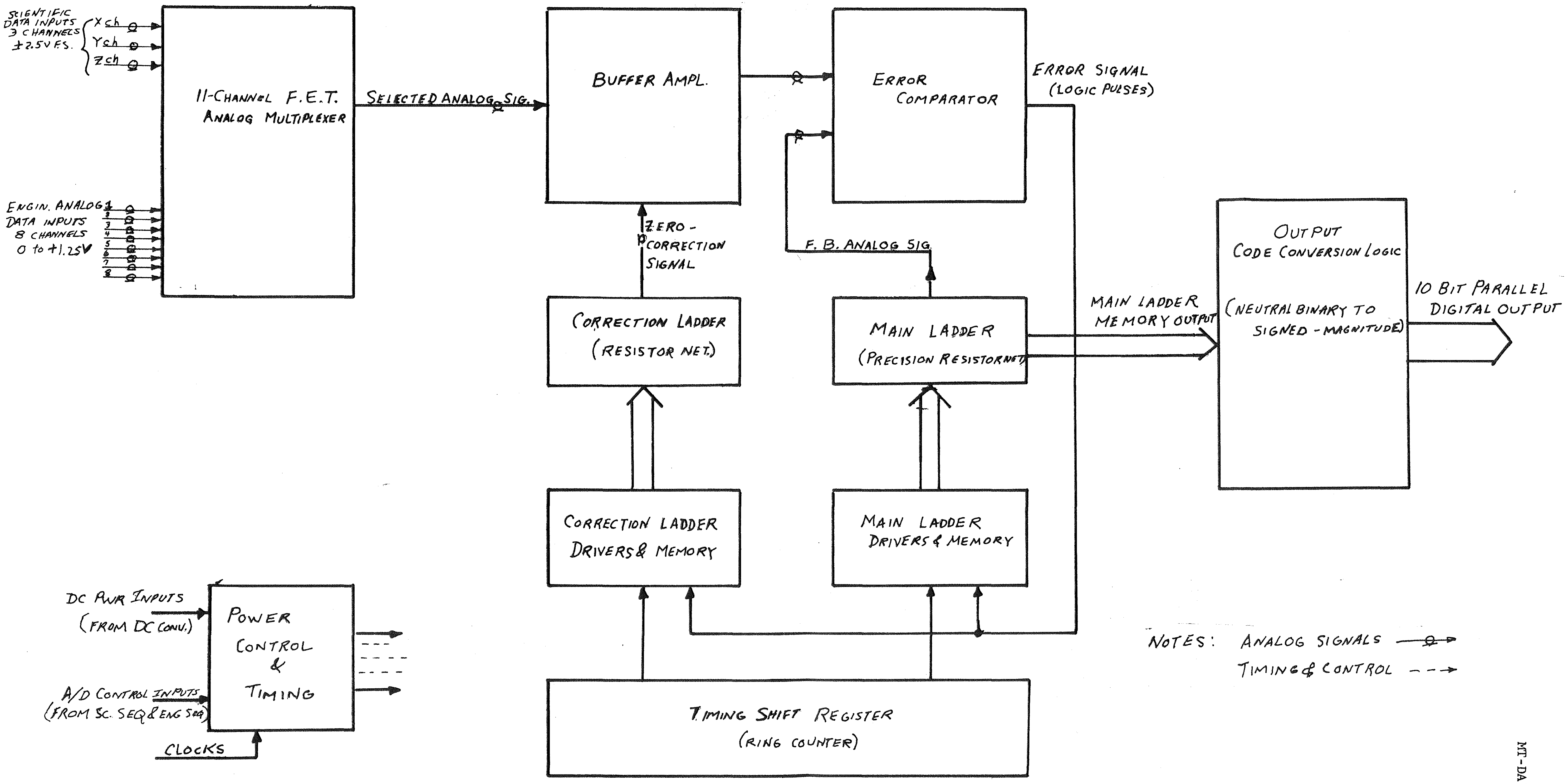
The total conversion time is 252 μs. This consists of a 168 μs data settling period and an 84 μs digitizing interval.

The block diagram of the MPX-A/D converter is given in Figure 4-22. The blocks will be referenced in the general explanation of the operations of the A/D converter which follows.

The control inputs for all operations performed by the A/D converter in digitizing an analog voltage are received from the Scientific and Engineering Sequencer subsystems. These control signals are conditioned and distributed to the appropriate A/D converter blocks by the power control and timing block. The continuous power inputs from the DC Converter Subsystem are also switched by the power control and timing circuits.

The 11-channel F.E.T. analog multiplexer selects one of the 3 X, Y, Z scientific analog channels, one of the eight engineering analog channels or the zero correction (analog ground) input channel. The sequence of channel selections for any one conversion sequence is as follows:

1. Scientific Data Conversion
    a. Select zero correction channel
    b. Select X channel
    c. Select Y channel
    d. Select Z channel
2. Engineering Data Conversion
    a. Select zero correction channel
    b. Select one of the eight engineering channels



MT-DA1609

Figure 4-22 MPX-A/D Converter Block Diagram

The buffer amplifier block conditions the selected analog data for presentation to the error comparator. This signal conditioning consists of: (1) doubling the selected analog voltage, and (2) averaging this doubled voltage with a 5-volt precision reference voltage. The effect of these two operations is to translate the input analog voltage range from (in the case of scientific data) a full-scale range of -2.5 to +2.5 volts to a 0 to +5 full-scale range. This is necessary in order to be able to employ a standard voltage ladder network supplied by a +5-volt reference. The engineering data (0 to +1.25 volts full scale) is translated to +2.5 to +3.75 volts full scale (as seen by the error comparator).

The buffer amplifier also contains circuitry for supplying an offset voltage to the analog data to correct zero drift. The offset voltage is supplied from a standard ladder network (the correction ladder block) during the zero correction cycle. This cycle will be explained under the description of the correction ladder drivers and memory.

The error comparator block consists of two high-input impedance matched amplifiers and a threshold detector. A logic level output is obtained as a function of the relative signal levels of the F.B. (feedback) analog signal and the analog output of the buffer amplifier. This logic signal controls the action of the main ladder and correction ladder drivers and memory.

The correction ladder drivers and memory function during the zero correction cycle. The zero correction cycle consists of the following steps:

1. Select the zero correction (analog ground) analog input channel and allow data to settle (168 μs).

2. In five successive approximation steps, select the zero offset correction voltage (84 μs). (NOTE: The main ladder drivers and memory remain stationary during this time with analog zero (+2.5 volts as seen at the Error Comparator) applied as the F.B. analog signal).

The main ladder drivers and memory function during the analog-to-digital conversion cycles. The sequence of operations is as follows:

1. Select the desired analog data input channel and allow the resulting analog signals to settle in the buffer amplifier.

2. In 10 successive approximation steps produce an F.B. analog signal which is less than 1 part in 2^{10} (of 5 volts) $\cong$ 4.883 mv

3. Read out the status of the main ladder memory (ten flip-flop states).

The correction ladder block consists of a five-bit, digital-to-analog resistor network converter. The digital input is a 0 or +5 volts (precision) on each of the five inputs. The analog output is 0 to 4.951 volts.

The timing shift register is a 10-bit ring counter which provides the timing control to the correction ladder and main ladder drivers and memories during the successive approximation conversion sequences. The ring counter outputs (5 to the correction ladder drivers and memory and 10 to the main ladder drivers and memory) feature variable time duration comparison intervals such that the most significant bits of the A/D conversion networks are given a greater relative time to settle, as compared to the least significant bits.

The output code conversion logic block converts the main ladder memory output to a signed magnitude representation. Truncation of scientific data is also provided at 31/32 of full scale, as previously explained.

4.2.2.2.2 Digital Filter

The digital filter is the name commonly used for the combination of arithmetic unit, data memory, and scientific sequencer. These units in reality comprise a general-purpose digital computer that is programmed to perform a filtering function. That is, using discrete delays rather than analog integrators, the analog signal represented by the digital output is operated upon to limit the frequency response of the output signal for compatibility with the ALSEP sampling rate.

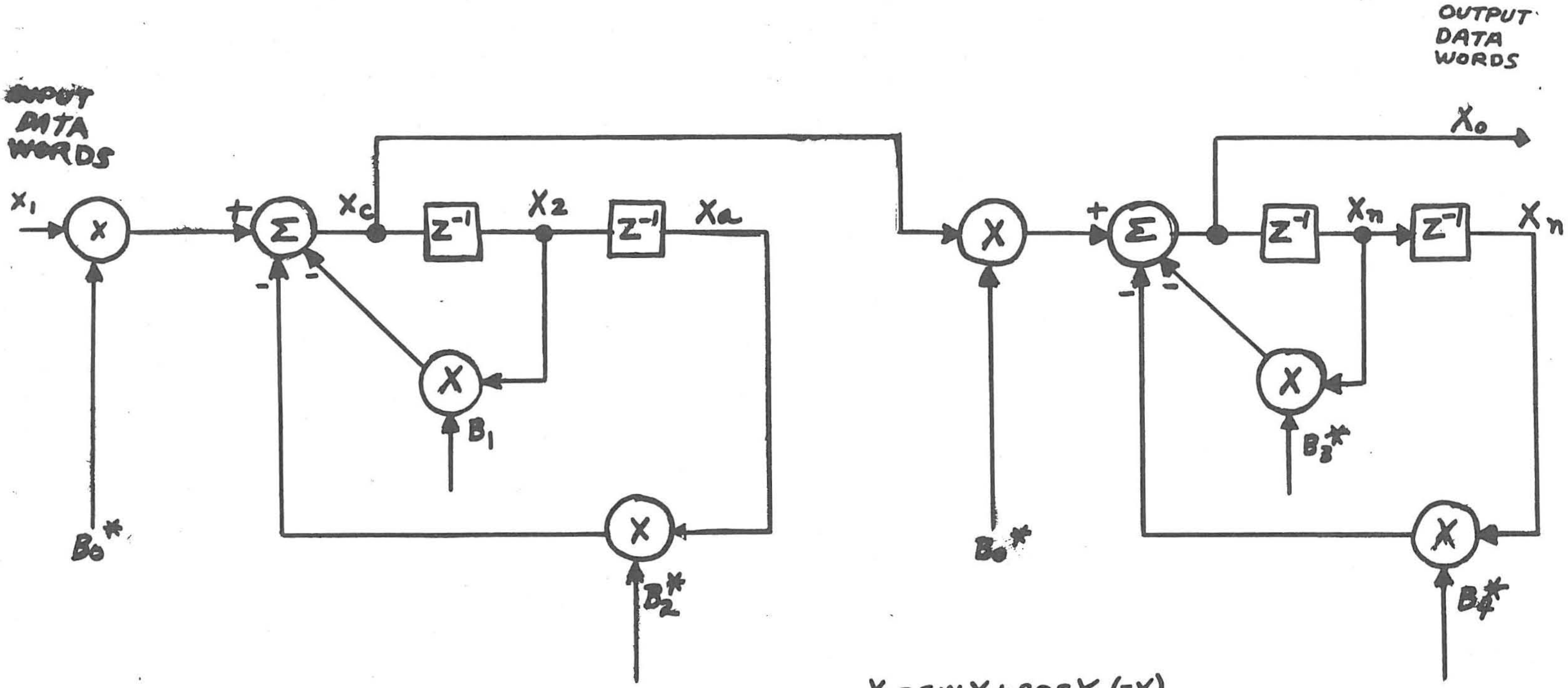
A representation of the digital filter in the Z-transform domain is given in Figure 4-23.

Scientific Sequencer Description

The scientific sequencer is a programmer whose purpose is to produce all the control signals necessary to the functioning of the digital filter. (The digital filter is a major system element comprised of three subsystems: the scientific sequencer, arithmetic unit and memory.)

Functionally the sequencer is organized into routines and sub-routines to facilitate repetition. An entire two-stage digital filter routine can be initiated by merely "calling" the filter routine. Figure 4-24is a mathematical block diagram of a 4-pole, 2-section Bessel filter implemented by the scientific sequencer, the arithmetic unit, and the memory.

The basic rhythm of the sequencer is controlled by Clock CL6. CL6 occurs at eight times the system sampling rate of 26.5 Hz. The leading edge (LE) of CL6 is defined as the starting point for the sequence. A reset pulse from the system timer resets all the counters at this time. The routine counter is synchronized with delayed TLM sync, which occurs near the beginning of telemetry word No. 4. From this point, the counter (a



*DIGITAL CONSTANTS

$X_1 = \text{SIN}\,X + \text{COS}\,Y\ (=X)$

$B_0 = 2^{-7} + 2^{-10}$

$B_1 = \text{SGN.} + 2^{0} + 2^{-1} + 2^{-2} + 2^{-3}$

$B_2 = 2^{-1} + 2^{-2} + 2^{-3} + 2^{-7} + 2^{-9}$

$B_3 = \text{SGN.} + 2^{0} + 2^{-1} + 2^{-2} + 2^{-4} + 2^{-6}$

$B_4 = 2^{-1} + 2^{-2} + 2^{-4} + 2^{-6}$

MT-DA1609

Figure 4-23 Digital Filter Mathematical Functional Block Diagram

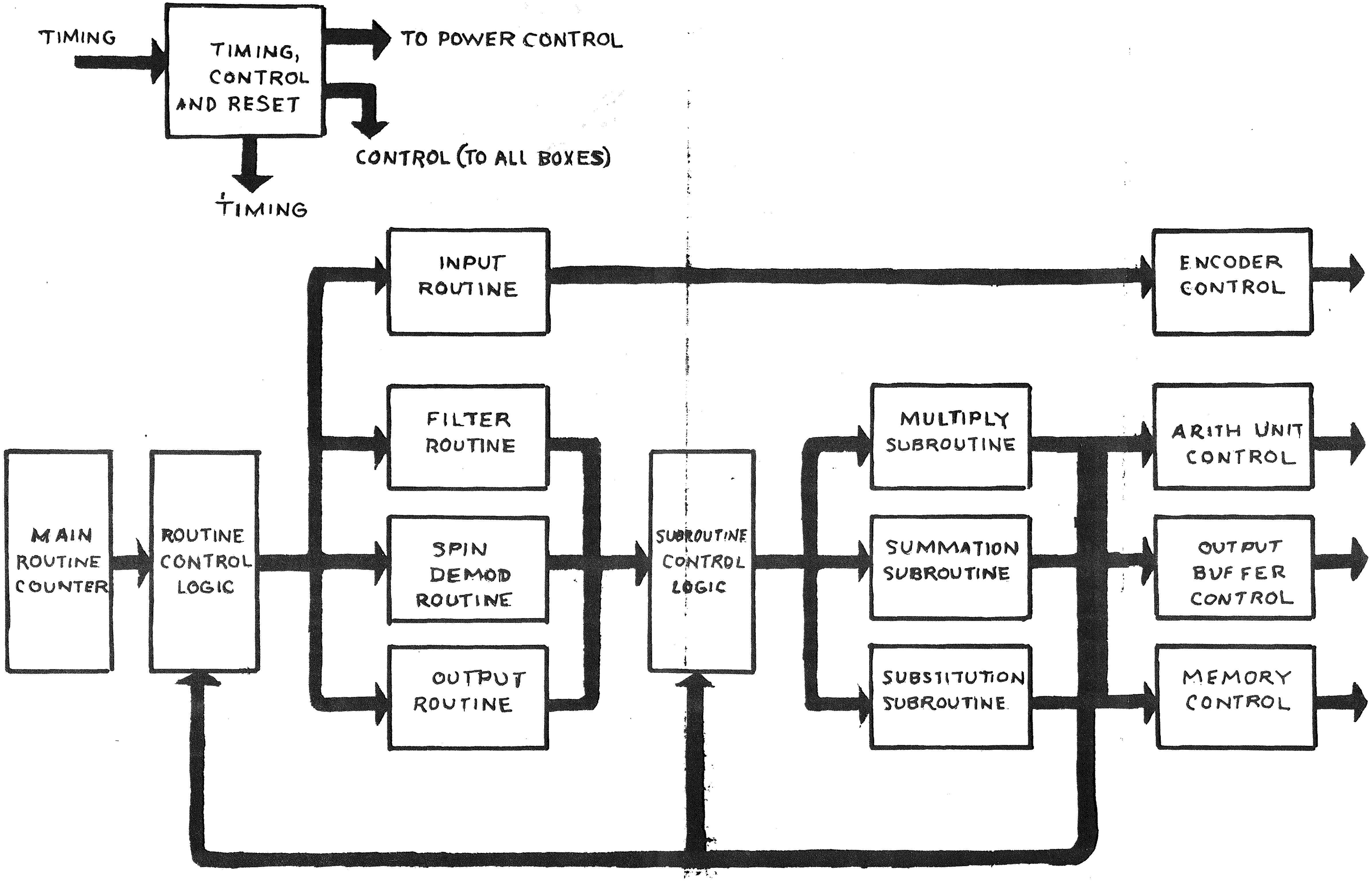


Figure 4-24 LSM Scientific Sequencer Flow Diagram

divide-by-eight) advances on CL6 as shown:

CL6	Routine
1	Output-Input
2	Spin Demod*
3	Filter
4	Dummy Step (state not used)
5	Filter
6	Dummy Step (state not used)
7	Filter
8	Dummy Step (state not used)

Upon receipt of each CL6 LE, the scientific sequencer and the arithmetic unit, power is turned on, a routine is performed, and power is turned off. The output routine is very short, so it is run together with the input routine.

Counter 00 and the majority of the control logic are run on full-time power, but the remainder of the circuitry is power-switched to achieve low average power consumption. The Arithmetic Unit (AU) and the Multiplexer-A/D Converter (A/D) both consume considerable peak power during their active conditions. The A/D is energized only during the input routine. Since no arithmetic operations occur during that time, the AU is given its own power bus (denoted by +5VSA), which is switched off during the input routine by the power control logic. (The full-time power bus is denoted by +5V, while the switched power to the rest of the sequencer is denoted by +5VSC.)

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*In this routine the unit executes the arithmetic steps of the Spin Demod routine, with fixed constants 1 and 0 for sine and cosine, respectively. The net result is that the data is unchanged. This is in contrast to the varying coordinates used for the Pioneer Magnetometer System(spinning spacecraft application).

In the detailed list of sequencer steps, there appear read-and-write operations termed "dummy." These are either read operations where nothing has ever been written into that location, or write operations that are never read out. This apparent peculiarity is deliberate. The memory is organized in this way to simplify the scientific sequencer. The dummy operations which cost little in memory power or size, permit the sequencer to be mechanized with only three subroutines. All the required steps of the sequencer were organized into groups of repetitive steps, the groups were reduced to three categories, and the most complicated one in each category was mechanized. The dummy steps tailor the subroutine to simpler functions at little cost. The memory is cleared out or zeroed by withholding all write commands for a complete sequence. The read operation is destructive, and all active locations are read in one complete cycle, or pass.

The timing inputs to the scientific sequencer are pulse trains. The outputs are pulse patterns on many different lines. The counter control states which define particular pulses, do not appear outside this subsystem. To check or troubleshoot the unit, a particular operation will have to be examined. There are many lines of decoded counter states emanating from this subsystem. In order to simplify troubleshooting, a piece of test equipment--called the Data Bus Display Unit (DBDU)--was designed. This equipment counts CL2 pulses and is reset by the 00 reset (OOR). It is held off whenever the scientific sequencer is held off. A counter in the DBDU can be pre-set to strobe a storage register or produce a trigger pulse at any count. The column title "Test Panel Steps" in the detailed list of sequencer steps is for the purpose of setting the DBDU.

The entire operation of the scientific sequencer is serial. If for any reason, the series of operations is halted at any point, the entire machine is stopped. To protect against this, the OOR and SR pulses are generated independently of any flip flop (FF) state and operate on the asynchronous entry ("C_p") of all counter and control FF's.

The worst that can happen is that a routine will remain on between CL6 pulses, causing a surge in input power.

LSM Arithmetic Unit Description (See Figure 4-25)

The arithmetic unit utilized in the LSM system has the capability of accepting parallel data in sign-magnitude form and performing addition, subtraction and multiplication operations upon command. There are certain rules governing the presentation of input data to the system that will be presented in another paragraph. The 24-bit arithmetic unit has an operation speed of approximately ten microseconds per addition operation or, when multiplying, approximately 10 microseconds per bit.

Interface Signals

INPUT	FUNCTION
Arithmetic Reset (AR)	Resets all control functions within the unit; usually given after power is applied to unit
Clear (CL)	Resets both the accumulator (A) and multiply (M) register. Must be given prior to any arithmetic operation.
Load Multiply Register (LM)	Dumps parallel data bus into M register in sign-magnitude form. Given to load multiplier into unit or for temporary storage.
Read Multiply Register ($\overline{\text{RM}}$)	Applies contents of M register onto data bus. Used only to acquire temporarily stored word from register.
Add Command ($\overline{\text{ADD}}$)	Adds data bus to accumulator
Subtract Command ($\overline{\text{SUB}}$)	Subtracts data bus from accumulator
Read Accumulator ($\overline{\text{RA}}$)	Applies contents of accumulator to data bus in sign-magnitude form. Used to retrieve results of addition-subtraction operation.

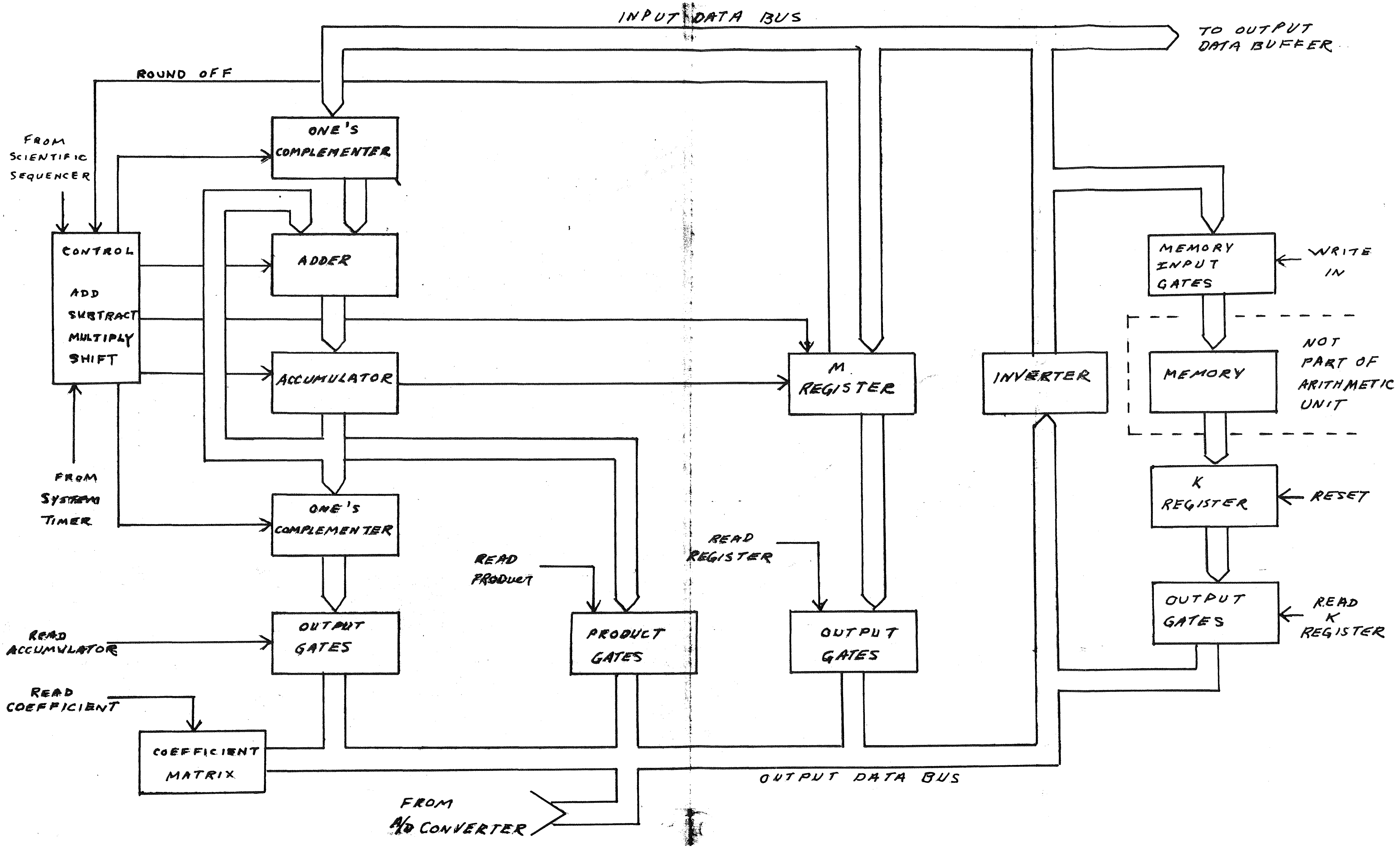


Figure 4-25 Arithmetic Unit Block Diagram

Input	Function
Multiply Command (MT)	Initiates multiply operation. Data bus multiplied by contents of M register. Data must be held on data bus during the entire cycle.
Read Product ($\overline{RP}$)	Applies product to data bus in sign-magnitude form.
Clock 1 (CL-1)	High frequency clock (~600 Kc) utilized to generate timing for multiply operations
Clock 2 (CL-2)	A second clock (~100 Kc) synchronous with CL-1 utilized for add/sub operation timing
OUTPUT	**FUNCTION**
Multiply hold-ff (MULT)	A logic signal that can be utilized to hold multiplicand on the data bus during multiply cycle. Signal remains high during the entire cycle.

Miscellaneous Requirements

1. Command Timing Requirements. All of the above-mentioned commands must be synchronous with the two clocks mentioned in the previous paragraph. Data must be presented at the parallel input to the system for one complete CL-2 period starting with the trailing edge of the command pulse for addition and subtraction operations. When loading the M register, it is necessary to have the data present during the command as the data is transferred at the leading edge of the command.

Data Logic Levels: Input Logic "1" = +5 volts
Output Logic "1" = 0 volts

Output data gates require external pull-up resistor for operation and will drive 10 unit loads per bit.

2. <u>Addition and Subtraction</u>. One's complement arithmetic without the end around carry is utilized in the unit. In order to convert from the sign magnitude format on the data bus to one's complement, a one's complementer is required on each line at the input. The logic equation relating the complement operation to the two operations is as follows:

$$C - (ADD)\ (\overline{SUB})(1_o) + (SUB)(\overline{ADD})(\overline{1_o}) \qquad (4\text{-}1)$$

where

C = complement all bits below sign bit

1_o = sign bit on data bus = logical "one".

The equation relating the sign bit to the operations is

$$1' = C = (ADD)(\overline{SUB})(\overline{1_o}) + (SUB)(\overline{ADD})(\overline{1_o}) \qquad (4\text{-}2)$$

i.e., the sign bit into the adder is a logical "one" whenever the rest of the data bus is complemented.

