Bendix Navigation & Control Division



# REVISED FINAL REPORT

# APOLLO TELESCOPE MOUNT (ATM) GIMBALLED STAR TRACKER

PREPARED PER THE REQUIREMENTS OF NAS-30105

1974

PREPARED BY
THE BENDIX
CORPORATION

GUIDANCE
SYSTEMS
DIVISION

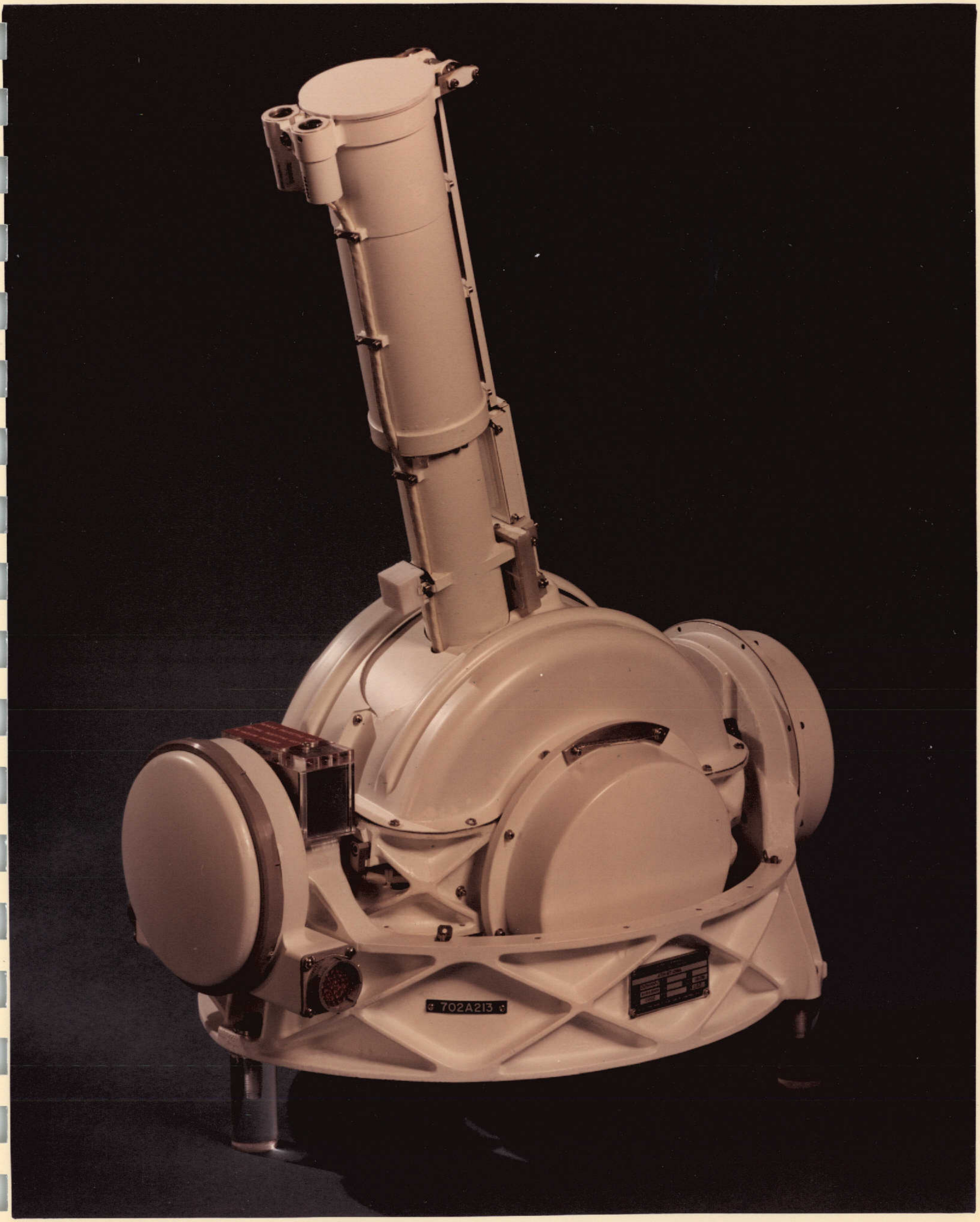
TETERBORO,
NEW JERSEY

PREPARED BY:

JOHN DELLA LANA
PROGRAM MANAGER

APPROVED BY:

STANLEY SEEB
SUPERVISOR-ELECTRO-OPTICS SYSTEMS






Bendix Navigation & Control Division

# FOREWORD

During a period from September 1968 to February 1974 the Guidance Systems Division of the Bendix Corporation designed, built and delivered to Marshall Space Flight Center, six gimballed star trackers for the Apollo Telescope Mount of Skylab. The flight unit performed successfully on Skylabs I, II and III, receiving a total accumulated usage time of approximately 3500 hours. The tracker contributed to the mission successes by providing accurate pointing for experiments and roll references for gyro updates.

This report will describe how the tracker is used, discuss the delivered design, describe its test equipment and qualification test results and summarize its reliability characteristics.

The appendices of this report contain a brief program history and discuss design changes incorporated during the life of the program.

# SECTION 1

# SECTION 1.0
# SUMMARY

## 1.0 ATM STAR TRACKER SYSTEM

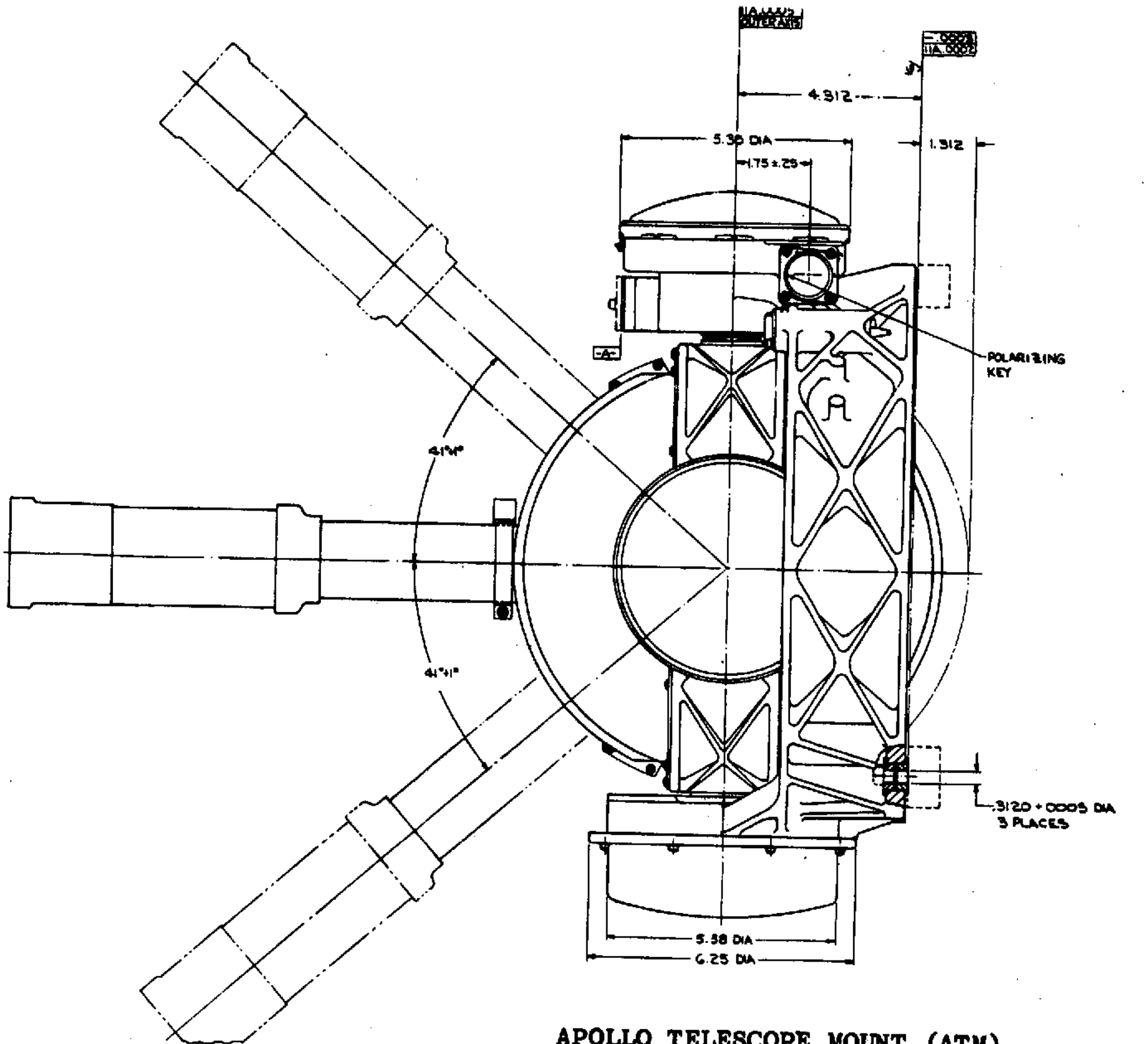
The ATM Star Tracker designed for NASA-Marshall Space Flight Center consists of a refractive telescope mounted in a double gimbal suspension. Each gimbal is driven by a direct drive D.C. torquer, while gimbal rate control is provided by D.C. Tachometers. Thirty arc second resolution optical encoders mounted on each axis provide the angular position information necessary to generate a roll reference for the ATM telescope. Gimbal freedoms of $\pm 87^{\circ}$ around the outer gimbal and $\pm 40^{\circ}$ around the inner gimbal are sufficient to track Canopus, Achernar and Acrux.

The telescope has a scanned field-of-view of $1^{\circ}$ square and an instantaneous field-of-view with a 10 arc minute square. This dual field-of-view provided a large viewing area while having low susceptibility to background effects. The Star Tracker automatically locks the instantaneous field at the star's position within the one degree field. The gimbals then drive the optical axis in line with the star line. A combination sun and earth albedo shade has been provided which will allow tracking of stars to within $45^{\circ}$ of the sun and $5^{\circ}$ of the earth.

An electronics package was designed to provide power supplies, servo amplifiers, Digital Logic Unit (DLU) encoder processing electronics, telemetry and other functions. Figures 1-1 and 1-2 show a photograph and outline of the ATM Optical Mechanical Assembly (OMA). Figure 1-3 is the outline of the Star Tracker Support Electronics (STE).

The ATM Star Tracker is capable of three modes of operation: manual, search and track. The manual mode provides the astronaut with a remote gimbal positioning capability. Automatically, the search mode, utilizing the electronic digital logic unit, initially scans a small $\pm 2^{\circ}$ field of view and locks onto any target star in this field. If no target star is located in this field, it automatically searches a larger + $5^{\circ}$ field of view about the inner gimbal axis and $\pm 15^{\circ}$ about the other gimbal axis until a target star is acquired. After the system acquires it, it switches to the track mode which provided high accuracy tracking of the target star.

The system successfully performed on all three Skylab missions and received an accumulated usage period of over 3500 hours.

