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TRAVERSE GRAVIMETER

OPERATION AND INSTRUCTION MANUAL

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure | Page

SECTION 1 GENERAL INFORMATION

SECTION 2 OPERATION

SECTION 3 FUNCTIONAL DESCRIPTION

LIST OF TABLES

Table

SECTION 1 GENERAL INFORMATION

SECTION 2 OPERATION

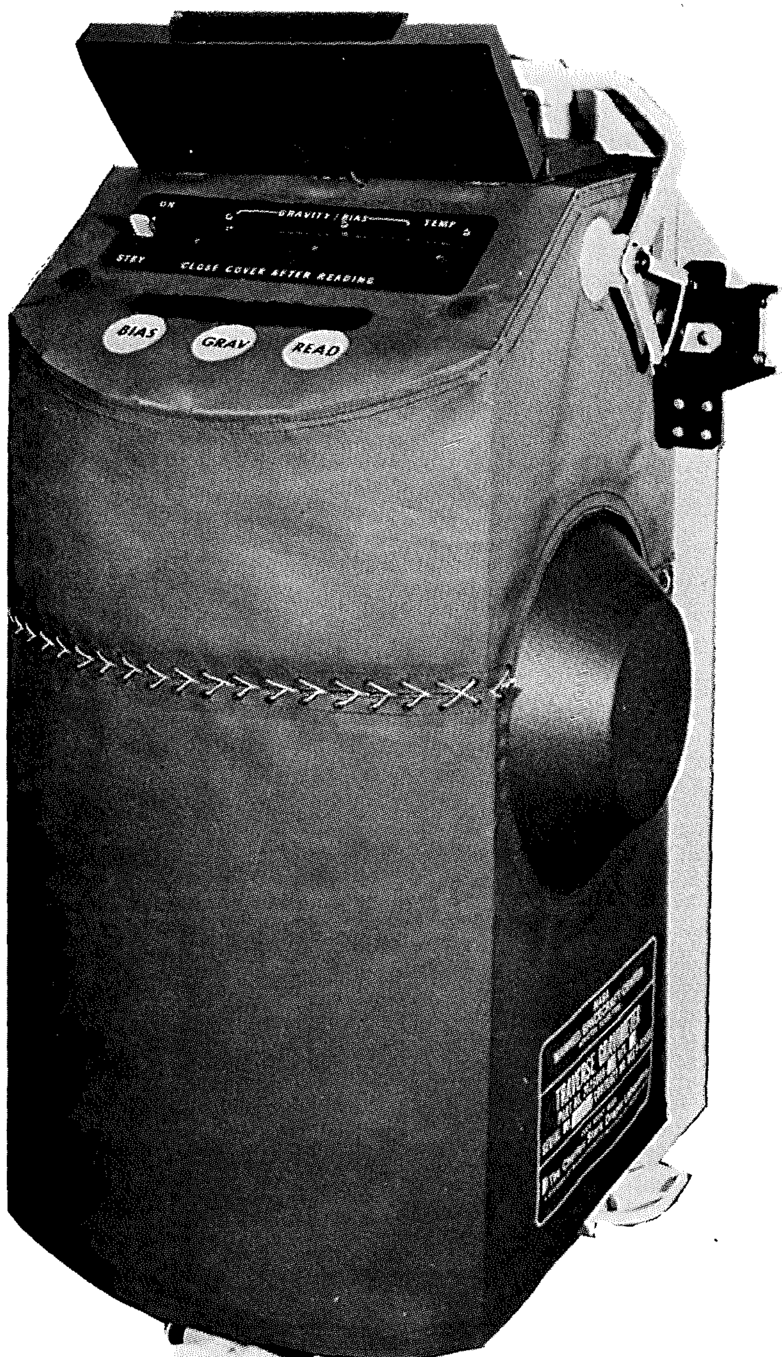

Figure 1.1 Traverse Gravimeter

SECTION 1

GENERAL INFORMATION

1.1 SCOPE

This manual has been prepared in accordance with item 5.2.18 of Exhibit A, Statement of Work, NASA Contract NAS 9-11555, dated January 1971.

This manual provides general information, functional description and lunar operational procedures for the Traverse Gravimeter.

1.2 GENERAL DESCRIPTION

The purpose of the Traverse Gravimeter Experiment (TGE) is to measure gravity at various points on the lunar surface to obtain information for a gravity profile. The profile will be used to reveal information related to density variations in the lunar subsurface. The gravity measurements will be made at predetermined stops along the route of a Lunar Rover Vehicle. Results of each measurement will be displayed to the astronaut who will, in turn, transfer the coded measurement to earth by way of voice communication.

The Traverse Gravimeter (TG), shown in Figure 1.1, will be transported to the lunar surface on the Lunar Module (LM) descent stage of Apollo 17. After LM landing the TG will be deployed on the lunar surface, initial measurements will be made in the vicinity of the LM and the coded data will be transmitted to mission control via voice communications. The TG will then be placed on the Lunar Rover Vehicle (LRV) and gravitational measurements will be made at various stations where the LRV is stopped for geological examinations. The TG will either remain on the LRV or be removed to the lunar surface and a gravitational measurement will be initiated by the astronaut. Upon initiation, the TG will automatically level, make a gravity measurement and be prepared to display this to the astronaut. Additional information about the status of the TG temperature is also available for display to the astronaut.

The TG is self-contained, light weight and essentially automatic in operation. Power is supplied by an internal 7.5 volt battery and there are no requirements for external power, recording devices or telemetry.

1.3 PHYSICAL DESCRIPTION

The TG consists of the instrument package, a battery pack assembly, a thermal blanket and an isoframe assembly. A cutaway view of the TG is shown in Figure 1.2. and an outline drawing is shown in Figure 1.3.

1.3.1 OUTER STRUCTURE. - The outer structure of the TG is cylindrical in shape with a flat rear surface. A folding handle at the top of the instrument is used for hand carrying and for latching the instrument to the isoframe assembly. Three feet at the base of the instrument enable lunar surface operations. A radiator at the top of the instrument provides the primary means of heat expulsion. The radiator as well as the display panel are protected from the environment by hinged insulating covers over each.

The outer surface of the TG is enclosed in the multilayered insulating blanket which provides thermal protection for internal components. The blanket covers all outer surfaces with the exception of the carrying handle, the display and radiator covers and the three feet. The isoframe assembly mounts to the rear of the TG and provides vibration isolation between the instrument and the pallet. To secure the TG to the isoframe assembly the two rear feet are placed in a cradle on the isoframe and the carrying handle is folded to a latched position. During the translunar phase of the mission three lanyard assemblies also secure the TG to the isoframe.

1.3.2 INNER STRUCTURE. - The inner structure of the TG consists of a two-axis gimbal system which contains a vibrating string accelerometer (VSA) housed in a thermally protected and evacuated two stage oven assembly. The oven assembly is enclosed in an electronic frame (E-Frame) assembly of similar structural design. The E-Frame