The parallel output from the complementer is then applied to the parallel full adder. The carry from each stage of the adder is propagated toward the most significant bit (MSB). The sum output of each stage is transferred into the accumulator for temporary storage. The sum is determined by adding the contents of the accumulator to the data bus, the new sum being strobed into the accumulator register. These operations, in equation form, are as follows:

Let X_o be the presence of a "one" on a particular data bus line and X' be the output of the complementer. Then,

$$X' = X_o \overline{C} + \overline{X}_o C \qquad (4\text{-}3)$$

is one input to the adder. If Q_x is the presence of a "one" in the particular location of the accumulator the "sum" output for the adder will be:

$$S = \overline{O}_i(Q_x \overline{X}' + \overline{Q}_x X') + C_i(\overline{Q}_x \overline{X}' + Q_x X') \qquad (4\text{-}4)$$

where C_i is the carry from the adder which is adjacent on the LSB side. The above equation is present on the pedestal input to the flip-flop, and is strobed into the register with a clock pulse at the appropriate time. Therefore, it is seen that the sum is present on a DC basis whenever data is present at the input and is not actually stored until a clock pulse is applied. The equation for the state of the flip-flop is

$$Q(N+1) = S = \overline{C}_i(Q_x \overline{X}' + \overline{Q}_x X') + C_i\ (\overline{Q}_x \overline{X}' + Q_x X') \qquad (4\text{-}5)$$

The sum, as stored in the accumulator, must again be converted to sign magnitude format, requiring an output one's complementer. The equation for complementing is

$$C = Q_1$$

where Q_1 is the sign bit or MSB in the register. An example will illustrate the above discussion.

Add -1.75
to +1.00

-1.75 $\longrightarrow$ 11.110000....0
1.00 $\longrightarrow$ 01.000000....0

Operation one: add 1 + 0

Contents of accumulator: 01.0000.....0

Since second number is negative, the input to the adder
will be: 10.001111.....1

Adding these numbers
yields: 11.001111.....1

As sign bit is one, the
result must be complemented
for the result: 10,11000......0
or -0.75

3. Multiplication. Contrary to the previous paragraph, this operation is performed for magnitude only, the sign of the result being determined separately. During multiplication, the MSB bit is inhibited so that it never is added to the accumulator register. Except for this difference, addition operations as described below are identical to those of the previous paragraph.

The accumulator has an additional function during multiplication, that of a shift register. Each bit is, as before, a storage element for the summation and also a bit of the shift register.

The Multiplier Register (M Register) is utilized in this operation and contains the multiplier as its name indicates. Operation is as follows:

a. Load multiplier into M Register

b. Apply multiplicand to data bus

The multiplication is accomplished with a series of add-shift operations, each of which is performed as described below:

a. Add Operation. The data bus is added to the accumulator if the LSB of the multiplier is a logical "one". It is not added if LSB is a "zero".

b. Shift Operation. The contents of the accumulator and M Register are shifted one bit toward LSB; data bus remains the same.

This operation is repeated up to the last operation where the shift is inhibited. This is done because of the location of the binary point, and will be apparent when the example is presented.

As a last operation, a round-off is performed. Due to the fact that the contents of the accumulator are being shifted into the M Register, a full 46 bits are available after the multiplication. Since it is desirable to round off to 23 bits, the first bit in the M Register (bit 24) is added to the last bit in the accumulator, rounding the result to 23 bits in magnitude.

The sign is determined by examining the sign of both numerals and deciding the sign of the product. The equation for this decision is

$$Q_1 = X_o \overline{X_m} + \overline{X_o} X_m$$

where

X_o = data bus (multiplicand)

X_m = sign bit of M Register (multiplier)

Example: (-1.75)(0.50)

contents of M (sign not included) = 1.11000000---0

Data bus (sign not included) = .100000-----0

Accum (sign not included) = 0.000000-----0

No additions are performed until the first one is encountered in the

M Register. At that time

M = 0.0------0111

A = 0.00-----000

DB = 0.10-----000

adding

A = 0.10-----000

after shift

M = 0.0------0011

A = 0.01-----000

DB = 0.10-----000

add

A = 0.11-----000

shift:

M = 0.0------001

A = 0.110----00

DB = 0.100-----00

add

A = 0.111-----00

Result = -0.875

As is seen from the example, inhibiting the last shift leaves the binary point in the correct position after multiplication.

4. <u>Timing</u>.Figure 4-26contains a timing diagram of the system for both arithmetic operations. The upper part shows the timing for an add or subtract operation illustrating the strobe that loads the sum into the accumulator register. During multiplication, the waveform called ADD/SHIFT ENABLE changes the function of the accumulator, alternately, between storage and shifting operations. The add and shift clocks are as shown in the diagram to allow a maximum amount of time for the carry to propagate in the adder before the add pulse occurs. This choice of pulses allows the maximum speed of operation during multiplication.

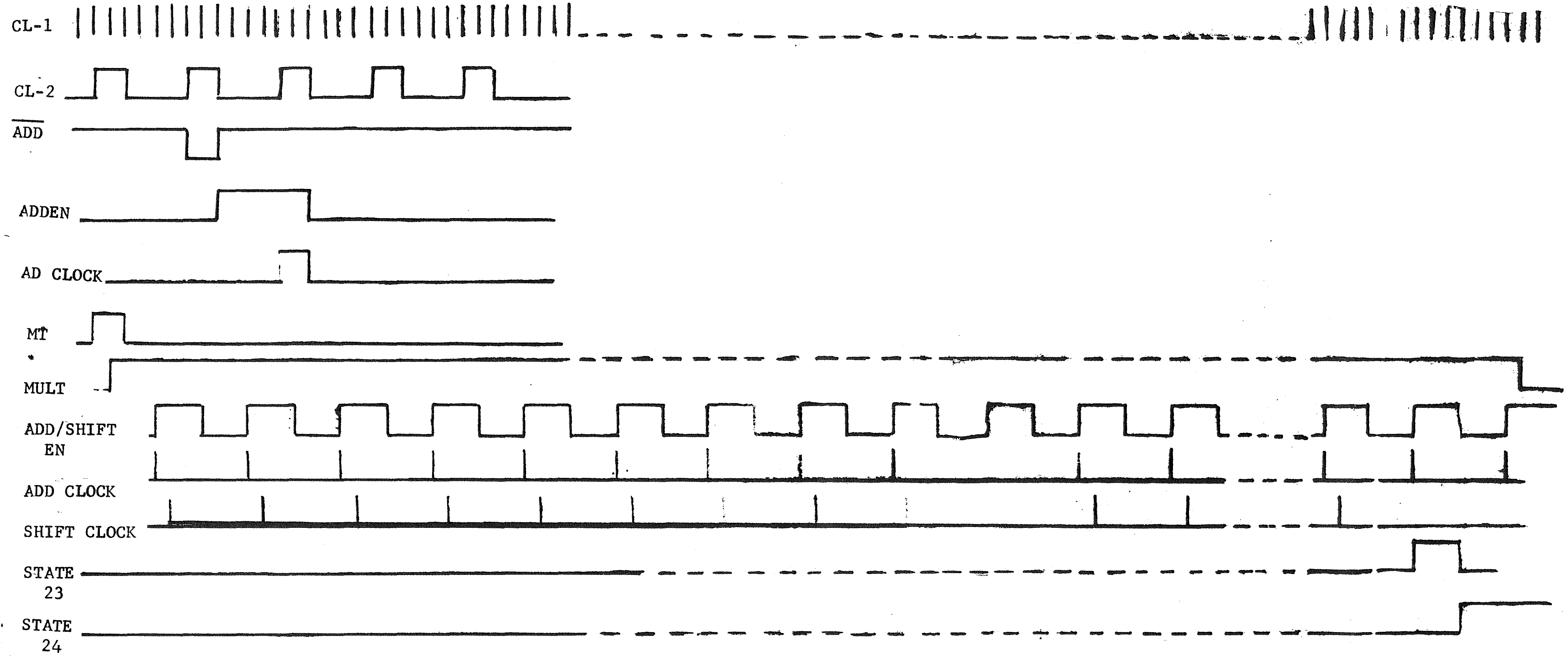


Figure 4-26 Timing Diagram - **Arithmetic** Unit

4.2.2.2.3 Output Data Buffer

The Output Data Buffer (ODB) formats LSM internal scientific and engineering data as required by the electrical interface with ALSEP. Figure 4-27 indicates the functional operation of the ODB which is comprised basically of three 10-bit shift registers connected in tandem plus associated gates and shift logic.

The scientific data input is received as a sequence of three 10-bit words (X, Y and Z), together with a data transfer (or load) command for each word. X, the first word to occur, is parallel-loaded into the first 10-bit shift register. Under control of the shift logic, 10 cycles of 190.8 Hz clock are used to shift this X-word into the second register prior to receipt of the next (Y) word. Similarly, when the Y word appears, it is loaded into the first register, followed again by 10 cycles of the 190.8 Hz clock. This shifts Y into the second register, and X from the second into the third register. Finally, Z is loaded into the first register. All data then resides stored in the total 30-bit register until a signal on the demand line occurs. The demand line signal allows 10 cycles of the 1060 Hz shift clock to shift out the contents of the third register to ALSEP. Since X is contained in the third register, it will be read out first. As X is shifted out, bit by bit, the entire 30-stage register is connected serially so that Y follows X into the third register, and likewise Z follows Y into the second register. A successive demand pulse, later in the telemetry frame, will enable the Y word to be shifted out in like manner; and, similarly, for the Z word, at a still later time in the frame.

Engineering data is loaded into the first register once per frame by an engineering load pulse at the appropriate time in the frame. This data, however, is not shifted into successive registers, but is gated directly out to ALSEP (at the 1060 Hz shift clock rate) when the demand line signal corresponding to the fifth word of the frame is received.

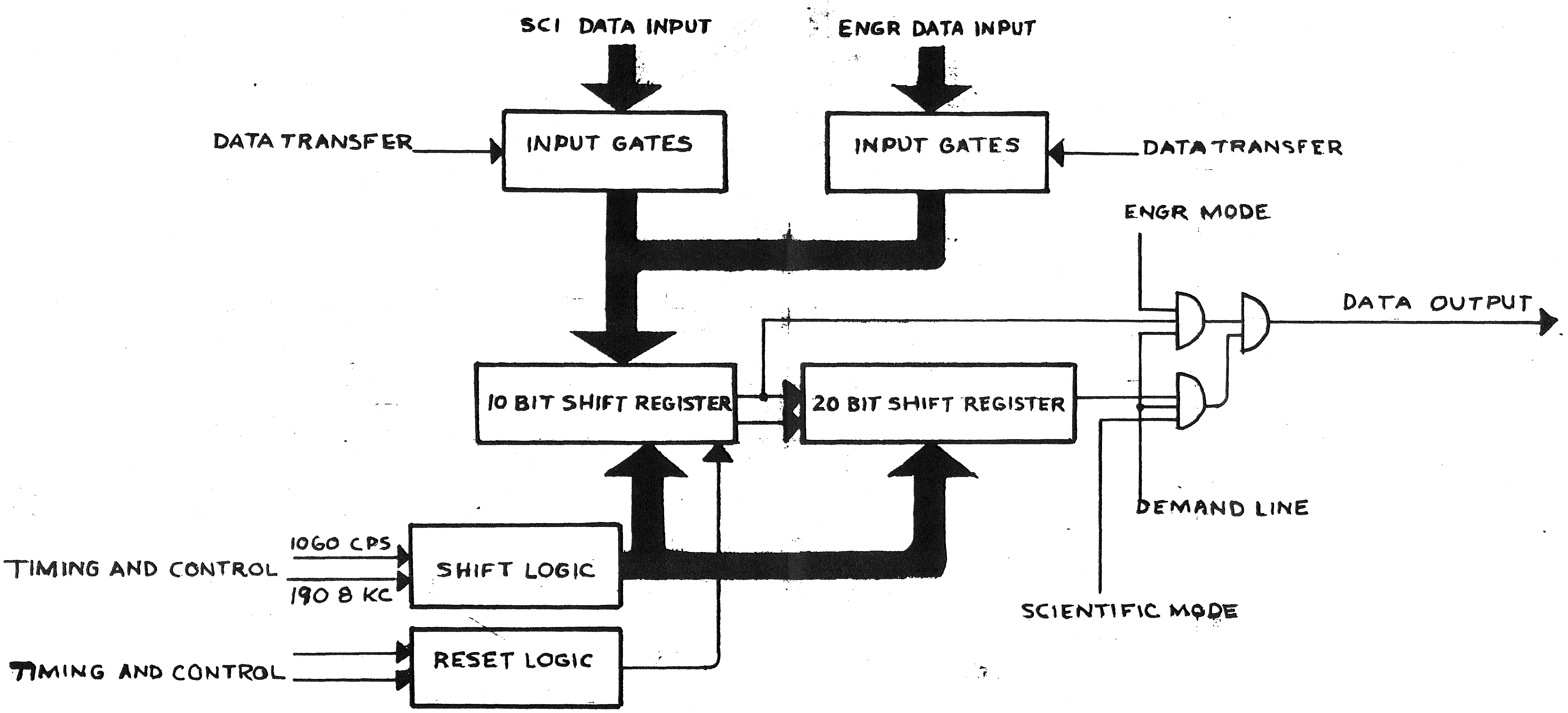


Figure 4-27 LSM Output Data Buffer Functional Diagram

4.2.2.2.4 Engineering Data Sequencer

The Engineering Data Sequencer (EDS) is an all-digital subsystem used in LSM to provide the timing and control necessary for the engineering data and status reporting portion of the LSM output.

Figure 4-25 is a block diagram depicting the major functions of the EDS. The engineering data control portion of the EDS is accomplished by a ÷ 8 counter and associated decode circuits which sequentially command the analog-to-digital converter (A/D) to: (1) turn power on, (2) perform a zero correction cycle, (3) sample and convert the appropriate analog engineering channel, (4) load the digitized information into the output data buffer and, (5) turn the A/D power off.

The status reporting control consists primarily of a ÷ 16 counter, multiplexer and associated gating circuitry. The counter is advanced every ALSEP frame and enables the multiplexer to select the appropriate bi-level data (status bits) for each particular frame. This bi-level data is loaded into the output buffer at the same time as the digitized engineering data. A total of 16 frames is required to cycle through all of the bi-level data. Every 16th frame, a flag bit is loaded into the output buffer to enable synchronization of the engineering words.

Since the above functions are only required once-per-frame, switched power (designated as +5 VSD) is furnished to most of the circuits in the EDS. This power is applied for approximately 1 ms and occurs immediately prior to the fifth word of each ALSEP frame.

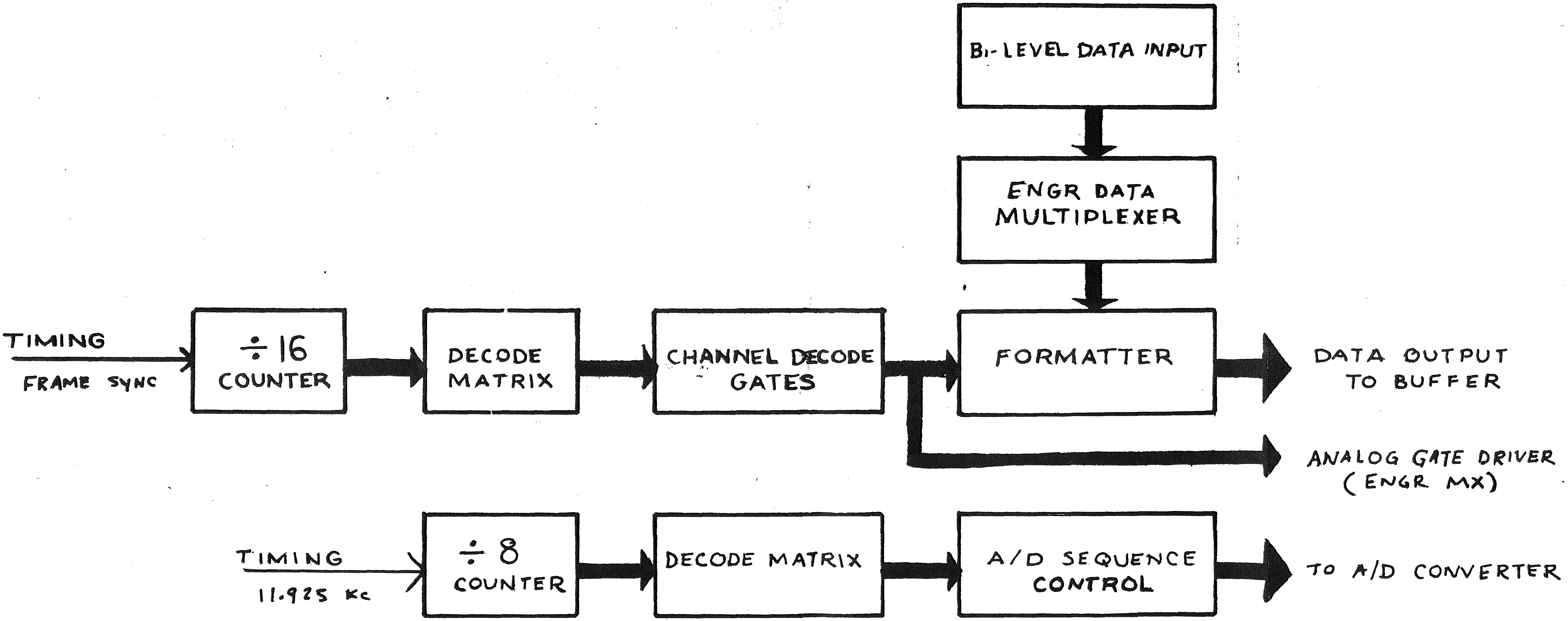


Figure 4-28 LSM Engineering Sequencer Functional Diagram

4.2.3 Calibration and Sequencing Function

4.2.3.1 Block Diagram Description

The calibration and sequencing function has reference to the external sequences generated by the LSM (i.e., Flip/Cal and Site Survey) as opposed to internal sequences generated by the scientific sequencer or the engineering data sequencer.

Figure 4-29 is a block diagram of the calibration and sequencing subsystem.

Generation of the calibration fields is discussed in Section 4.2.1 and will not be repeated here. Thus, the Site Survey/Flip/Cal programmer and the offset command logic are the subsystems of primary interest.

The flip-calibration and site survey sequences are activated via ground command. The flip-calibration has an additional command interface in the flip/cal inhibit command. This command inhibits the flip/cal cycle by preventing the next flip/cal initiate command in the cycle from being made. The flip/cal inhibit does not inhibit the site survey sequence, however.

4.2.3.2 Calibration and Sequencing Detailed Description

4.2.3.2.1 Site Survey/Flip Cal Programmer

The function of this programmer is two-fold. It performs the instrument programming necessary (a) for executing a flip-calibrate sequence and (b) for executing a site survey sequence. These are separate but interrelated routines. The flip-cal routine is an independent sequence of steps, consisting of flip-motor actions and calibrate step patterns

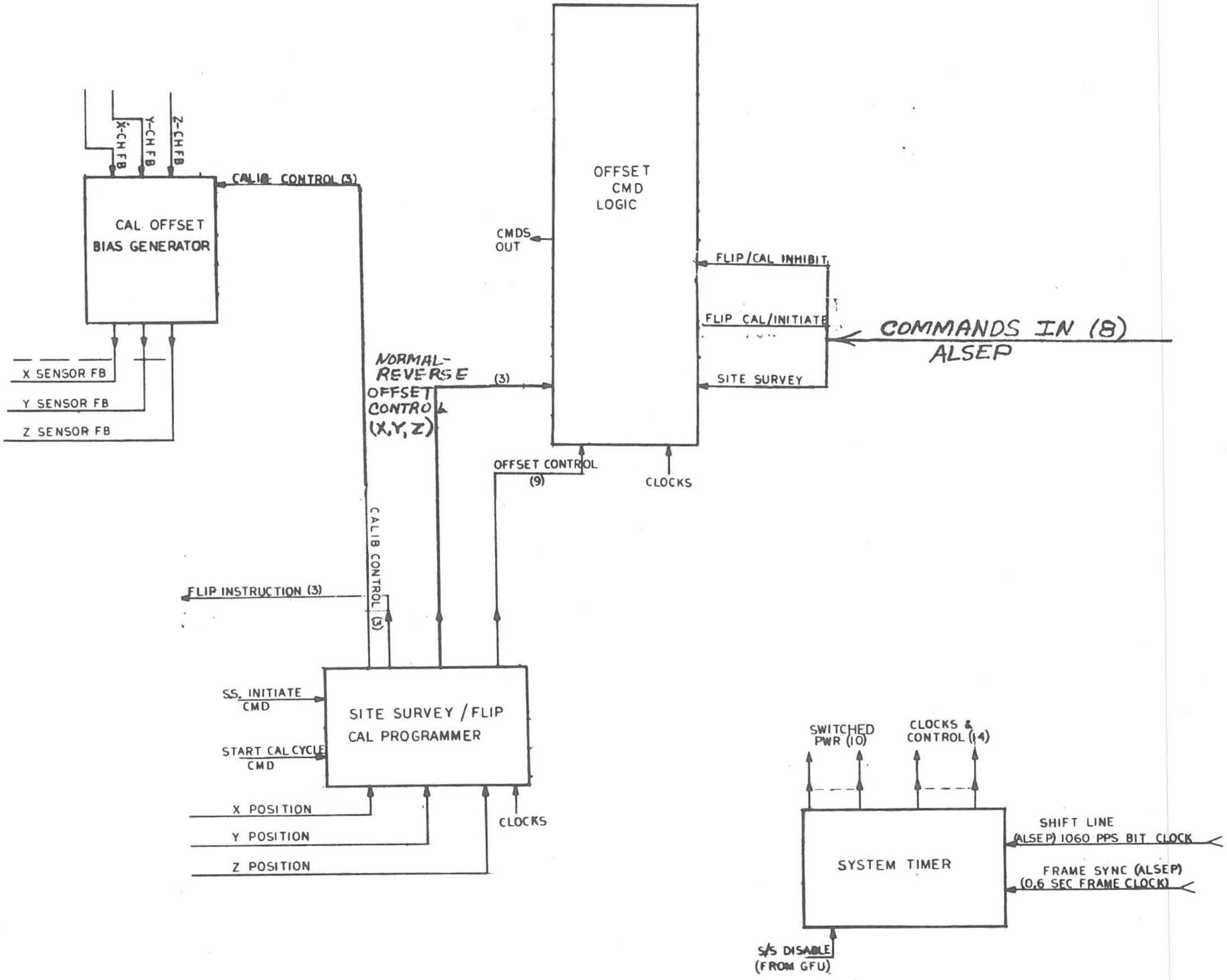


Figure 4-29 Calibration & Sequencing Functional Block Diagram

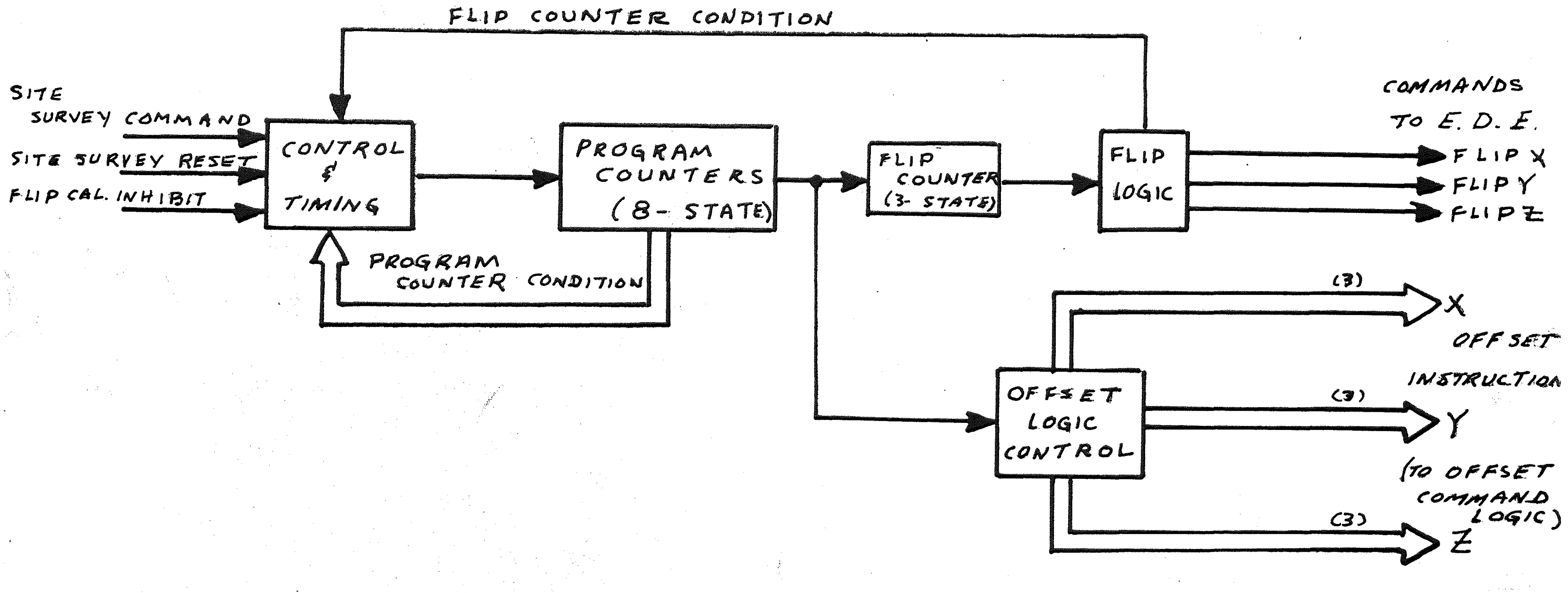
(raster). The site survey routine is a program of flip-motor actions, gimballing actions, calibrate steps, and scientific data taking. It is pointed out that the flip-cal routine is a sub-routine of the site survey routine.

Site survey is employed once during initial set-up of the instrument on the lunar surface. Following completion of the survey, permanent automatic disablement of the function is accomplished to reduce system power requirements. Flip-Cal is employed during the site survey (as a subroutine), and thereafter as commanded automatically from ALSEP or as required from the ground. (See Figure 4-34 for illustration of the operational sequence.) The functional block diagram, Figure 4-30, shows the basic composition of this subsystem as being comprised of two independent autonomous sections, the flip cal section and the site survey section. Operation is as described in the following paragraphs.