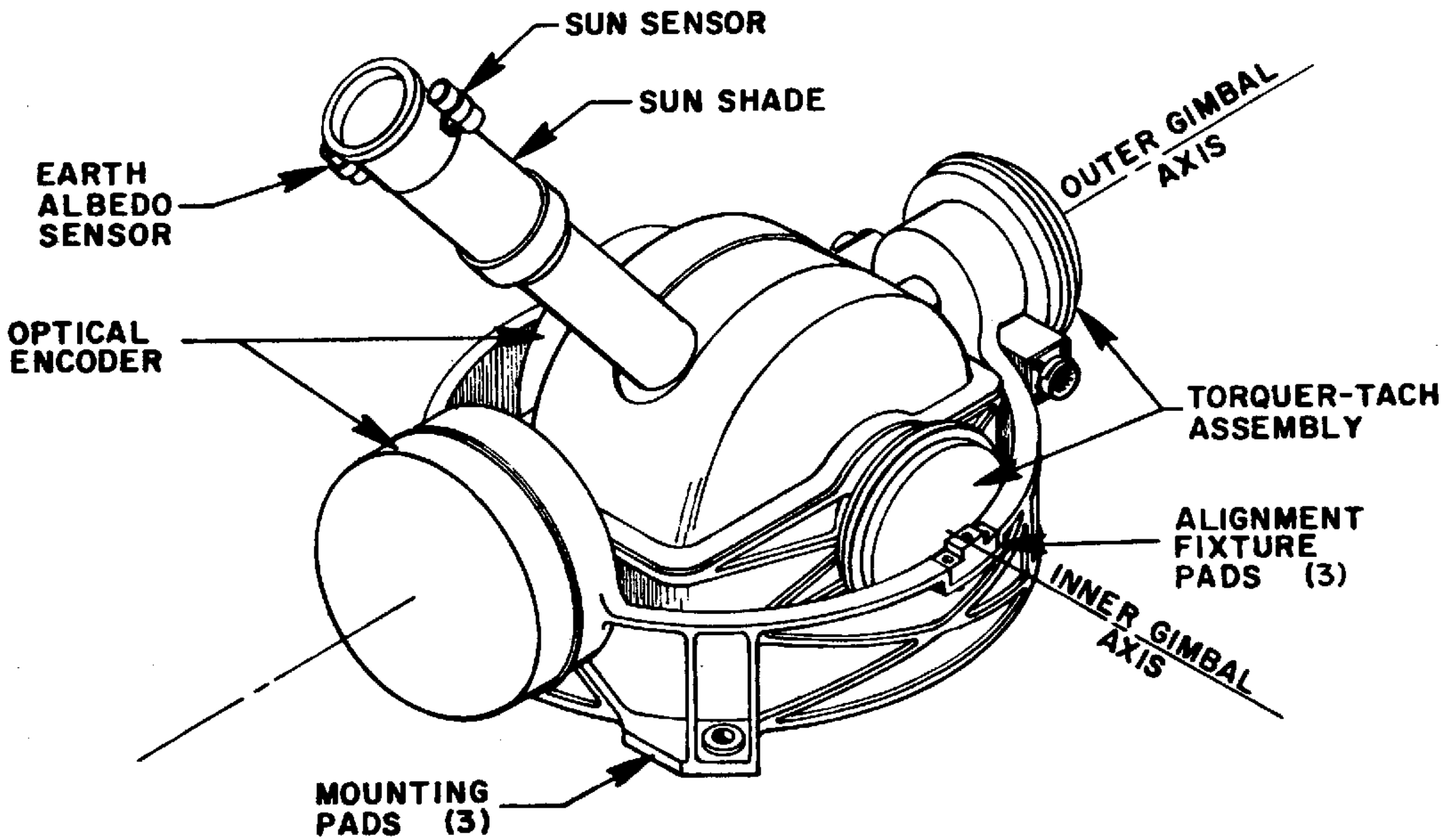



APOLLO TELESCOPE MOUNT (ATM)
OPTICAL MECHANICAL ASSEMBLY (OMA) OUTLINE
FOR SKYLAB
FIGURE I-1

## SUMMARY OF CHARACTERISTICS

| | | |
|---|---|---|
| FIELDS OF VIEW | GIMBAL | $\pm 87^{\circ}$OG, $\pm 40^{\circ}$IG |
| | TELESCOPE | $1^{\circ}$ SEARCH<br>10' TRACK |
| ACCURACY | 30ARC SEC | |
| TARGET STARS | CANOPUS, ACHERNAR, ACRUX (+1.2 MAG) | |
| MAGNITUDE CAPABILITY | +2.0 | |
| OPTICS | 175mm F/6.8 (FOLDED) | |
| DETECTOR | FW143 (ITT) | |
| MODULATION | GIMBAL SEARCH ($10^{\circ}$x$30^{\circ}$):<br>ELECTRONIC RASTER $1^{\circ}$x$1^{\circ}$<br>CRUCIFORM TRACK | |
| WEIGHT | 38 LBS (OMA) | |
| POWER | 15 WATTS | |

# ATM STAR TRACKER




APOLLO TELESCOPE MOUNT (ATM)
OPTICAL MECHANICAL ASSEMBLY (OMA) OUTLINE
FIGURE 1-2

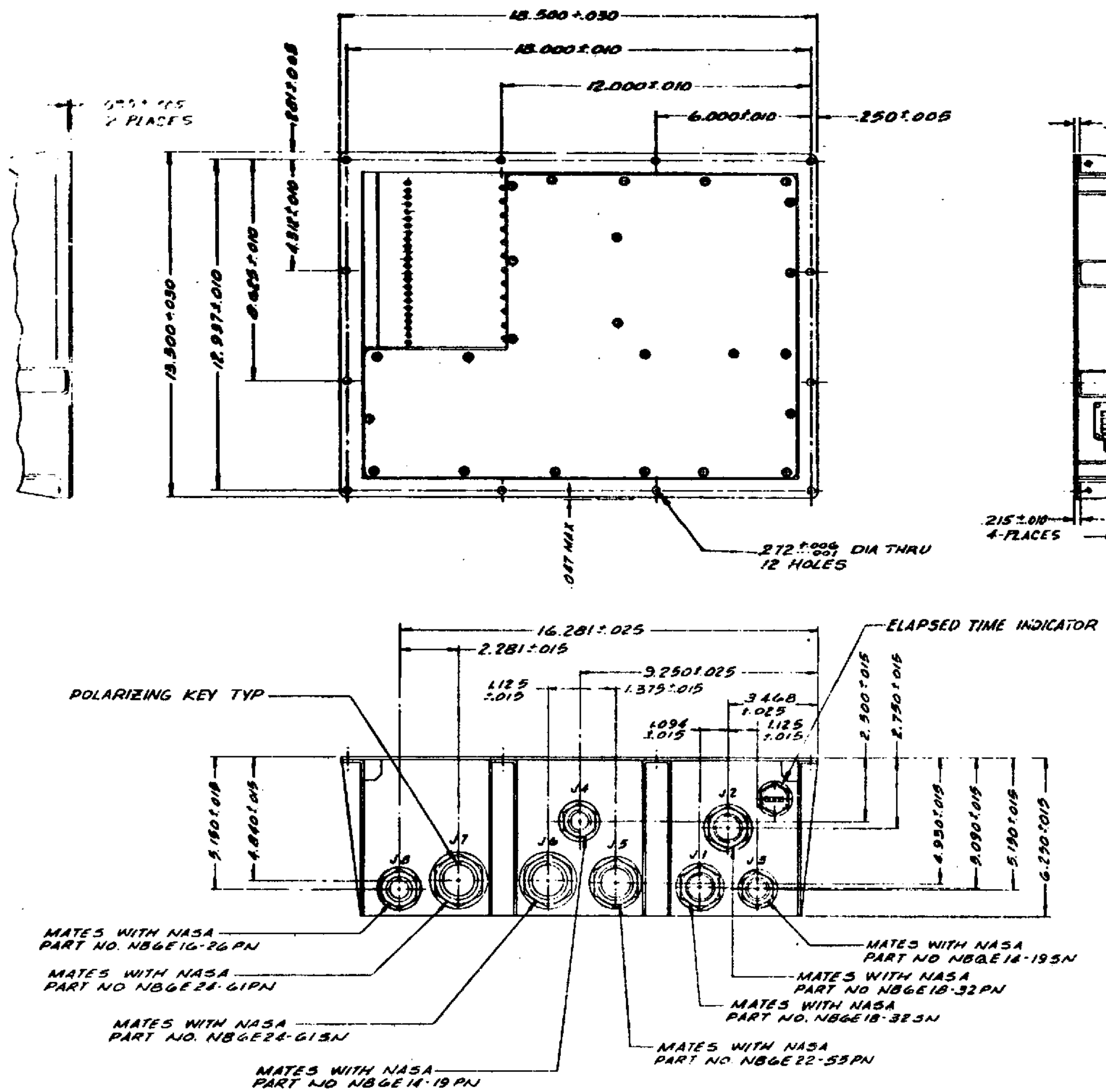



FIGURE 1-3

NOTES:
1. ALL EXTERIOR HOUSING SURFACES (EXCEPT MOUNTING SURFACE) PAINTED WITH FLAT BLACK TEMPERATURE CONTROL PAINT (CAT-A-LAC 463-3-8) PER 1854097(PS).
2. NUMBER 2-56 SCREWS PROVIDED FOR REFERNCE DESIGNATION PLATE.

| 2125800-1 | 50M221.. | S/N |
|---|---|---|
| VENDOR PART NO | MSFC PART | SERIAL NO |

SPECIFICATION CONTROL DRAWING

ATM STARTRACKER ELECTRONICS ASSY

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

F 50M22146

SCALE 1/2

AT-MST-STE

FOLDOUT FRAME 1

FOLDOUT FRAME 2

# SECTION 2

# SECTION 2.0
# STAR TRACKER DESCRIPTION

## 2.1 SYSTEM APPLICATION AND DESCRIPTION

The ATM Star Tracker consists of a refractive telescope mounted in a double gimbal suspension. Each gimbal is driven by a direct drive DC torquer, while gimbal rate control is provided by DC Tachometers. A modified fifteen bit (30 arc second resolution) optical encoders mounted on each axis provide the angular position information necessary to generate a roll reference for the ATM telescope. Gimbal freedoms of $87^{o}$ around the outer gimbal and $\pm 40^{o}$ around the inner gimbal are sufficient to track Canopus, Achernar, and other guide stars.

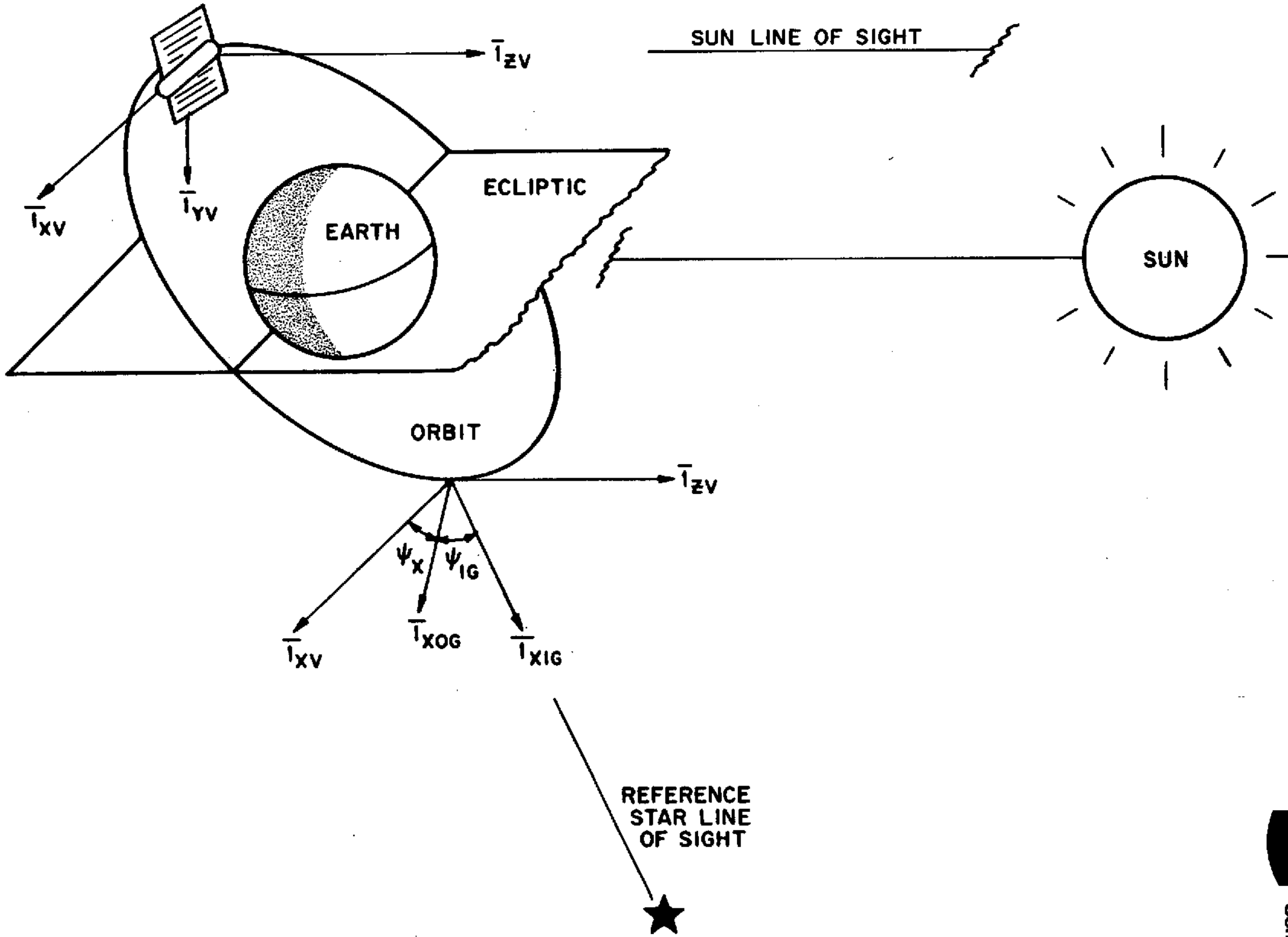
### 2.1.1 System Application

The two-axis gimballed star tracker was used to serve a dual function for the Apollo Telescope Mount (ATM) vehicle's control and stabilization system:

(a) A determination of the orientation of the Solar North Pole relative to the experiment telescope's reticle.