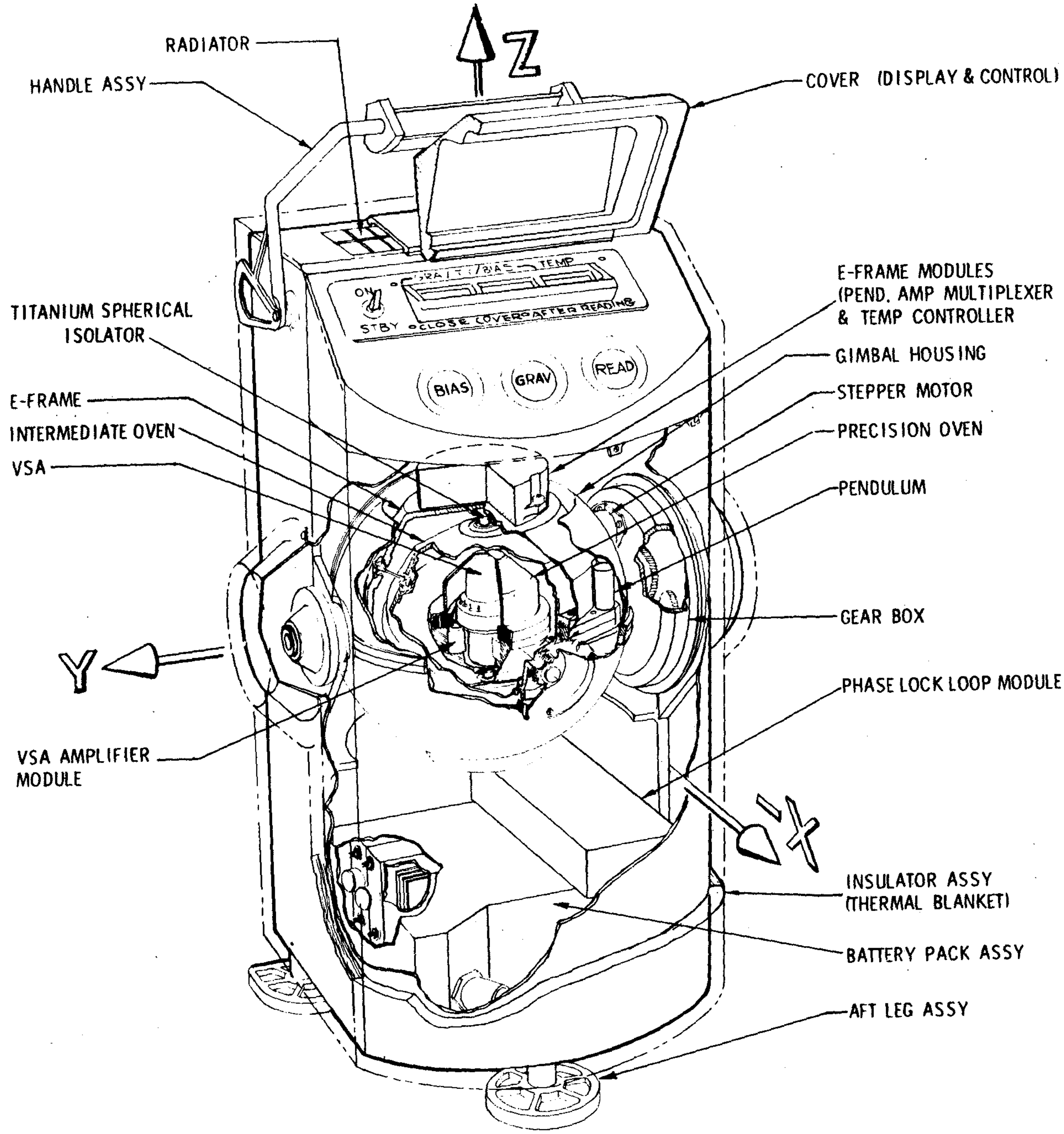

Figure 1.2. Traverse Gravimeter, Cutaway View

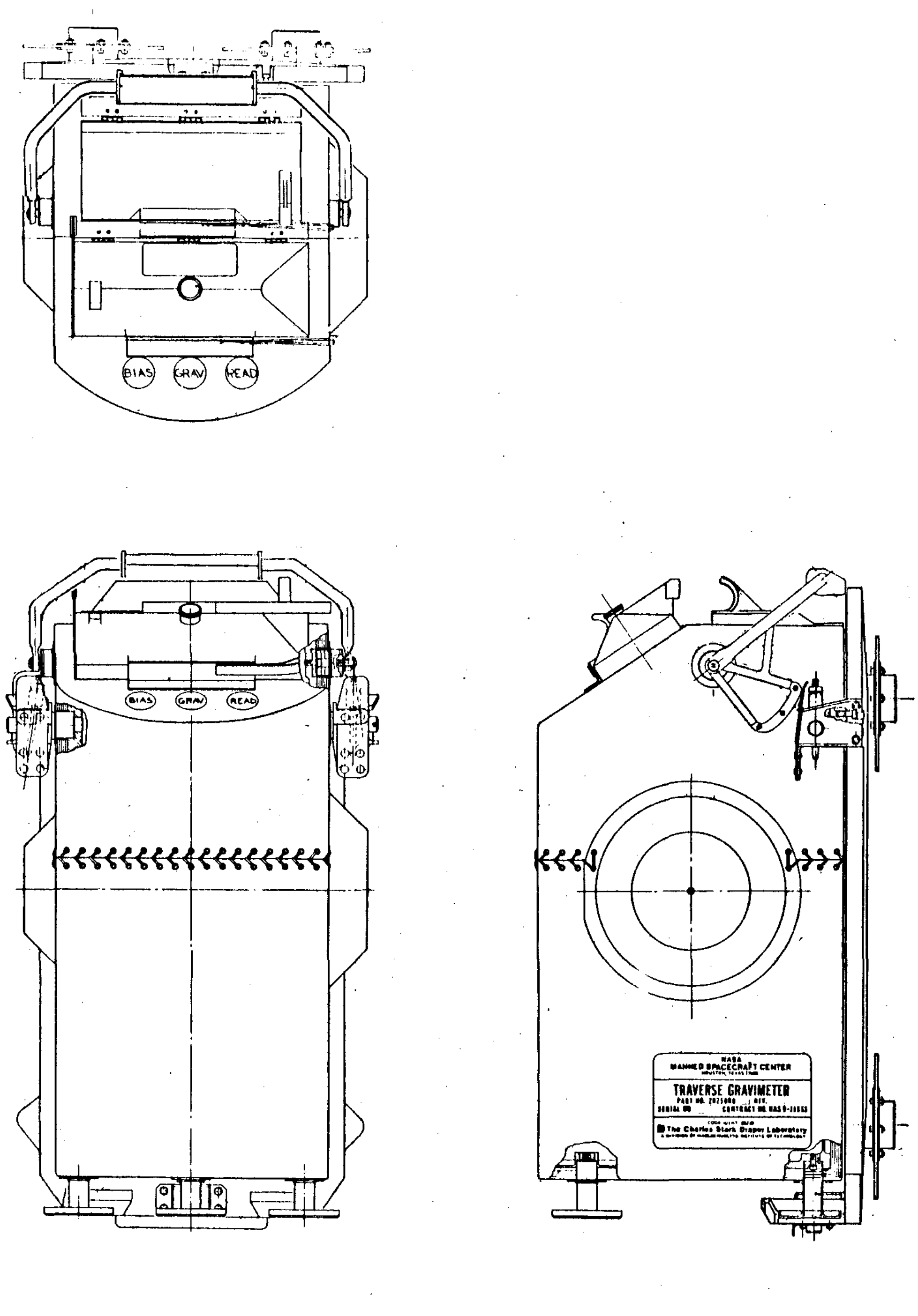

Figure 1.3. Traverse Gravimeter, Outline Drawing

assembly is pivoted about its axis and supported by a middle gimbal assembly. The middle gimbal controls the vertical positioning of the inner gimbal over a 30 degree range. The middle gimbal assembly is attached through bearings to the base housing and can rotate through 210 degrees. Stepper motors and a gear train provide the drive and positioning of the gimbal assemblies. The stepper motors react to signals from pendulums which act as level sensors.

A controlled temperature system supplies heat for thermal protection of the inner (precision) oven. The intermediate oven is thermally protected by a preset on-off thermostatically controlled, electrical heater system.

1.4 REFERENCE DATA

Table 1.1 lists lunar reference data for the TG.

TABLE 1.1 REFERENCE DATA

Characteristic	Data
Height	20.0 inches
Width	11.0 inches
Depth	9.75 inches
Weight	36 pounds max. (including isoframe)
Volume	1.25 ± .10 cubic feet
Number of controls	One toggle switch (ON/STBY) and three pushbuttons (BIAS, GRAV and READ)
Number of displays	One nine digit numerical display, of which the first seven digits are for GRAVITY/BIAS information and the last two are for temperature Level/Measure indicator

TABLE 1.1 (Continued)

Characteristic	Data
Selectable modes	Primary: ON STBY (standby) Secondary: GRAV (gravity measuring) BIAS (bias measuring) READ (display) Phase lock loop bypass
Level cycle times:	
Gravity mode	0 to 20 seconds
Bias mode	90 to 130 seconds
Measure cycle times: (including delay times)	
Gravity mode	120 to 140 seconds
Bias mode	60 to 75 seconds
Display time	18 ± 5 seconds (each time the READ push-button is pressed)
Level/Measure indicator:	
Flashing	Duration of level cycle
Illuminated steadily	Duration of delay and measurement cycle
Duty cycle	0.25 seconds on; 0.75 seconds off
Measurement Range:	170 gals.
Data Quantization	0.03 milligals in both normal and bias modes
Battery Power	300 watt hours over a 15 day period
Power Consumption	Refer to power curve, Figure 1.4

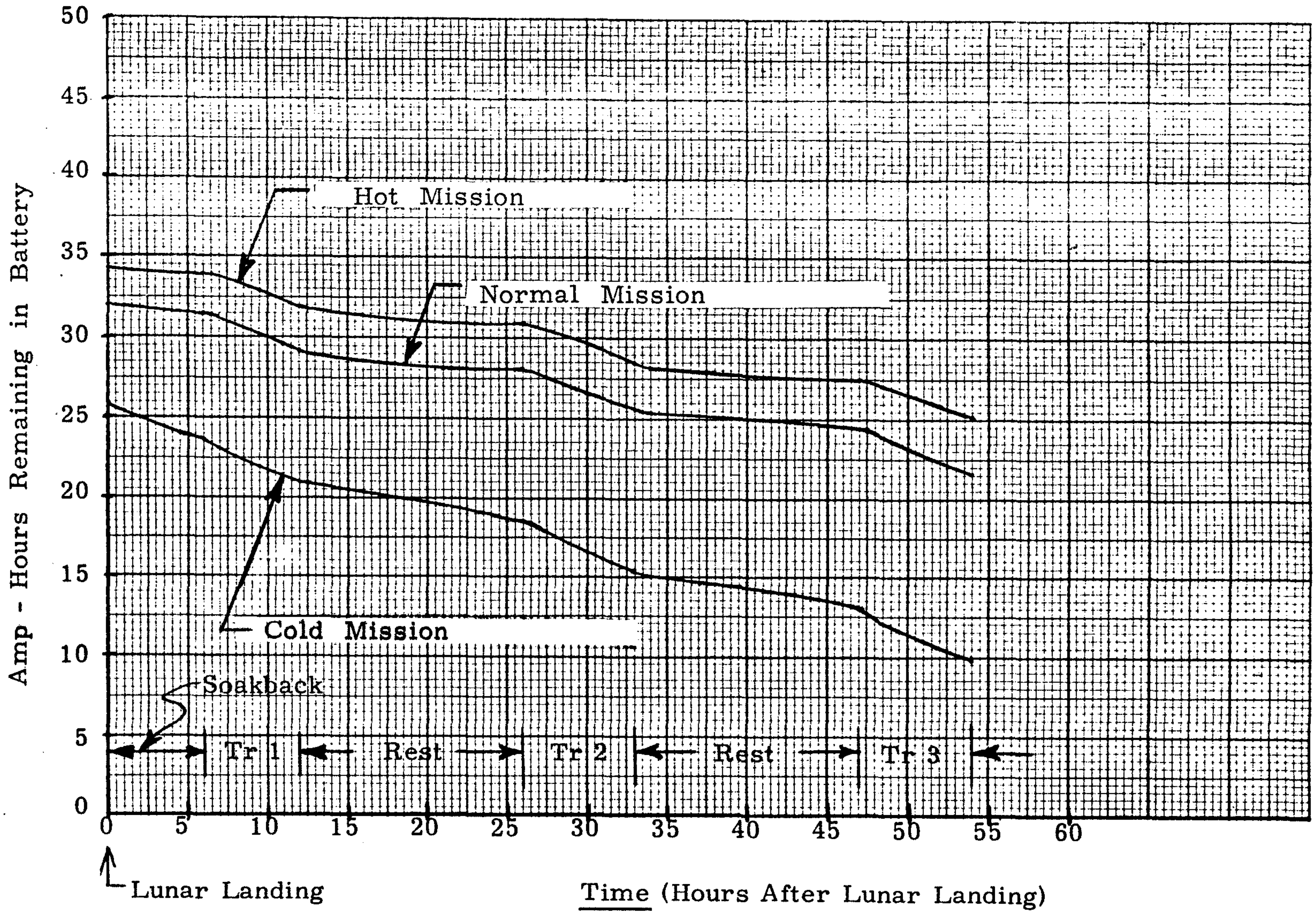

Figure 1.4 Hot, Cold, and Normal Mission Power Curve

TGE THERMAL MISSION CONDITIONS

HOT MISSION

(1) Hottest Quad III pallet temperature as supplied by Grumman (160 hr duration).

(2) 6 - Hour post-touchdown Quad III soakback.

(3) Landing sun elevation angle = 20.3 degrees.

(4) Blanket surface characteristics:

$$\alpha_s = \varepsilon_H = 1.0$$

(5) Pallet-to-Case conductance in stowage = .128 $^{BTU}/_{Hr}{}^{o}F$.

(6) Rest periods on edge of LM shadow.

COLD MISSION:

(1) Hottest Quad III pallet temperature is supplied by Grumman (160 hr duration).

(2) 6 - Hour post-touchdown Quad III soakback.

(3) Landing sun elevation angle = 6.8 degrees

(4) Blanket surface characteristics:

$$\alpha_s = 0.6 \ , \ \varepsilon_H = 0.9$$

(5) Pallet-to-Case conductance = 0.128 $^{BTU}/_{Hr}{}^{o}F$.

(6) Rest periods in full LM shadow.

NORMAL MISSION

(1) $50^{o}F$ Quad III pallet temperature during translunar and soakback (160 hr. translunar).

(2) 6 - Hour post-touchdown Quad III soakback.

(3) Landing sun elevation angle = 13.3 degrees.

(4) Blanket surface characteristics:

$$\alpha_s = \varepsilon_H = 1.0$$

(5) Pallet-to-Case conductance in stowage = .128 $^{BTU}/_{Hr}{}^{o}F$.

(6) Rest periods in full LM shadow.