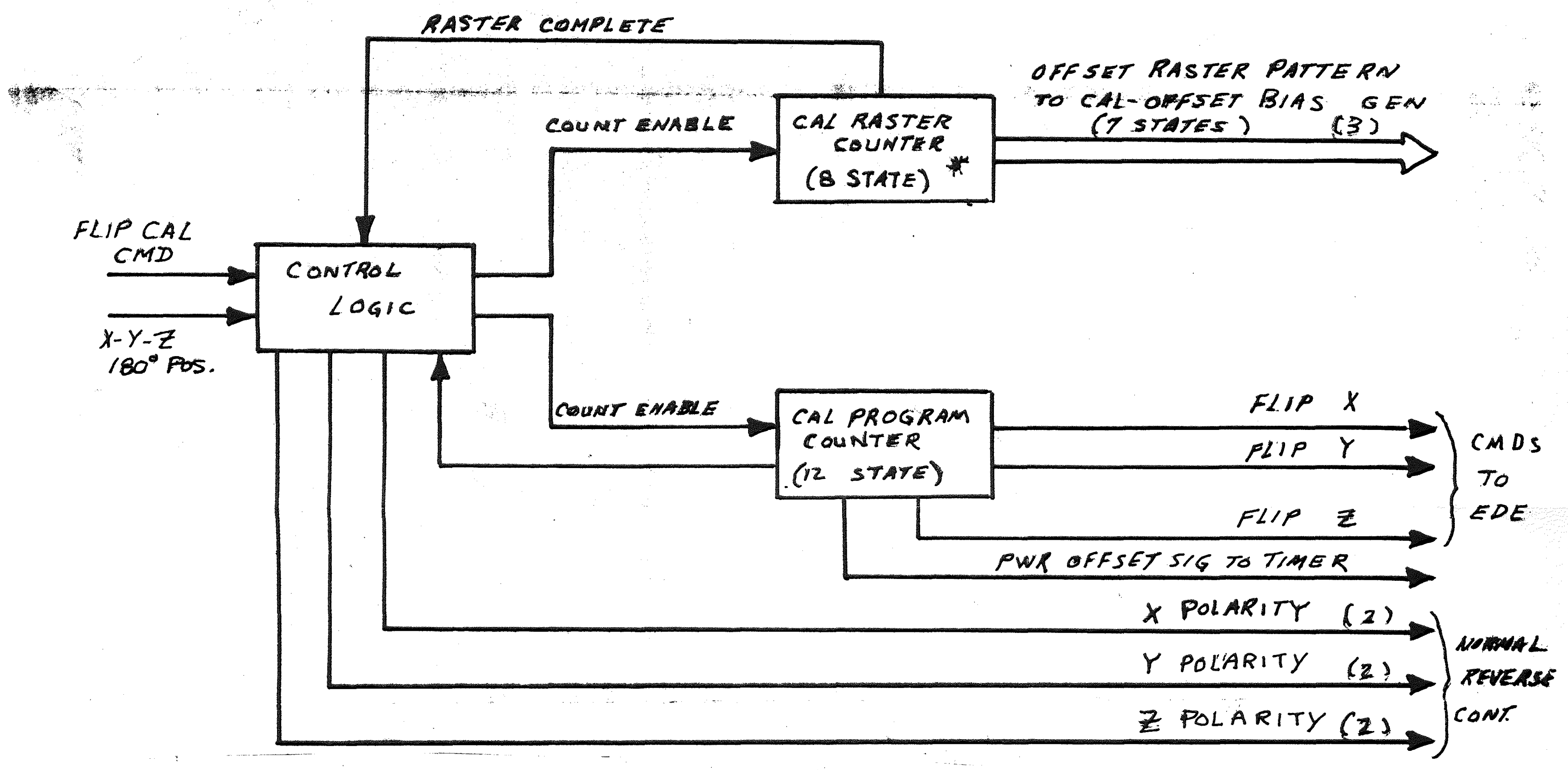
Flip Cal. The flip cal section produces the sequence of steps required to generate a calibrate raster pattern and to enable X, Y, and Z motor flipping. Three logic functions are employed: control logic, cal raster counter, and cal program counter (See Figure 4-30). Timing and commands from the system timer start the sequence of events. The control logic functions to enable and to clock the 8-state cal-raster counter for two complete cycles (16 steps). Output of this counter is a 3-bit parallel word containing the 7-state cal-raster pattern. This is applied to the cal-offset bias generator.

When two rasters have been performed, a sequence of flip commands is produced by the cal program counter. This is a 12-state counter that generates Flip X, Flip Y, and Flip Z controls for the EDE Subsystem.

Site Survey. This element is a logic programmer comprised of five functions: control and timing, program counter (8-state), flip counter (2-state), offset logic control, and flip logic (See Figure 4-30). Command



SITE SURVEY SECTION



* COUNTER HAS 8 STATES, WITH 7 UNIQUE OUTPUTS

FLIP CAL SECTION

Figure 4-30 Site Survey - Flip/Cal Program - Block Diagram and timing inputs are received from the System Timer Subsystem. The control and timing logic generates signals that advance the 8-state program counter. This is the main sequence control unit of the Site Survey Subsystem. It controls the entire site survey main routine.

The flip counter and flip logic produce three flip commands (Flip X, Y, and Z) for enabling motor flip operation by the EDE Subsystem.

Offset instructions required to apply correct steady field offsets in the sensor electronics are generated by the offset logic control. The offset logic control decodes inputs from the program counter. Outputs represent offset switching instructions for all three axes. These signals interface with the Offset Command Logic Subsystem.

4.2.3.2 Offset Command Logic

The two principal functions of this subsystem are to process commands received from ALSEP and to provide range and offset control information to the sensor electronics.

When commands are received, they are synchronized to an internal LSM clock. Static storage (from flip flops) is provided in this subsystem for the flip-cal inhibit command. Pulse type outputs are generated for the site survey and flip-cal initiate. Status information from the stored commands, and for the range and offset controls, is produced and applied to the engineering sequencer for multiplexing with output data.

4.2.4 Power Control Function

4.2.4.1 Block Diagram Description

The power control function of the LSM has three major aspects: (1) conditioning of 29VDC power for use by LSM Processor Electronics, (2) time-sharing high power loads of the motors and heaters, and (3) time-sharing electronics power during interval sequences so that peak and average power demands on the ALSEP are greatly reduced.

Figure 4-31 is a block diagram of the power control function and indicates the LSM loads that couple directly to the ALSEP 29V line, as well as internal power distribution requirements.

The LSM power profile is presented in Section 3.3. The power conditioning function is performed by the DC/DC converter. The motor-heater control is a part of the engineering data electronics; and the internal power sharing is controlled by the system timer.

4.2.4.2 Power Control Detailed Descriptions

4.2.4.2.1 DC/DC Converter

The converter utilizes a saturable core transistor switching technique and is designed to operate over primary line excursions from 24 VDC to 30 VDC. The converter design may be broken down into five primary functions: regulation, conversion, filtering, current surge limiting, and feedback.

Regulation

The initial function of the design involves a magnetically-coupled, free-running oscillator. Generally, the operating frequency is an independent

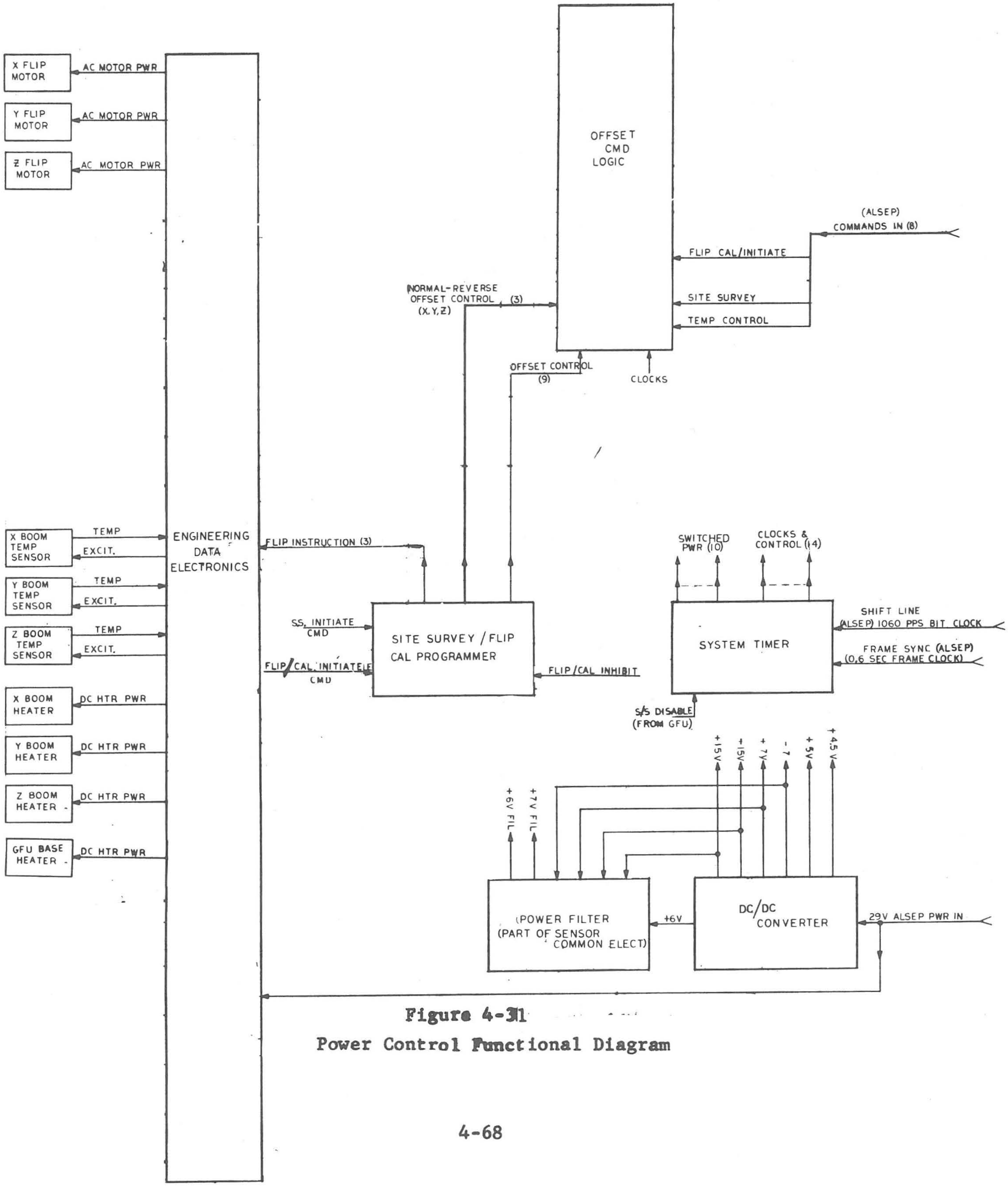


Figure 4-31

Power Control Functional Diagram

parameter, and is chosen to reduce the size and weight of magnetic filtering. The pulse width modulator follows the oscillator driver. The rate at which pulses occur is controlled by the preceding oscillator driver.

The pulse width modulator, like the preceding oscillator, is a magnetically-coupled device but, unlike the oscillator, is not free-running. With each change of state in the oscillator driver, a constant voltsecond pulse is generated which has the desired characteristics for regulation. High power transfer is accomplished by driving an inverter stage with the constant voltsecond waveform.

Conversion

Conversion is provided by an inverter and by full-wave rectification at the secondary of the output transformer and filtering to DC.

Filtering

Integrating L-C filters are used at each output. High frequency operation (70 KC) allows reduced filter sizes and improved response.

Feedback

The feedback loop utilizes a differential amplifier for stable temperature operation and provides fine regulation control.

Current Surge Limiting

An active series line switch provides sufficient suppression of the initial turn-on surge current. At turn-on, limited power (12 W max. input) is supplied by a series bypass resistor on the switch until output capacitors in the output filters are nearly fully charged. At this time, the series transistor switch is driven hard-on, allowing full-power transfer.

Characteristics of the converter output lines are given in Table 4-2.

4.2.4.2.2 Engineering Data Electronics (EDE)

The EDE provides two major power control functions: motor control and heater control. The heater control function is a command interface. The temperature control command allows three choices of heater control:

X-channel sensor temperature
Y-channel sensor temperature
Heaters Off

Motor Control Electronics

This section consists of a drive generator capable of sequentially producing two-phase, 400-Hz power for each of the three flip motors, along with selection and control logic. Figure 4-32 is a block diagram of the motor control logic. (NOTE: One output of this section is a Heater Disable command so that the motors and heaters can not be on at the same time.)

Heater Control

The function of the heater control is to monitor a fluxgate sensor temperature and to apply primary ALSEP power to heaters in the heads and in the internal electronics. Heater power is switched on when the controlling temperature sensor reads less than +35°C. The controlling sensor is the thermistor located in either the X or Y sensor head. Selection is implemented by ground command. The sequence of ground command functions is:

Command No. 0	(System Power On): Monitor X-axis fluxgate temperature
Command No. 1	Monitor Y-axis fluxgate temperature (Power On)
Command No. 2	Heater Power Off (Monitor X)
Command No. 3	Monitor X-axis fluxgate temperature (Power Off)
	Etc.

TABLE 4-2

OUTPUT LINE	BASE LINE VOLTAGE		PULSE-STEP VOLTAGE		PEAK-PEAK TRANSIENT		BASELINE CURRENT-ma		PULSE CURRENT-ma		CHOPPER RIPPLE VOLTAGE-MAX.		AVERAGE CURRENT
	NOM	TOL	NOM	LIMITS (MAX)	NOM	LIMITS	NOM	TOLERANCE	NOM	TOLERANCE	ON BASE LINE	DURING PULSE LOAD	MA
+5	5.25	±1.5%	0.4V	.5V	0.5V	.75V	160	1½%	300	1½%	50MV	50MV	220 ±3%
+4.4	4.60	±1.5%	0.4V	.5V	0.6	.75	4.0	1½%	9.0	1½%	50MV	50MV	6 ma
+7	8.2	±1.5%	0.7V	.8V	0.7	.9	66	1½%	70.8	1½%	50MV	50MV	79.5±3%
-7	8.2	±1.5%	1.6V	3.5V	2.0	3.5	1 ma	1½%	29.5	1¼%	N.A.	50MV	7 ma
+15	15.2	± 1.5%	1.2V	1.4V	1.5	1.6	11	1½%	70	1½%	50MV	75MV	24.1±3%
-15	15.2	±1.5%	1.2V	1.4V	1.5	1.6	2.0	1½%	50	1½%	50MV	75MV	11.2±3%
+6	7.70	±1.5%	.3V	.4V	0.4	.5	13	1½	NONE	-	50MV	50MV	13±3%

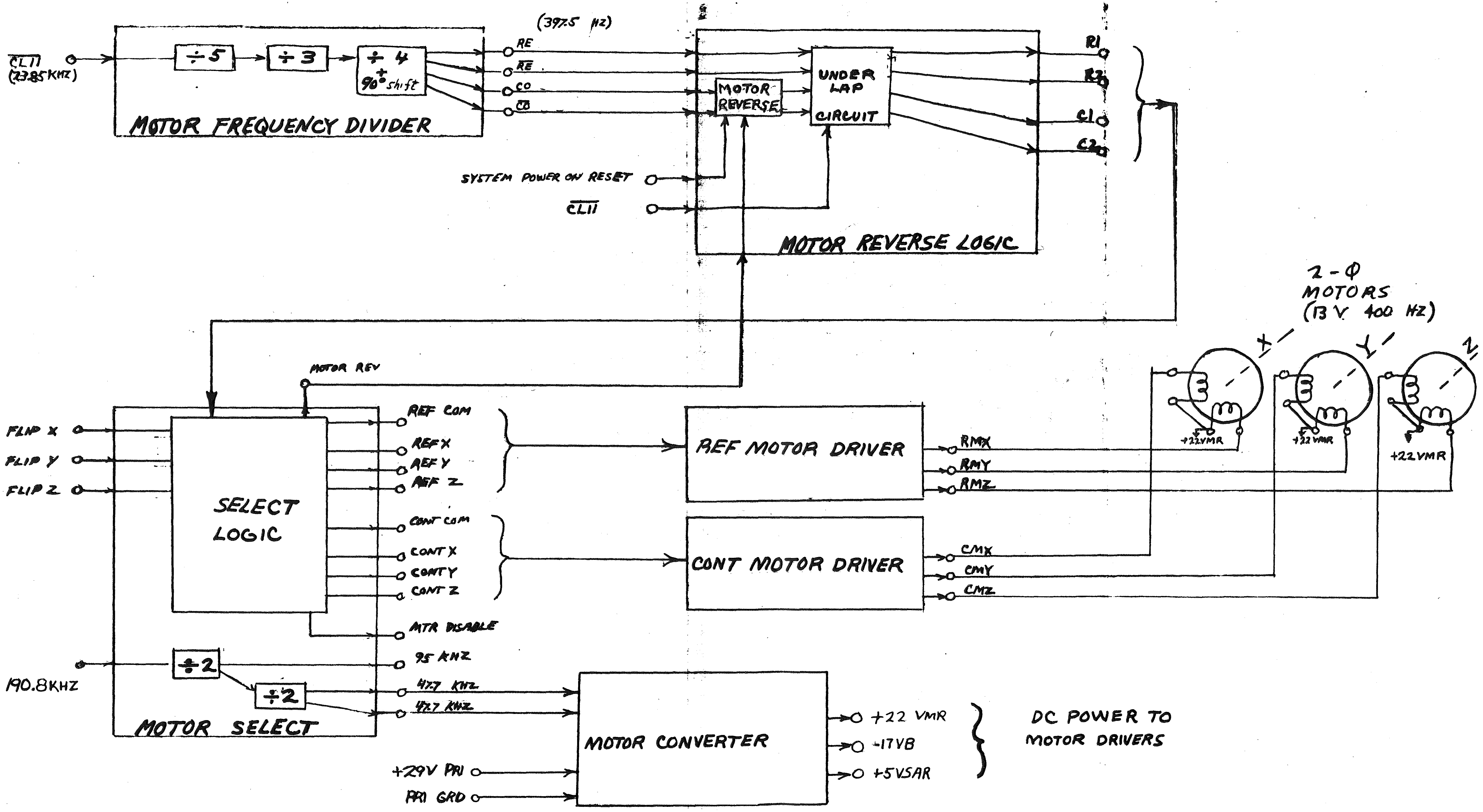


Figure 4-32 Motor Logic & Drivers - Block Diagram

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The block diagram of the heater control electronics has been presented previously in Section 4.2.1.3 (Reference Figure 4-11).

4.2.4.2.3 System Timer

The System Timer performs three basic functions. It provides coherence with the 1060 Hz ALSEP clock; it generates system clocks derived from ALSEP clock; and it provides switched power to some subsystems of the LSM.

ALSEP-LSM coherence is accomplished as follows: The 1060 Hz ALSEP clock is chopped by an internally-generated LSM clock in the phase detector. The output is applied to a low-pass filter and, in turn, to a unity gain buffer. The buffer drives a VCO by shifting the DC voltage to the frequency controlling input. Closing the phaselocked loop is a 1/540 counter which divides 572.4 kHz VCO output to 1060 Hz internal chopping frequency. Twelve system clocks are taken from the 1/540 and a further 1/640 divider such that any bit of any word within the TLM frame may be uniquely selected.

Ten switched power outputs are driven from the timing dividers. System synchronism is maintained, in that clocks and switched powers are derived from the same divider chain. A system power-on reset pulse is generated to initialize subsystems as required.

More importantly, however, the initializer insures that the power switches remain off until lock has been acquired.

Switched Power. The timing details of switched power in the LSM are extremely complex and will be discussed only in general.

1. +5VSA. Five-volt power supplied to the Arithmetic Subsystem for computation power during the output, despin and filter routines. This power switch is turned on by system CL6 (clock 6) and turned off by end-of-routine signals from the Scientific Sequencer Subsystem.

2. +5VSB. Five-volt power supplied to the "K" register. The switch is turned on by CL6 and off by end-of-routine signals. It differs from +5VSA in that power remains on after output routine, and is turned off by end of input routine. In addition, it contains a one-millisecond power pulse occurring during bit 8 of word 4 (once per TLM frame). This is necessary to transfer the digitized engineering analog data from the A/D converter to the output data buffer via the "K" register.

3. +5VSC. Five-volt power supplied to the scientific sequencer and memory. Identical to +5VSB except it does not include the 1-ms power pulse for engineering data.

4. +5VSD. (Five-volt pulse), +12 VST (12-volt pulse), -6VSJ (-6 volt pulse). All supplied to the Engineering Data Electronics Subsystem during TLM word 4 bit 8 (see 2 above).

5. +5 VSG. Five-volt power supplied to the output data buffer. This switch is powered three times during a TLM frame. The sequence is as follows:

	ON		OFF	
	Word	Bit	Word	Bit
Engineering Data	4	6	6	2
Scientific Data Sample 1	16	6	22	2
Scientific Data Sample 2	48	6	54	2

On and Off instructions are derived from the bit and word rate divider chain.

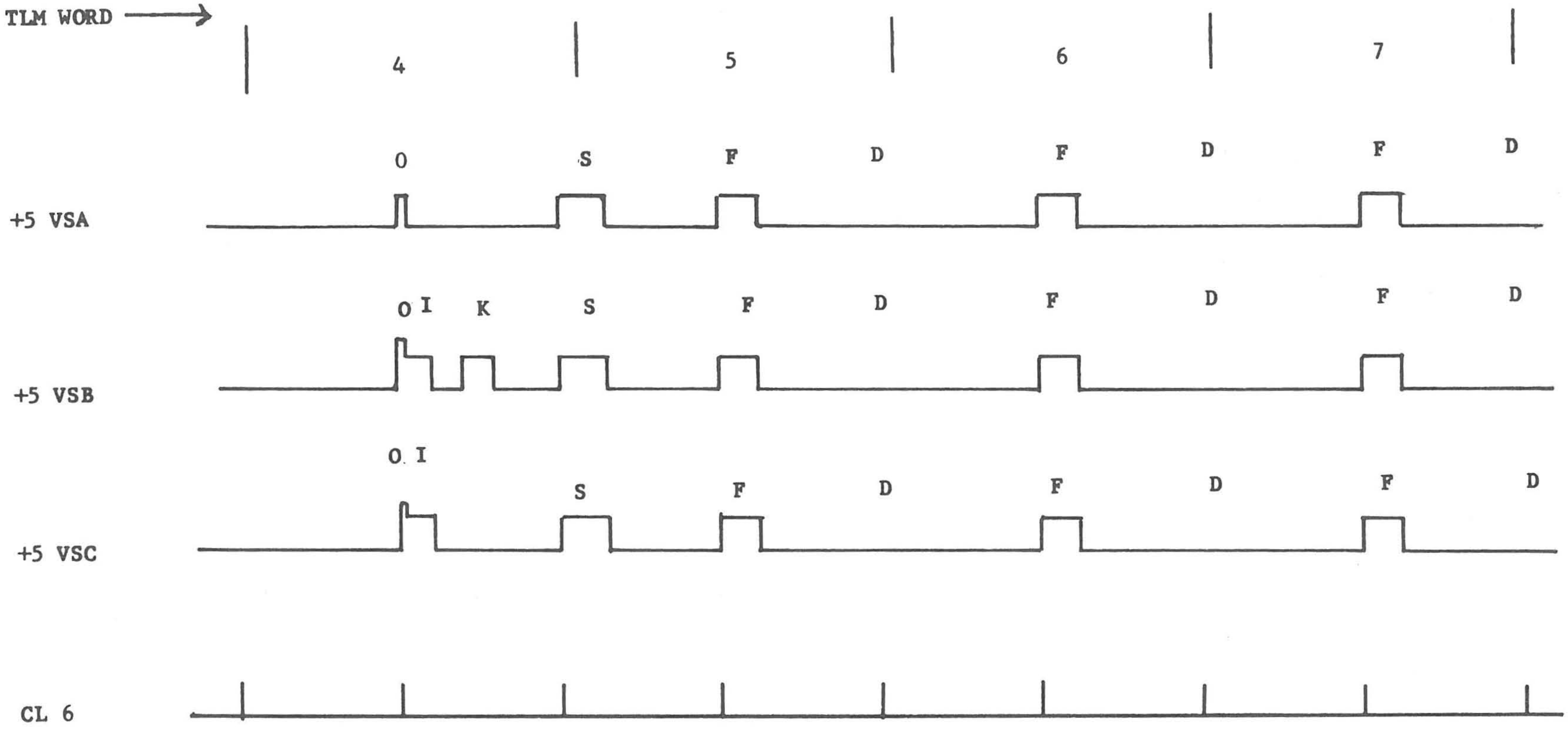
6. +5 VSE. Five-volt power supplied to the Site Survey Sequencer and Engineering Data subsystems. The first site survey command switches +5 VSE on. It remains on for an indeterminate length

of time, as each axis survey is initiated by a separate command. At the conclusion of the Z axis survey and calibration, the site survey cam switch closes, removing site survey power for the remainder of the mission.

7. +5 VSF. Five-volt power supplied to the Flip Cal Programmer Subsystem. This switch is commanded on from two sources. The calibrate command from ALSEP (ground command or 12-hour clock) and the cal mode command from the site survey sequencer. This power remains on during the flip cal cycle, and is commanded off by the flip cal programmer.

8. +5 VSK. Five-volt power supplied to the Engineering Data Subsystem. This switch is closed for either +5 VSE or +5 VSF.

The Timing Diagram is shown in Figure 4-33.



O - Output routine - 16 Times/Frame
I - Input Routine - 16 Times/Frame
K - K Reg Power - Once/Frame
S - Spin Demod Routine - 16 Times/Frame
F - Filter Routine - 48 Times/Frame
D - Dummy Routine - Power is inhibited

Figure 4-33 Timing Diagram Showing Relationship of Power Pulses to TLM Frame

4.2.5 Sensor Orientation Function

4.2.5.1 Block Diagram Description

As described in Section 2, the design of the LSM provides the capability for operation in a calibration and a site survey mode in addition to the normal scientific mode. This capability is manifested in several mechanically and electronically sequenced operations performed automatically following initiation. The calibration mode requires that signals and mechanical functions be provided such that the three magnetic sensors are flipped 180° one at a time and a series of zero offsets are applied. The site-survey operation requires that all magnetic sensors be aligned parallel to each of the three coordinate axes in turn. Figure 4-34 shows the sequence of events for each sensor and indicates that a calibration flip is periodically required during the site-survey mode.

Section 3.2.1 explains the mechanical components in the sensor heads and in the Gimbal Flip Unit which provide the mechanical capability to perform the flip-calibrate and site-survey functions. Figure 4-35 is a block diagram which shows the electromechanical drive system in relation to the various influences which affect the positioning of the sensors.