(b) To determine the orientation of the spacecraft's longitudinal axis relative to the orbital plane.

Relative to (a) above, the experiment roll angle correction is calculated in an airborne digital computer as a function of (1) the known Solar North orientation relative to the ecliptic, (2) position of earth in the




SPACECRAFT IN ORBIT
FIGURE 2.1.1-1

solar orbit, (3) star tracker gimbal positions, (4) right ascension and declination of the reference star, and (5) the orientation of the experiment telescope relative to the spacecraft. This experiment roll angle correction is then made available for ATM display and/or telemetry for correlation with experiment data.

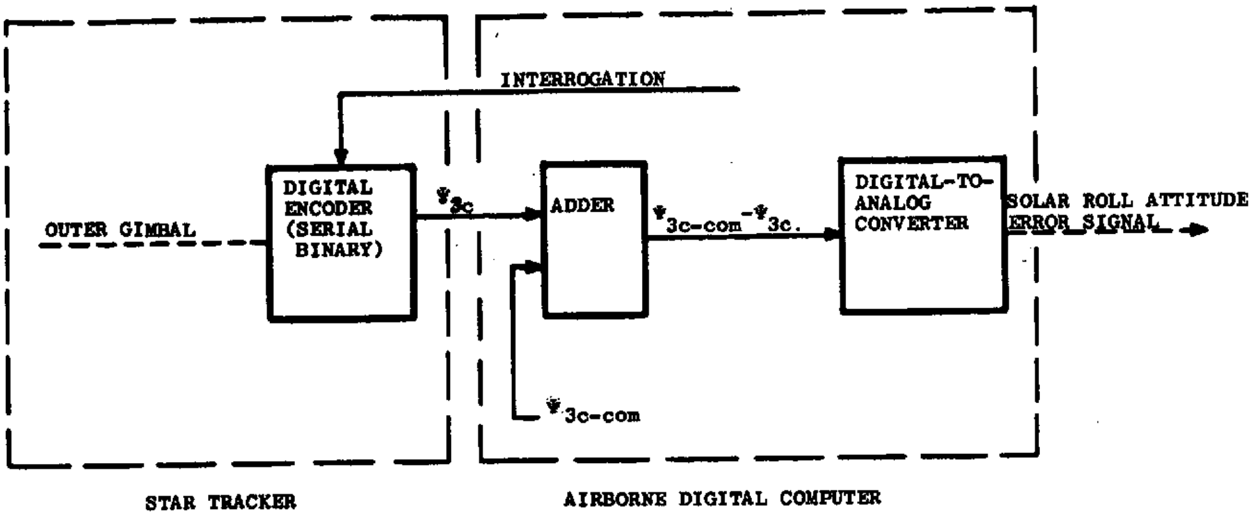
Relative to (b) above, the spacecraft's longitudinal axis is defined as that coinciding with the vehicle's minimum principlal axis of inertia. During the sun-lit portion of the orbit, the desired orientation of the spacecraft is along the solar roll ($\bar{I}_{zv}$) axis pointing towards the sun and with the longitudinal ($\bar{I}_{xv}$) axis constrained to the orbital plane. Orientation of the $\bar{I}_{xv}$ axis in this manner thereby minimizes the magnitude of steady gravity gradient moments on the spacecraft.

Figure 2.1.1-1 illustrates the spacecraft in orbit, including the orientation of the vehicle's $\bar{I}_{xv}$ $\bar{I}_{yv}$ and $\bar{I}_{zv}$ axes. Also

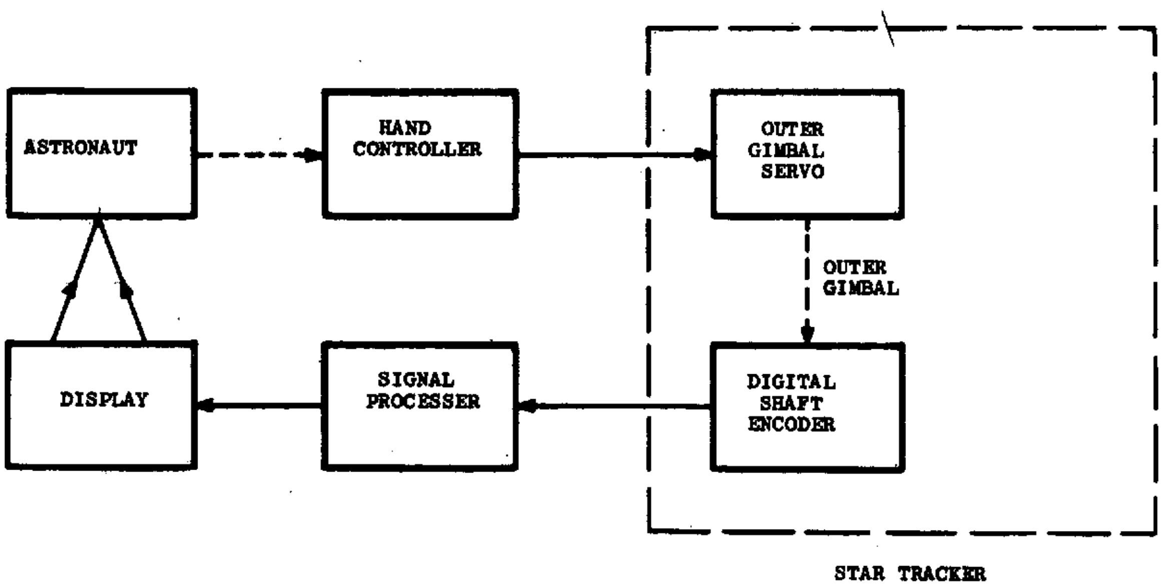
$\Psi_{3c}$ = rotation of the star tracker's outer gimbal about $\bar{I}_{zv}$ or the solar roll axis.

$\Psi_{1c}$ = rotation of the star tracker inner gimbal to align its telescope along the line-of-sight to the reference star.

The outer gimbal angle position is normally controlled as shown in Figure 2.1.1-2. The $\Psi_{3c}$ outer gimbal encoder signal is combined with the outer gimbal command signal ($\Psi_{3c-com}$) in the digital computer. The $\Psi_{3c-com}$ - $\Psi_{3c}$ signal then is used as a solar roll attitude error




OUTER GIMBAL CONTROL
FIGURE 2.1.1-2




INNER GIMBAL POSITIONING
FIGURE 2.1.1-3

error signal for the $z_v$ axis of the spacecraft. The required $\Psi_{3c-com}$ angle is determined on the ground or computed in the airborne digital computer.

For a better understanding of the star tracker's application to the ATM mission, the operation for several conditions will be discussed briefly.

### 2.1.1.1 Initial Acquisition

The initial acquisition of the reference star is accomplished through the following steps:

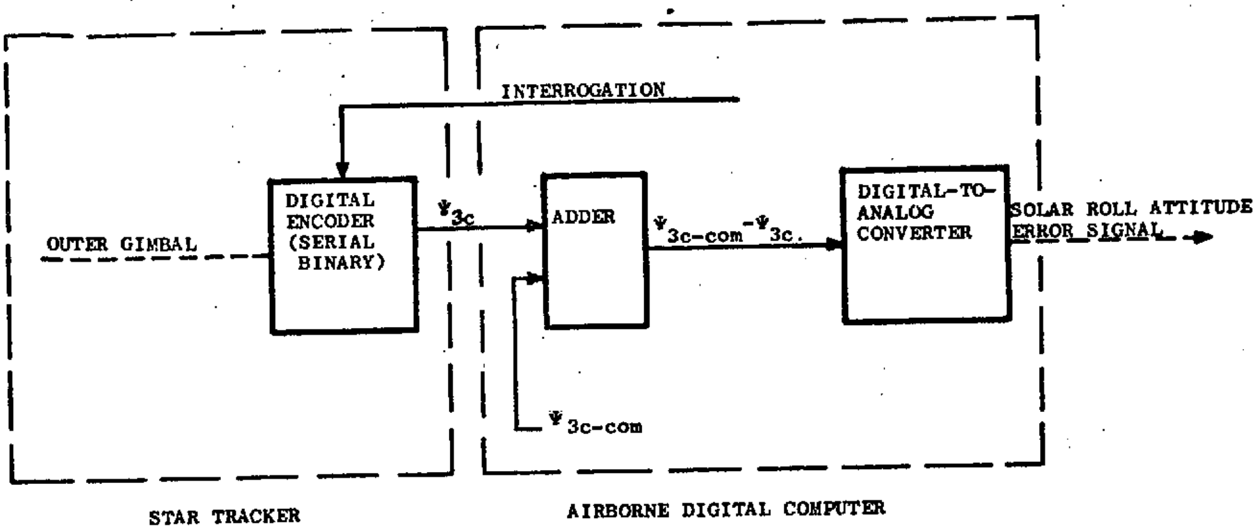
(a) The $\bar{1}_{zv}$ axis of the vehicle must be approximately along the solar reference line; e.g., as may be obtained with a coarse or "acquisition" sun sensor.

(b) The astronaut then approximately aligns the longitudinal ($\bar{1}_{xv}$) axis by slewing the vehicle until this axis is within 15 degrees of the orbital plane.

(c) The astronaut then receives the desired $\Psi_{1c}$ and $\Psi_{3c}$ angles from the ground control.

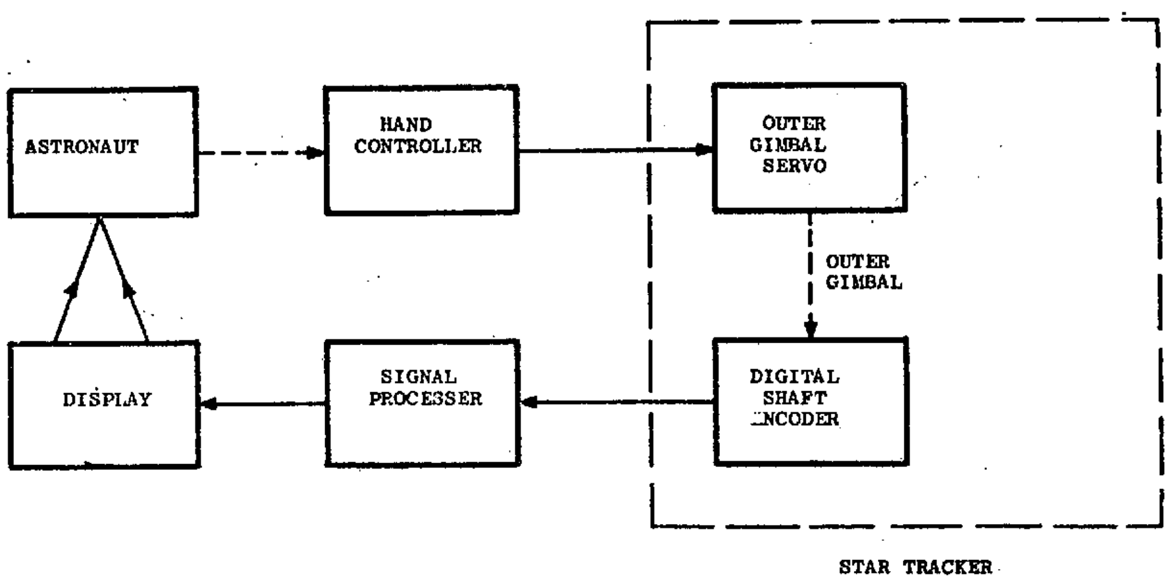
(d) The astronaut may then drive the tracker's inner gimbal (Manual Mode) to match the $\Psi_{1c}$ desired by using the hand controller until the corresponding $\Psi_{1c}$ angle is read on the digital display. See Figure 2.1.1-3.