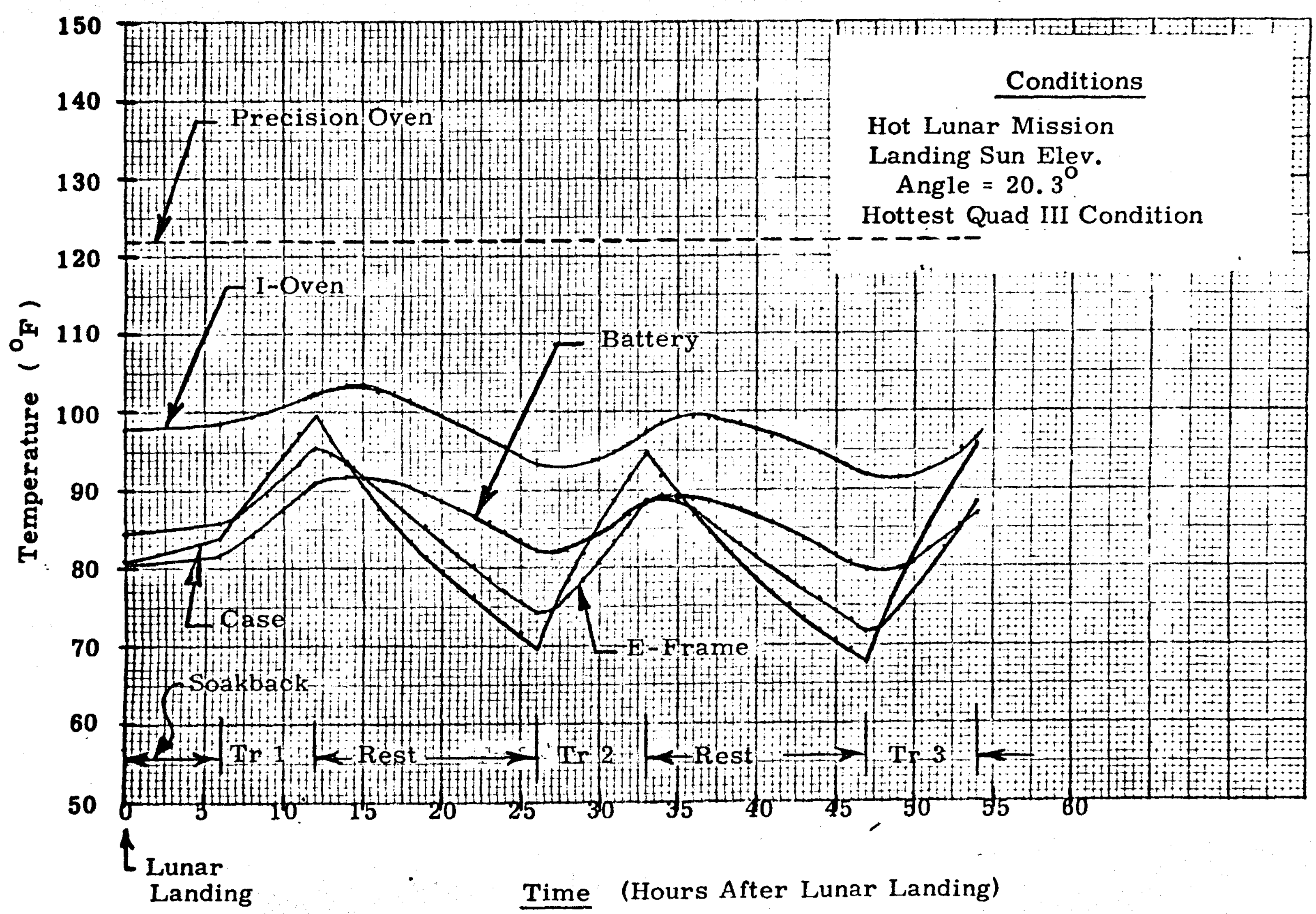

Figure 1.5a TGE Hot Mission Thermal Response

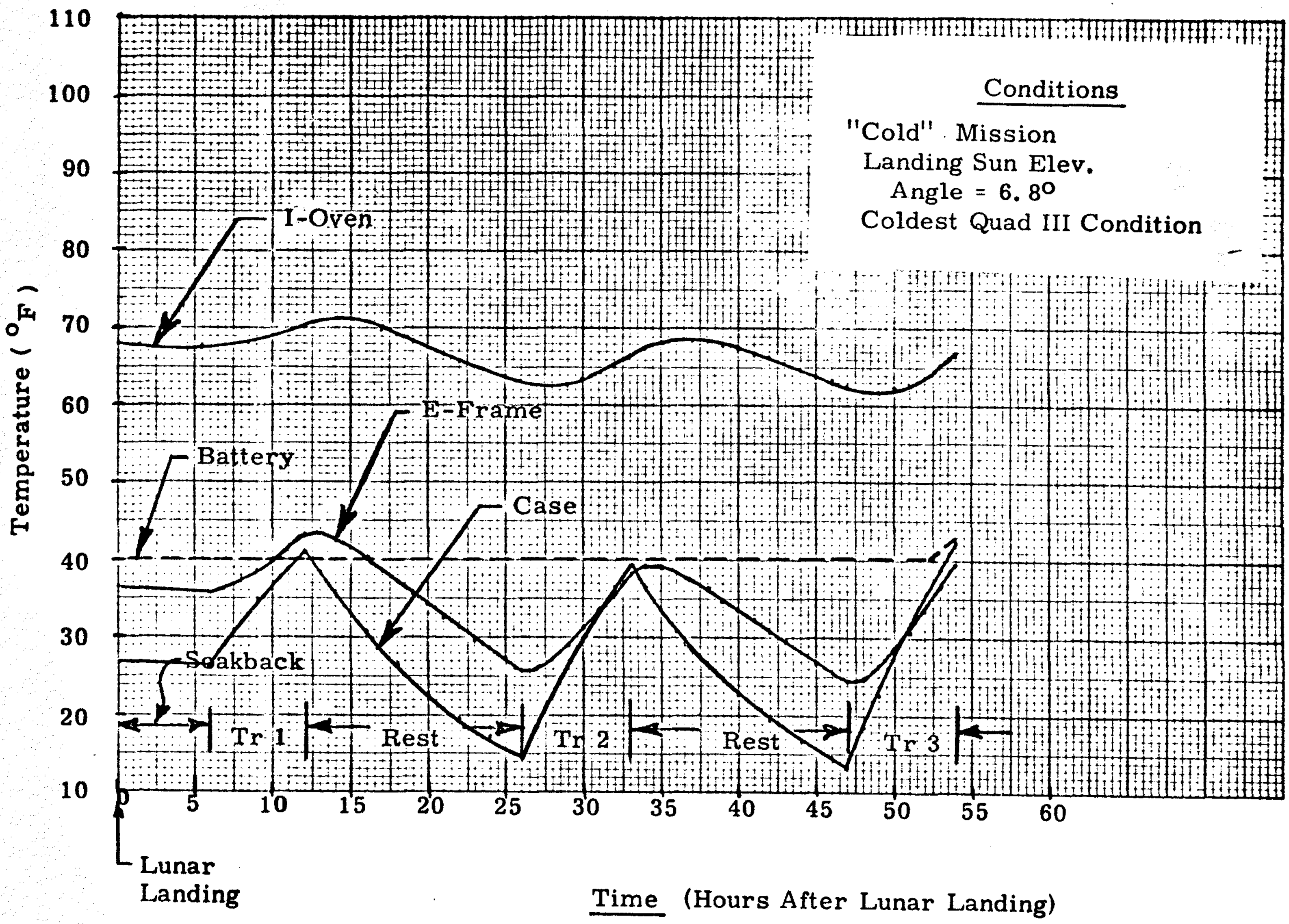

Figure 1.5b TGE Cold Mission Thermal Response

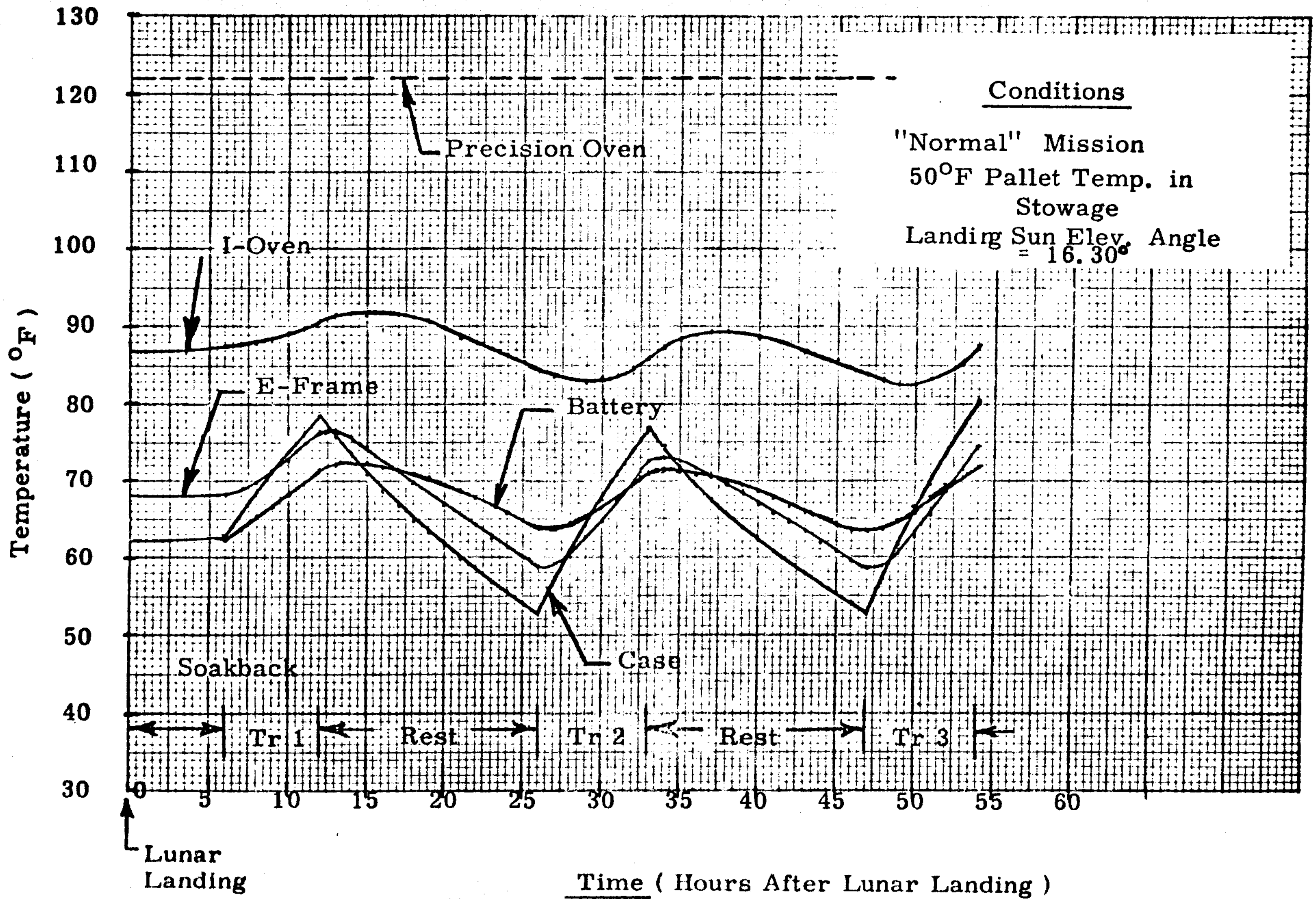

Figure 1.5c TGE Normal Mission Thermal Response

SECTION 2

OPERATION

2.1 THEORY OF OPERATION

The two basic modes of operation of the TG are determined by the ON/STBY toggle switch on the display panel. In the standby mode (STBY position), used from launch until deployment on the lunar surface and during rest periods, power is applied only to the VSA oscillator amplifiers mounted with the VSA in a controlled oven, and to the temperature controller for the oven. At least 90 seconds before the gravity measurements are to be made, the system is placed in the operate mode (ON position of switch). Power is then supplied to a crystal oscillator and to a small part of the mode control logic. The BCD counter also is enabled to permit the storage of the last gravity reading taken, and to make it available for display.

A sequencing diagram of the gravity measurement function is shown in Figure 2.1. To initiate a gravity measurement, the GRAV pushbutton is depressed, supplying power to all system elements except the GRAVITY/BIAS and TEMP displays. The Level/Measure indicator will then flash for less than 20 seconds indicating that the leveling loops are in operation. When the VSA assembly is within 7 arc minutes of the correct orientation with respect to gravity, the Level/Measure indicator will illuminate steadily for approximately 120 seconds as the measurement cycle begins. The instrument must remain level (within 7 arc minutes) for the first 50 seconds of this period or else the leveling and delay will be automatically recycled. Gravity data is only taken in the last 60 seconds of this measurement period. When the measurement is complete, the system automatically returns to the operate mode. Depressing the READ pushbutton activates the GRAVITY/BIAS and TEMP displays. To conserve power, the displays go off after approximately eighteen seconds, but may be reactivated once by again depressing READ.

To initiate a bias measurement, the BIAS pushbutton is depressed. The VSA assembly is then automatically leveled, inverted 180^{O} and leveled again before the measurement is carried out. The Level/Measure indicator will flash while the VSA is leveled, inverted and releveled and will illuminate steadily while the measurement is being made. Reinversion of the VSA assembly occurs for 90 seconds after the Level/Measure indicator extinguishes.

2.2 CONTROLS AND INDICATORS

Control and indicators of the TG are shown in Figure 2.2 and described in the following paragraphs.

2.2.1 ON/STBY SWITCH. - This switch applies power to select a standby (STBY) or operate (ON) mode. In the STBY position, used from launch up to TG deployment on the lunar surface, power is supplied only to the oven temperature controls and VSA oscillator-amplifiers to maintain a constant thermal environment for the VSA. With the switch in the ON position, power is also applied to the crystal oscillator, part of the mode control logic to enable operation of the TG and to the BCD counter and associated logic to permit storage of the last gravity reading taken. Cycling the switch from ON to STBY and back to ON will erase any stored data as well as clear the PLL bypass mode of operation.

2.2.2 BIAS PUSHBUTTON. - This control is a momentary contact pushbutton which initiates a bias gravity measurement. When pressed, the VSA assembly is automatically leveled and inverted 180^{O} for the measurement. The VSA assembly is then leveled again and a gravity measurement is made. On completion of the measurement cycle, the VSA assembly is returned to its normal orientation automatically.