4.2.5.2 Sensor Orientation Detailed Description

4.2.5.2.1 Accuracy

The three magnetic sensors in their thermally controlled housings are normally oriented along axes aligned with their individual support arms. These axes form an orthogonal system such that the pyramidal bisector is approximately vertical. The sensor orientation accuracy requirement is that a known time-varying magnetic field be measured by the LSM and reconstructed with respect to the LSM reference coordinates from the output data with a misalignment-produced error of no more than ±1.5% for

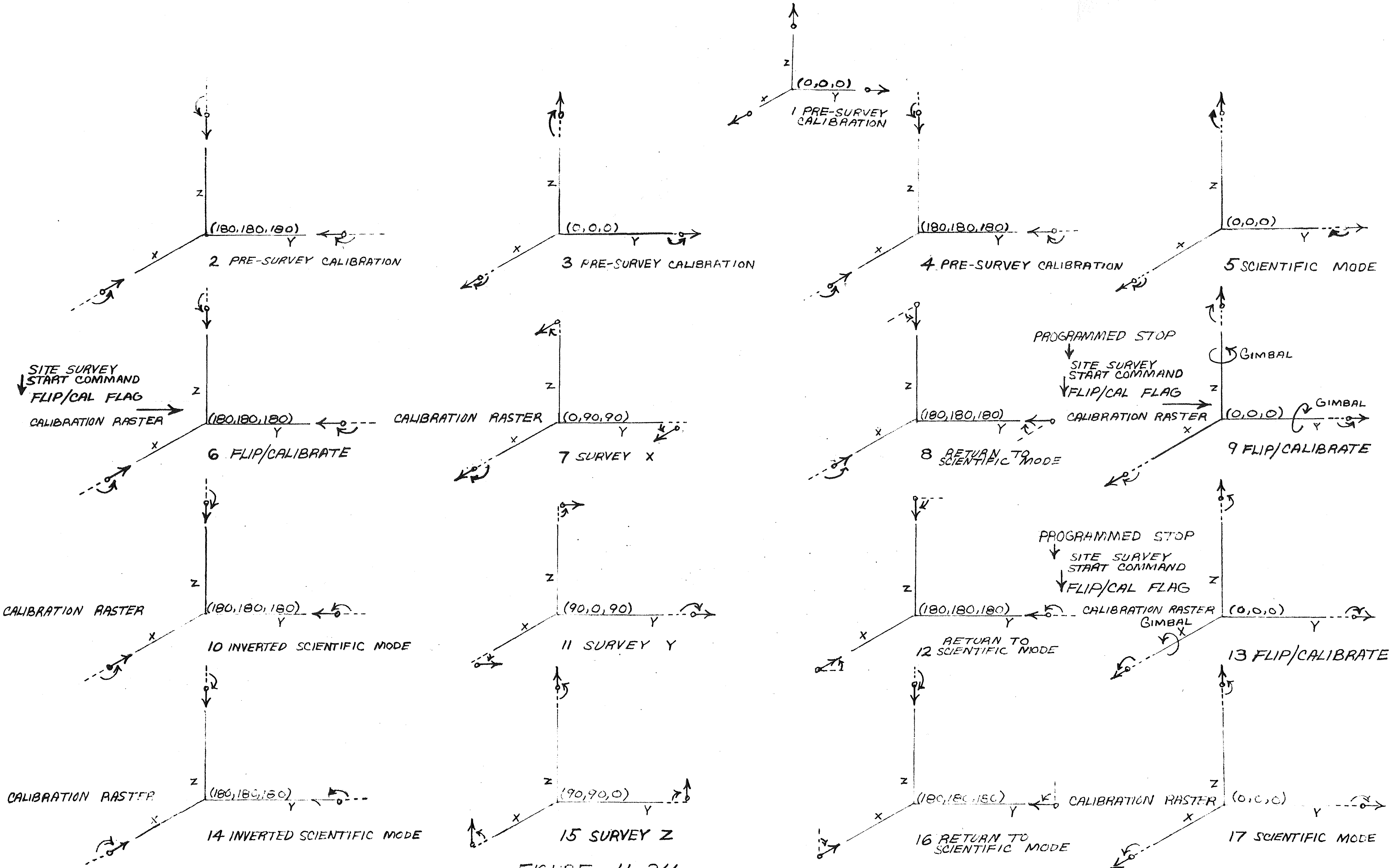


FIGURE 4-34
SITE SURVEY SEQUENCE

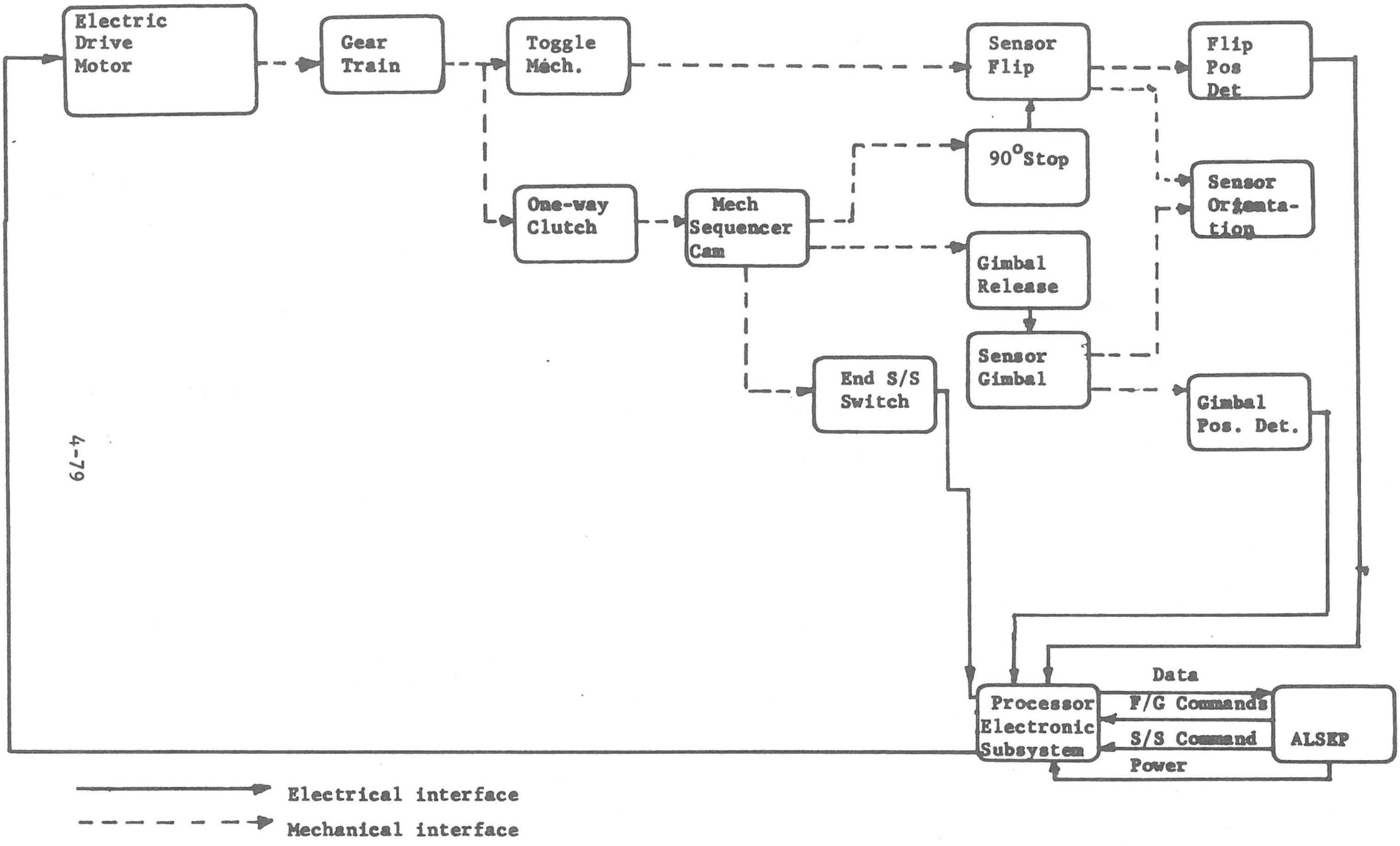


Figure 4-35 Sensor Orientation Block Diagram

all operating modes. This accuracy requirement is equivalent to requiring that each sensor axis be aligned within a cone of half-angle 0.6^{o} (centered about a nominal reference coordinate system axis). To insure that this orientation accuracy is obtained, the boom arms and the sensors are optically aligned and adjusted. The optical alignment technique involves the use of an autocollimating theodolite and a special mirror which attaches to the sensor. Boom arm alignment adjustment is achieved by shimming. Sensor alignment accuracy is achieved by adjusting the 0 and 180 degree sensor position stops.

4.2.5.2.2 Operation

As shown in Figure 4-28, the flip-calibrate sequence simply flips the sensor from its 0^{o} stop to its 180^{o} stop or vice-versa depending on the staring point. The direction of flip action is determined by a simple electronic alternation. Should the system get out of step for any reason, the flip motor will drive in the wrong direction. The integral overrun clutch with the motor will protect the system in this case, and the system will be in step for the next flip-cal operation.

The flip-cal operation is accomplished when the motor driving through its integral overrun clutch and 400:1 gear train moves the segment gear through 90^{o} (± 5'). This in turn causes the driver primary arm to rotate the toggle primary arm. Once past the toggle-over point, the springs connecting the primary toggle arm to the secondary toggle arm will pull the secondary arm over to the stop. The secondary arm is, in turn, connected to the output drive pulley through 2:1 speed increaser gears.

This pulley drives the dacron-covered glass filament cables which run up the support arm to the magnetic sensor. Cable redundancy is accomplished by applying two separate cables instead of a continuous one. Thus, if one cable breaks, the other can drive the sensor to the remaining scientific mode position.

During the site survey operation, the sensor flip drive operations are virtually identical with those for flip-cal. A difference arises when 90° positions are required. (See Figure 4-34.) This action is expedited as the 0° flip is about to take place through the positioning of the 90° stop pawl. (See Figure 4-36.) This pawl is pulled into position by a drive cable similar to the sensor cables which is connected at its lower end to the 90° stop cam. As a lobe of the cam raises, the follower (the 90° stop panel) is pulled into position just before the sensor is flipped from the 180° position. Then, as the toggle spring flips the sensor, the sensor contacts the pawl and is positioned accurately at 90°. The 90° stop pawl is spring-loaded in the retracted position so that release of the drive cable when the follower rides to a cam groove results in the pawl retracting. The sensor can then flip to the 0° position.

As shown in Figure 4-34, the gimbal action is required once for each sensor during the site-survey program. This action is programmed by the setting of the gimbal release eccentric crank pin on the 90° stop cam. The cam itself is driven through the one-way clutch which rectifies the reciprocating action of the primary toggle arm to intermittent unidirectional rotation. The gimbal release crank pin pulls the gimbal release cable at the bottom of its stroke, thus pulling the gimbal release pin in the sensor head. Pulling this pin allows the preset gimbal spring to rotate the yoke-sensor assembly through 90° to the gimballed position. As can be seen, the combinations of 0° flip position, 90° flip position or 90° flip/90° gimbal positions allow the attainment of all sensor orientations required for the site-survey, flip/calibrate, or scientific modes of operation. The site-survey positions are mechanically programmed by the cam motions which are positively controlled by the eight-point detent gear (Figure 4-36). The mechanical and electrical programs are automatically shut-off at the end of the site-survey by virtue of a toothless section of the detent/cam drive gear and a shut-off switch actuated by the detent gear at the end of the program. This switch deactivates the electronic site survey sequencer.

4.2.6 Thermal Control Function

4.2.6.1 Thermal Control Block Diagram Description

Overall operation of the thermal control system is depicted in Figure 4-36, which presents a block diagram indicating the direction of influence of the major components.

4.2.6.2 Thermal Control Detailed Description

The Lunar Surface Magnetometer is designed to operate over the temperature range $-50^{\circ}C$ to $+125^{\circ}C$. This range applies to the interior of the electronics and electromechanical base package and of each sensor head. Maintenance of the instrument interior temperatures within the above range in the severe lunar thermal environment is accomplished by a combination of the insulation, control surfaces, and heaters as described in Section 3.2.3.

All external surfaces of the sensor heads, sensor support arms, and the base package (with the exception of the thermal control surfaces) are covered with a highly efficient insulation. Insulation blankets are used to thermally isolate the LSM package from its surrounds so that the PRA's are the controlling mode of heat transfer between the LSM and its lunar environments. On the bottom and sides of the EGFU (except where the control surfaces are mounted), and on the sensor support arms, this insulation is in the form of 40 layers of double-surface, aluminized 1/4-mil mylar separated with 40 layers of 3-mil glass fiber mat. This total blanket thickness of 1/2 inch on the EGFU and varies from 1/2 inch at the ends of the sensor arms to 1/4 inch at the center hinge. The hinge itself is not insulated, since this represents a minimum heat sink point from the sensor or EGFU due to the use of low conductivity materials in the arm components.

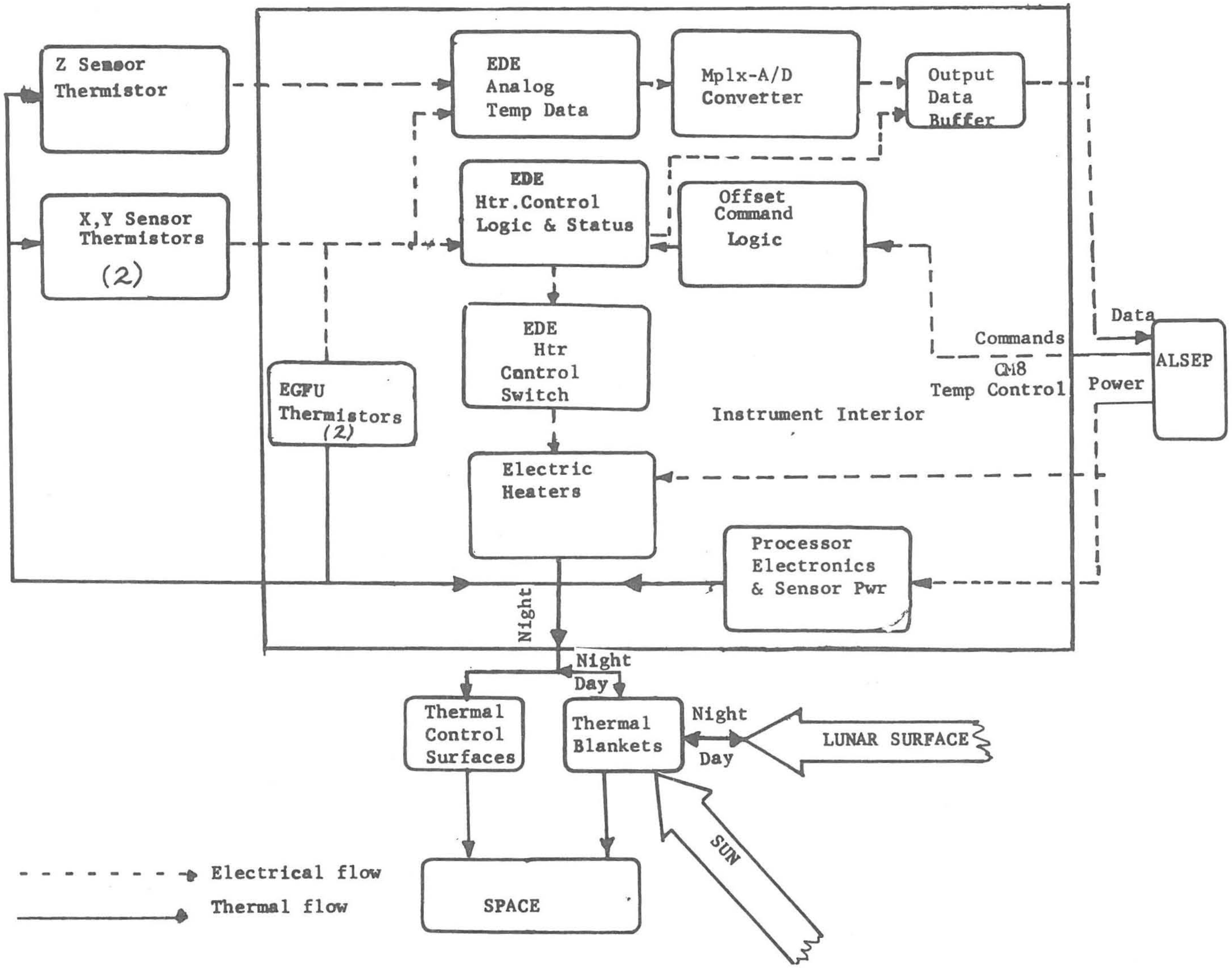


Figure 4-36. Thermal Control Block Diagram

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The top of the EGFU and the sides of the magnetic sensor housings are covered with a 1/2 inch thick blanket of glass fiber. The sensor blankets are in the form of a nylon-covered boot which is removable, while the **EGFU** blanket is a glass heat felt material encased in a fiberglass shell. This blanket is supported over the GFU by a fiberglass-reinforced epoxy shroud. All external surfaces of the insulation subassemblies are covered with 1-mil thick single aluminized H-Film (aluminum side in).

The thermal control surfaces are as described in Section 3.2.3. As stated, the sensor head thermal control surface is composed of a 4-inch diameter cap forming the top surface of the head. Heat generated within the sensor head by the small amount of power dissipated by the sensor windings (approximately 14 mw) and by the electric heaters is radiated to the lower surface of the control surface. In addition, some heat is conducted through the fiberglass shroud which supports the thermal control surface and the insulation boot. Radiation from the sensor itself, the sensor yoke, and the support shroud is minimized by the addition of a gold surface finish with an emissivity of approximately 0.05. The emissivity of the inside surface of the thermal control surface is controlled with a value of approximately 0.10. The top surface has a low α/ϵ coating in order to minimize absorption of solar heat. S-13G white paint with an α/ϵ of 0.23 is used. Thus, daytime thermal absorption is limited by the low α/ϵ coating and the low conduction insulation blanket, while nighttime heat losses are minimized by the low emissivity internal surfaces as well as the blanket. Maximum sensor temperature during the day is expected to be +50°C, while the minimum nighttime temperature, with 1.0 watt of heater power, will be +35°C.

The EGFU thermal control surface, the PRA, is also physically described in Section 3.2.3. The system consists of vertical low-emittance parabolic reflectors in conjunction with horizontal high-emittance radiating fins. Radiation emanating from the lunar surface is reflected away by the parabolic array while internally generated heat is dissipated to space.

Impingement of direct solar radiation on the horizontal radiators is eliminated by aligning the PRA in the plane of the ecliptic and using a small solar shield for shading. Fabrication is of non-conduction plastic foam for the reflecting surfaces and conductive aluminum for the baseplate and radiator fins. Mandrels machined to ±0.001"are used to form the parabolic surfaces. The mandrels with aluminized Mylar stretched across their parabolic surfaces are clamped into a tooling jig which also locates the radiator fin and backing structure with respect to the parabolic surface. The assembled tooling jig is then filled with a polyurethane foam to form the parabolas and also to lock the PRA assembly in the proper relationship. Final assembly consists of trimming the foam casting and bonding the PRA to the electronics box with a thermally conductive adhesive. Decoupling the reflectors and fins in the manner results in the minimum absorbed external heat flux and a smallest required PRA for the given temperature limit.

The performance of the PRA is affected primarily by the surface characteristics and the geometry. The reflective surfaces require a low absorptance for solar energy reflected from the lunar surface (aluminized surfaces yield about $\alpha = 0.10$), while the radiator fins must necessarily have a high emittance. (The white paint specified yields $\epsilon = 0.9$.) Imperfections in the surface of the parabolic reflectors, such as waviness, nonspecularity of diffuseness, or incorrect shape, can cause reflected energy to impinge on the radiator fins, causing a decrease in performance. Generally, specularity on the order of 90% or more for lunar reflected energy is achievable for the parabolic surfaces.

The PRA is adjusted during instrument acceptance testing to provide the proper thermal resistance to maintain instrument temperature limits. Adjustment of the resistance is accomplished by controlling the frontal area of the PRA. Thus, an adjusted instrument may have gold foil tape covering some sections of the PRA.

Sunshades are included over each PRA to minimize the amount of solar flux which can impinge directly on the radiator fins. The sunshield geometry was derived directly from the angular uncertainties of the experiment position of the lunar surface and is designed to prevent insolation of the radiator surface. Since the shades cover only the top of the PRA, the ends of the fins can "see" the sun at low sun elevations. Analysis indicates that the resulting system temperature change does not warrant the inclusion of more complicated all-encompassing shades.

Electric heaters installed in the sensor heads and in the EGFU supply sufficient heat to cope with the various heat leaks such as penetrations for LSM/ALSEP mounting system, support legs, blanket-PRA interface, controlled leaks in the thermal control surfaces, and others not readily located. In addition, the inclusion of electric heaters makes it possible to reduce the requirements of the blanket, and the thermal control surfaces and allow fabrication of a more predictable and practical system from production line techniques.

Thermal Analysis

The large temperature swings of the lunar surface - acting as a heat source during lunar day, and a near perfect heat sink during lunar night - dictates a thermal control system insensitive to the lunar surface. The concept of utilizing parabolic reflectors with radiating fins most nearly fulfills the requirements for a lunar heat rejection system. Low emittance parabolic surfaces minimize the thermal coupling of the experiment package to the lunar surface while high emittance fins facilitate heat rejection to space. Sketches of the reflector configuration are shown in Figures 4-37 and 4-38. The reflector consists of a diffuse, high-emittance flat surface parallel or nearly parallel to the lunar surface and a specular, high-reflectance parabolic surface. In Figure 4-38 the parabolic flat reflector configuration is designed so that:

ANGULAR UNCERTAINTIES ASSOCIATED WITH PLACEMENT OF LSM ON LUNAR SURFACE		
Angle	Magnitude	Cause
θ	Nominal ±5°	Tilt
ϕ	Nominal ±5°	Tilt
β	Nominal ±5°	Misalignment
ω	Nominal ±5°	Lunar Angle Off Equator
ψ	Nominal ±2°	Lunar Libration

Table 4-3

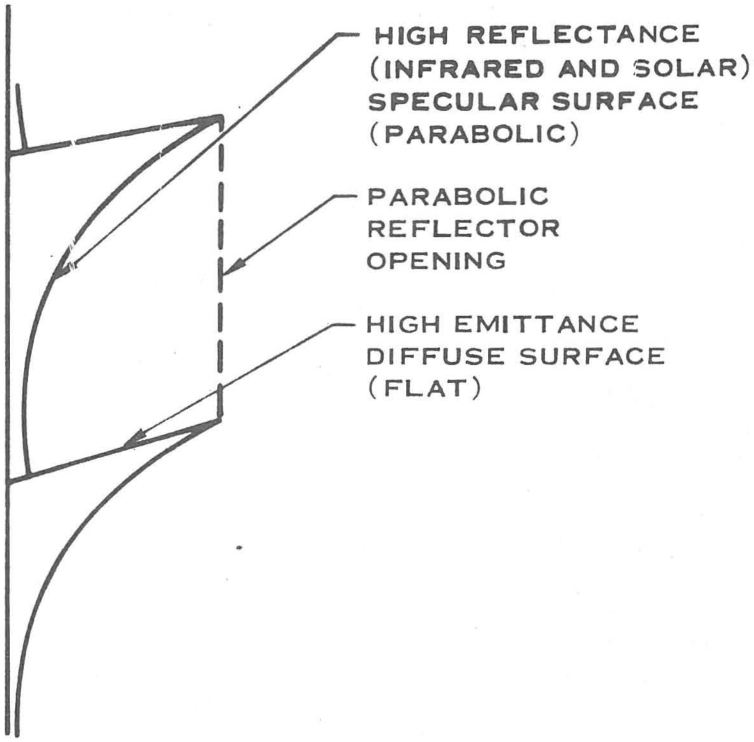


Figure 1 Side View of Parabolic Reflector

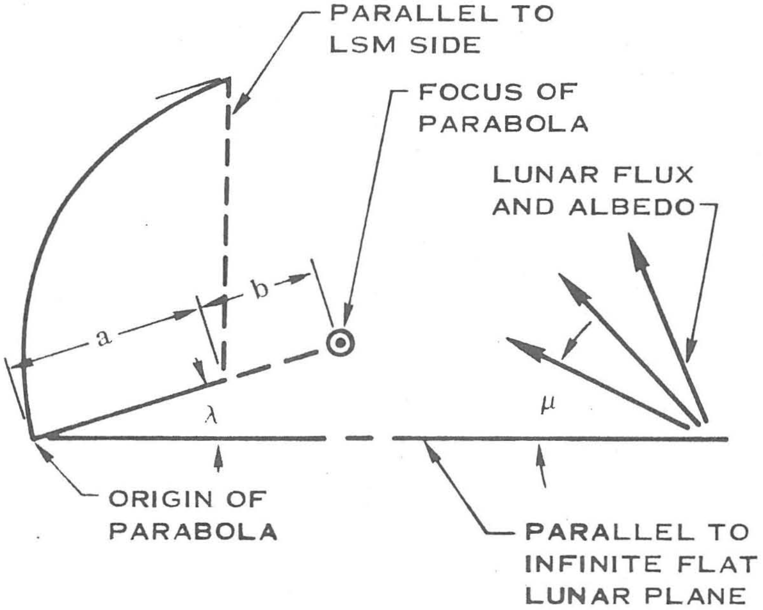
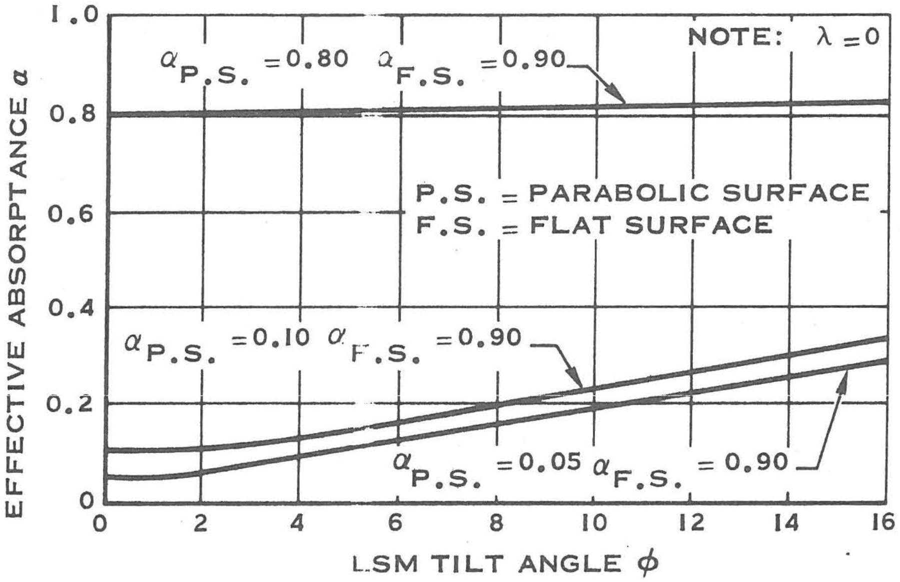


Figure 4-37

Orientation of Parabolic Reflector



Effective Absorptance of an Infinitely Wide Parabolic Reflector

Figure 4-38

$$\lambda \geq \Phi \max$$

$$b/a \leq 0.2$$

$$b > 0$$

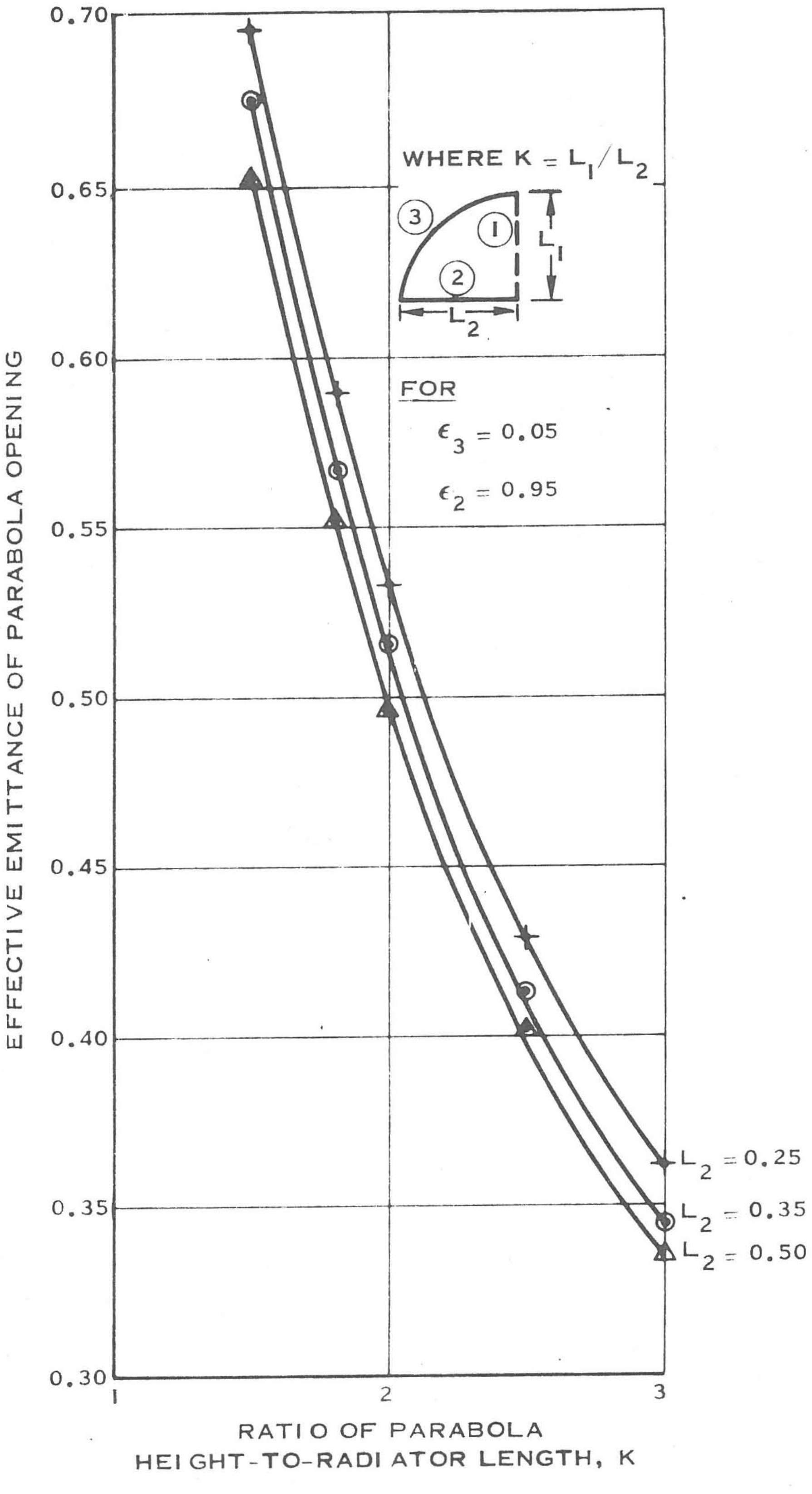
For the lunar flux and albedo striking the reflector opening from the flat infinite lunar plane:

$$0 \leq \mu \leq 90^\circ$$

Thus, for all $\lambda > \Phi$, no direct lunar flux and albedo strike the flat surface, but rather strike the parabolic surface. For a perfectly specular parabolic surface, all lunar flux and albedo striking the parabola parallel to the a - b line (flat surface) will be reflected beyond the focus, i.e., at a point $> a + b$. Thus, if $b > 0$, no direct or reflected lunar and albedo energy should strike the flat surface a. The ratio $b/a \leq 0.2$ was chosen to take into account machining or fabrication errors.