(e) After "locking" the inner gimbal (Inner Gimbal Hold) the tracker's outer gimbal $\Psi_{3c}$ is then set to the angle desired by the astronaut using the hand controller and the $\Psi_{3c}$ digital display.




OUTER GIMBAL CONTROL

FIGURE 2.1.1-2




INNER GIMBAL POSITIONING

FIGURE 2.1.1-3

(f) The astronaut then commands the star tracker to transfer to the Automatic Mode; more specifically, the Acquisition Search Sub-Mode.

(g) The star tracker then goes through a dual search pattern. Initially a $4^{o} \times 4^{o}$ area is searched in a short period of time and, then the full $\pm 5^{o}$ inner gimbal by $\pm$ 15 outer gimbal area is searched about the positions obtained in (e) above.

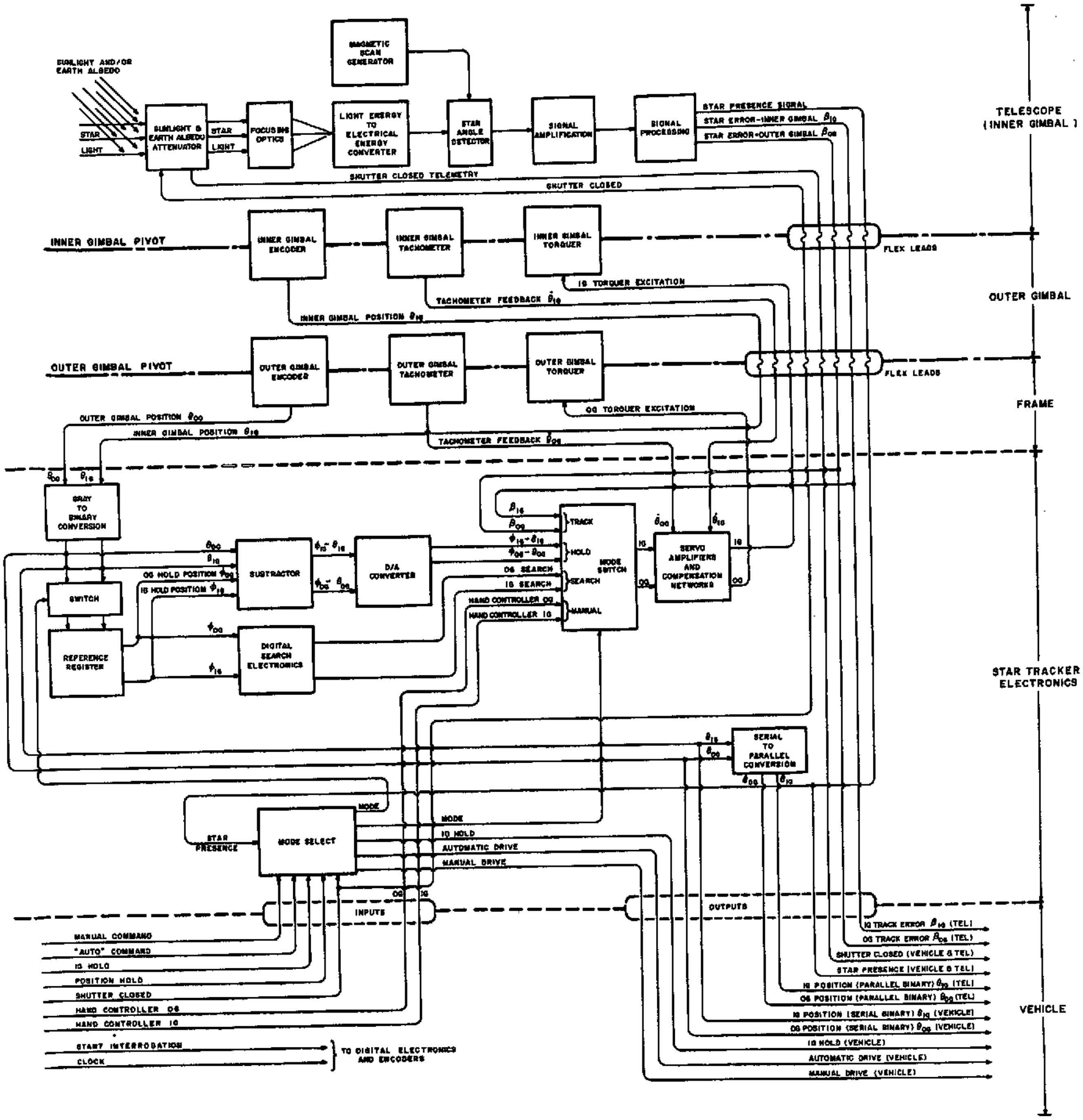
(h) When the reference star is acquired, the star tracker transfers to the Track Sub-Mode.

2.1.1.2 Earth Occultation of the Reference

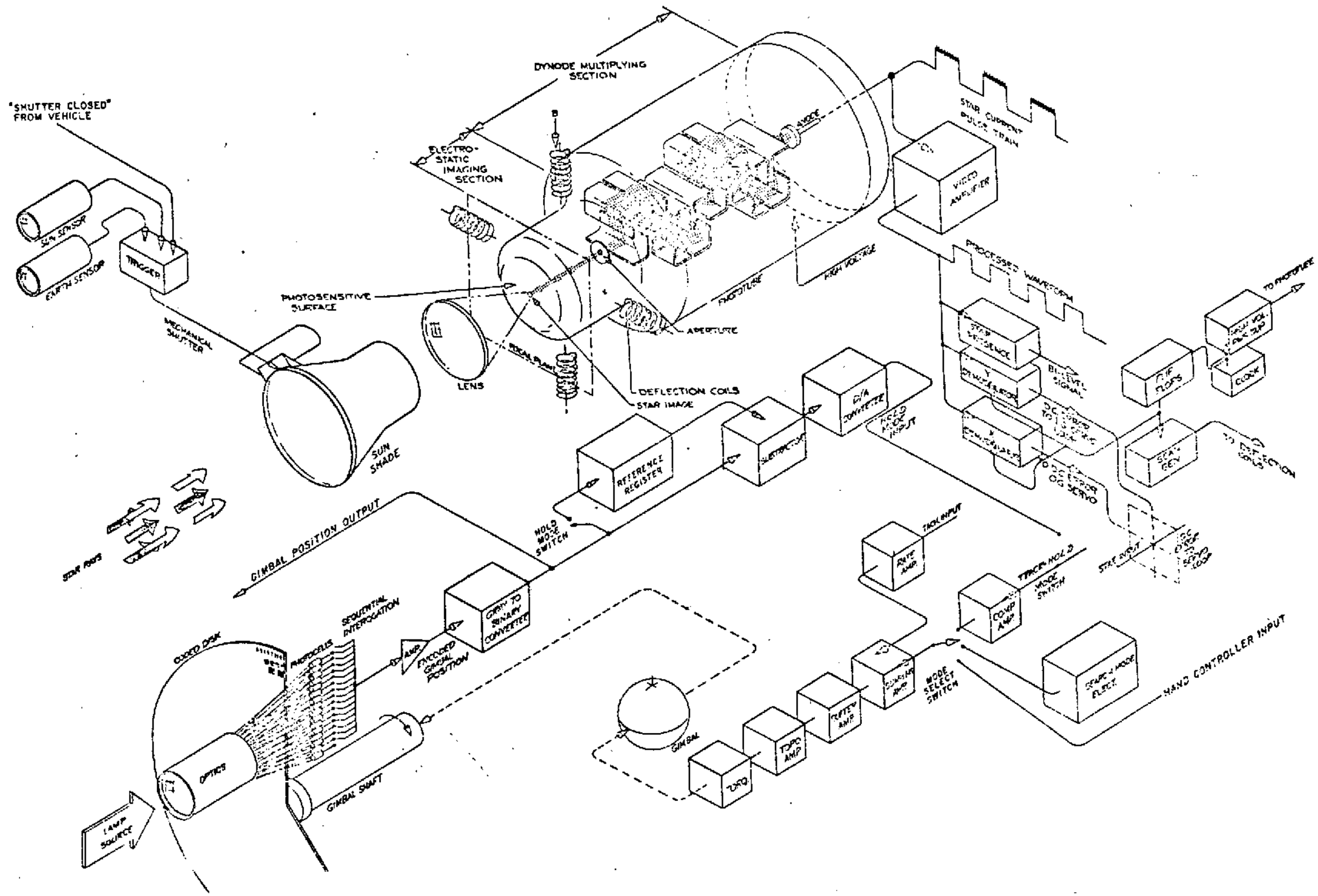
(i) A star occult signal (originating from memory storage or ground telemetry) is obtained from the digital computer at a designated time before the reference star is occulted. Under this condition, the star tracker shutter is closed and both gimbals are electronically "locked" by a position loop. (Hold Mode).

(j) At a designated time after earth occultation, a digital computer discrete commands the tracker to return to the Automatic Mode; the shutter is opened and the Hold Mode removed.

(k) If the star tracker is then aligned within $\pm$ 30 arc min. from the reference star line-of-sight (as detected by telescope electronics), the tracker reverts back to the Track Sub-Mode.




SYSTEM FUNCTIONAL BLOCK DIAGRAM
FIGURE 2.1.2-1




SYSTEM PICTORIAL BLOCK DIAGRAM

FIGURE 2.1.2-2

(1) However, if in (k) the star tracker is aligned more than $\pm$ 30arc min from the star line-of-sight, the tracker enters the acquisition Search Sub-Mode.

2.1.1.3 Cluster Occultation of the Reference Star

When the reference star is about to be occulted by an obstruction of the cluster in the tracker's normal field-of-view, a Hold Mode discrete is issued from the airborne digital computer. Information concerning the obstructed regions is stored in an on-board memory or originates from ground system control. A cluster occult alarm is displayed whenever $\Psi_{1c}$ and $\Psi_{3c}$ indicate an occulted tracker orientation. At this time, the astronaut notifies the computer and ground control that an alternate reference star is to be used for the solar roll reference and to keep the $\bar{1}_{xv}$ spacecraft axis in the orbital plane.

2.1.2 System Description

2.1.2.1 Block Diagrams

A functional block diagram of the Star Tracker is shown in Figure 2.1.2-1. Functions contained within the inner gimbal, the outer gimbal, and those in electronics are clearly separated. In addition, a pictorial block diagram of the system is shown in Figure 2.1.2-2.

### 2.1.2.2 Star Tracker - ATM Interface

The Star Tracker interfaces with the ATM Digital Computer (ATMDC), the ATM Control and Display Panel (ATM C and D), the ATM Experiment Pointing Electronics Assembly (EPEA), and telemetry. The more significant inputs and outputs are listed below.

<u>Inputs from ATMDC</u>

1. An "inner-gimbal-readout-request" envelope for inner-gimbal encoder interrogation.

2. An "outer-gimbal-readout-request" envelope for outer gimbal encoder interrogation.

3. A 10 KHz clock signal to control the serial transmission of the inner and outer gimbal data words.

4. An "Auto" discrete which places the tracker in the automatic mode of operation. This command cannot override a Manual command or a Shutter-Close/Hold command from the C and D panel.

5. A "Shutter-Closed/Hold" discrete which places the tracker in the shutter-closed/hold mode of operation. This command cannot override a Manual command from the C and D panel.

<u>Outputs to ATMDC</u>

1. Inner-gimbal position information, in serial binary form. The serial word is 15 bits in length, is transmitted MSB first at a 10 KHz rate, and has a scaling of 30 arc seconds per increment.