2.2.3 GRAV PUSHBUTTON. - This control is a momentary contact pushbutton which initiates a gravity measurement. When the switch is

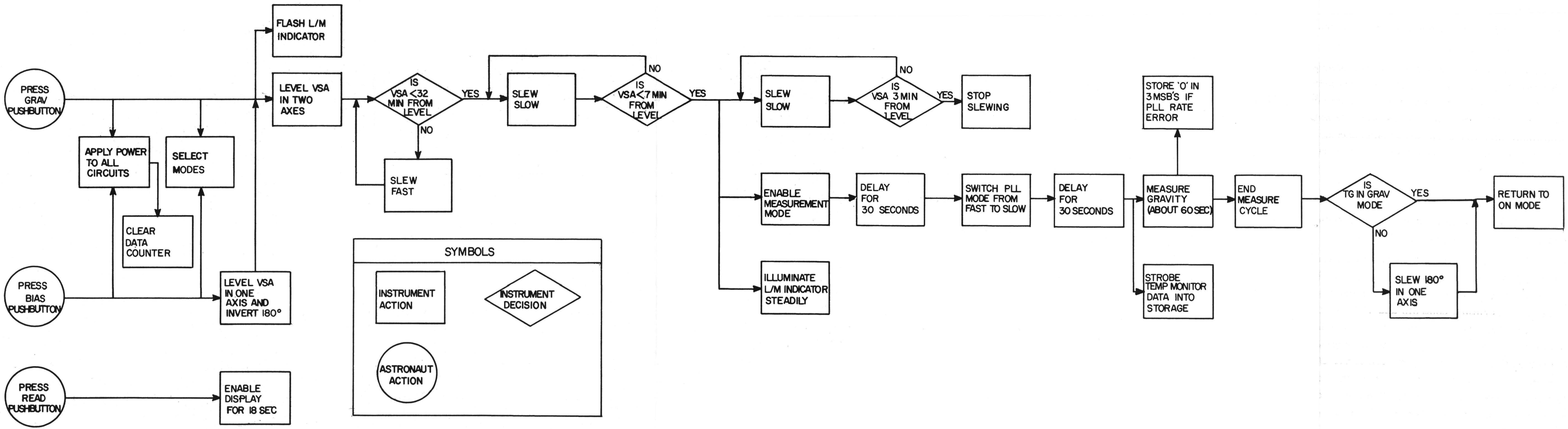

Figure 2.1 TG Sequencing Diagram

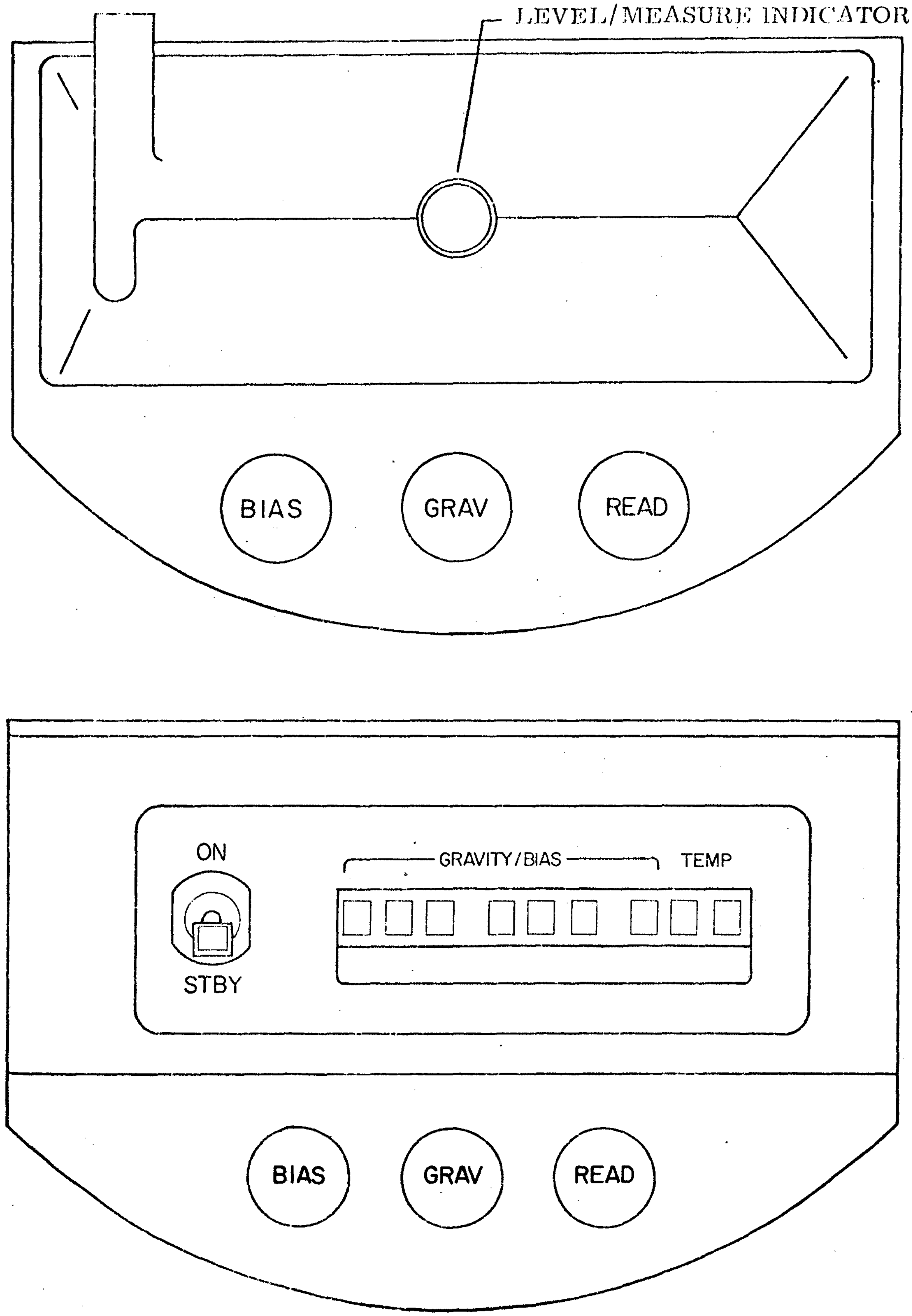

Figure 2.2 TG Controls and Indicators

pressed, the TG leveling loops go into operation and a gravity measurement is made.

An additional function of the GRAV pushbutton is to work in conjunction with the READ pushbutton to enable a phase lock loop bypass mode of operation. This mode is initiated by depressing the GRAV and READ pushbuttons simultaneously. This mode is indicated by a zero in the most significant digit of the numerical display when the read function is activated. To return to the phase lock mode, the ON/STBY switch must be toggled.

2.2.4 READ PUSHBUTTON. - This control is a momentary contact pushbutton which enables the GRAVITY/BIAS and TEMP displays. The enable is held for approximately eighteen seconds only, but may be re-initiated by pressing the pushbutton once again. As stated in paragraph 2.2.3, an additional function of this switch is to enable the phase lock loop bypass mode.

2.2.5 LEVEL/MEASURE INDICATOR. - This indicator displays the status of the TG when in the ON mode of operation. The indicator flashes while the TG is leveling, illuminates steadily during a measurement, and extinguishes when the measurement is complete. (The extinguished state indicates a completed cycle in the gravity measuring mode but the bias cycle requires an additional 90 seconds after the indicator extinguishes to reinvert the VSA assembly.)

2.2.6 GRAVITY/BIAS DISPLAY. - This display indicates a seven digit number which represents the measured lunar gravity or bias value. The display will be active for approximately eighteen seconds each time the READ pushbutton is pressed. The displayed value will be relayed to earth, via the astronaut, where it will be interpreted.

In addition to the gravity and bias values, the display will also indicate the status of various TG conditions. These conditions are described in the following sub-paragraphs.

2.2.6.1 Phase Lock Loop Bypassed. - This condition is displayed by a zero in the first significant digit of the display and indicates that the phase lock loop is not in use.

2.2.6.2 Excess Vibration. - This condition is displayed by zeros in the first three significant digits of the display and indicates that the TG received too much vibration during a measurement cycle.

2.2.6.3 Excess Tilt. - This condition is displayed by zeros in all seven digits of the display and indicates that the TG base is positioned more than 15 degrees from the horizontal.

2.2.7 TEMPERATURE ALARM STATUS DISPLAY. - This indicator, the eighth digit of the numerical display, indicates a number from 0 to 7 which represents the status of the TG temperature alarms. The indication is updated each time the READ pushbutton is pressed and will be active for approximately eighteen seconds each time the READ pushbutton is pressed. Table 2.1 lists the interpretations for each number which may be displayed.

TABLE 2.1. TG TEMPERATURE ALARM INTERPRETATIONS

Digit 8	Thermal Status	Thermal Condition		P-Oven Temperature Deviation
		I-Oven	Battery	
0	Normal	15°C to 35°C	> 8°C	+.005°C per unit of ninth digit
1	Normal	15°C to 35°C	> 8°C	-.005°C per unit of ninth digit
2	Cold	15°C to 35°C	4°C to 8°C	+.005°C per unit of ninth digit
3	Cold	15°C to 35°C	4°C to 8°C	-.005°C per unit of ninth digit
4	Warm	35°C to 43°C	> 8°C	+.005°C per unit of ninth digit
5	Warm	35°C to 43°C	> 8°C	-.005°C per unit of ninth digit
6	Hot	> 43°C	> 8°C	+.005°C per unit of ninth digit
7	Hot	> 43°C	> 8°C	-.005°C per unit of ninth digit

2.2.8 VSA TEMPERATURE DISPLAY. - This indicator, the ninth digit of the numerical display, indicates a number from 0 to 7 which represents a deviation of the VSA (P-Oven) temperature from set point of .005°C times the digit displayed. Polarity of the deviation is obtained from the value displayed in the eight digit (see Table 2.1). This display is updated at the beginning of each gravity or bias measurement only.

2.3 OPERATING PROCEDURES

Operational procedures for the TG on the lunar surface include: deployment on the lunar surface, installation of the TG on the Lunar Rover Vehicle (LRV), initial gravity and bias measurements in the vicinity of the LM, and lunar traverse operations. The following paragraphs provide step by step procedures for these operations.

2.3.1 INITIAL DEPLOYMENT. - Proceed as follows to remove the pallet containing the TG from the LM, install it on the LRV, take initial temperature measurements and place the TG on the lunar surface.

> CAUTION
>
> The TG should remain in the quadrant III equipment bay no longer than 20 hours as overheating of the TG circuits may occur.

<u>Step 1.</u> Remove pallet from the quadrant III equipment bay and install it on the LRV.

<u>Step 2.</u> Remove and dispose of Velcro launch latches from the display and radiator covers.

<u>Step 3.</u> Place the ON/STBY switch (located under the TG display panel protective cover) to the ON position.

<u>Step 4.</u> Press the READ pushbutton and lift the display panel protective cover to check the reading of temperature display. (It should be noted that the GRAVITY/BIAS display and digit 9 will be meaningless in this measurement and should be ignored until the GRAV or BIAS button is pressed.)

CAUTION

Ensure that the display panel protective cover is closed after each operation.

NOTE

If the temperature alarm display (eighth) digit) indicates a hot condition (6 or 7 displayed), the TG should be cooled by placing the unit in a shaded area and/or opening the radiator cover located at the top of the unit. These actions will be taken under the direction of mission control.

Step 5. Pull TG latch handle to vertical (unlatched) position.

Step 6. Remove lanyard assemblies (see Figure 2.3) by performing steps 6a through 6c.

Step 6a. Pull up on left lanyard to release lock pin and continue pulling until shoulder pin is released. Discard lanyard assembly.

Step 6b. Pull to the right on right lanyard to release lock pin and continue pulling until shoulder pin is released. Discard lanyard assembly.

Step 6c. Pull straight out on bottom lanyard to release lock pin and ensure that bottom shoulder pin falls out. Discard lanyard assembly.

CAUTION

Ensure that bottom shoulder pin falls out. Damage will result to the insulating blanket when the TG is reinstalled on LRV if the pin is not removed.

Step 7. Lift TG by latch handle and deploy unit on lunar surface.