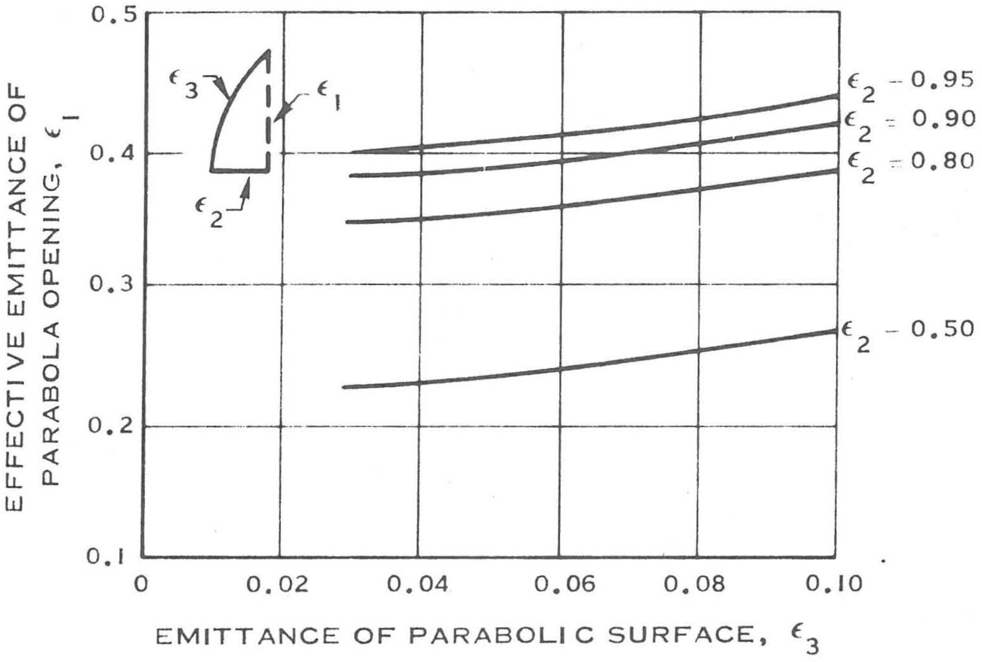
The optical properties of parabolic reflector arrays (PRA) were parametrically studied in an effort to optimize the design used in the LSM thermal control system. Figures 4-39 through 4-41 show the results of these parametric studies. In Figure 4-40 the effective absorptance of the reflector (parabolic) is shown as a function of tilt towards the lunar surface. Assumptions used are delineated in Figure 4-39. Figures 4-40 and 4-41 show the effect of geometry and surface optical properties on the emittance of the parabolic reflector array.

The focus of the parabolic surface was set at 0.10 inch in front of the radiating fin ($b/a = 0.29$ for a fin width of 0.35). By establishing a qualitative requirement that no energy reflected by the parabolic surface (incident from or below the horizon) impinge on the radiation fin. The position of the focus allows geometric errors of approximately 0.020 inch in the parabolic reflector shape. For this particular application, a PRA size of 35 in.^{2} (frontal area) was required with an effective emittance



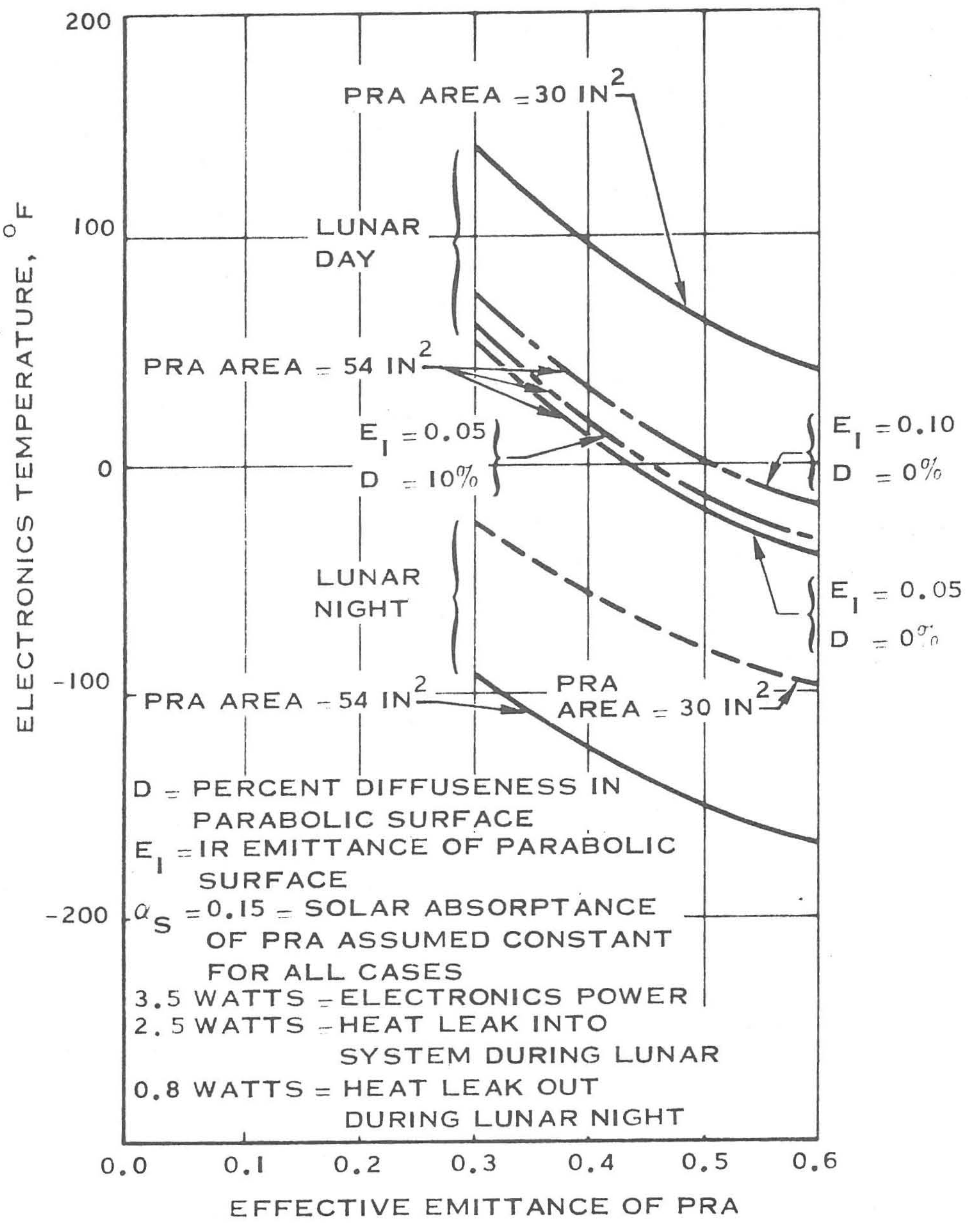
Effective Emittance as a Function of Parabola Characteristic, K

Figure 4-39



Parabolic Reflector Array Effective Emittance as a Function of Parabola Surface Emittance for Various Radiator Surface Emittances

Figure 4-40



LSM Electronics Temperature for
Various PRA Characteristics

Figure 4-41

of 0.40. A radiator fin width of 0.35 inches was selected to allow for protective covers over the PRA and still remain within the 0.50 inch thickness constraint. From Figure 4-40 the height of the parabolic surface was established at 0.875 inch.

A heat balance on the electronics box with the thermal control system was established as:

$q_{out} = q_{in}$

$q_{out} = \epsilon_i A_i T_1^4$ (Radiation to Space)

$q_{in} = q_{power} + q_{\text{absorbed lunar}} + q_{\text{heat leaks}}$

q_{power} = Electronic dissipation + Supplemental heaters

$q_{\text{absorbed lunar}} = A_p \left[\epsilon_1 F_M Q_M + \alpha_s F_M Q_{MR}\right] (1 + D)$

= Lunar energy (IR and reflected solar) absorbed through PRA's

$q_{\text{heat leaks}} = q_M + q_{GHF} + q_{BOOMS}$

= Heat leaks through insulation blankets and from sensor support booms

q_{MLI} = Heat leak through multilayer blanket

$= \frac{KA}{L} \Delta t_{MLI}$

q_{GHF} = Heat leak through glass heat felt insulation

$= \frac{KA}{L} \Delta t_{GHF}$

q_{booms} = Heat leak from wiring extending from booms into electronics box

$= \Delta t / R(\text{booms})$

In the preliminary analyses used to develop the parabolic reflector design, the heat leak terms were held fixed at 2.5 watts into the electronics box during lunar daytime conditions and 0.8 watts away during nighttime conditions. The heat leak assumptions were based on results of tests performed on multilayer insulation blanket wrapped around a model of the same approximate size as the LSM electronics box. Figure 4-41 shows the predicted electronics box temperature during lunar day and night for various PRA sizes and optical properties. As depicted in Figure 4-41, the electronics temperatures show a marked sensitivity to the absorptance of the PRA. Thus it was recognized early that the parabolic surfaces of the PRA must be treated as optical surfaces and care exercised to prevent their contamination.

SECTION 5

MAINTENANCE

5.1 GENERAL

The maintenance philosophy for the LSM dictates that most operations requiring replacement of parts be carried out at Philco-Ford in Palo Alto. This philosophy is necessitated by the extreme complexity of the instrument, the requirement for clean room operations, which may be performed at Philco-Ford's assembly area, the special tools required for many of the procedures, the special size flux tanks, and the precise realignment procedures which must be followed.

5.2 FIELD MAINTENANCE

Field maintenance measures, i.e., those operations which may be performed away from the Philco-Ford assembly area, are as follows:

a. Replacement of EGFU top thermal blanket
b. Replacement of sensor support arm lower thermal boot
c. Replacement of sensor head thermal boot
d. Replacement of sensor head thermal control surface
e. Replacement of support leg fiberglass link and foot pad
f. Application of gold foil tape to thermal control surface to cover smudges or fingerprints
g. Replacement of ancillary mounting parts in foam insert, upper mounting bracket, brace, etc.
h. Replacement of shadowgraph assembly

In all cases involving repairs or replacements of components other than those listed, the LSM should be replaced in its shipping container and shipped to Philco-Ford in Palo Alto.

5.3 MALFUNCTION ISOLATION

If a malfunction of the ALSEP/LSM system is suspected, the ALSEP System Test Set should be employed. This will allow isolation of the malfunction to the experiment level. If it is determined that the LSM is the source of the problem, the instrument should be tested with the LSM GSE. A full operational test (Reference: Operational Test Procedure SRS-SJ-173030) should be performed to acquire malfunction base point data. At this point the Philco-Ford field engineer should advise NASA/ARC as to the nature of the malfunction and the probable remedial actions required.

SECTION 6

HANDLING, STORAGE, AND TRANSPORTATION

6.1 HANDLING

6.1.1 General

Ground handling of the complete LSM instrument is required, in general, during instrument checkout and test, final scientific calibration, and final installation in ALSEP.* Typical operations involving ground handling include:

a. Installation of the fully stowed** instrument into the LSM shipping container.

b. Removal of the fully stowed instrument from the LSM shipping container.

c. Deployment from the fully stowed configuration to:

   1. The partially deployed configuration**
   2. The fully deployed configuration**

---

*Astronaut handling of the LSM on the Lunar surface (or on the ground during training) is covered in Section 7.

**Definitions:

1. Fully stowed configuration: Instrument configuration with arms and legs folded (stowed), PRA protective covers in place, and upper mounting bracket and brace installed.
2. Partially deployed (or stowed) configuration: Instrument configuration with arms folded, legs deployed, PRA protective covers in place, and upper mounting bracket and brace removed.
3. Fully deployed configuration: Instrument configuration with arms and legs deployed, PRA protective covers removed, and upper mounting bracket and brace removed.

d. Installation of the fully deployed instrument into:
   1. Configuration A Flux Tanks
   2. Configuration B Flux Tanks

e. Achievement of the fully stowed configuration starting from the fully deployed configuration.

f. Installation of the fully stowed instrument into ALSEP.

Detailed procedures for the accomplishment of each of the above indicated operations are presented in Paragraphs 6.1.2 through 6.1.5. Apparrel, such as lab coats and gloves, will be worn, and procedures necessary to insure the cleanliness of the instrument will be observed through the handling operations.

6.1.2 Removal Procedure - LSM Shipping Container

Preliminary Steps. Prior to opening the outer (barrel) portion of the LSM shipping container, prepare a clean, stable surface on which to place the LSM. This surface should be a table at least 3 ft x 6 ft covered with at least ¼ in. foam rubber, which is in turn covered with a clean Mylar (or equivalent) blanket. Then proceed as follows:

1. Ensure that the barrel (outer container) is free of dirt and other contaminants.
2. Record the humidity reading
3. Depress the breather valve button before opening the lid.

Removal of Container Lid. To remove the lid of the outer container, proceed as follows:

1. Remove the clamping ring lock-wire and seal from the ring bolt.
2. Remove the ring bolt from the clamping ring assembly.

3. Release the clamping ring from the lip of the barrel and lift the lid, exercising care to avoid breaking the rim seal.

<u>Exposure of the Inner Container</u>. To achieve access to the inner container stowed within the barrel, remove the following items in the order indicated:

1. Top foam cover (pad No. 1)
2. Dessicant, four each eight unit bags from slots provided, pad No. 2
3. Magnetic recorder from center slot, pad No. 2
4. Bottom foam covered (Pad No. 2)

<u>Removal of Inner Container</u>. To remove the inner container from within the outer container, proceed as follows:

1. Manually restrain the outer container from lifting.

2. Using two hands, grasp the web straps which encircle the inner container.

3. Lift the inner container free of the outer container and place on the prepared surface (c.f. 6.1.2.) , with the surface marked TOP facing upward.

<u>Removal of the LSM from the Inner Container</u>. To remove the instrument from the inner container, proceed as follows:

1. Verify that the inner container is oriented correctly; i.e., that the surface marked TOP faces upward. (NOTE: for additional confirmation, the bottom surface has distinctive indentations which locate mounting pins.)

2. Release the web straps and remove (by lifting) the upper half of the inner container. The LSM in the lower half of the inner container is shown in Figure 6-1.

3. Remove the hold-down wing nut and washer from the ALSEP Cable Spool Container (CSC).

4. Lift the ALSEP CSC upward to clear and remove from the tie-down rod. Place alongside the inner container.

PRECAUTIONARY NOTE: Avoid kinking the flat tape cable.

5. Using a Phillips screwdriver, remove the two screws and washers from the upper mounting plate located within the inner container.

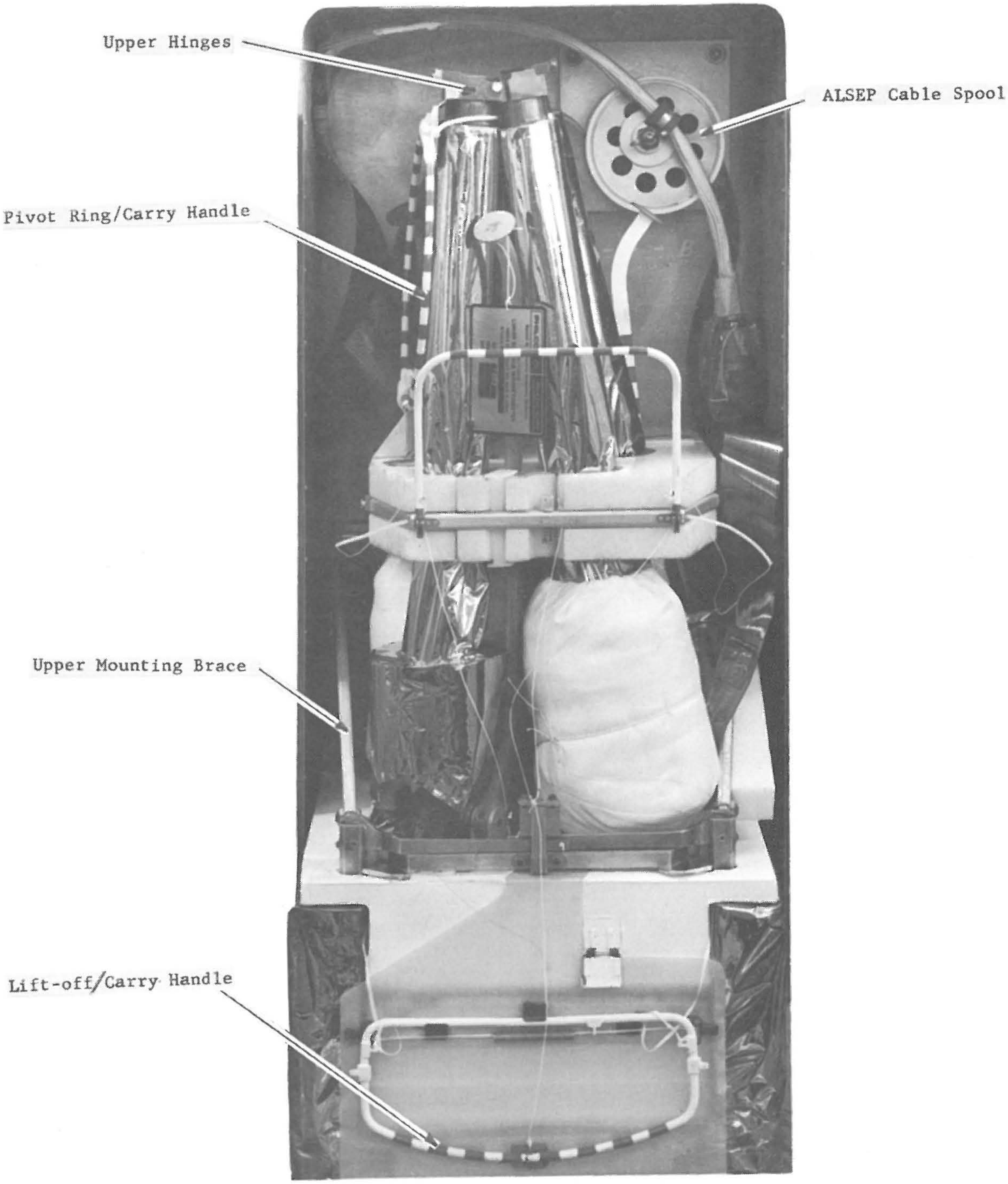
6. Holding the lower half of the inner container securely in place, proceed with the following steps in the order indicated:

   a. Grasp the lift off/carry handle and withdraw the handle until it resists further withdrawal.

   b. The Upper Mounting Brace is shown in Figure 6-1. To remove the LSM from within the container, lift the instrument vertically utilizing as handholds both the brace and the lift off handle. Since the instrument is balanced about the lift off/carry handle, the brace should be used to provide only a stabilizing action.

   c. Carefully transfer the hold on the mounting brace to the pivot ring/carry handle (Figure 6-1). Slowly rotate the instrument to a vertical orientation, gradually transferring the weight to the pivot ring/carry handle.

   d. Gently place the instrument on the prepared surface.



LSM in Shipping Container

Figure 6-1

7. Reassembly the ALSEP CSC wing nut and washer on the threaded tie-down rod in the inner container.

8. Retain the inner container for use as a container for various LSM mounting components which will be removed in subsequent operations.

6.1.3. Instrument Deployment for Test

1. With the instrument resting on the EGFU bottom cover (on the prepared table surface (Paragraph 6.1.2), grasp the upper mounting bracket handle and pull until the frame is clear of the inner foam parts. Lift handle (and frame section) causing the three cables attached, to:

   a. Release and pop up the lift-off handle
   b. Release the brace locking levers and move them to the unlocked position
   c. Pull brace assembly away from mating brackets. (A jerking motion may be required to accomplish this.)

   Pull the handle/frame up sufficiently to clear the brace assembly of the LSM and remove the assembly to the shipping container. It will be necessary to resist the overturning tendency by restraining the sensor support arms at the upper hinge points (Figure 6-1).

2. Withdraw each support leg from the plug in its slot in the foam insert and cover gently until the foot pad rests on the table. Grasp the pivot ring/carry handle and raise the LSM about 6 inches off the table. The support legs are spring loaded and will automatically lock into place. Manually ascertain that each leg is locked down by attempting to work the leg.

3. Lower the LSM to the table. Lower the pivot ring/carry handle along the Y-axis arm.

   NOTE: At this point, the instrument is in the partially deployed configuration (See Figure 6-2).

4. Remove the foam insert pieces and place them in the shipping container.

5. Grasp the Y sensor arm above the upper hinge and rotate to the deployed position. Verify that the upper hinge has locked. Repeat for the Z arm and the X arm.

6. Do not remove the PRA cover assembly.

6.1.4 Installation in the GSE Flux Tanks

This section will cover installation of the LSM on the flux tank mounting fixture (both A and B configurations), but does not cover the operations required on the tanks themselves, i.e., lid installation, etc.

1. Preparation

   a. Remove the sensor head thermal boot by releasing the VELCRO tape retainers on each head.

   b. Remove the eight titanium screws around the base of the fiberglass shroud on each head. See Figure 6-3. Remove the shroud and thermal control surface, being careful not to degrade any surfaces. The shrouds and the boots should be stored in a protected controlled receptacle.

   c. Install the "reinitialization" strings on the sensor mounting frames.

Figure 6-2

Partially Deployed LSM

Figure 6-3
Removal of Sensor Head Titanium Screws

d. Thread the strings through the holes in the sensor head plexiglas covers. Mount the covers on the support arm and plates.

2. Installation in "A" configuration flux tanks. (Not less than four (4) men will be required during the installation operations.)

   a. The three support legs shall be grasped by two men near the uppermost points of the legs. The LSM is then lifted off the table. One man observes the sensor arms and heads and may provide a steadying action on the arms if required. The LSM is then carried to the flux tank LSM support fixture on the mounting pin side. The Z leg (striped) is passed to the fourth man standing on the opposite side of the mounting fixture.

   b. The LSM is lowered to the mounting pins with two men guiding the sensor heads past the flux tanks. The pins are engaged and the LSM gently pushed to full pin insertion. The locking tool of the upper mounting bracket handle is then pushed in until the locking mechanism passes its detent point. Ascertain that the pins are locked by carefully attempting to with the instrument.

   c. Lower the flux tank Helmholtz coils and engage the locking pins on the plexiglas covers. See Figure 6-4.

4. Installation in "B" configuration tanks

   a. Transport the LSM to the flux tanks using the methods described in Paragraph 2.

   b. Two men grasp the three sensor arms above the upper hinges and raise them to approximately a 15° angle with the vertical.