2. Outer-gimbal position information, in serial binary form. This serial word is 15 bits in length, is transmitted MSB first at a 10 KHz rate, and has a scaling of 30 arc seconds per increment.

3. Automatic mode indication

4. Manual mode indication

5. Shutter closed indication

6. Star presence indication

Inputs from C and D Panel

1. A "Star Tracker Off" command, which disconnects the primary power source and closes the shutter.

2. A "Star Tracker On" command, which connects the primary power source and places the tracker in the Shutter-Closed/Hold mode.

3. A "Manual" command, which opens the shutter and places the tracker in the manual mode of operation.

4. An "Auto" command, which places the tracker in the Automatic (Search/Track) mode of operation.

5. A "Shutter-Close/Hold command which places the system in the Shutter-Close/Hold mode of operation.

Outputs to C and D Panel

1. Star Presence discrete
2. Shutter Closed discrete
3. Automatic Mode discrete
4. Manual Mode discrete
5. Inner-gimbal direction
6. Outer-gimbal direction.

Inputs from EPEA

1. Inner-gimbal band controller drive signal in DC form.
2. Outer-gimbal band controller drive signal in DC form.

Inputs from Telemetry

1. Gimbal angle readout pulse.

Outputs to Telemetry

1. Inner gimbal angle in 15-Bit parallel binary format. The resolution is 30 arc seconds per increment.
2. Outer gimbal angle in 15-Bit parallel binary format. The resolution is 30 arc seconds per increment.
3. Star presence indication
4. Shutter closed indication
5. Inner-gimbal tachometer voltage
6. Outer-gimbal tachometer voltage.

| MF | | REVISIONS | | |
|---|---|---|---|---|
| | SYM | DESCRIPTION | DATE | APPROVAL |
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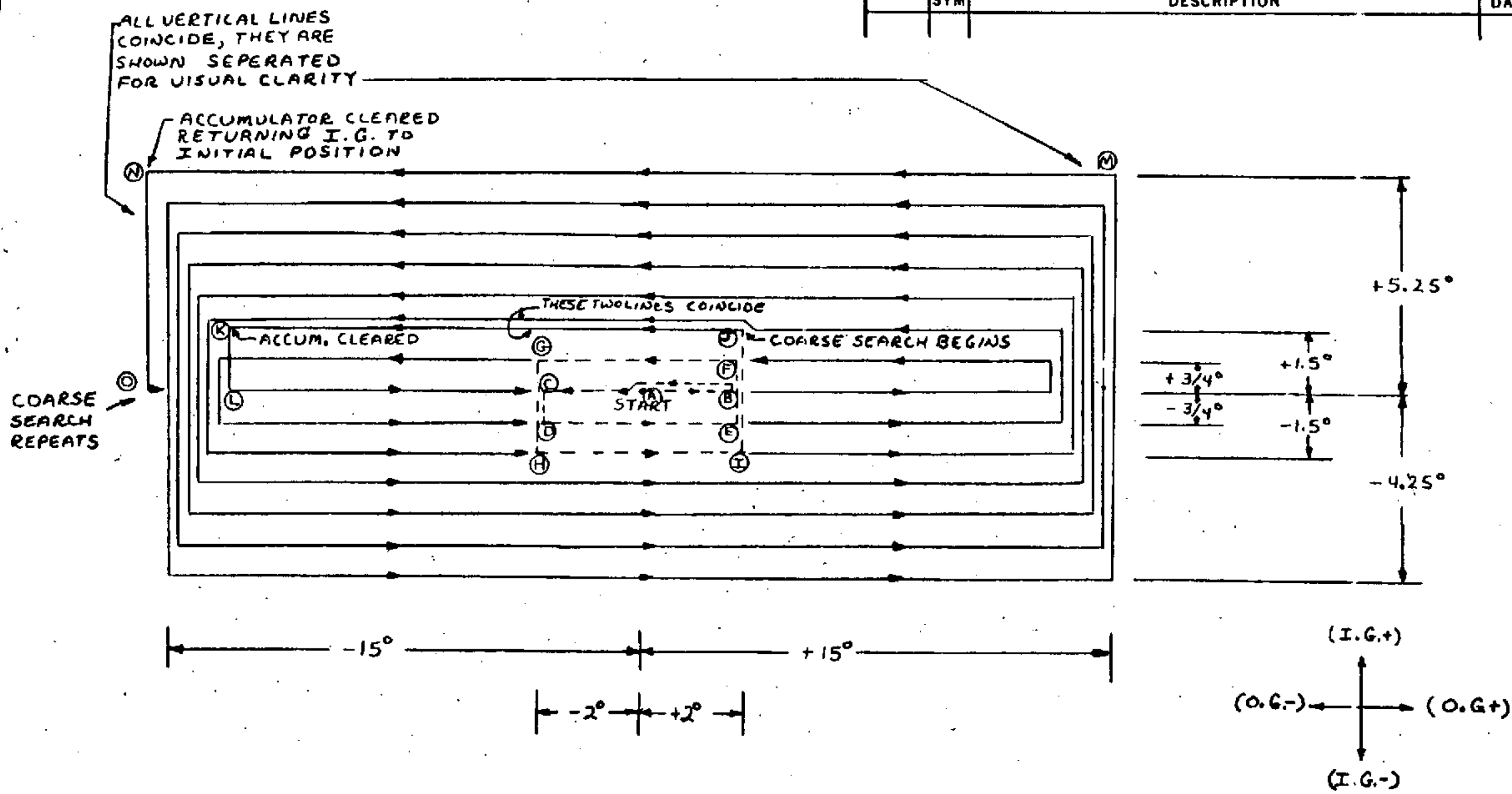



NOTE: DASHED LINES INDICATE FINE SEARCH
SOLID LINES INDICATE COARSE SEARCH

| THE Bendix CORPORATION | ECLIPSE - PIONEER DIVISION TETERBORO, NEW JERSEY, U.S.A. | |
|---|---|---|
| CODE IDENT NO. 19315 | SIZE B | TWO AXIS GIMBAL SEARCH DIAGRAM |
| SCALE | WT | SHEET |

FIGURE 2.1.2-3

### 2.1.2.3 Modes of Operation

The Star Tracker responds to three externally commanded modes of operation: automatic, manual, and shutter-close/hold. The operation of the tracker in each of these modes is described below.

Automatic Mode

In the automatic mode, the tracker automatically searches for, acquires, and tracks the reference star. During search, the gimbals are raster-scanned in two modes: a fine mode in which a $\pm$ 2.5 degree by $\pm$ 2 degree area, centered about the starting position, is searched, followed by a coarse mode in which an angle of $\pm$ 15.5 degrees about the outer gimbal starting position and + 5.75 and - 4.75 degrees about the inner gimbal starting position is searched. If a star has not been acquired before the coarse search has ended, the inner gimbal is returned to its initial position and the coarse search pattern only is repeated until new commands are received.

A diagram of the search pattern just described is given in Figure 2.1.2-3. The general pattern is achieved by rotating the outer gimbal at a fixed rate, while holding the inner gimbal, and then holding the outer gimbal while indexing the inner gimbal by a multiple of $\pm$ 3/4 degree. Thus, the search pattern is characterized by a series of 4 degree or 30 degree sweeping about the outer-gimbal axis with each sweep being separated by 3/4 degree of inner-gimbal motion. Since the acquisition field-of-view of the telescope is one degree, the star will always be found during one of the outer gimbal sweeps; and hence, the outer-gimbal sweep speed should be as uniform as possible. To accomplish this, the outer gimbal is driven by a one deg/sec command applied directly to its rate loop, with the gimbal encoder being used only to determine when the proper angle (± 2 degrees of ± 15 degrees from the initial angle) has been reached. The inner gimbal is indexed the required angle by means of its position loop, since uniformity of speed is unimportant along this axis.

When a star of proper magnitude enters the one degree acquisition field, an internally generated "End Search" pulse terminates the mechanical gimbal search, and, after a small time delay, switches the system to the Track mode of operation. In the Track mode, the inner and outer gimbals are controlled with error signals generated by the telescope electronics.

While tracking, should the star be lost (indicated by loss of the Star Presence signal), the system automatically reverts to the search operation. A fine search pattern, followed by a coarse search pattern, is generated, with the center coordinates being those at which the star was last tracked.

Manual Mode

The Manual mode is used to position the Star Tracker gimbals such that the target star is within the search limits of the automatic mode. A switch to the automatic mode then causes the star to be acquired and tracked.

If the star has been acquired in the Manual mode (indicated by an active Star Presence signal), the switch to the automatic mode results in immediate star tracking.

The Manual mode is implemented by connecting the two-axis DC inputs from the hand controller directly to the appropriate gimbal rate loop. The telescope can then be driven to any orientation within the gimbal limits.

Shutter-Close/Hold Mode

In the Shutter-Close/Hold mode, the shutter is closed and both gimbals are held in a fixed position. This position is the last position read out by the optical encoders before the initiation of the mode.

The "hold" operation is accomplished by storing each gimbal position readout in an "initial-position" register. When the Shutter-Close/Hold command is received these registers are no longer updated. Subsequent encoder readouts are then subtracted from the words in the "initial-position registers, and the resulting error signals are converted to analog voltages which drive the gimbal position sensor to null.

2.1.2.4 Internal Operating Configurations

In response to the three externally commanded modes (automatic, manual, and shutter-close/hold) the system assumes several internal operating configurations. The relationship between the system mode and the internal servo loop configuration is tabulated below.

| SYSTEM MODE | GIMBAL | SERVO LOOP Error Source | Type |
|---|---|---|---|
| Manual | Both | Hand Controller | Rate |
| Shutter-Close/ Hold | Both | Digital Electronics | Position |
| Automatic (Search) | I.G. | Digital Electronics | Position |
| | O.G. | Digital Electronics | Rate * |
| Automatic (Track) | Both | Telescope Electronics | Position |

* Encoder controls time duration of applied rate.

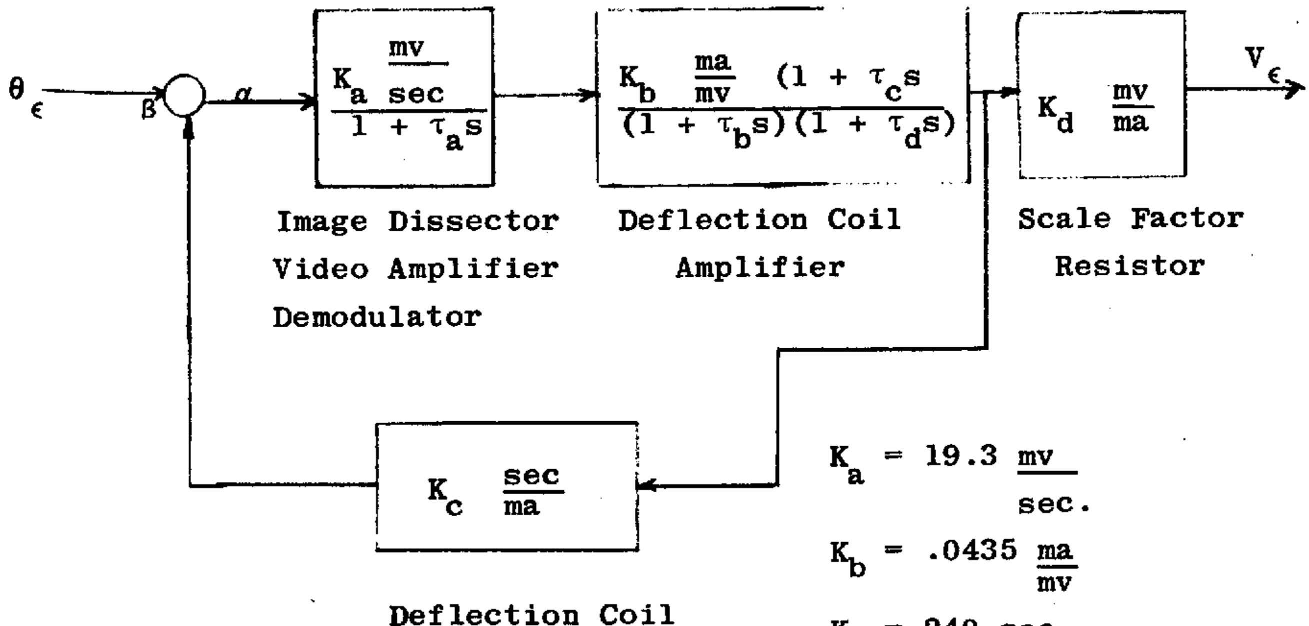
The various servo loops are described in the following sections.