2.3.2 INITIAL MEASUREMENTS AND FIRST TRAVERSE. - Proceed as follows to make the required measurements in the vicinity of the LM and during the first traverse:

Step 1. Take a gravity measurement by performing steps 1a through 1f following:

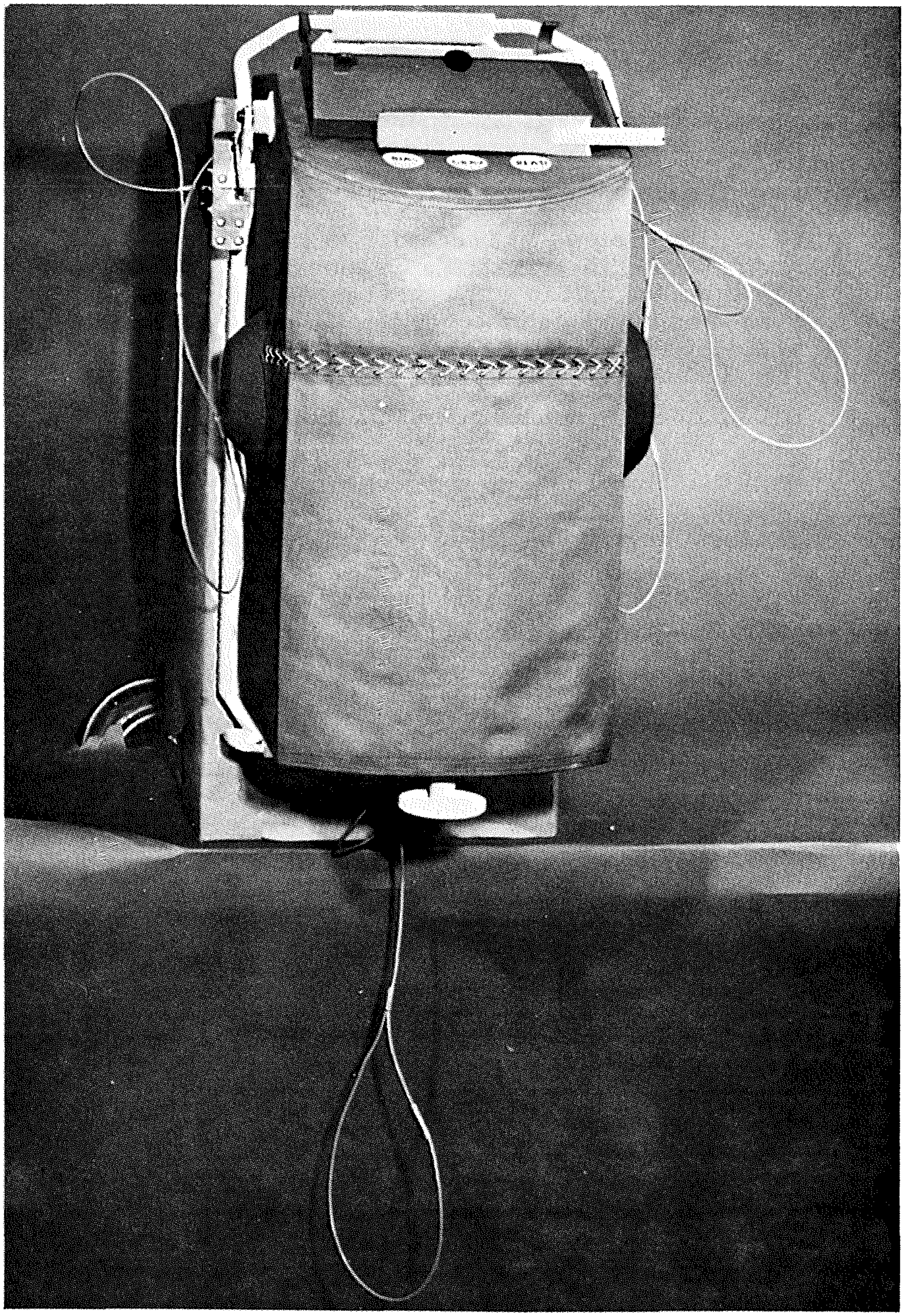

Figure 2.3 TG on Pallet with Lanyard Assemblies Installed

Step 1a. Press the GRAV pushbutton to initiate the leveling and measurement cycles.

Step 1b. Check that the Level/Measure indicator flashes for not more than 20 seconds, indicating that the TG is in a leveling cycle.

> NOTE
>
> If the Level/Measure indicator extinguishes after flashing, the TG base is positioned more than 15° from the horizontal and the leveling loops cannot properly level the VSA assembly. If this is the case, the TG should be realigned, and a new measurement should be initiated.

Step 1c. Check that the Level/Measure indicator illuminates steadily, indicating that the leveling cycle is complete and the TG is in a measuring cycle.

> NOTE
>
> The operator should not touch the TG while the Level/Measure indicator is illuminated. If the TG is bumped early in the measurement cycle, it will return to the start of that cycle and increase the measurement time. A vibration later in the measurement cycle may cause the GRAVITY/BIAS display to output a reading of 000 in the first three digits when the READ pushbutton is pressed.

Step 1d. When the Level/Measure indicator extinguishes, alert mission control that a measurement is going to be transmitted via voice communication.

Step 1e. Open the display cover and press READ pushbutton to initiate display of the gravity measurement and the temperature information. (The GRAVITY/BIAS and TEMP displays will illuminate for eighteen seconds but may be reactivated by pressing READ again.)

CAUTION

Lamp overheating may occur if the READ pushbutton is pressed more than twice in quick succession.

NOTE

If seven zeros are displayed in the GRAVITY/BIAS display, the TG base is positioned more than 15° from the horizontal and must be realigned.

NOTE

A normal display for a gravity measurement is 650 XXX XXX. If the first three digits of the display are 610 or 730, the reading may be out of phase lock loop range. Without moving the TG, take a bypass mode measurement as specified in paragraph 2.3.4, steps 3 through 5.

Step 1f. Transmit the nine digit value obtained from the display.

NOTE

Conversion of the displayed value to milligals is given in paragraph 2.4.

Step 2. Take a bias measurement by performing steps 2a through 2d following:

Step 2a. Press the BIAS pushbutton.

CAUTION

If the TG should fall over during a bias measurement, place the instrument upright immediately and press the READ pushbutton when the Level/Measure indicator is extinguished. Report status of the instrument to mission control.

Step 2b. Check that the Level/Measure indicator flashes approximately 110 seconds, indicating that the VSA is being leveled, slewed 180° and leveled again.

Step 2c. Check that the Level/Measure indicator illuminates steadily for 60 to 75 seconds indicating that the leveling cycle is complete and the TG is in a measurement cycle.

CAUTION

Do not switch ON/STBY switch for at least 90 seconds after Level/Measure indicator is extinguished.

Step 2d. Read and transmit the bias measurement and temperature information as stated in steps 1d through 1f.

NOTE

A normal display for a bias measurement is 340 XXX XXX.

Step 3. Install the TG in the traverse position on the pallet and secure the carrying handle against the Isoframe Assembly.

Step 4. After 90 seconds have elasped since the end of the last measurement, take a gravity measurement on the LRV by performing steps 1a through 1f.

Step 5. Take a gravity measurement at each science stop on the traverse and upon returning to the LM site.

Step 6. After the last measurement is relayed to earth, set ON/STBY switch to STBY.

Step 7. Place TG on lunar surface in the center of the LM shade and open the radiator cover (as shown in Figure 2.4) until just prior to the next traverse.

2.3.3 SECOND AND THIRD TRAVERSE OPERATIONS. - Proceed as follows to operate the TG during the second and third lunar traverses.

Step 1. Place TG on the LRV and secure TG by pressing latch handle down against Isoframe Assembly.

Step 2. Set ON/STBY switch to ON and allow 90 seconds warm up time.

Step 3. Take a gravity measurement before leaving LM area.

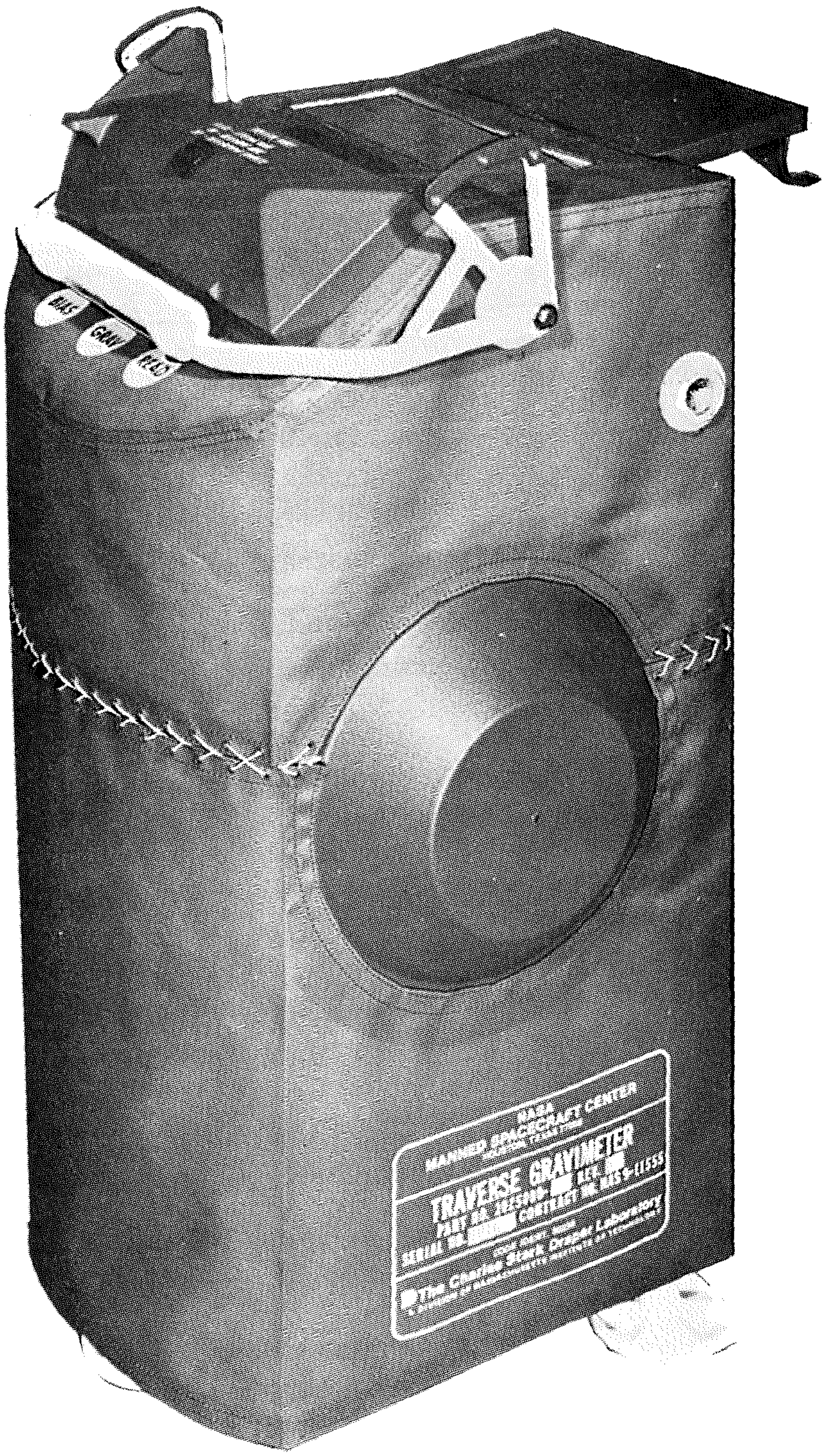

Figure 2.4 TG with Radiator Cover Open

> **CAUTION**
>
> Ensure that display cover is closed prior to lunar traverses.

Step 4. Take a gravity measurement at each science stop and at the end of each traverse.

Step 5. Upon return to the LM at the end of each traverse, perform steps 5a through 5d.

Step 5a. Set ON/STBY switch to STBY position.

Step 5b. Place TG in the center of the LM shade on the lunar surface.

Step 5c. Ensure that display cover is closed.

Step 5d. Open radiator cover.

2.3.4 ALTERNATE INSTRUMENT OPERATIONS. - If the measurement is out of phase lock loop range, use the following procedure (as directed by mission control) during stops of each traverse.

Step 1. Pull TG latch handle to vertical (unlatched) position.

Step 2. Lift TG by the latch handle and deploy the instrument on the lunar surface in a stable position so that the base of the instrument is less than 15 degrees from the horizontal.

Step 3. Press GRAV and READ pushbuttons simultaneously for the first bypass measurement to place the TG in a PLL bypass mode.

> **NOTE**
>
> The TG is now in a bypass mode until the ON/STBY switch is used. Further bypass readings may be made by pressing the GRAV pushbutton only or GRAV and READ simultaneously as desired.

Step 4. Check that the Level/Measure indicator flashes for not more than 20 seconds and then illuminates steadily for not more than 140 seconds.

> **NOTE**
>
> If the Level/Measure indicator is illuminated for more than 3 minutes, press the READ pushbutton and relay the results to mission control.

Step 5. When the Level/Measure indicator is extinguished, press the READ pushbutton and relay the results.

NOTE
The display for a bypass measurement is 0XX XXX XXX.

Step 6. Place and secure the TG on the LRV.

2.4 CONVERSION OF DISPLAY TO GRAVITY

The value of gravity measured by the TG can be computed from the following relationships which are applicable to the normal Gravity and Bias modes of operation:

$$\Delta f = K_0 + K_1 g + K_2 g^2 + K_3 g^3 \quad \text{(Normal Gravity)}$$

$$\Delta f = K_0 - K_1 g + K_2 g^2 - K_3 g^3 \quad \text{(Bias Measurement)}$$

where:

K_0 = VSA Bias (7 to 8 Hz)

K_1 = VSA Scale Factor (128 to 129 Hz/g)

K_2 = VSA Second Order Term (approximately -0.0004 Hz/g^2)

K_3 = VSA Third Order Term (approximately 0.003 Hz/g^3)

Δf is the VSA string difference frequency which is calculable from one of the following relationships:

$$\Delta f = \frac{1.152 \times 10^9}{D} \quad \text{(on earth)}$$

$$\Delta f = \frac{1.92 \times 10^8}{D} \quad \text{(on moon in Gravity mode)}$$

$$\Delta f = \frac{4.8 \times 10^7}{D} \quad \text{(on moon in Bias mode)}$$

where D is the 7 digit gravity value from the first seven digits of the TG display.