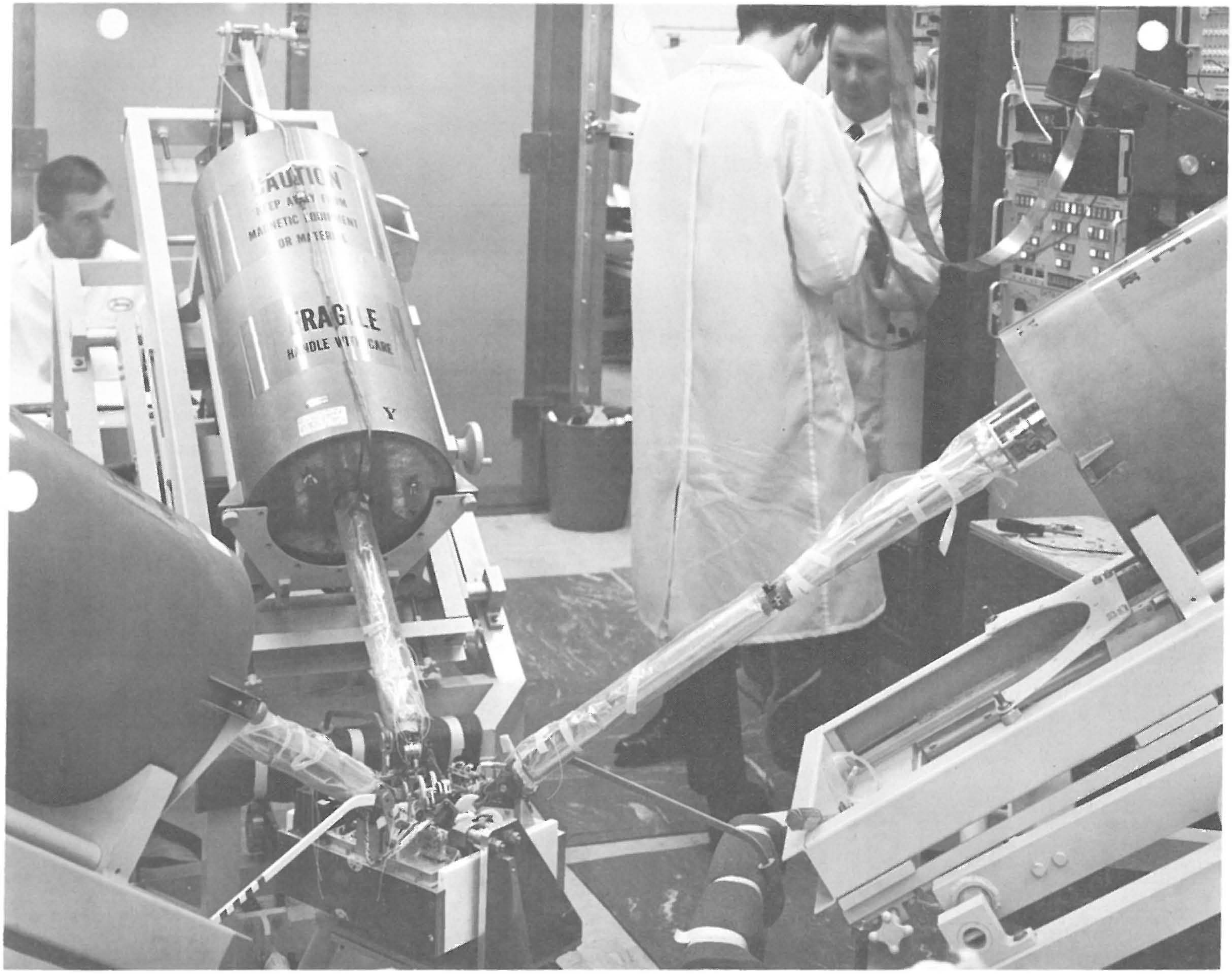


Figure 6-4

LSM in "A" Configuration Flux Tanks

The LSM is then rotated to a horizontal position with the pin holes down, maintaining the approximate sensor arm positions.

c. Lower the LSM to the mounting pins and engage. Care must be taken not to snag the thermal insulation or the PRA cover as the pins are inserted. Insertion and pin locking procedure is as in Paragraph 2.

d. The sensor head covers are then locked to the Helmholtz coils, after which the arms need not be supported (See Figure 6-5).

e. Insure that the reinitializing strings are clear to pass down along the sensor arms.

6.1.5 LSM Stowage

Preparation for Stowage

This section describes the operations required to return the LSM to the fully stowed position starting from the fully deployed condition mounted in the flux tank assembly.

1. Removal from Flux Tanks. This procedure is the reverse of Paragraph 6.1.4.2 and 6.1.4.4. Care must be taken with configuration "B" tanks to support the sensor arms before disengaging the Helmholtz coil mating blocks, and to maintain this support until the LSM is returned to the upright position.

2. If the PRA covers have been removed, the following procedure should be followed:

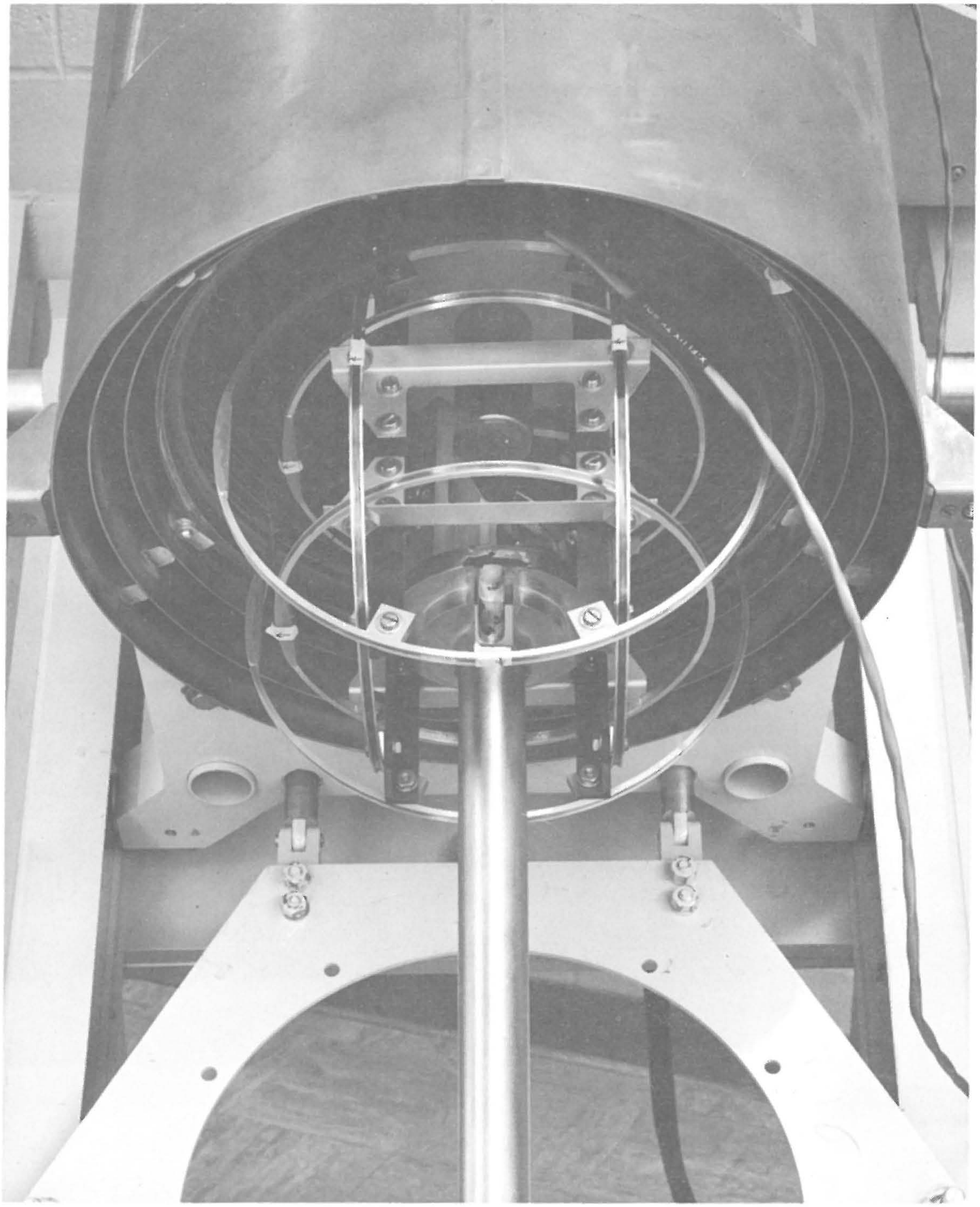


Figure 6-5

Sensor Head Mated to Helmholtz Coils

a. With the LSM placed on the prepared table surface (Reference Paragraph 6.1.2), place PRA cover assembly beneath the EGFU oriented so that the two holes for the mounting block pin holes are in a position which will eventually coincide with the pin holes in the EGFU. Arrange securing strings to facilitate attachment.

b. Commence wrapping the PRA cover assembly from the bottom up. Depress both PRA sunshades with gloved fingers and hold in place with tongue depressors. Press PRA covers over both PRA sunshades and withdraw tongue depressors. Fold shadowgraph reticle and gnomon plates and hold down with the tongue depressors. Fold PRA cover ends over the top of the EGFU, hold in place, and withdraw tongue depressors. Pull back outer plunger of the PRA release mechanism until locking balls are in the release position. Insert inner plunger attached to PRA securing string and allow outer plunger to move to locked position (See Figure 6-6.).

Secure PRA release handle in its stowed position (Figure 6-6) on the Y sensor arm with Velcro tape. Ascertain correct placement of the cover assembly, especially in the area of the LSM mounting pin holes.

3. Remove plexiglas sensor head covers and replace the fiberglass flight type covers, thermal control surface and thermal boots (Reference Paragraph 6.1.4).

4. Fold X sensor arm by releasing lock at upper hinge.

5. Arrange pivot ring/carry handle so that the Z and Y arms will fold over the cable.

Figure 6-6

Covering PRA

6. Fold Z arm and Y arm, respectively. Place carrying handle in a convenient place on top of the hinges. Ascertain non-fouling of PRA cover release cable.

7. LSM Support Leg Stowage Preparation

   a. Adjust each LSM support leg to approximately the mid-range position.

   b. Raise the LSM approximately 6 inches above the table by means of the pivot ring/carry handle.

   c. Release each leg by depressing detent lever on the leg short link. Raise each leg to the vertical position.

   d. Lower LSM gently to the prepared table top and lower tht legs to a semi-deployed position with foot pads on the table.

   e. Replace pivot ring/carry handle on top of hinges.

8. Upper Mounting Bracket Installation

   a. Place one of the outer (large) sections of the upper mounting bracket foam insert generally in place (adjacent to sensor heads - see Figure 6-7).

   b. Push the arms into the slots of the foam insert section.

   c. Push the two smaller sections into the mating tongue and grove sections of the installed outer sections.

   d. Push the remaining outer section into the remaining mating tongue and groove sections.

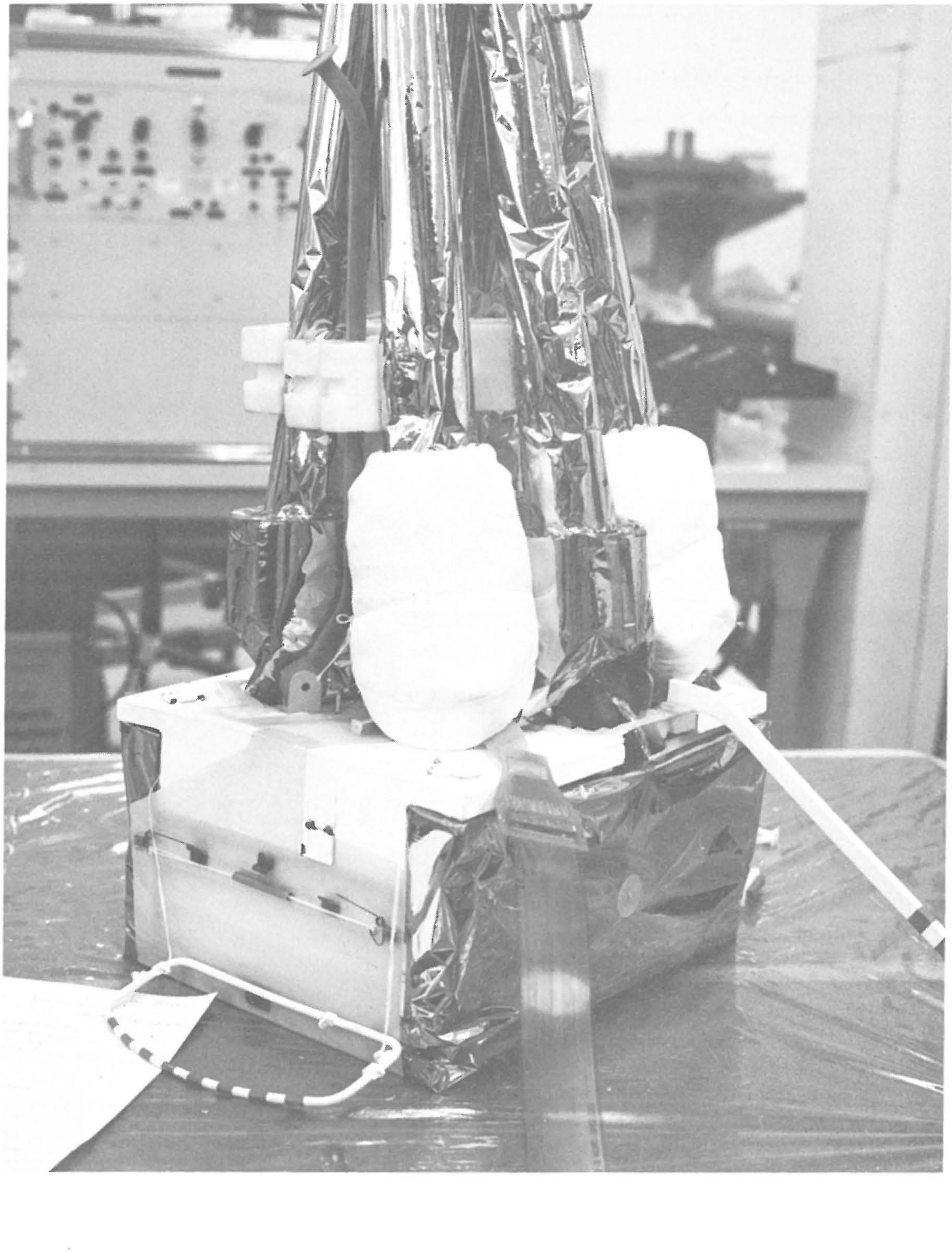


Figure 6-7

Position of Foam Insert

e. Raise each LSM support leg and insert into mating slot in the foam insert (hallowed by plug).

f. Slide lower frame half into mating groove in foam insert.

g. Similarly slide upper frame half into place. (Bracket securing cable, brace release cable and clamp securing cable will be attached.)

9. Brace Installation

a. Attach a thin piano wire (≈0.01" dia.) to both the retracted brace pins.

b. After making sure release and securing cables are not twisted, place upper mounting bracket brace in its general position.

c. Push the brace assembly into position making sure that the tube ends of the brace drop into the counter bores of the pin holes.

d. Pull the pins to their extended positions by means of the piano wire. Move the two locking levers to this stowed position making sure that they each engage the pin correctly. Remove the piano wire.

e. Install locking lever securing mechanism.

i. Withdraw inner plunger to release locking balls.
ii. Install retainer clip over levers; and outer plunger into release mechanism.
iii. Release inner plunger. Make sure unit it locked and pull strings are not fouled.

Stowage

In this section it will be assumed that procedures for stowage of the LSM in the shipping container will be identical to those for stowage in the ALSEP. Therefore, the shipping container will be used in the following procedural description.

1. By means of the pivot ring/carry handle raise the LSM off the table.

2. Grasp the lift-off/carry handle and carefully rotate the LSM to that horizontal position.

3. Lower the unit carefully into the shipping container and onto the mounting pins. Make sure the thermal blanket is not damaged or carried into the pin holes by the pins. Push the LSM firmly down to the pin shoulders.

4. Push the life-off/carry handle all the way in. The ring should be flush against the side of the EGFU. Secure the ring with the Velcro tape.

5. The fastener holes of the upper mounting bracket should line up with the holes in the container. If they do not quite match, the top frame may be loosened and the foam insert pushed slightly up or down the sensor support arms as needed.

6. Insert the two securing screws through the keyed cable lugs, the brace mounting holes, the bracket holes and into the shipping container threaded holes. Turn the screws right down.*

---

* Quick release fasteners are used in place of the machine screws in ALSEP.

7. Thread the upper mounting bracket securing cable through the guides.

8. Push in on the securing cable tensioner lug on the end opposite from the head. The head will move out against its retainer spring. While in this free position, fit a wrench to the head and turn in a clockwise direction until the bracket securing cable is tight. Push the head while slightly rotating the lug to find a locking position. Lock in the tightest position possible.

9. With the cable reel tool, roll up the ALSEP cable in the cable reel.

10. Place cable on mounting lug in shipping container and secure with wing nut and washer. Lock with cotter pin.

Shipping Container Closure

1. Installation Procedure, Inner Container

   a. Lift the container to a vertical position with the EGFU down and verify the following:

      i. That the LSM is secure and properly supported.
      ii. That the ALSEP cable spool is not loose and the GSE cable end is secure.

   b. Lay the container back down on a flat surface, install the lid and place the external strap assembly around it with the buckle ends at the boom end, being careful not to drop or jar the container during the operation.

   c. Secure the straps by buckling the two strap ends, working the strap harness as required to remove any slack.

2. Installation Procedure, Outer Container

a. Remove the cover clampling ring and bolt, cover, and top inner inner foam rubber pad from the LSM shipping container (barrel assembly). Verify the following:

   i. That the cover gasket is in good condition.
   ii. That the shipping container is identified properly and is in good condition inside and out.
   iii. That the barrel is free of dirt and moisture inside. Record the humidity indicator reading.

b. Install the inner container into the shipping container with the boom end (buckle end) up until it rests on the foam bottom.

c. Install the following items:

   i. Dessicant, four each, eight unit bags, per MIL-D-3464 around on top of pad No. 2 (slots provided).
   ii. Magnetic recorder, in center of pad No. 2 (slot provided).
   iii. Top foam cover, pad No. 1, and press firmly in place.
   iv. Locking tool.
   v. Three sensor head protective covers.

d. Close shipping container by installing gasket lid and clamping ring assembly. Torque ring bolt to 30 ±5 inch pounds.

e. Lock wire container cover and seal.

f. The LSM shipping container shall be prominently marked to indicate the following:

    i. Fragility of contents (delicate scientific equipment)
    ii. Preferred orientation (cover end up)
    iii. Use no hooks
    iv. Necessity of avoiding the proximity of magnets and large magnetic-field-producing electrical equipment.

g. Carrying handles and/or straps shall be utilized in transporting the LSM shipping container.

h. The LSM shipping container shall not be stored, even temporarily, on elevated shelves, racks, platforms, etc., without being securely fastened in place.

i. LSM pre-shipping procedure complete.

6.2 STORAGE REQUIREMENTS

6.2.1 Storage (Prior to ALSEP Integration)

The following are the requirements governing the storage of the LSM prior to integration with the ALSEP.

6.2.1.1 Environment (Non-Operating)

The maximum and minimum environmental levels to which the LSM may be subjected in the non-operating mode are as follows:

1. Vibration. Non-applicable
2. Shock. Non-applicable
3. Acceleration. Non-applicable
4. Temperature
    a. Packaged. The packaged LSM shall not be exposed to a temperature range exceeding $-30^{\circ}C$ to $+55^{\circ}C$. The LSM shall not remain packaged for more than 2 years.

    b. Unpackaged (Non-Operating). The unpackaged LSM shall not be exposed to an air temperature range exceeding $-30^{\circ}C$ to $+45^{\circ}C$ plus solar flux of 360 $Btu/hr/ft^2$ for up to 6 hours per day. The LSM shall not remain unpackaged for more than 2 weeks.

5. Magnetic Fields. The LSM shall be protected by the storage environment from all magnetic fields in excess of 1 gauss.

6. Pressure. The LSM packaged or unpackaged shall not be exposed to pressures greater than sea level or less than 11.78 psia (6000 feet altitude). The period of exposure to pressures less than sea level shall not exceed 2 years.

7. Radiation. During storage, the LSM shall not be exposed to radiation levels producing a total integrated dose in excess of ten percent of the total integrated dose expected during one year of lunar operations, as specified in Paragraph 4.1 of GAEC LED-520-1D.

8. Humidity. The relative humidity to which the LSM is exposed during storage shall not exceed 50 percent for longer than 2 weeks, in the unpackaged condition. The packaged LSM may be exposed to a humidity as high as 95 (+3, -5) percent at a temperature of 85 ($\pm$5)$^{\circ}$F for a period not to exceed 2 weeks; for longer periods of exposure in the packaged position, the relative humidity shall not exceed 50 percent.

9. Other Environments. The facility in which handling of the unpackaged LSM occurs shall provide protection against exposure to the following environments:

   a. Sand and dust
   b. Fungus
   c. Hazardous gases (including ozone)
   d. Rain
   e. Salt fog

   as defined in MIL-P-116E, Method II (see Section 4.1.4.1.8).

6.2.1.2 Precautionary Techniques (Requirements)

1. Wherever and whenever feasible, the LSM shall be stored within the protection shipping container.

2. If storage of the LSM outside of the protective shipping container is required, the storage environment shall be as follows:

   a. Temperature: $20^{\circ}C \pm 10^{\circ}C$

b. Dust:	All air shall be filtered to eliminate at least 99% of all dust particles over 100 microns in diameter.
c. Corrosive Atmosphere:	The storage environment shall protect the instrument from corrosive atmosphere.

3. A Magnetic recorder shall be affixed within the LSM shipping container, as appropriate, to monitor LSM magnetic field exposure.

6.2.2 Storage (After ALSEP Installation)

The following are the requirements governing the storage of the LSM after installation in the ALSEP.

6.2.2.1 Environments (Non-Operating)

The maximum and minimum environmental levels to which the LSM may be subjected in the non-operating mode are as follows:

1. Vibration. Non-applicable
2. Shock. Non-applicable
3. Steady-State Acceleration. Non-applicable
4. Temperature. The LSM, installed in ALSEP, shall not be exposed to a temperature range exceeding -30°C to +55°C.
5. Pressure. The LSM, installed in ALSEP, shall not be exposed to pressures greater than that of sea level nor less than that of 50,000 feet.
6. Magnetic Fields. The LSM shall not be exposed to magnetic fields in excess of 1 gauss. If necessary, this requirement shall be met by utilization of magnetic shielding either of the magnetic field sources or of the flux-gate sensor heads.

7. Radiation. During storage, the LSM shall not be exposed to radiation levels producing a total integrated dose in excess of ten percent of the total integrated dose expected during one year of Lunar operation, as specified in paragraph 4.1 of GAEC LED - 520-1D.

8. Other Environments. Non-applicable (applied to ALSEP package).

6.2.2.2 Precautionary Techniques (Requirements)

One or more magnetic recorders shall be affixed within the LSM shipping container, as appropriate, to monitor LSM magnetic field exposure.

6.3 TRANSPORTATION/DELIVERY (PACKAGED)

The following are the requirements governing the transportation/delivery of the LSM in the LSM shipping container.

6.3.1 Environments (Non-Operating)

The maximum and minimum environmental levels to which the LSM may be subjected in the non-operating mode are as follows.

Vibration

The maximum sinusoidal vibration along each of the three major mutually perpendicular axes to which the LSM, packaged for shipment, shall be exposed is as follows:

Frequency Range	Acceleration (0 to peak)	Sweep Rate
5 Hz to 25 Hz	1g	Non-Applicable
25 Hz to 50 Hz	3g	Non-Applicable
50 Hz to 500 Hz	4g	Non-Applicable

Shock

The LSM packaged for shipment shall not be subjected to flat drops in excess of 18 inches to a flat concrete surface (refers to both directions along each of the three major mutually-perpendicular axes).

Steady-State Acceleration

The LSM packaged for shipment shall not be subjected to steady-state acceleration in excess of 5.0 g applied along each of the three major mutually-perpendicular axes.

Temperature

The temperatures to which the packaged LSM is exposed shall not exceed the following:

1. Air Transportation: $-43^{\circ}C$ to $+60^{\circ}C$ for 8 hours
2. Ground Transportation: $-50^{\circ}C$ to $+70^{\circ}C$ for 2 weeks

Pressure

The pressures to which the packaged LSM is exposed shall not exceed the following:

1. Air Transportation: Minimum of 3.45 psia (35,000 feet altitude) for 8 hours
2. Ground Transportation: Minimum of 11.78 psia (6,000 feet altitude) for 2 weeks

Magnetic Fields

The packaged LSM shall not be exposed to magnetic fields in excess of 10 gauss.

Radiation

Negligible.

6.3.2 Precautionary Techniques (Requirements)

1. During transportation, the LSM shipping container shall be placed on the lowest surface or shelf available in the minimum potential energy configuration and, if possible, shall be tied or strapped in place.

2. Storage of other boxes or containers on top of the LSM shipping container shall be avoided.

3. Stowage of the LSM shipping container in the vicinity of magnetic field producing units (e.g., motor/generators, permanent magnets, etc.) shall be avoided.

4. One or more magnetic recorders shall be affixed within the LSM shipping container, as appropriate, to monitor LSM magnetic field exposure.

SECTION 7

OPERATIONAL REQUIREMENTS

7.1 LUNAR SURFACE DEPLOYMENT OPERATIONS

7.1.1 Removal from ALSEP

It is assumed that the operations start with the LSM mounted in the pallet in its stowed configuration position and that the pallet is resting upright on the lunar surface.

1. Using the universal tool (Figure 7-1), release the two quick-release fasteners securing the upper mounting bracket assembly to the pallet. The fasteners are released by pushing down and turning one quarter of a turn CCW (counter clockwise) with the tool. Replace tool in the pallet.

2. Grasp handle of upper mounting bracket assembly frame and lift upward until the frame is clear of the inner foam parts (Figure 7-2). Pull handle (and frame section) to the right (away from base of LSM) causing the three cables attached to:
   a. Release and pop-up the lift-off handle
   b. Release the brace locking levers and move them to the unlocked position
   c. Pull brace assembly away from mating brackets. (A jerking motion may be required to accomplish this.)

   Raise the handle/frame up sufficient to clear the brace assembly of the LSM and discard the entire assembly (Figure 7-3).