### 2.1.2.4.1 Track Mode Servo Loop

The Track mode of operation is characterized by two servo loops, one all electronic in nature which centers the instantaneous field-of-view about the star line, and one electromechanical which aligns the telescope's optical axis, by torquing the gimbals, to the star line. Each of these loops is discussed below.

## Electronic Tracking Loop

A block diagram of the Electronic Tracking loop is shown in Figure 2.1.2-4.




$K_a = 19.3 \frac{mv}{sec.}$

$K_b = .0435 \frac{ma}{mv}$

$K_c = 240 \frac{sec.}{ma}$

$K_d = 680$ mv/ma

$\tau_a = \frac{1}{140}$ sec.

$\tau_b = \frac{1}{.69}$ sec.

$\tau_c = \frac{1}{49}$ sec.

$\tau_d = \frac{1}{575}$ sec.

ELECTRONIC TRACKING LOOP

FIGURE 2.1.2-4

The terms used in Figure 2.1.2-4 are defined as follows:

$\theta_\epsilon$ = Angle between the star line and the telescope's optical axis.

B = Angle between the tracker's instantaneous field-of-view and the telescope's optical axis.

$\alpha$ = Angle between the star line and the instantaneous field-of-view of the tracker.

$V_\epsilon$ = Output voltage signal proportional to $\theta_\epsilon$.

The open-loop transfer function, A(s), of the servo loop is

$$1)\quad A(s) = \frac{K_a K_b K_c \; (1 + \tau_c S)}{(1+\tau_a S)(1+\tau_b S)(1+\tau_d S)} =$$

$$\frac{202 \; (1 + \frac{S}{49}}{(1 + \frac{S}{.69})\;(1 + \frac{S}{140})\;(1 + \frac{S}{575})}$$

and a Bode plot is shown in Figure 2.1.2-5.

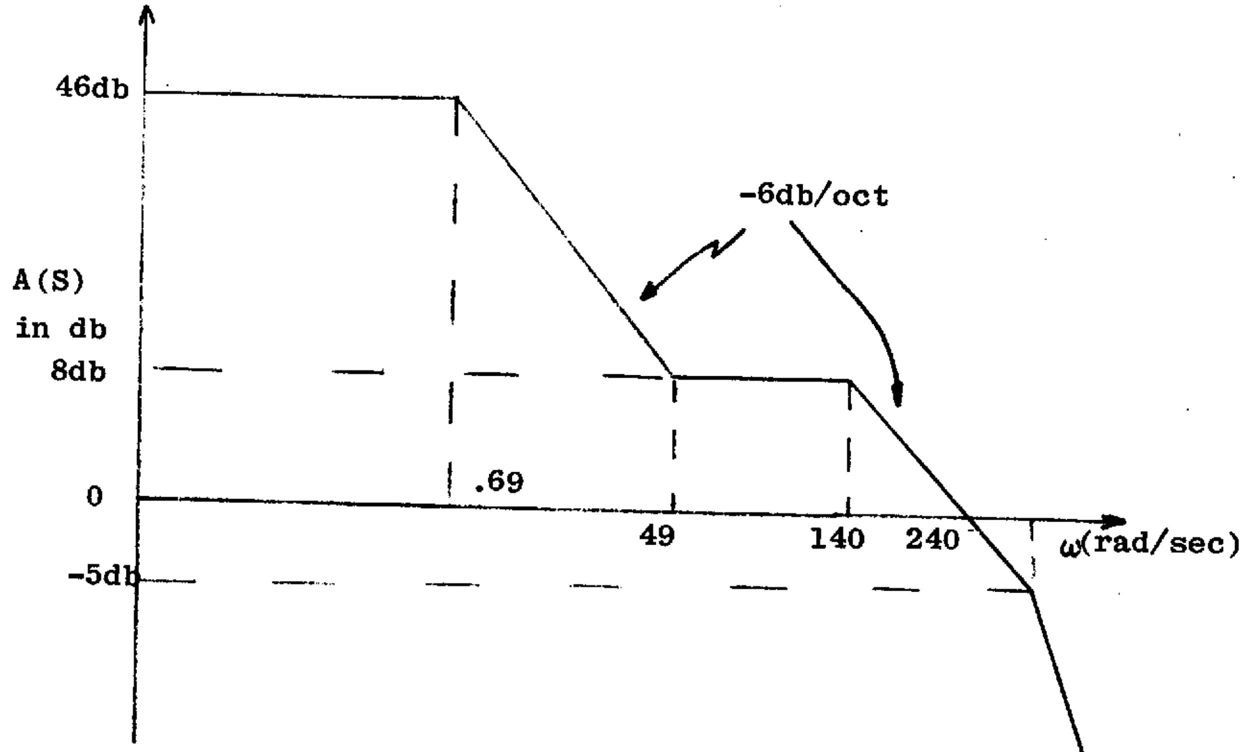
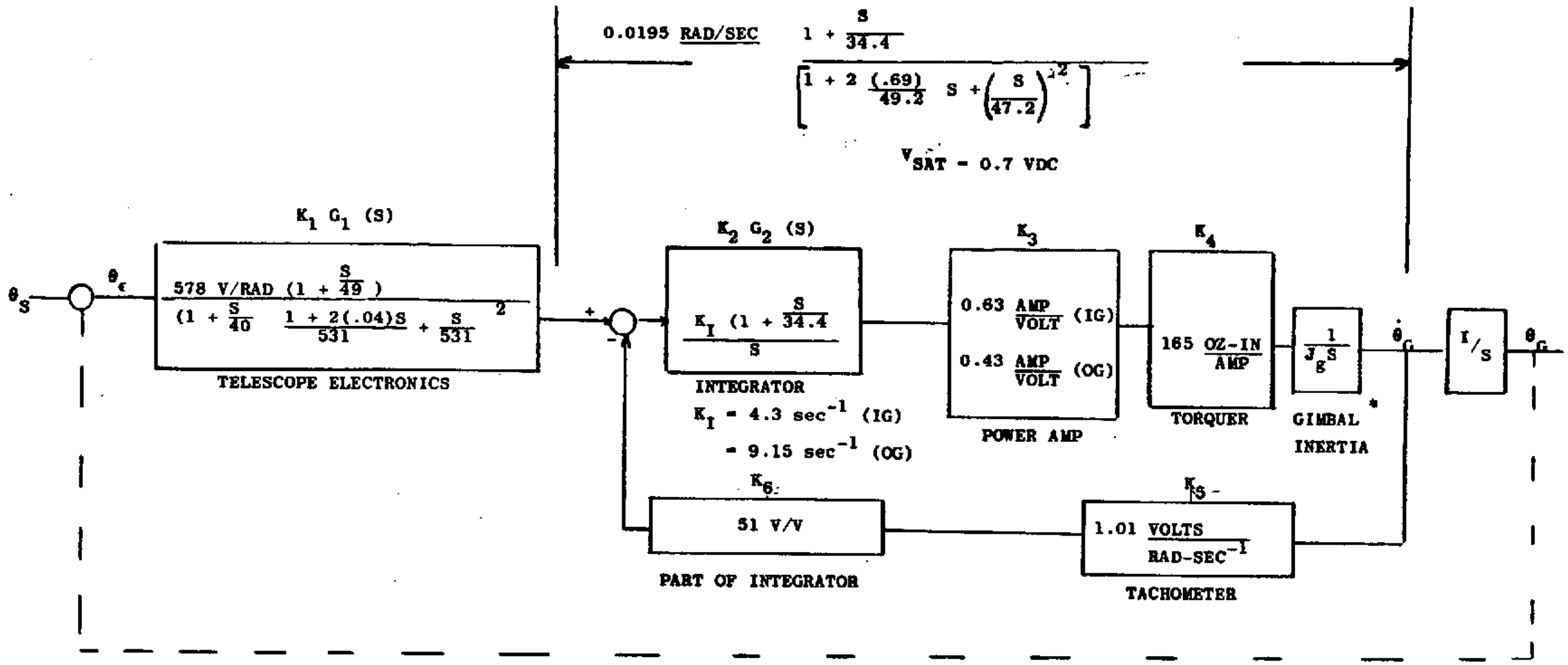



FIGURE 2.1.2-5

The Bode plot shows the loop to be stable, (phase margin $\approx$ 85°), and to have a cross-over frequency of about 240 rad/sec.

The closed-loop transfer function of the electronic tracking loop is:

$$\frac{V_\epsilon}{\theta_\epsilon} = \frac{2.8 \frac{mv}{sec} \left(1 + \frac{S}{49}\right)}{\left(1 + \frac{S}{40}\right)\left[1 + \frac{2(.64)S}{531} + \left(\frac{S}{531}\right)^2\right]}$$




$*J_g$ = 16.5 oz-in-sec$^2$ (OUTER GIMBAL)

$J_g$ = 10.3 oz-in-sec$^2$ (INNER GIMBAL)

TRACK MODE SERVO LOOP
FIGURE 2.1.2-6

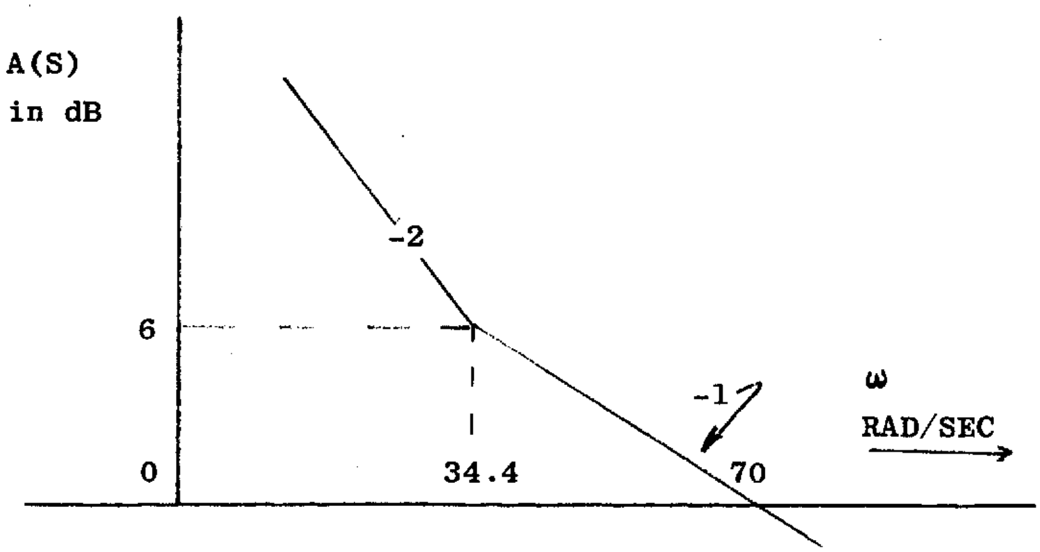
Electromechanical Tracking Loop

A block diagram of the complete track mode servo loop is shown in Figure 2.1.2-6, and consists of a rate loop (inner loop) and a position loop (outer loop). Note that K, G, (S) is the closed loop transfer function of the electronic tracking loop just described.

The open-loop transfer function of the rate loop, applicable to both inner and outer gimbals, is

$$A(S) = \frac{K_s K_3 K_4 K_5 K_6 G_2(S)}{J_g S} = \frac{2230\ (1 + \frac{S}{34.4})}{S^2}$$

A Bode plot of this transfer function is shown in Figure 2.1.2-7. The phase margin of the loop is about 64 degrees and the crossover frequency about 70 rad/sec.




BODE PLOT - RATE LOOP
FIGURE 2.1.2-7

The open-loop gain of the position loop, also applicable to both inner and outer gimbals, is:

$$A(S) = \frac{11.3\left(1 + \frac{S}{34.4}\right)\left(1 + \frac{S}{49}\right)}{S\left[1 + \frac{S}{40}\right]\left[1 + \frac{2(.69)S}{47.2} + \left(\frac{S}{47.2}\right)^2\right]\left[1 + \frac{2(.64)S}{531} + \frac{S}{531}^2\right]}$$

An asymptotic Bode plot of this transfer function is sketched in Figure 2.1.2-8. The loop has a phase margin of 86 deg. and a zero dB crossover frequency of 11.3 rad/sec (1.8 Hz).