EXAMPLE:

If the value displayed by the TG is 650 000 0XX for a moon gravity mode, the difference frequency is calculated as follows:

$$\Delta f = \frac{1.92 \times 10^8}{6.5 \times 10^6} = 29.54 \text{ Hz}$$

The value of gravity is calculated as follows:

$$29.54 = 7.5 + 128.5g + (-0.0004)g^2 + 0.003g^3$$

To simplify the calculations, assumed g values of 0.167 are substituted into the second and third order terms. This entails no significant loss of precision because of the small values of K_2 and K_3.

$$29.54 = 7.5 + 128.5g + (-0.00001) + 0.000014$$

$$g = 0.1715$$

The value of gravity is converted to milligals as follows:

$$\text{gravity} = 0.1715 \times 9.8 \times 10^5 \text{ milligals}$$

$$= 1.68 \times 10^5 \text{ milligals}$$

SECTION 3

FUNCTIONAL DESCRIPTION

3.1 GENERAL

The TG has two basic modes of operation (on and standby) which are controlled by a toggle switch on the control panel. In the on mode, three measurement taking submodes and one display submode are selectable by pushbuttons, also located on the control panel. These submodes include: normal gravity measuring, selected by pressing the GRAV pushbutton; bias gravity measuring, selected by pressing the BIAS pushbutton; normal gravity measuring with the phase lock loop bypassed, selected by pressing the GRAV and READ pushbuttons simultaneously; and display, selected by pressing the READ pushbutton. Within each measurement submode the TG automatically sequences through various cycles. The normal gravity submode consists of a normal leveling cycle and a normal measuring cycle. In the bias submode, however, the VSA must be inverted 180^{o} prior to a measurement. Cycles of the bias submode include normal level, normal exit, bias measure and bias exit.

The TG measures and displays gravity by processing signals from a vibrating string accelerometer (VSA) which is encased along with oscillator-amplifiers in a low heat loss, precisely-controlled oven. Upon initialization of a gravity measurement, the TG seeks to level the VSA in two axes. After settling to level for a preset period of time, the difference frequency of the VSA is counted down and a gate is generated that is inversely proportional to the difference frequency. The width of this gate is measured by counting a precision clock train and the count is stored in a BCD counter which serves the dual function of counter and storage register. The contents of the register are transferred to the numerical display when the READ pushbutton is pressed.

The major functional sections of the TG include: control, temperature control and monitoring, leveling and inversion, measurement, and display. These functional sections are described in the following paragraphs. Figure 3.1, a functional block diagram, shows the relationship of each functional section to the overall function of the TG.

3.2 CONTROL SECTION

The control section, shown on sheet 1 of Figure 3.1 controls the distribution of power and selects the operating modes for the TG.

The TG has two primary modes of operation, STBY (standby) and ON. In the STBY mode battery power is supplied only to two 5 volt dc power supplies (+ and -) and a 4 kHz ac power supply. The 5 volt supplies provide power for the VSA and oscillator-amplifiers and the temperature control and monitor circuits. The 4 kHz supply provides excitation and a demodulator reference for the temperature control and monitor circuits.

When the TG is placed in the ON mode two additional 5 volt power supplies are energized as well as a +12 volt supply. The 5 volt supplies provide power to the control switching logic and part of the phase lock loop circuitry. The +12 volt supply energizes the 4 MHz crystal oscillator. Once the oscillator is energized, a warm up period of 90 seconds should be allowed before proceeding to a BIAS or GRAV mode. This is to insure stability of the oscillator output prior to a measurement cycle.

When a GRAV or BIAS mode is initiated by pressing the appropriate pushbutton, power is supplied to all sections of the TG except the displays. At the completion of a leveling and measurement cycle for the selected mode, the TG reverts back to the ON mode to conserve power.

Selection of the display function (READ pushbutton pressed) energizes K3 for a period of 18 seconds. During this time, VRDIS (+5 volts) is energized as well as the +4 volt power supply for the gravity/bias and temperature display. At the completion of the 18 second hold the display will be disabled. The READ pushbutton may be pressed again, however, to enable the displays without loss of stored information.

The +5V OPER voltage applied to the switching logic enables the selection of the BIAS or GRAV mode. When either pushbutton is pressed, the +5V OPER voltage is gated to produce the 5 volt VLONA. This signal is used to drive relays K1 and K2 which in turn energize a -5 volt power supply for the analog circuits and a +28 volt power supply for the stepper motors. Relay K1 also switches the +5V OPER to produce +5V LOGIC voltage for the control logic.

A command delay pulse (VLDLY) of approximately 15 msec duration is intiated by the switching through K1 of the -5V LOGIC voltage. This signal is used to initialize the flip-flops in the leveling and measurement sections to a known state.

The switching logic controls the selection and sequencing of the various TG modes. When the GRAV pushbutton is pressed, the GRAV MODE SELECTED and GRAV OR BIAS SELECTED signals are both enabled. These signals are supplied to the leveling and inversion section, and enable stepper motor response to the normal X and Y pendulum outputs. The NORMAL CONTROL signal is also enabled and supplied to the phase lock loop and the display section.

When the BIAS pushbutton is pressed, the BIAS MODE SELECTED and GRAV OR BIAS SELECTED signals are generated. These signals automatically sequence the TG through the four submodes of the BIAS mode. The first of these submodes is the same as a normal level mode, where the X and Y gimbals are leveled in response to pendulum outputs. At the completion of the leveling the TG goes directly into a normal exit submode. In this submode, the CAM SWITCH RESET supplied from the leveling section is inhibited by the BIAS MODE SELECTED. The bias submode enables the Y gimbal to be inverted 180° under control of the BIAS COUNTER CONTROL. The END OF COUNT signal informs the switching logic that the gimbal has been inverted and the leveling section is ready for a measurement. At the completion of the measurement, the Y gimbal is rotated back 180° and the mode is terminated by the MODE RESET signal. The COUNT DOWN signal extinguishes the level/measure indicator when the Y gimbal is being rotated back.

The PLL BYPASS signal is enabled when the GRAV and READ pushbuttons are pressed simultaneously. In this condition, the unfiltered difference frequency is selected for readout.

3.3 TEMPERATURE CONTROL AND MONITORING SECTION

This section, shown on sheet 1 of Figure 3.1, provides precision temperature regulation and monitoring for the inner (precision) and outer ovens. The section consists of: a precision oven temperature control and monitor circuit, an outer oven thermostat and heater circuit, and an outer oven temperature monitor circuit.

The VSA and oscillator-amplifiers are encased in the precision oven which is maintained at a temperature near $49^{o}C$ to within $0.01^{o}C$ by the temperature control and monitor circuit. The precision oven in turn is encased in an outer oven and is protected from external thermal distrubance by this oven. Under normal conditions the outer oven is quiescent and only extended exposure of the TG to lunar shade or sunlight could be expected to slowly change its temperature.

The precision oven temperature circuit is a proportional plus rate-controller loop employing a resistance thermometer element for a sensor, and an electrical heater. The complete temperature sensor is an ac excited bridge, two arms of which are thermistors; the other two arms are standard resistors. Excitation voltage for the bridge is supplied by a regulated 1.6 volt ac supply. Output of the bridge is approximately 54 mv per degree C.

The bridge output is amplified and supplied to a diode ring demodulator. Reference voltage for the deomodulator is 7.50 volts at 4 kHz. The amplifier that receives the demodulator output is a derivative-plus-proportional amplifier. Output of this amplifier is supplied through a DC amplifier to the control drivers. The precision heaters react to the drivers to maintain the temperature of the oven to a tolerance of $\pm .01^{o}C$.

A tap from the demodulator output is amplified and supplied to the leveling and inversion section as the TEMPERATURE DATA. The signal is multiplexed and converted to digital form by that section and then supplied to the display section. The VSA temperature data is decoded by the displays to drive digit 9 of the TEMP display. Displayed readings will be from 0 to 7, which are interpreted as 0.000 to 0.035 degrees C from the nominal value. Polarity of the deviation (+ or -) is obtained from the temperature alarm display (digit 8).

The outer oven temperature monitor circuit consists of thermostat switches which provide switch closure signals to indicate temperature changes in the outer oven. The signals represent the status of the outer oven and battery and indicate a cold, warm or hot condition. The signals are supplied directly to decoders in the display section where they are used to drive the eighth digit of the nine digit display. Output of the display is a number 0 to 7 which is interpreted as: 0 or 1 no alarm, 2 or 3 cold alarm, 4 or 5 warm alarm, and 6 or 7 hot alarm. An even number indicates that the VSA temperature deviation is positive, an odd number indicates it is negative.

The outer oven thermostat and heater circuit merely reacts to temperature changes to control the power supplied to a heater.

3.4 LEVELING AND INVERSION SECTION

The leveling and inversion section is shown on sheet 2 of Figure 3.1. The purpose of this section is to level the normal and bias pendulums for normal gravity and bias measurements and to inform the measurement section when a level condition exists.

Control of the section is initiated by selection of the gravity or bias mode of operation at the TG control panel. When a mode is selected, a discrete indicating the selected mode is supplied to the multiplexer drive logic. The drive logic controls the switching through the multiplexer of normal and bias pendulum outputs and temperature data. At any one time that the normal or bias modes are active, the multiplexer will pass signals from a Y-axis pendulum (normal or bias), an X-axis pendulum (normal or bias), and temperature data. Timing for the multiplexer is generated from the 4 kHz clock fed to a ripple counter followed by a shift register.

After data has been selected and switched by the multiplexer, it is fed to the analog to digital converter and read into the converter by the ENCODE COMMAND from the timing logic. The data is converted to digital form and supplied to the storage registers by the X-, Y-, and temperature data-strobes. The strobe pulses follow the encode pulse of a particular channel; that is, a Y pendulum strobe pulse follows a Y encode multiplexer control pulse. The X and Y strobes are generated by outputs from the counter in this section. Strobing of the temperature data, however, is controlled by the VSA readout logic in the measurement section.

The temperature data which is supplied through the converter is stored in a 4-bit register. Since the temperature will be read only during the display mode, the register is driven by the +5V OPER voltage so that the data will remain after the leveling and inversion section has been de-energized. The temperature register is strobed by the synchronization of the TEMP MEASUREMENT GATE as a slow clock and the temperature strobe as a fast clock. This synchronization will generate one pulse which is started by the first temperature strobe pulse after the gate has been enabled, and is turned off by the second temperature strobe pulse which occurs during this period. This means that the temperature data is being recorded at the beginning of each measurement sampling period.

The leveling logic, consisting of the high range analog comparator and the low range digital comparator, determines the positions (from null) of the pendulums and generates signal to control rotation of the pendulums either clockwise, counterclockwise, rapidly, slowly or stopped. The high range comparator upon sensing that either pendulum is greater than 32 arc minutes from null (+ or -) will command that pendulum to slew fast (either FAST X, FAST Y, or both). Conversely if the comparator senses that the pendulums are within ±32 arc minutes of null, SLOW X and SLOW Y commands are generated.

The low range digital comparator provides the slewing commands for input to the X and Y storage registers. When the comparator senses that a pendulum is greater than 3 arc minutes from null, SLEW X and/or SLEW Y commands are generated and supplied to the storage registers. When the pendulums are within the 3 arc minute range, the slew commands are disabled.

The COUNT UP (clockwise) and COUNT DOWN (counterclockwise) commands determine the direction of slewing for the stepper motors. These commands are determined by the polarity of the SIGN BIT.

The motors control logic processes the information received from the X and Y storage registers to drive the X and Y stepper motors in the required direction and at the speed determined by the comparators. Other inputs to this logic include a fast and slow clock, a mode selected signal, and 15^{o} cam switch signals. The clocks are gated in the control logic to provide the fast (61 Hz) and slow (3.8 Hz) clock signals for slewing the motors. The cam switches are located at the $+15^{o}$ and -15^{o} positions of the X and Y gimbals. Signals from these switches provide for removal of power in the event a gimbal is being slewed in the wrong direction. For instance if the stepper motor counter was trying to slew up (COUNT UP) and the $+15^{o}$Y position was reached, then a CAM SWITCH RESET would be enabled which would reset the VLONA signal and remove power from the logic circuits.