Figure 7-1

Releasing Quick-Release Fasteners

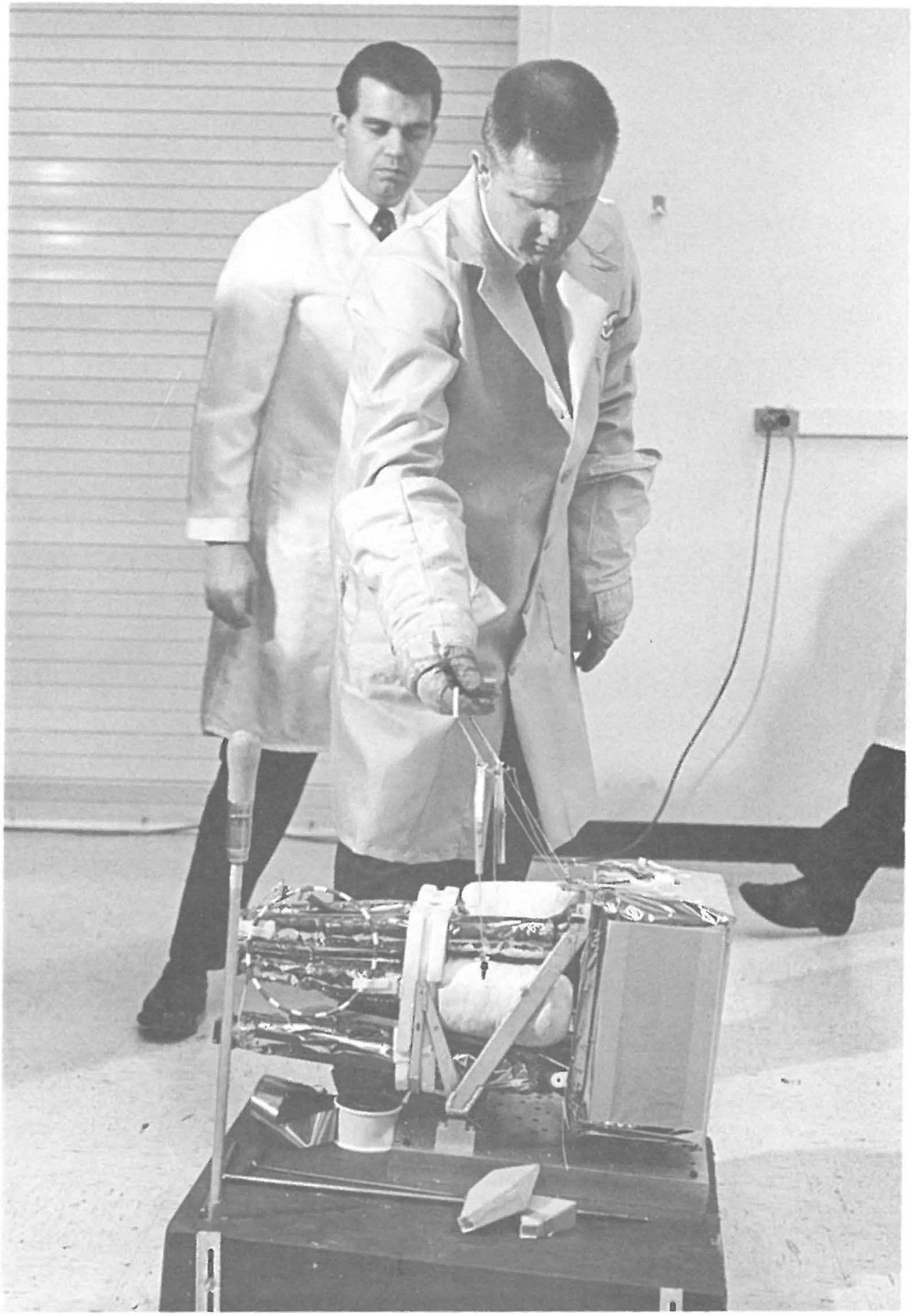


Figure 7-2

Lifting Upper Mounting Bracket Handle

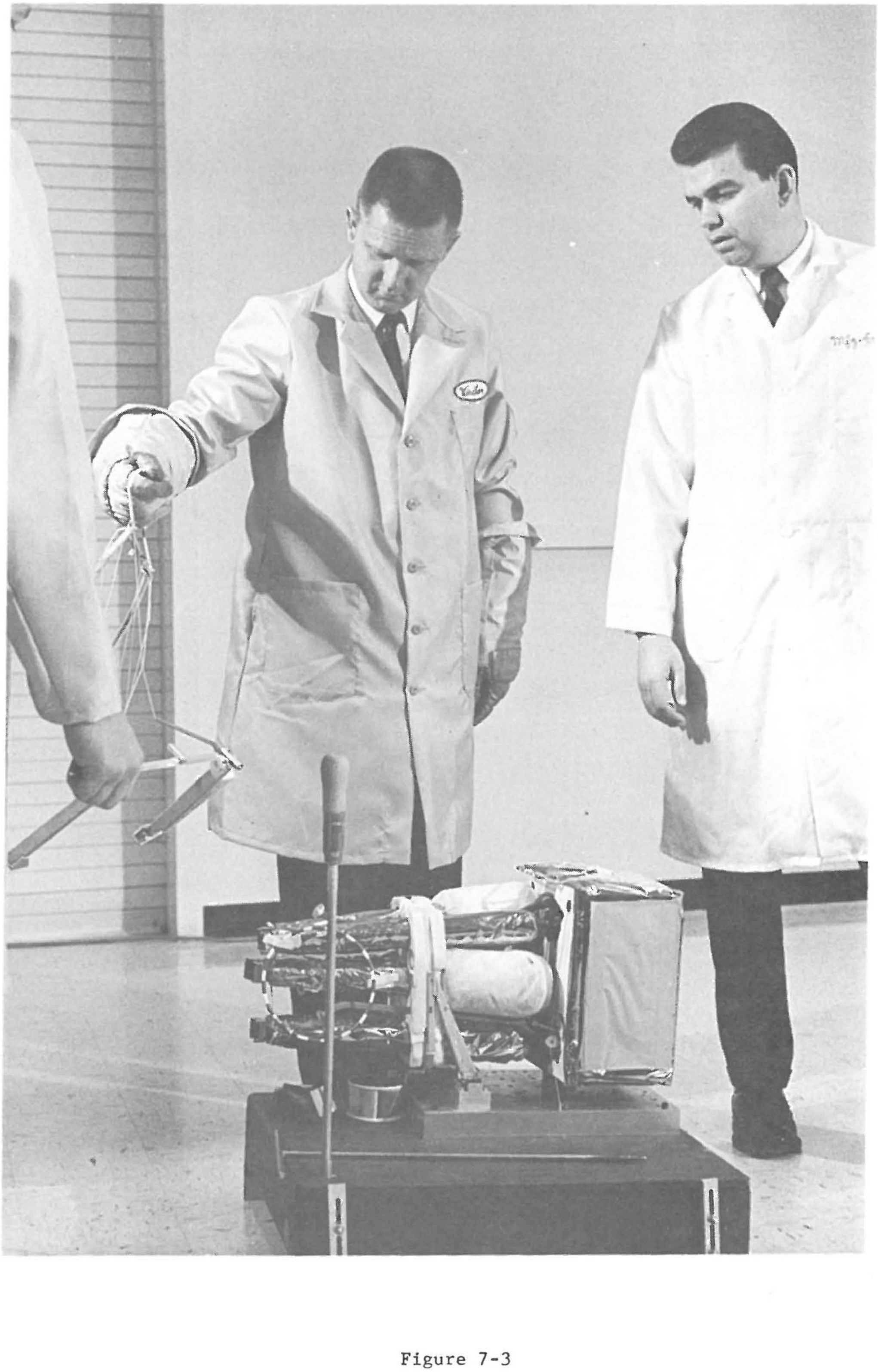


Figure 7-3

Removing Handle/Frame Assembly

3. Grasp the lift-off/carry handle with the left hand and lift upward (Figure 7-4), releasing the pin locking mechanism and lifting the LSM off its mounting pins. A slight back and forth rocking motion may be necessary.

4. With the LSM suspended horizontally, grasp the pivot ring/carry handle with the right hand (Figure 7-5). Slowly rotate the instrument until the weight is totally shifted to the right hand (Figure 7-6).

5. Lower the LSM to the lunar surface and drop the pivot ring/carry handle.

7.1.2 Transportation to Deployment Site

1. Return to the LSM after completing other ALSEP tasks with universal tool in the suit scabbard.

2. With the right hand grasp the pivot ring/carry handle and lift the LSM vertically (Figure 7-7) until the lift-off/carry handle can be grasped with the left hand. Slowly rotate the instrument until the weight is shifted to the left hand (Figure 7-8).

3. Walk to the deployment site (approximately 50 feet) taking care not to foul the ALSEP cable or take up all cable slack.

7.1.3 Site Selection

The lunar site at which the operating LSM will be located will be approximately 50 feet away from ALSEP and will lie roughly along the LEM-ALSEP radial. The precise location of the site, however, will be chosen at the astronaut's discretion subject to the following considerations:

1. The site shall be as flat and as free from minor rocks, protuberances, sand and dust, and craters or depressions as local conditions permit.

Figure 7-4

Grasping Lift-Off/Carry Handle

Figure 7-5

Grasping Pivot Ring/Carry Handle

Figure 7-6

Rotating the Instrument

Figure 7-7
Lifting the Instrument

Figure 7-8

Rotating the Instrument

2. The site shall not be in the immediate vicinity of large rocks or accumulations of lunar debris, local conditions permitting.

7.1.4 Initial Placement

1. With the LSM suspended horizontally, grasp the pivot ring with the right hand (Figure 7-9). Slowly rotate the instrument until the weight is totally shifted to the right hand.

2. Using the left hand, grasp the lift-off/carry handle of the lower half frame (Figure 7-10); withdraw and discard.

3. Pull the three support legs out of the foam insert and allow them to drop (Figure 7-11). They are spring-loaded and will automatically lock into place.

4. Remove and discard the two large halves of the foam insert with the left hand. A slight up and down motion with the left hand will assist in this task. An East arrow is located on the insert for direction orientation of the LSM.

5. Gently lower the LSM to the surface and drop the pivot ring. The LSM shall be placed on the surface such that no support leg will rest either on a rock or raised portion of the lunar surface or within a depression or crevice. Care shall be exercised during emplacement to avoid raising sand and dust which might subsequently settle on the instrument.

7.1.5 Sensor Arm Deployment

The sensor arms are to be deployed with the astronaut standing in the crew station, between the X and Z arms facing the instrument (Figure 7-12).

Figure 7-9
Grasping the Pivot Ring/Carry Handle

Figure 7-10

Grasping the Lift Off/Carry Handle

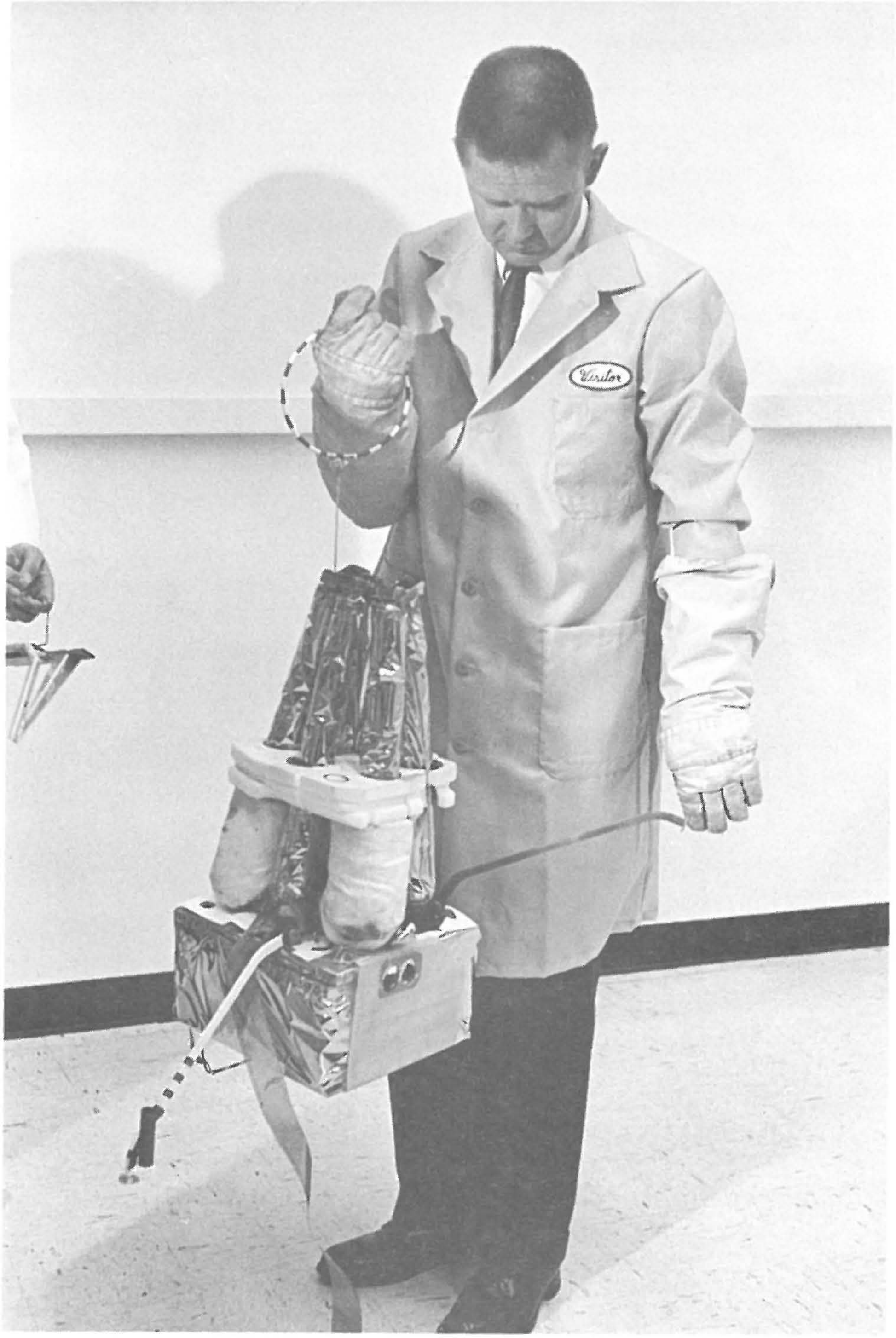


Figure 7-11

Releasing the Support Legs

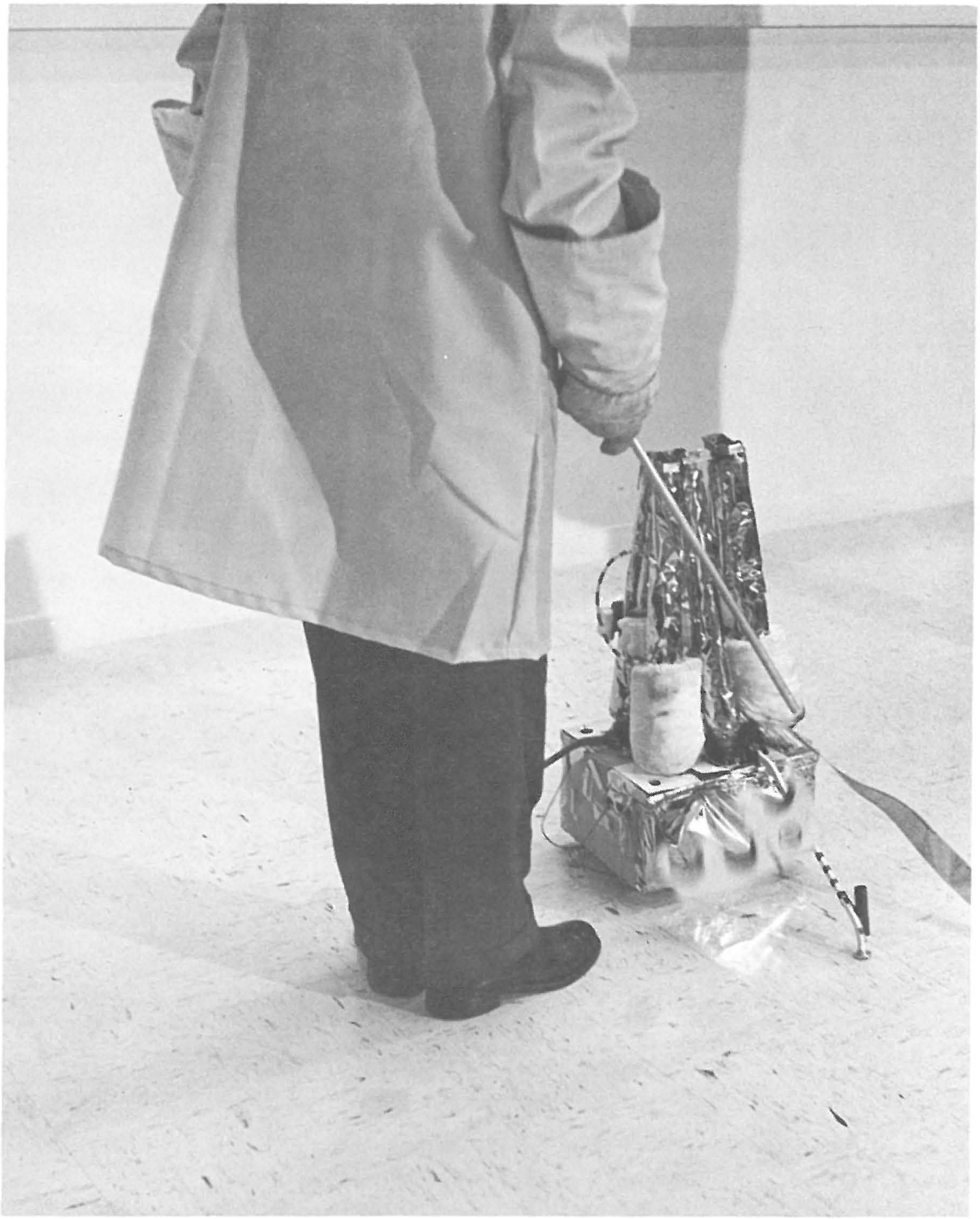


Figure 7-12

Astronaut Standing at Crew Station

1. The Y arm should be deployed first. Grasp the upper arm with the right hand and raise it until the middle arm hinge locks into position (sensor arm straight. Gentle lower the arm as far as possible and let it drop into the deployed position. Because of reach limitations, the arm will be dropped from a position slightly over vertical.

2. Deploy the Z and X arms in similar fashion - the X arm is deployed last (Figures 7-13 and 7-14).

7.1.6 PRA Cover Removal

The PRA covers are removed by pulling the PRA release ring attached to the X arm. The initial pull will pull the release ring off the X arm and release the PRA covers. Further pulling towards the crew station will remove the covers from beneath the LSM. Discard the covers when they are free of the instrument.

Removal of the PRA covers will automatically deploy both PRA sunshades and the solar shadowgraph.

NOTE: During the balance of the deployment operations extreme care should be exercised to avoid kicking gravel or dust which may impinge on the PRA surfaces.

7.1.7 Alignment and Leveling

1. Using the universal tool, remove any debris remaining on the upper thermal blanket. This may include small pieces of the foam insert and the pivot ring.

NOTE: An additional east arrow is provided on the upper thermal blanket for reference.

Figure 7-13

Deploying Z Sensor Arm

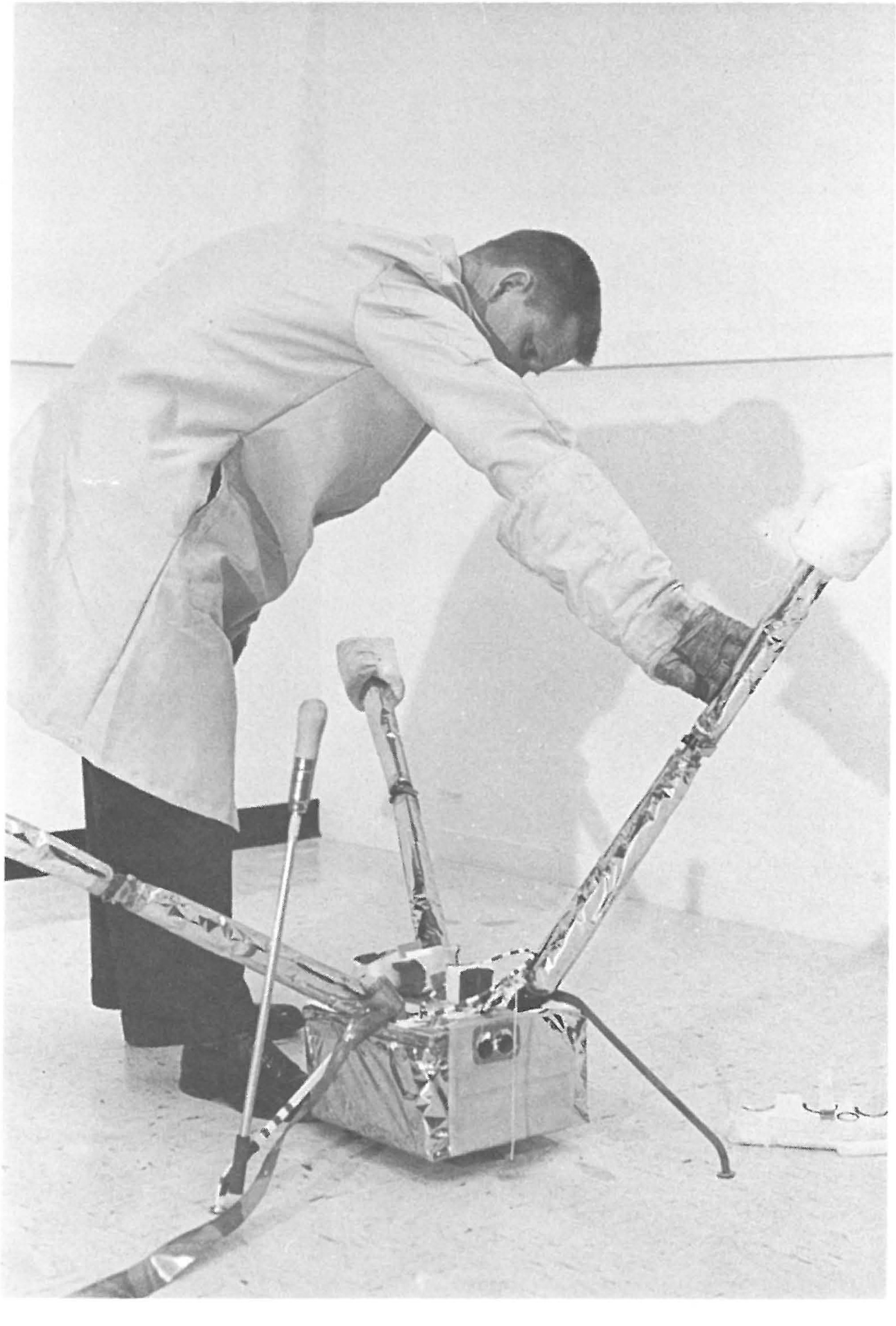


Figure 7-14

Deploying X Sensor Arm

2. Grasping the X sensor arm above the upper hinge with the right hand, gently rotate the instrument while watching the image of the shadowgraph gnomon on the reticle until the image falls within the group of vertical lines (Figure 7-15). Each line from the center represents 1° of azimuthal alignment. This position will signify that the LSM is aligned to within 3° of azimuth.

3. Insure that none of the three support legs are resting on rocks or surface irregularities which may hamper leveling operations and realign azimuthally if necessary.

4. Using the universal tool in the right hand initially level the instrument by turning the level adjustment screws (Figure 7-16) provided for each leg. Location of the screws is marked by a red ring. A bubble level with three concentric circles, each representing 1° of tilt, is provided on the upper thermal blanket for visual aid in the leveling operation. On all leg adjustment screws, a clockwise (CW) turn with the tool raises that corner of the LSM. Continue adjustment until the bubble is within 3° or outer circle of the bubble level.

5. Following initial leveling, the azimuthal alignment should be rechecked and adjusted if found to be outside of the 3° reticle. Following this, the bubble level should be rechecked and adjusted. With azimuthal alignment and level set within 3° tolerance, the shadowgraph reading should be determined to within 1° and reported.

6. Before leaving the instrument check and insure that the ALSEP calbe and the lift-off/carry handle are not directly in front of the PRA's or interferring with the PRA sunshades.

Figure 7-15

Aligning the Instrument

Figure 7-16

Leveling the Instrument

7.2 REAL TIME DATA ACQUISITION

7.2.1 Operational Plan

The real time data will be visually monitored at the MSC during the initial deployment of the magnetometer system. Temperature, voltage, magnetic field, and other status information will be used to determine scale settings, scale offset currents, and calibration. The time required for lunar surface deployment, site survey, and magnetometer scale determination is shown in Figure 7-17. The recorded data from the various receiving sites will automatically fold in calibration and instrument status in order to plot tapes for the final reduced data.

7.2.2 LSM/ALSEP Operational Interface

7.2.2.1 General

The operational interface between the magnetometer and the ALSEP is defined to encompass only the command and telemetry data word assignments. Other interfaces, including power and mechanical, are treated in Section 3 and 4.

7.2.2.2 Command Assignments

The LSM responds to eight different incoming (ground or, in the case of CM-5, ALSEP originated) commands supplied on individual lines in the ALSEP/LSM cable (Reference Figure 4.1 of Section 4). These commands are listed below:

INPUTS TO LSM

Designation	Command	Source
CM-1	Range Select	Ground
CM-2	Steady-Field Offset	Ground
CM-3	Offset Address	Ground
CM-4	Flip/Cal Inhibit	Ground
CM-5	Flip/Cal Initiate	Ground (as required) or ALSEP (Once per 12 hrs)
CM-6	Filter Bypass	Ground
CM-7	Site Survey	Ground
CM-8	Temperature Control	Ground

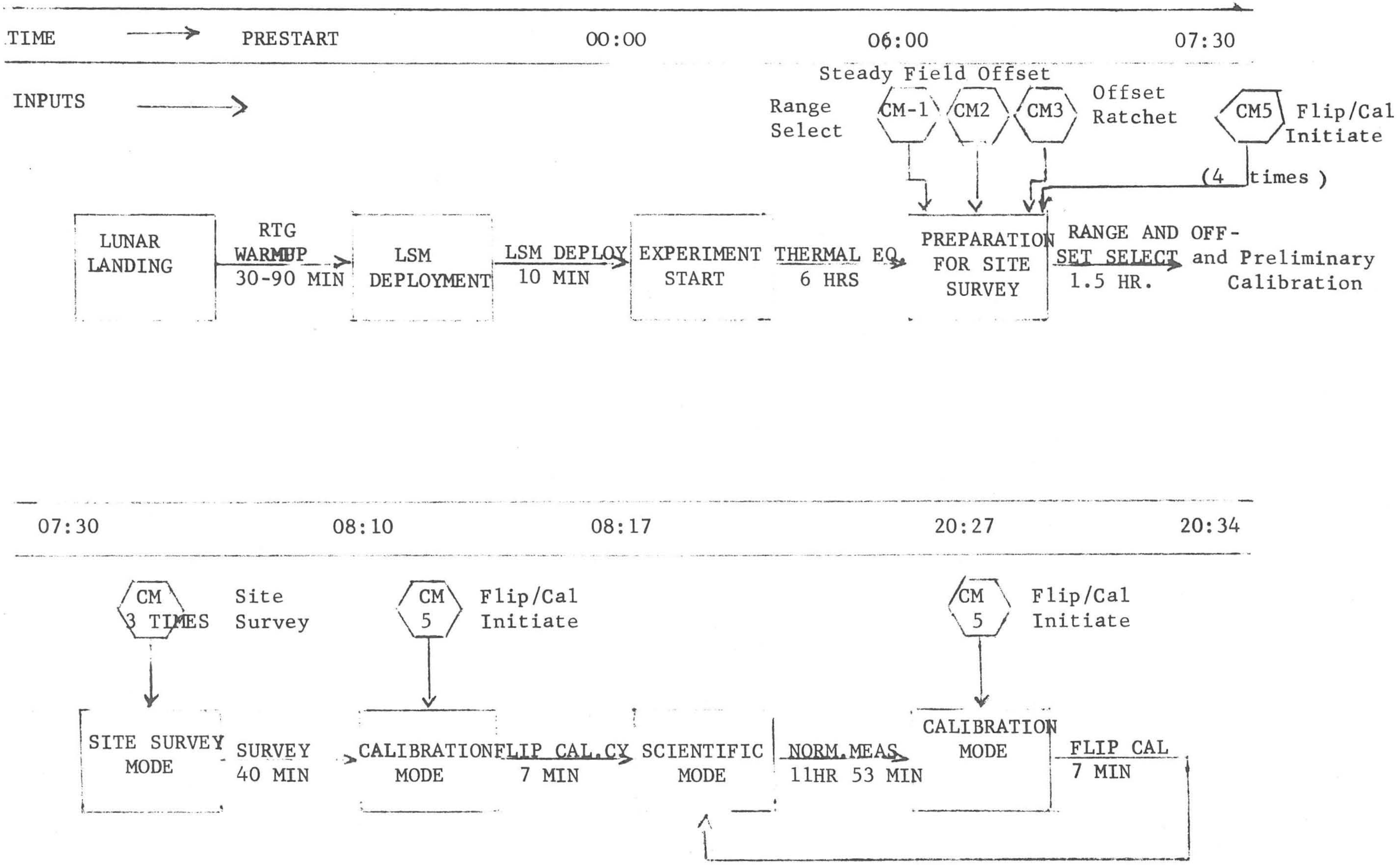


Figure 7-17 LSM Experiment Operational Flow Chart

A detailed discussion of the purpose and operation of each command listed above is given in Section 4.