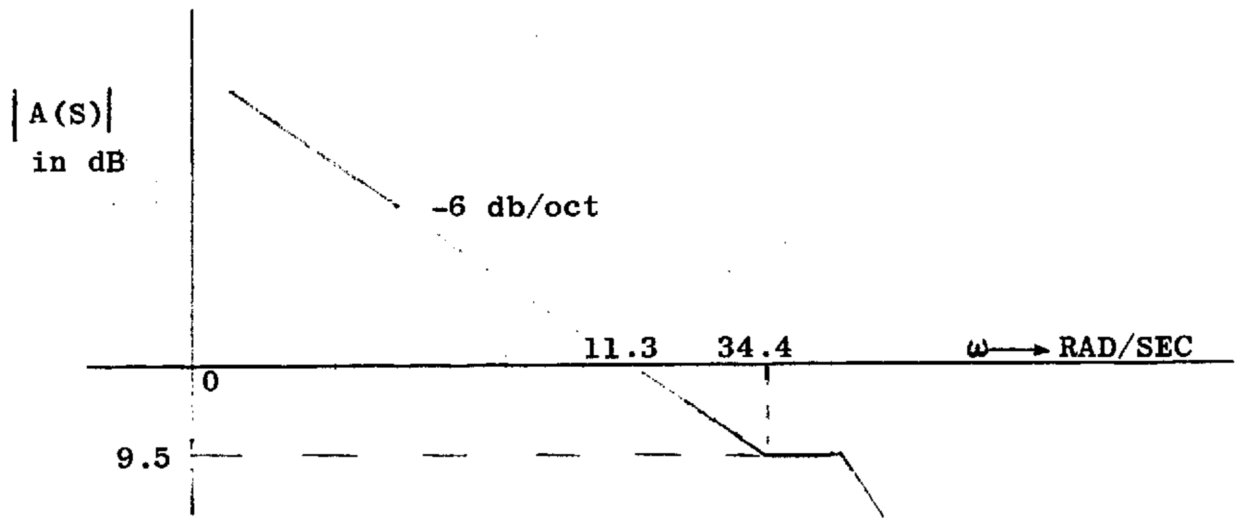
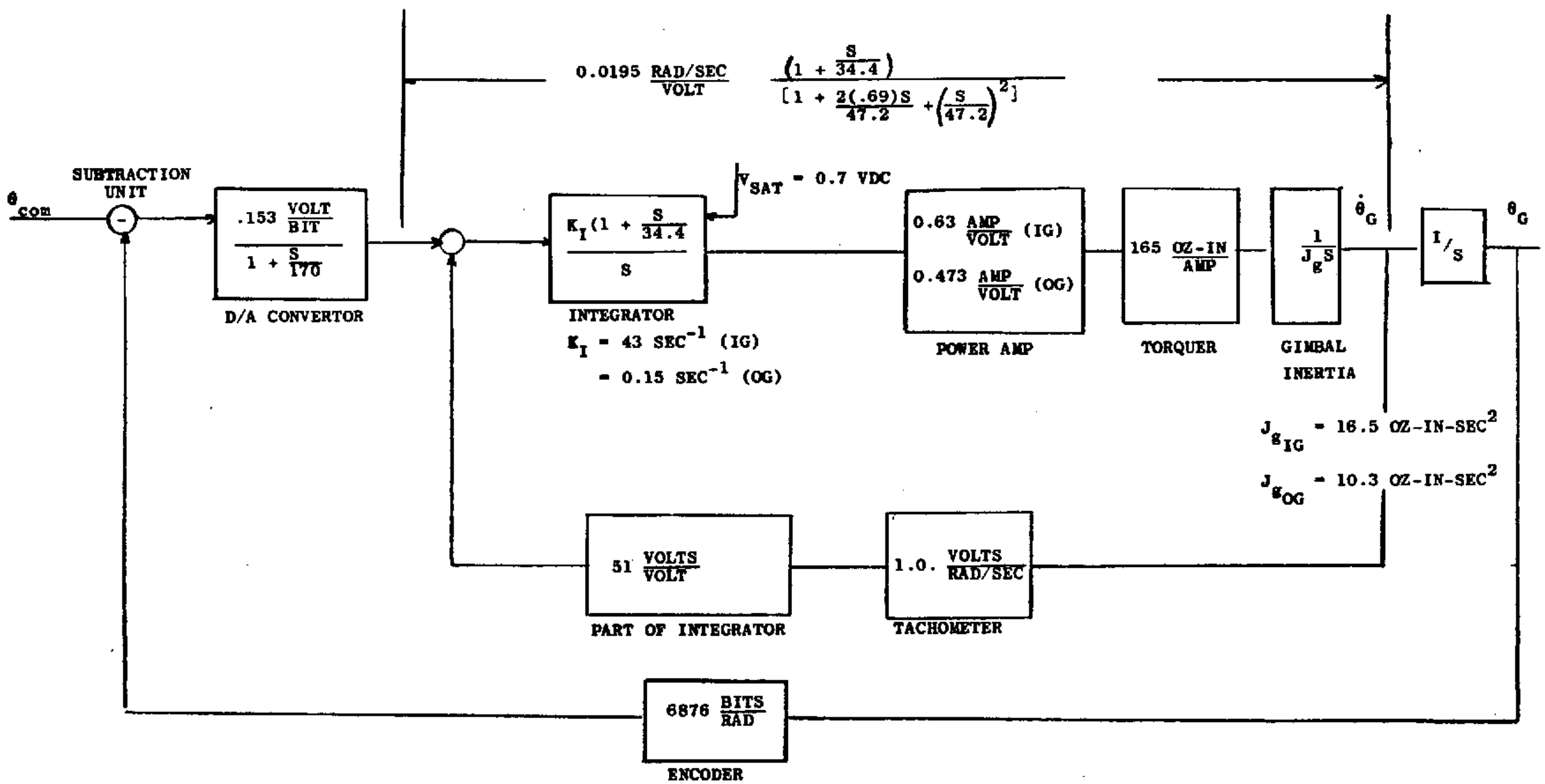



FIGURE 2.1.2-8




GIMBAL POSITION SERVO LOOP

FIGURE 2.1.2-9

### 2.1.2.4.2 Position Hold Loop

In the Shutter-Close/Hold mode, position-type loops are configured to hold both gimbals in a fixed position. This type servo loop is also implemented for the inner gimbal during automatic search, this time with the input command being a varying position.

The loop is similar in form to the track loop described in the previous section; the telescope and telescope electronics are replaced by a command register, digital subtraction unit, and D/A converter, and a digital encoder is used to provide the required feedback signal. A scaled block diagram of the inner and outer gimbal position loops is shown in Figure 2.1.2-9.

The open-loop transfer function of the position loop is:

$$A(S) = \frac{20.5}{S} \quad \frac{\left(1 + \frac{S}{34.4}\right)}{\left[1 + \frac{2(.69)S}{47.2} + \left(\frac{S}{47.2}\right)^2\right]\left[1 + \frac{S}{170}\right]}$$

A Bode plot of this transfer function is sketched in Figure 2.1.2-10. The loop has a zero dB cross-over frequency of 20.5 rad/sec (3.27 Hz), and a phase margin of 77.6 degrees.

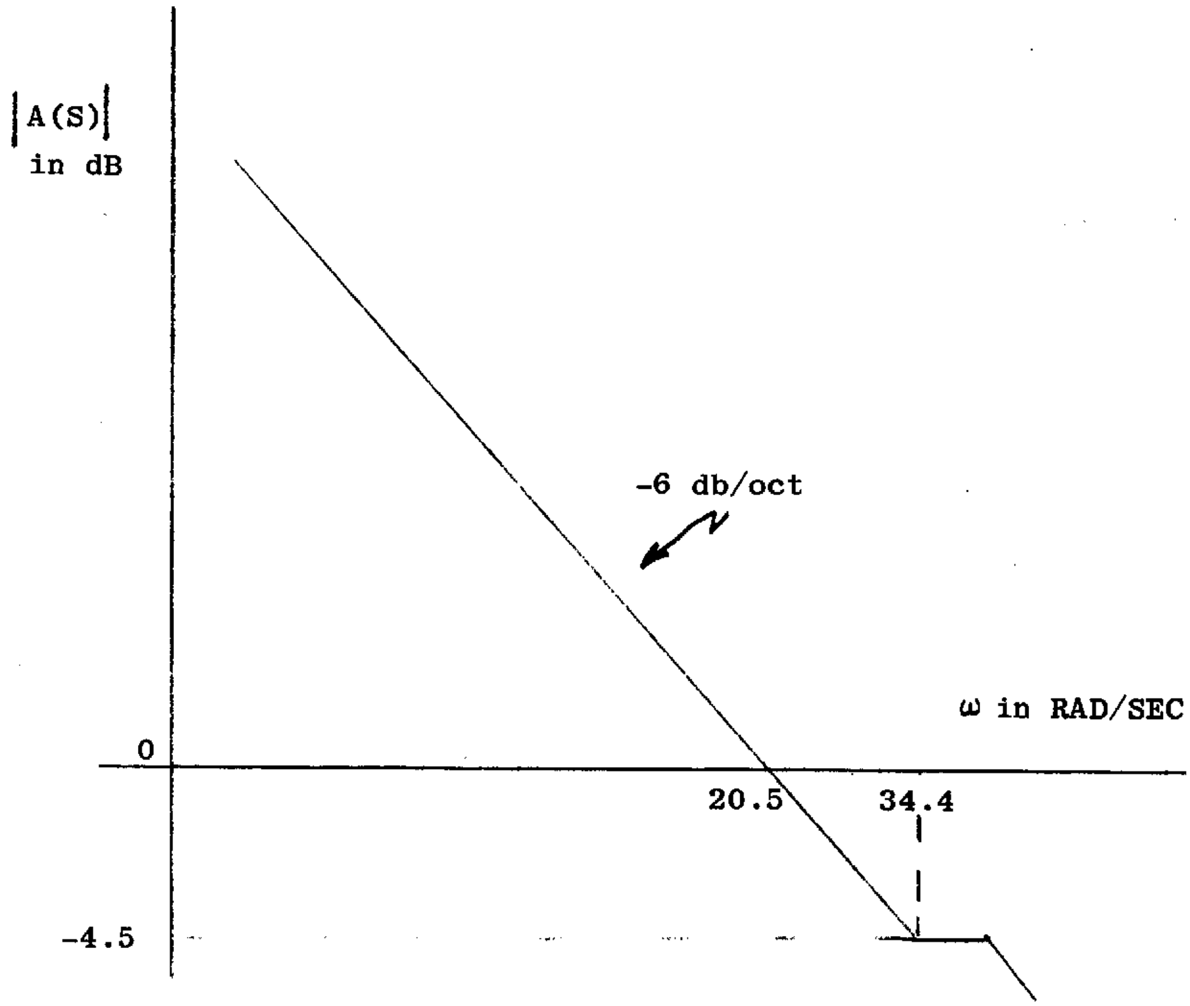



FIGURE 2.1.2-10

2.1.2.4.3 Manual Mode Servo Loop

In the Manual mode, DC signals from the hand controller are routed directly to the gimbal rate loops, the telescope electronics and D/A converters being disconnected. In this mode the rate loop is characterized by a scale factor of 0.224 deg/sec/volt.

2.1.2.4.4 Outer Gimbal/Automatic Search

The outer-gimbal loop configuration implemented during automatic search is shown in Figure 2.1.2-11. Reference to the figure shows that gimbal motion is achieved by driving the outer-gimbal rate loop of a constant speed, with the encoder being used to determine the duration and polarity of the rate command.