Control of the motors drive logic is determined by the mode selected (normal or bias). When the normal mode is selected (GRAV pushbutton pressed), the leveling section looks at the normal X and Y pendulum outputs and drives the stepper motors as per the pendulum information. The bias mode however, consists of a series of four submodes which are automatically sequenced when the BIAS pushbutton is pressed.

The first submode in the sequence is the normal level, bias mode. In this the system is leveled as in a normal mode but instead of proceding to take the data, the drive control logic enters the next submode in the bias sequence. This is the normal exit, bias mode which ignores the reset signal that originates from the + and - 15° cam switches, the COUNT UP Y and COUNT DOWN Y signals and the SLEW Y signal. The SLEW Y signal is disabled in such a way that the Y register will continue to count regardless of the SLEW Y signal. An internal slew fast Y is also generated which works independent of the SLEW Y. This mode also disables the $\overline{\text{READ}}$ so that no reading of the data counter can occur and the SLEW X signal so that the X stepper motor cannot operate. At this point the BIAS COUNTER CONTROL signal is enabled which in turn enables the motor counter to count through a total of 5400 pulses. These pulses are equivalent through gear reduction to a 180 degree swing of the Y gimbal. When the last pulse is counted the counter generates an END OF COUNT which places the leveling section in a bias submode. This mode reacts similarly to a normal mode except that ±15°X and Y signals are disregarded and leveling data is taken from the bias pendulum instead of the normal pendulum through control of the multiplexer.

After leveling and data acquisition in the bias submode, the bias exit mode is selected. This mode is similar to the normal exit mode except that the Y gimbal is first inverted back 180° to a normal position, then the bias mode is terminated.

3.5 MEASUREMENT SECTION

The measurement section, shown on sheets 3 and 4 of Figure 3.1, consists of the VSA and oscillator amplifiers, the phase lock loop and the readout logic. The VSA and oscillator-amplifiers are encased in the inner (precision) oven and are energized in all of the TG modes. The oven is maintained at a temperature near 49°C to within 0.01°C by the oven temperature control circuit.

The VSA is a high-sensitivity accelerometer consisting of two single vibrating strings back to back. The strings, when energized, each generate continuous vibrations which are amplified by the oscillator-amplifiers. Output of the amplifiers is a sine wave of a frequency between 9.25 and 9.75 kHz. Since the VSA and oscillator-amplifiers are energized in all modes, the VSA output frequency signals are always available at the inputs to the phase lock loop module. The phase lock loop module, however, is completely energized only when the gravity submode is selected at the control panel (GRAV pushbutton pressed).

The purpose of the phase lock loop module is to determine the difference frequency between the two outputs of the oscillator-amplifiers and to filter the frequency to remove any undesirable vibrations. The VSA oscillator-amplifiers outputs are supplied to a mixer consisting of a ring demodulator and a filter-integrator circuit. The difference frequency output of the mixer is a square wave whose frequency is that of the sine wave produced by the ring demodulator.

Any vibration on the TG will appear as a frequency modulation component on the VSA frequency. Since the main components of this noise will be at very low frequencies, a very narrow-band filter is used in the phase lock loop. For stability, a narrow bandwidth requires a low loop gain, hence a small lock-on range. Since the bias of a VSA can drift, it is necessary that the acquisition range be much larger than the hold-in range for the phase lock loop. Therefore, a two-mode filter system is employed. A fast loop, consisting of a wide band phase detector and filter is provided for rapid lock-on to bring the voltage-controlled oscillator close to the desired operating frequency. The slow loop is essentially in parallel with the fast loop and consists of a narrow band phase detector and a low pass filter.

When the phase lock loop is initially energized, outputs of both the fast and slow loops are summed by a capacitor summing network to drive the voltage controlled oscillator (VCO). Approximately twenty seconds after the TG is in a level condition, the HOLD command causes the fast loop input to the VCO to be sampled and held. The wide band filter of the fast loop is then switched out and the narrow-band filter of the slow loop controls the input to the VCO. Output of the VCO is then counted to determine the difference frequency and supplied to the VSA readout logic.

Should any vibrations cause the input frequency from the VSA to exceed the limit of the slow loop once the fast loop is switched out, the rate detector circuit will generate a PL RATE ALARM (out-of-lock discrete). If a large amount of vibration continually causes a rate alarm during the measure cycle, a phase lock loop by-pass mode can be initiated, in which the unfiltered difference frequency is taken directly from the mixer.

The VSA readout logic receives both the unfiltered and the filtered outputs of the phase lock loop. A phase lock loop/by-pass circuit selects the desired frequency dependent upon the mode selected by the control section. If a phase lock loop by-pass mode was selected by pressing the GRAV and READ pushbuttons simultaneously, the PLL BYPASS signal will cause the selection of the unfiltered difference frequency. The filtered difference frequency is selected if only the GRAV pushbutton is pressed (NORMAL CONTROL signal enabled).

A timing diagram of the measurement function is shown in Figure 3.2. The readout section is initialized by the VLDLY signal (15 msec delay pulse) which sets the timing flip-flops to a known state and gates the $\overline{\text{READ}}$ command. Timing for the section is provided by the counted down difference frequency of the ripple counter (20 Hz nominal).

When the TG is within ±7 arc minutes of a level condition, the $\overline{\text{READ}}$ command is supplied to the readout section. This is gated with the VLDLY signal to produce the GATED READ command for the gate generator and delay circuit. Primary output of this circuit is the HOLD command for the phase lock loop. The HOLD output will be delayed from 2 to 4 cycles (ripple counter cycles) after the circuit is enabled by the GATED READ command.

Once the HOLD is enabled, there is a total of four cycles before reading of the VSA data commences. This delay (approximately 30 seconds) is to insure stability of the phase lock loop output prior to a read cycle. Reading occurs when the 125 KHz clock, counted down from the 4 MHz crystal oscillator, is gated under control of the ripple counter output to produce the GRAVITY COUNT. The count is enabled for a total of six cycles, enabling the data to be read for approximately one minute. Synchronous with this count gate is the TEMP MEASUREMENT GATE which is supplied to the leveling and inversion section to enable transfer of the VSA TEMPERATURE DATA to the displays. The GRAVITY COUNT is fed to the input of a seven stage decade counter in the display section. One cycle after the reading has been completed and the data sent out, a MODE RESET is generated which removes power.

In the event the phase lock loop drops out of lock during a measurement, the rate alarm will generate a LACK LOCK signal. This signal will clear the three most significant digits of the decade counter and the display will show zeros in the first three digit positions. If the TG is in a phase lock loop by-pass mode, the PLL BYPASS signal will cause the first significant digit of the display to be zeroed.

3.6 DISPLAY SECTION

The display section, shown on sheet 4 of Figure 3.1, processes the gravity, temperature and mode status information to drive the nine digit display and the Level/Measure indicator.

The numerical display, when activated, presents the gravity or bias measurement in the first seven digits, the outer oven temperature in the eighth digit and the VSA temperature in the ninth digit. The gravity or bias data is received from the measurement section and held in the seven stage decade counter. The counter holds the data until the display is activated or a new measurement cycle is initiated. The temperature data is held in readout gates until the display is activated.

When the READ pushbutton is pressed +4 volts and +5 VRDIS is supplied to the display section to activate the numerical display and enable the data transfer from the counter and the temperature readout gates. The display is only activated for 18 seconds but may be reactivated (without loss of information) by pressing the READ pushbutton again.

If a loss of phase lock occurred during the measurement cycle, the LACK LOCK signal will cause the first three significant digits of the counter to be reset. This in turn will cause zeros to be displayed in the first three digits when the display is activated. A zero in only the first digit of the display indicates that the TG is in a phase lock loop, bypass mode. This is accomplished by the PLL BYPASS RESET signal resetting the most significant digit of the counter.

The Level/Measure indicator displays the status of the level and measure cycles and is only activated during the GRAV or BIAS modes. When the TG is in a leveling cycle, a 1 Hz clock, counted down from the 4MHz crystal oscillator, will cause the indicator to flash. The indicator will continue to flash until the TG is within ± 7 arc minutes of level. The $\overline{\text{READ}}$ signal from the leveling and inversion section will then cause the indicator to illuminate steadily until the measurement cycle is complete. The $\overline{\text{COUNT DOWN}}$ signal will extinguish the indicator when the TG is in a bias exit mode and the Y gimbal is being inverted.

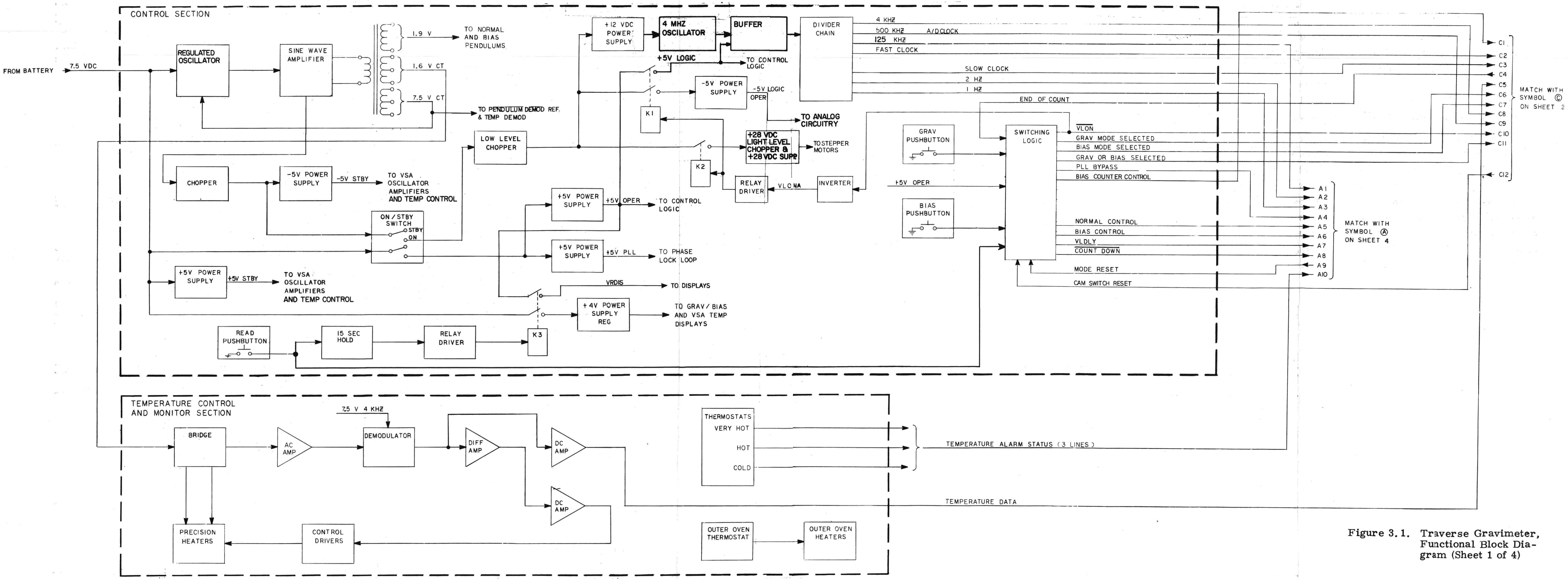

Figure 3.1. Traverse Gravimeter, Functional Block Diagram (Sheet 1 of 4)