7.2.3 Real Time Data Requirements

7.2.3.1 Inputs

The magnetometer data is contained in ALSEP words 5, 17, 19, 21, 49, and 53.

1	2	3	4	▨ 5	6	7	8
9	10	11	12	13	14	15	16
▨ 17	18	▨ 19	20	▨ 21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
▨ 49	50	▨ 51	52	▨ 53	54	55	56
57	58	59	60	61	62	63	64

Each ALSEP word contains 10 bits and the transmission rate is either 1060 or 530 bits per second. Word 5 contains engineering data and status information and words 17, 19, 21, 49, 51, and 53 contain magnetic field information.

Words 17 and 49 represent two successive X-axis values, words 19 and 51 represent two successive Y-axis values, and words 21 and 53 represent two successive Z-axis values. Each 10 bit X, Y, and Z word has the following format:

2^9	2^8 2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0
POLARITY BIT	DATA

The polarity bit 0 is + and 1 is - and the conversion factors for the three ranges are: (a) 0.1959γ/bit on 100γ range, (b) 0.3908γ/bit on 200γ range and 0.7816γ/bit on the 400γ range.

The engineering word 5 has the following format:

2^9	2^8 2^7 2^6 2^5 2^4 2^3 2^2	2^1 2^0
SUBFRAME MARK BIT	DATA	STATUS BITS

This engineering data and instrument status information is contained in 16 subcommutated ALSEP frames and the format is as in Table 7-1.

The status bit information is shown in Table 7-2.

Another data input is obtained from the communications channel with the astronaut. The astronaut will read the shadowgraph and report the azimuthal orientation to within ±1 degree.

7.2.3.2 Outputs

7.2.3.2.1 Visual Pen Recording (Brush)

The magnetometer experiment can utilize the Brush Model 200 Recorders with the 30 inch display table for real time monitoring during the first month of the ALSEP mission. An example of magnetometer data is shown on a strip of Brush paper in Table 7-3. The paper speed should be 0.5mm per second and the channel assignments are as follows:

Upper Edge   Timing code NASA 1/hour binary time code

TABLE 7-1
ALSEP WORD 5 FORMAT

COMMUTATOR POINT	SUBFRAME MARK BIT	ANALOG CONVERTED TO 7 BIT DIGITAL DATA	STATUS BITS
	2^9	2^8 2^7 2^6 2^5 2^4 2^3 2^2	2^1 2^0
1	1	Temperature X Range -50→+125°C 1.378°/bit	X flip position
2	0	Temperature Y Range -50→+125°C 1.378°/bit	Y flip position
3	0	Temperature Z Range -50→+125°C 1.378°/bit	Z flip position
4	0	Temperature E1 Range -50→+125°C 1.378°/bit	X gimbal position Y gimbal position
5	0	Temperature E2 Range -50→ +125°C 1.378°/bit	Z gimbal position Thermal control selection
6	0	Level #1 Range -15°→+15° 0.236°/bit	Spare
7	0	Level #2 Range -15°→ +15° 0.236°/bit	Range
8	0	Voltage Range 0→6.25v 0.0492 v/bit	Spare
9	0	Temperature X Range -50°→ +125°C 1.378°/bit	X field offset
10	0	Temperature Y Range -50°→+125°C 1.378°/bit	X field offset Y field offset
11	0	Temperature Z Range -50°→ +125°C 1.378°/bit	Y field offset
12	0	Temperature E1 Range -50°→+125°C 1.378°/bit	Z field offset
13	0	Temperature E2 Range -50°→+125°C 1.378°/bit	Z field offset Calibration Mode
14	0	Level #1 Range -15°→ +15° 0.236°/bit	Offset address
15	0	Level #2 Range -15°→+15° 0.236°/bit	Filter status Calibrate inhibit
16	0	Voltage Range 0→6.25v 0.0492v/bit	Heater

TABLE 7-2

COMMUTATOR POINT	SUBFRAME MARK BIT	STATUS BITS		FUNCTION	STATUS
	2^9	2^1	2^0		
1	1	0	0	X Flip Position (FX)	Not 0°, 90°, or 180°
1	1	0	1	X Flip Position (FX)	0°
1	1	1	0	X Flip Position (FX)	90°
1	1	1	1	X Flip Position (FX)	180°
2	0	0	0	Y Flip Position (FY)	Not 0°, 90°, or 180°
2	0	0	1	Y Flip Position (FY)	0°
2	0	1	0	Y Flip Position (FY)	90°
2	0	1	1	Y Flip Position (FY)	180°
3	0	0	0	Z Flip Position (FZ)	Not 0°, 90°, or 180°
3	0	0	1	Z Flip Position (FZ)	90°
3	0	1	0	Z Flip Position (FZ)	180°
4	0	0	-	X Gimbal Position (GX)	Pre Site-Survey Pos.
4	0	1	-	X Gimbal Position (GX)	Post Site-Survey Pos.
4	0	-	0	Y Gimbal Position (GY)	Pre Site-Survey Pos.
4	0	-	1	Y Gimbal Position (GY)	Post Site-Survey Pos.
5	0	0	-	Z Gimbal Position (GZ)	Pre Site-Survey Pos.
5	0	1	-	Z Gimbal Position (GZ)	Post Site-Survey Pos.
5	0	-	0	Thermal Control (TC)	X axis control
5	0	-	1	Thermal Control (TC)	Y axis control
6	0	0	0	Spare	
7	0	0	0	Measurement Range (RG)	± 100 Gamma
7	0	1	0	Measurement Range (RG)	± 200 Gamma
7	0	1	1	Measurement Range (RG)	± 400 Gamma
7	0	0	1	Measurement Range (RG)	Errors Somewhere
8	0	0	0	Spare	
9	0	0	0	X Field Offset (OX)	-75%
10	0	0	-	X Field Offset (OX)	-75%
9	0	1	-	X Field Offset (OX)	-50%
10	0	1	-	X Field Offset (OX)	-50%
9	0	0	1	X Field Offset (OX)	-25%
10	0	0	-	X Field Offset (OX)	-25%
9	0	0	1	X Field Offset (OX)	0%
10	0	1	-	X Field Offset (OX)	0%
9	0	1	0	X Field Offset (OX)	25%
10	0	0	-	X Field Offset (OX)	25%
9	0	1	0	X Field Offset (OX)	50%
10	0	1	-	X Field Offset (OX)	50%
9	0	1	1	X Field Offset (OX)	75%
10	0	0	-	X Field Offset (OX)	75%

TABLE 7-2 CONTINUED

COMMUTATOR POINT	SUBFRAME MARK BIT	STATUS BITS		FUNCTION	STATUS
	2^9	2^1	2^0		
10	0	-	0	Y Field Offset (OY)	-75%
11	0	0	0	Y Field Offset (OY)	-75%
10	0	-	0	Y Field Offset (OY)	-50%
11	0	0	1	Y Field Offset (OY)	-50%
10	0	-	0	Y Field Offset (OY)	-25%
11	0	1	0	Y Field Offset (OY)	-25%
10	0	-	0	Y Field Offset (OY)	0%
11	0	1	1	Y Field Offset (OY)	0%
12	0	-	1	Y Field Offset (OY)	25%
11	0	0	0	Y Field Offset (OY)	25%
10	0	-	1	Y Field Offset (OY)	50%
11	0	0	1	Y Field Offset (OY)	50%
10	0	-	1	Y Field Offset (OY)	75%
11	0	1	0	Y Field Offset (OY)	75%
12	0	0	0	Z Field Offset (OZ)	-75%
13	0	-	0	Z Field Offset (OZ)	-75%
12	0	0	0	Z Field Offset (OZ)	-50%
13	0	-	1	Z Field Offset (OZ).	-50%
12	0	0	1	Z Field Offset (OZ)	-25%
13	0	-	0	Z Field Offset (OZ)	-25%
12	0	0	1	Z Field Offset (OZ)	0%
13	0	-	1	Z Field Offset (OZ)	0%
12	0	1	0	Z Field Offset (OZ)	25%
13	0	-	0	Z Field Offset (OZ)	25%
12	0	1	0	Z Field Offset (OZ)	50%
13	0	-	1	Z Field Offset (OZ)	50%
12	0	1	1	Z Field Offset (OZ)	75%
13	0	-	0	Z Field Offset (OZ)	75%
13	0	0	-	Calibration Mode (CM)	On (Calib)
13	0	1	-	Calibration Mode (CM)	Off (Sci)
14	0	0	0	Offset Address (OR)	Not X, Y, or Z
14	0	0	1	Offset Address (OR)	Y
14	0	1	0	Offset Address (OR)	X
14	0	1	1	Offset Address (OR)	Z
15	0	1	-	Digital Filter (FT)	(Bypassed)
15	0	0	-	Digital Filter (FT)	In
15	0	-	1	Flip Cal Inhibit (CI)	Inhibited
15	0	-	0	Flip Cal Inhibit (CI)	Enabled
16	0	0	0	Heaters (H)	On
16	0	1	0	Heaters (H)	Off

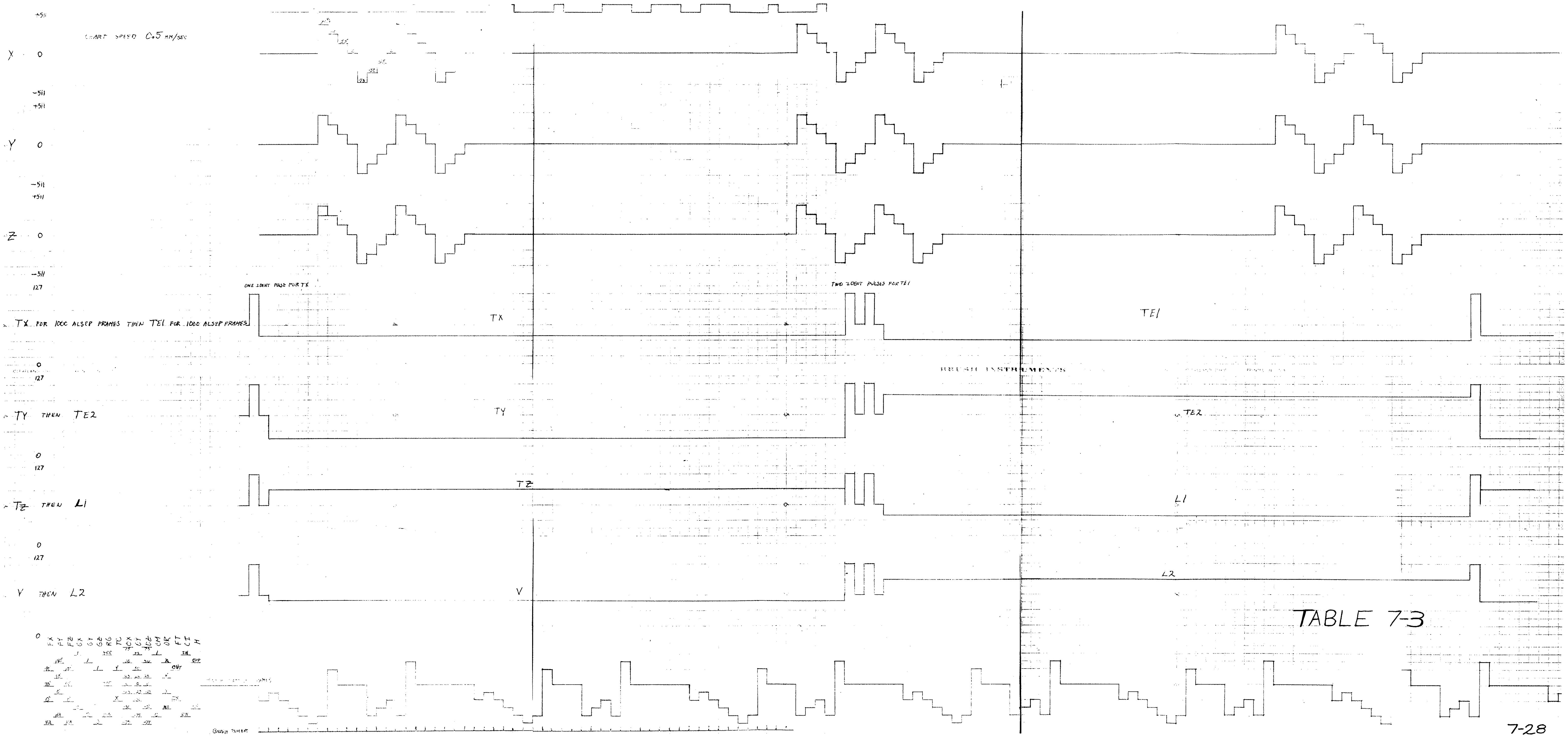

+511
CHART SPEED 0.5 MM/SEC
X 0
-511
+511
Y 0
-511
+511
Z 0
-511
127
ONE IDENT PULSE FOR TX
TWO IDENT PULSES FOR TE1
TX FOR 1000 ALSEP FRAMES THEN TE1 FOR 1000 ALSEP FRAMES
TX
TE1
0
127
BRUSH INSTRUMENTS
TY THEN TE2
TY
TE2
0
127
TZ THEN L1
TZ
L1
0
127
V THEN L2
V
L2
0
FX FY FZ GX GY GZ RG TC CX CY CZ CM OR FT CT H
ON
OFF
BRUSH TIMER

TABLE 7-3

Channel 1	X value of magnetic field. Range is from -511 bcd to +511 bcd. Word 17 and 49 of each ALSEP frame.
Channel 2	Y value of magnetic field. Range is from -511 bcd to +511 bcd. Words 19 and 51 of each ALSEP frame.
Channel 3	Z value of magnetic field. Range is from -511 bcd to +511 bcd. Words 21 and 53 of each ALSEP frame.
Channel 4	TX is the temperature of the X sensor. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 1 and 9. This TX value is recorded for 1000 ALSEP frames and then commutated on the Brush output to TE1. TE1 is the temperature of the thermal control surface. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 4 and 12. Brush record TE1 for 1000 ALSEP frames and commutate back to TX.
Channel 5	TY is the temperature of the Y sensor. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 2 and 10. This TY value is Brush recorded for 1000 ALSEP frames and then commutated to TE2. TE2 is the temperature of the DC-DC converter in the electronics package. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 5 and 13. Brush record TE2 for 1000 ALSEP frames and commutate back to TY.
Channel 6	TZ is the temperature of the Z sensor. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 3 and 11. This T2 value is Brush recorded for 1000 ALSEP frames and then commutated to

Li. L1 is the level sensor for the plane defined by the vertical and X boom axis. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 6 and 14. Brush record L1 for 1000 ALSEP frames and commutate back to TZ.

Channel 7 V is the voltage of the power supply used to generate the calibrate raster and offset values. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 8 and 16. This V value is Brush recorded for 1000 ALSEP frames and then commutated to LZ. LZ is the level sensor for the plane defined by the vertical and the Y boom axis. Range from 0 to 127 bcd. Data obtained from ALSEP word 5 subcommutated points 7 and 15. Brush record L2 for 1000 ALSEP frames and commutate back to V.

Channel 8 This channel records all the status information. One complete set of status information should be stored for the 16 ALSEP frames and then placed on the Brush recorder in the form shown in Table 3. The Brush channel 8 pen is then held in the center of the channel for 100 ALSEP frames and then the above record print process is repeated. This allows one complete set of status information to be presented for approximately every 370 ALSEP frames. Definitions for each of the abbreviations, such as FX, is given in Table 2 in the Function column.

Lower Edge Time pulse every 10 seconds

The Brush recorder channel should be calibrated two times per day. The calibration should be 10 points or levels for each channel and the level should be generated at the digital input by a 10 sec per step raster for approximately 10 minutes duration. The calibrate time should be determined by the PI so that it will not interfere with critical data recording times. All real time information during the first 45 days except for the 10 minute calibration periods should be recorded on the Brush recorder. Fifty hour periods during lunar sunrise and sunset as well as the time during the lunar transit of the earth's magnetosphere should also be recorded.

7.2.3.2.2 Computer Print Out

A computer printout of the magnetometer data is required in order to diagnose instrument health and determine site survey results. This information is also used to establish command requirements for the magnetometer. The print format is shown in Table 7-4. The only symbols not defined in Table 7-2 are: DTM is time from mission start in days, hours, minutes, seconds, tenths of seconds, (2) $\overset{F}{R}$ is subframe mark bit, (3) $\overset{C}{P}$ is commutator point. Each printout page should contain one complete set of subcommutated data and 32 scientific values for each of the three orthogonal coordinates. The value 7 should be used to identify the flip position for "not 0^{o}, 90^{o}, 180^{o}." The other notations follow those given in Table 7-2. The amount of printed magnetometer data will depend upon lunar magnetic activity and it is anticipated a print of 20 minutes real time data per day to be required.

7.2.3.2.3 Magnetic Tape Output

In order to produce timely reports it is necessary to further reduce the real time data at Ames Research Center. A magnetic tape containing one day's real time data should be recorded and air mailed to ARC at the completion of each day. This will eliminate the requirements for a data phone. The format should be as follows:

Label Record

4 words; 36 bits per word

word 1) Experiment
word 2) ALSEP number
word 3) Mission
word 4) Quantity of data on tape

One Logical Record

	Field	Bits	Content
Word 1	A	26	Lapse time from start of mission in seconds
	B	4	Tenths of seconds
	C	4	Station I. D.
	D	1	Data rate 1060 or 530 bps
	E	1	Frame Identification of ALSEP, 1 followed by 89 zeros
Word 2	F	6	Bit error rate
	G	10	ALSEP Housekeeping W33
	H	10	ALSEP Command and Verification W46
	I	10	LSM Engineering
Word 3	J	10	LSM Magnetic X
	K	10	LSM Magnetic Y
	L	10	LSM Magnetic Z
	M	6	Spare
Word 4	N	10	LSM Magnetic X
	O	10	LSM Magnetic Y
	P	10	LSM Magnetic Z
	Q	6	Spare

144 bits per record
36 bits per word
4 words per record
115 records per block

Last block to be filled with zeros, if necessary. Tape should be 800 BDL

7.2.3.2.3 T.V. Display

A real time T.V. display is available in addition to the other data outputs. The format for the display is given in Table 7-5.

Table 7-4

LSM Data Readout

```
               F  ⑨                                                                                                    T O                   C F C
   TM          R  F HX        HY        HZ         TX    TY    TZ    TE1    TE2   L1    L2     V   FX    FY    FZ GX GY GZ   RG C R   OX    OY    CZ M T I F
D H M S S  ----------------------------------------------------------------------------------------------------------------------------------------------------
12 08.16.12.11 1 10.0     10.0      10.0
               1    10.2      10.2      10.2
               0  2 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  3 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  4 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  5 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  6 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  7 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0  8 10.0      10.0      10.0
               0    10.2      10.2      10.2       21    21    21    21     21    21    21    21
               0  9 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 10 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 11 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 12 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 13 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 14 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 15 10.0      10.0      10.0
               0    10.2      10.2      10.2
               0 16 10.0      10.0      10.0                                                      7     7     7
               0    10.2      10.2      10.2       21    21    21    21     21    21    21    21   9     9     9  0  0  0  100 2 0   75    75    75 1 0 1 0
           ----------------------------------------------------------------------------------------------------------------------------------------------------
               F                                                                                                       T O                   C F C
   TM          R    HX        HY        HZ         TX    TY    TZ    TE1    TE2   L1    L2     V   FX    FY    FZ GX GY GZ   RG C R   OX    OY    CZ M T I F
```

Table 7-5

LSM T.V. Display

☐ ALSEP LUNAR SURFACE MAGNETOMETER HISTORY PAGE 1 ■■■■ ○

	SITE	■~■						
	GMT							
	LSM FRAME NO	■■					LOW	HIGH
DM01	SENSOR TEMP X °C							
DM02	SENSOR TEMP Y °C							
DM03	SENSOR TEMP Z °C							
DM04	BASE TEMP °C							
DM05	INTERNAL TEMP °C							
DM15	THERMAL CONTROL, AXIS							
DM06	LEVEL SENSOR #1, DEG							
DM07	LEVEL SENSOR #2, DEG							
DM08	SUPPLY VOLTAGE							
DM20	SCI/CAL/MODE STATUS							
DM23	CAL INHIBIT STATUS							
DM22	FILTER STATUS							
DM21	OFFSET RATCHET ADDRESS							
DM16	RANGE, ± (GAMMA)							
DM25	SENSOR OUTPUT X							
DM26	SENSOR OUTPUT Y							
DM27	SENSOR OUTPUT Z							
DM09	FLIP POS X, DEG							
DM10	FLIP POS Y, DEG							
DM11	FLIP POS Z, DEG							
DM12	GIMBAL POS X							
DM13	GIMBAL POS Y							
DM14	GIMBAL POS Z							
DM17	OFFSET FIELD, X, %							
DM18	OFFSET FIELD, Y, %							
○ DM19	OFFSET FIELD, Z, %							

GLOSSARY

ALSEP	Apollo Lunar Surface Experiment Package
Analog Signal	A continuous signal
AU	Arithmetic Unit
Autocollimating Theodolite	A telescope which provides collimated light and measures the angle of its reflection from a plane mirror to a fraction of an arc second
Cal	Calibration
Calibration Raster	Voltage step patterns used to calibrate the instrument
CL	Clock
Cordwood Module	A "building block" of the electronics subsystem compsed of discrete electronic components (resistors, capacitors, etc.) potted in a plastic foam
CSC (ALSEP)	Cable spool container
Curie point	The temperature above which the spontaneous ferromagnetic moment vanishes
Curl	A vector quantity which is the cross product of the differential operator with a vector, written $\Delta X \bar{A}$
DBDU	Data Bus Display Unit
Digital Signal	A discrete signal of step functions according to a number system
EDE	Engineering Data Electronics
EDS	Engineering Data Sequencer
EGFU	Electronic/gimbal flip unit

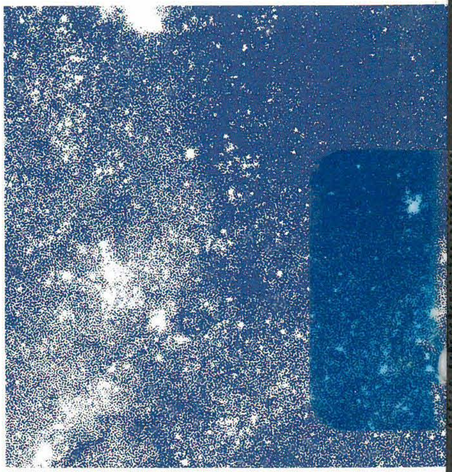
F.B.	Feedback
FET	Field Effect Transistor
Flip/cal	180° rotation of each sensor to calibrate the device by observing the difference in field strength for sensor-up and sensor-down positions (sensor offset)
Flip-flop	A bi-stable multivibrator circuit which switches between two states
Flip motion	Rotation about the sensor's transverse axis
Flux tanks	An enclosure in which a uniform magnetic field may be produced by the use of Helmholtz coils and which is magnetically shielded from the earth's field
Formed Substrate Module	A "building block" of the electronics subsystem composed of integrated circuits potted in a plastic foam
$\gamma = 10^{-5}$ gauss	A measure of the strength of a magnetic field
GFU	Gimbal flip unit
Gimbal motion	Rotation of the sensor head about the support arm
Glass heat felt	A fiberous thermal insulating material
Gnomon	An accurately positioned dot on a transparent plate, the image of which is projected on the recticle plate by the sun's rays
Gradiometer	An instrument which measures the gradient or change in the magnetic field with distance
GSE	Ground Support Equipment
Helmholtz Coils	Two parallel coils placed a distance apart equal to their common radius, which give a uniform field halfway between the coils

Hertz (Hz)	Cycles per second
Housekeeping	Engineering functions which monitor and command the mode of operation of the LSM
LE	Leading edge
LEM	Lunar Excursion Module
LSB	Least significant bit
LSM	Lunar Surface Magnetometer
Lunation	A lunar month - the time necessary for the moon to make one revolution with respect to the sun
Motherboard	A circuit board which supports and interconnects modules
MPX-A/D	Multiplexer Analog-to-Digital Converter
MSB	Most significant bit
μs	Microsecond
$\mu\sigma$	Electromagnetic diffusivity
ODB	Output Data Buffer
Offset	A DC compensation field which can be applied to each sensor independently
OOR	00 reset
Orthogonal	Each axis perpendicular to the plane of the other axes
Plasma	A high-temperature state containing completely ionized particles
PRA	Parabolic Reflector Array, a passive thermal control device
"Reinitialization" strings	Strings used to flip the magnetometer in the flux tanks without the use of the EGFU

Reticle	Accurately positioned lines arranged in known intervals
Shadowgraph	An alignment instrument which permits the astronaut to azimuthally orient the LSM and to determine the angle between the LSM and the East-West (Sun) line. Composed of a gnomon plate and reticle plate
Site Survey	The initial mode of operation of the LSM, used to determine local magnetic gradients
Solar wind	An outflow of charged particles from the sun which carries a magnetic field
Thermistor	A temperature measuring device utilizing the fact that the resistance of a substance changes with temperature
TLM	Telemetry
Tubelet	An electrical connection hole in the motherboard
Velcro tape	A two part attachment tape, one stip of which contains fine hooks, the other of which contains fine button holes. When pressed together the hooks and holes interlock, but can be disassembled without damage.

Commands

Designation	Command	Source
CM-1	Range Select	Ground
CM-2	Steady Field Offset	Ground
CM-3	Offset Address	Ground
CM-4	Flip/Cal Inhibit	Ground
CM-5	Flip/Cal Initiate	Ground (as required for ALSEP
CM-6	Filter Bypass	Ground
CM-7	Site Survey	Ground
CM-8	Temperature Control	Ground



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