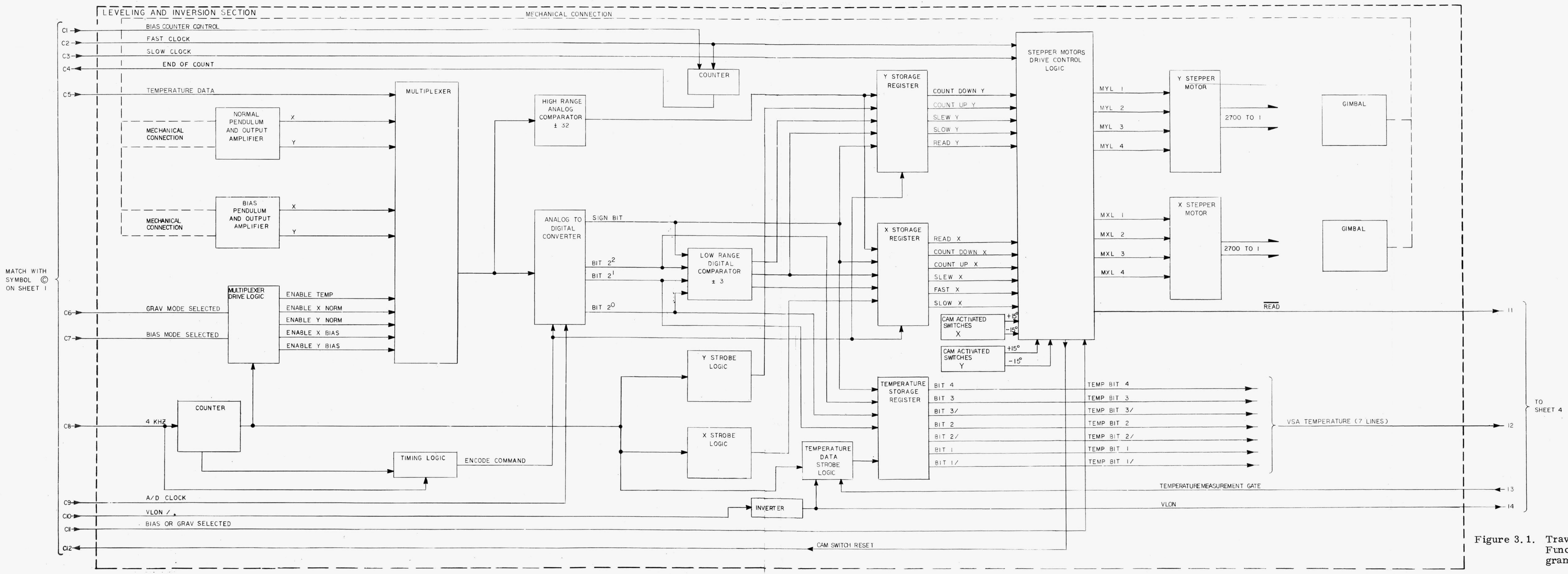

Figure 3.1. Traverse Gravimeter, Functional Block Diagram (Sheet 2 of 4)

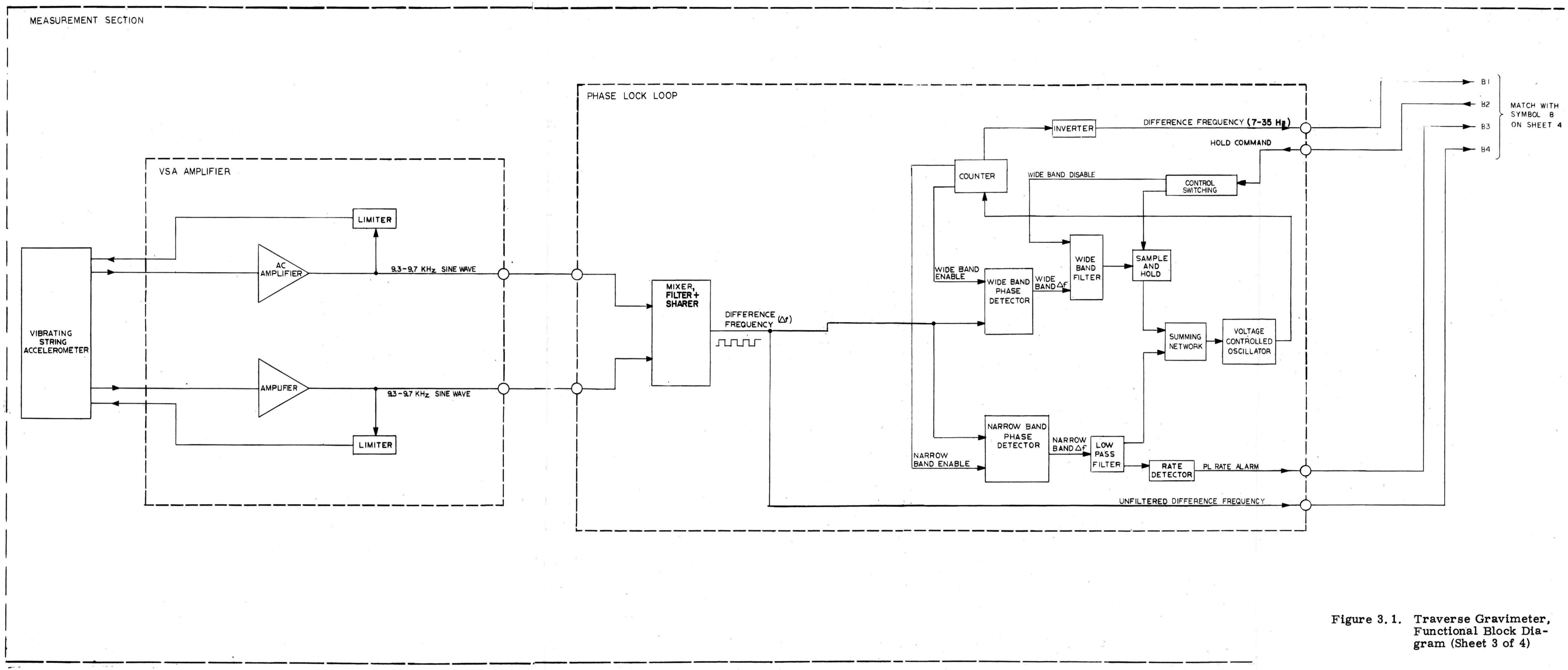

Figure 3.1. Traverse Gravimeter, Functional Block Diagram (Sheet 3 of 4)

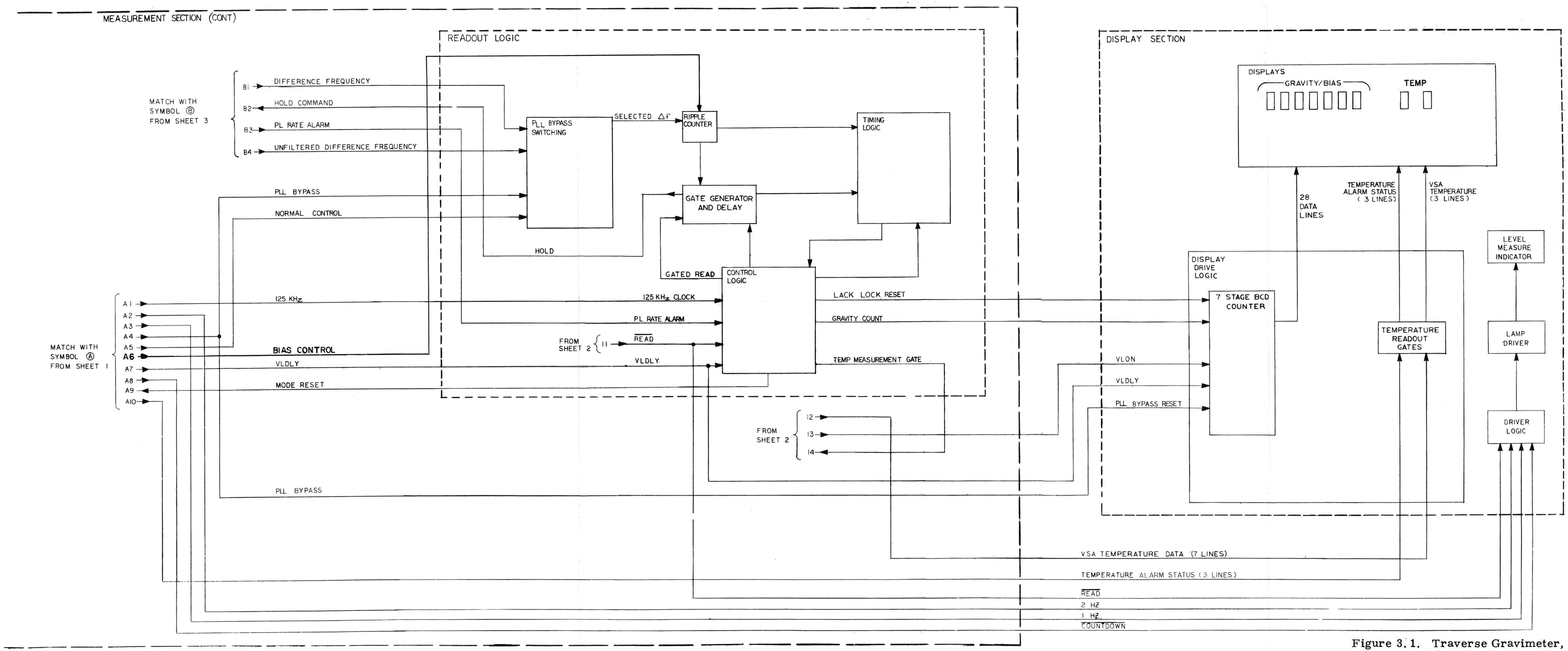

Figure 3.1. Traverse Gravimeter, Functional Block Diagram (Sheet 4 of 4)

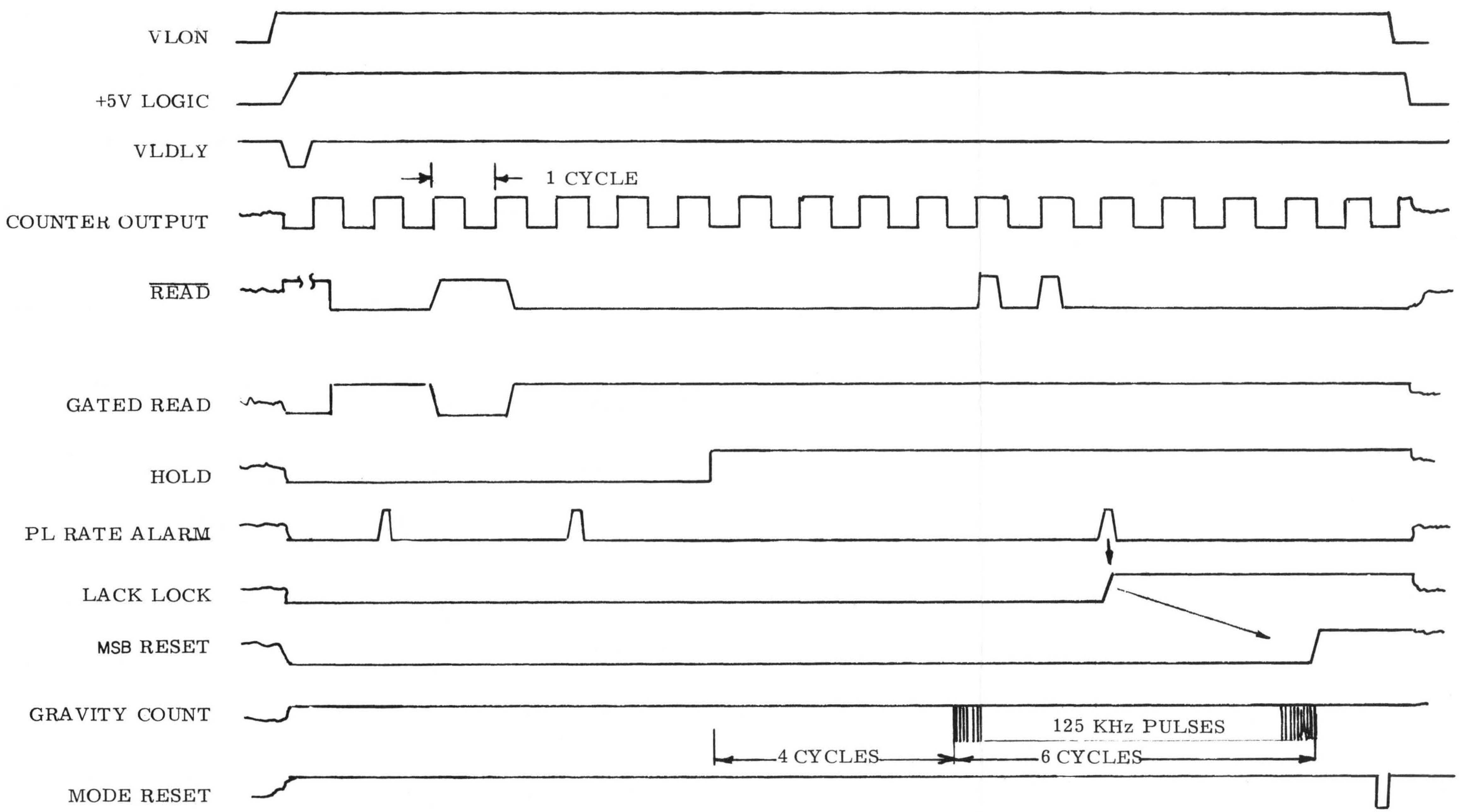

Figure 3.2. Measurement Function, Timing Diagram