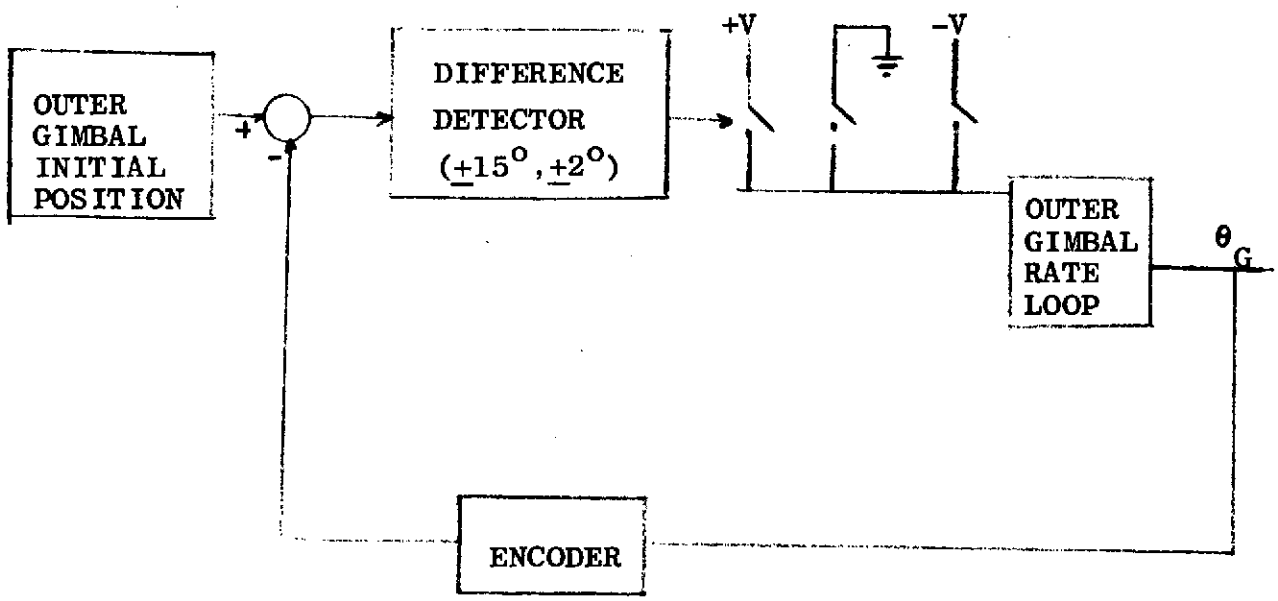



FIGURE 2.1.2-11

## 2.2 Telescope

The function of the telescope is to first determine whether a star of proper magnitude is within the $1^{o}$ field-of-view. When this occurs, a star presence signal is generated. Secondly, it must supply coordinate analog signals representing the error between the null reference axis (optical axis) and the impinging star line. When a proper star is located, a position feedback loop is closed, through the servo amplifiers, between these error-signals and the gimbal torquers, driving the error to zero.

Star light initially enters the telescope through the sun shade. The requirements of the sun shade are to reduce the intensity of the oblique rays from the sun (13,600 lumens per $cm^2$) or earth (1600 lumens per $cm^2$ steradian at 0.35 albedo) or other obstruction reaching the lens and subsequently the detector. This level must be lower than the intensity of Canopus and Achernar (the sun attenuation must be approximately $10^{13}$).

The collimated star light is then focused by an acromatic lens through a reflecting wedge onto the photocathode face of the detector. The 1.0 inch clear aperture of the lens is sufficient to collect sufficient star light energy to generate a high signal-to-noise ratio, a figure of merit inversely proportional to the magnitude of the telescope accuracy. The reflecting wedges not only folds the light path, thus reducing the overall package length, but also act as a mechanical nulling device through rotation on their mounts to align the optical axis of the telescope to the mounting pads during assembly.

Light energy is converted to electrical energy at the photocathode surface. The tube used is an S-20 type, ruggedized combination image dissector and multiplier tube (ITT FW 143) with high cathode sensitivity (250 micro amperes per lumen) and high gain ($2.5 \times 10^6$). The operation of the detector is such that electrons coming off the photocathode, from the point of focused star light, are subsequently accelerated by a 600 volt potential. (An additional 1400 volts is applied across the dynode section). They are then electrostatically focused by another field at the plane of the square field aperture. The size of this instantaneous aperture represents a field-of-view of 10 arc minutes. Electrons entering the aperture are multiplied by a chain of 16 dynodes resulting in an anode signal current.

A magnetic coil encircles the image dissector portion of the tube, the area between the photo-cathode and square aperture. The coil deflects the electron beam such that electrons emitted from a relatively large area of the photocathode can be deflected so as to pass through the aperture.

Essentially, star position information is obtained by electronically measuring the distance between the focused point of star light on the photocathode and the null point. (Star line coincident with the optical axis). This distance is proportional to the angle between the star line and optical axis.

The detection system measures this distance by measuring the magnetic coil current necessary to deflect the electron beam through the center of the 10 arc minutes square aperture. The x and y coordinates of this current are the error signals used in the feedback loop to position the telescope.

During the Acquisition mode, the electron beam is scanned in a raster pattern over a $1^{\circ}$ square. This can be depicted as if the 10 arc minute square instantaneous field-of-view if being scanned over the $1^{\circ}$ square.

When a star of proper magnitude enters the field, the raster scan currents are held and a small amplitude cruciform scan is superimposed on the raster scan. The amplitude of the cruciform is 10 arc minutes in the positive and negative directions of each of the two coordinate axes. Thus two axes information is generated. This scan produces a modulated star position signal which, after demodulation, represents the distance between the star image and the center of the instantaneous 10 arc minute field. These relatively small coordinate signals are used to modify the raster scan currents and thus bring the star image to the center of the instantaneous field.

If the system is in track mode, the loop between these telescope error signals and gimbal torquers will drive the optical axis into alignment with the star line. The telescope also provides for protective sensors to close the protective shutter when the sun comes within $45^{\circ}$ and the earth comes within $5^{\circ}$ of the optical axis. The earth angle triggering point assumes an albedo of 0.35.

The ATM Tracker Sunshade can provide tracking to within $5^{\circ}$ of the earth. When the earth, or other equal intensity object, moves within less than this angle, the telescope will not track to the specified accuracy. Actual protection of the detector is not required until a smaller angle is reached.

## 2.3 Optical System

For star trackers the important subsystem, which initiates the performance of the tracker is the optical system. While the sun shade attenuates all oblique light, the optics collect radiant energy from the star and image the star onto the photosensitive surface of the image dissector.

### 2.3.1 Objective Lens with Prism

The optics of the Bendix star tracker systems consist of an acromatic doublet and 2 aluminized reflecting wedges. The objective lens is a 6.833 inch focal length, F/4.6, aplanatic doublet. The major considerations taken into account in the lens design are good imagery in the spectral range from 365 Mμ to 800 Mμ, and the use of radiation protection (non-browning) glasses. The objective has a 1.500 inch clear aperture stopped to 1.00 inches by a baffle in order to attenuate stray light and to reduce the total sunshade length. The wedges used with the objective is employed to fold the optical path, therefore, yielding a more compact telescope assembly.

2.3.1.1 Image Quality

In the image plane of the optics, the star image blur circle is less than 0.002 inch diameter and contains approximately 80% of the star energy transmitted through the components.

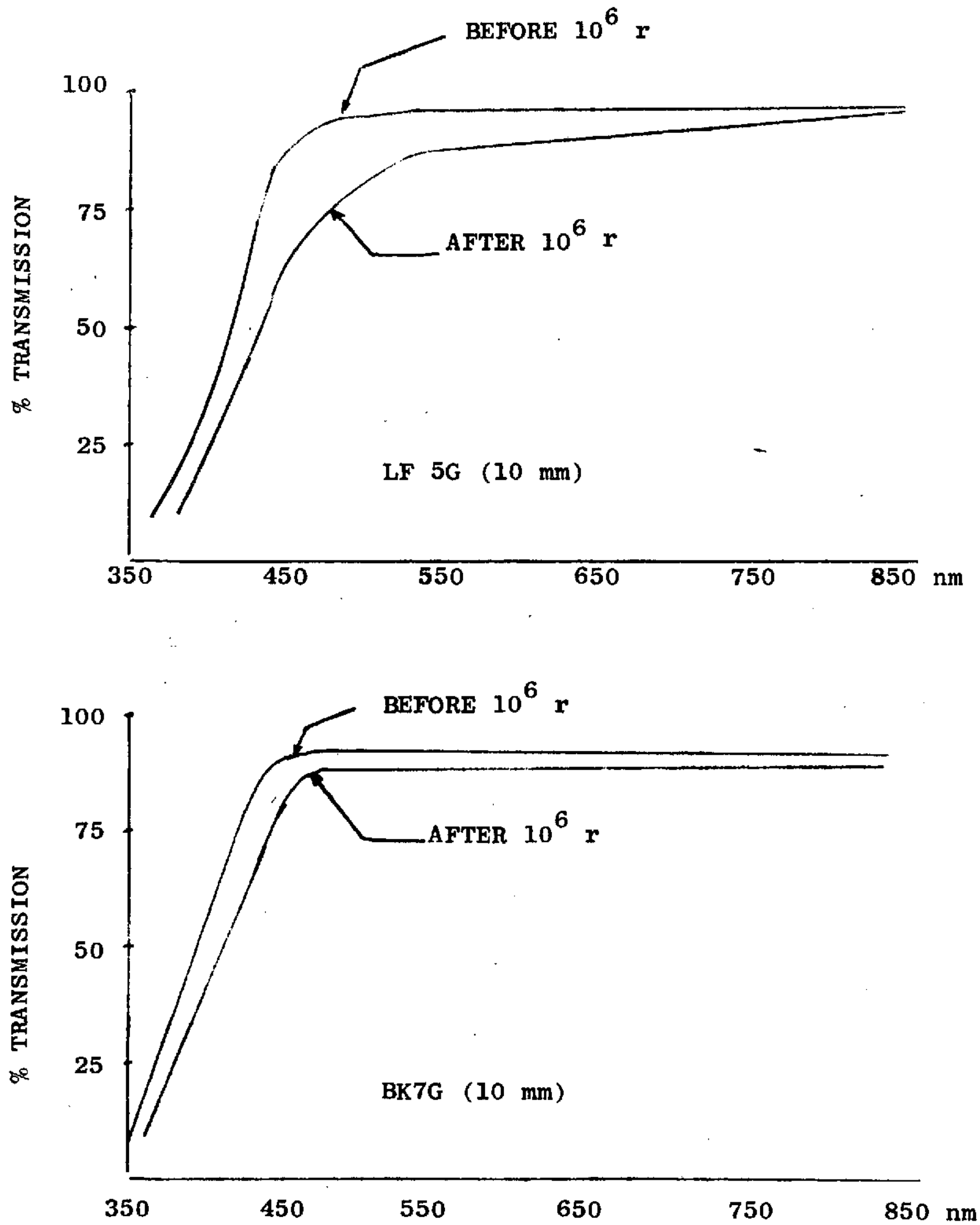
2.3.1.2 Lens Design and Transmission Characteristics

The objective was designed to function with the wedges used to fold the optical path. The front element of the objective is made of Schott BK7G, a boroscilicate crown glass doped with cerium oxide to provide radiation protection. An air space exists between the front element of the objective and the rear element. The rear element of the objective is made of Schott LF5G, a light flint also doped with cerium oxide. The transmission characteristics of the two glasses are given in Figure 2.3.1.2-1.

From the figure it can be seen that the transmission characteristics of the two glasses remain with 90% of the initial values after being subjected to radiation dosages of $10^6$ rads.

2.3.1.3 Stray Light Attenuation

An optical coating (Luxorb) is applied to areas of the lens element edges which do not transmit or reflect the star light energy. This reduces off-axis stray light. Unless substantially attenuated, the stray light can, through multiple internal reflections, reach the detector and appear as extraneous noise. According to the Fresnel Equation of Reflection, light is reflected whenever it is incident on surfaces where there is a difference




LENS ELEMENT RESISTANCE TO RADIATION

FIGURE 2.3.1.2-1

of optical index on both sides of the surface. The index of refraction of the Luxorb used is matched to the third decimal point to the glass on which it is applied. Therefore, reflection virtually does not occur at the glass-Luxorb interface, and the light is absorbed by dyes which are an ingredient of the Luxorb. Reflection attenuations on the order of $10^{-5}$ have been experimentally verified by tests performed at Bendix.

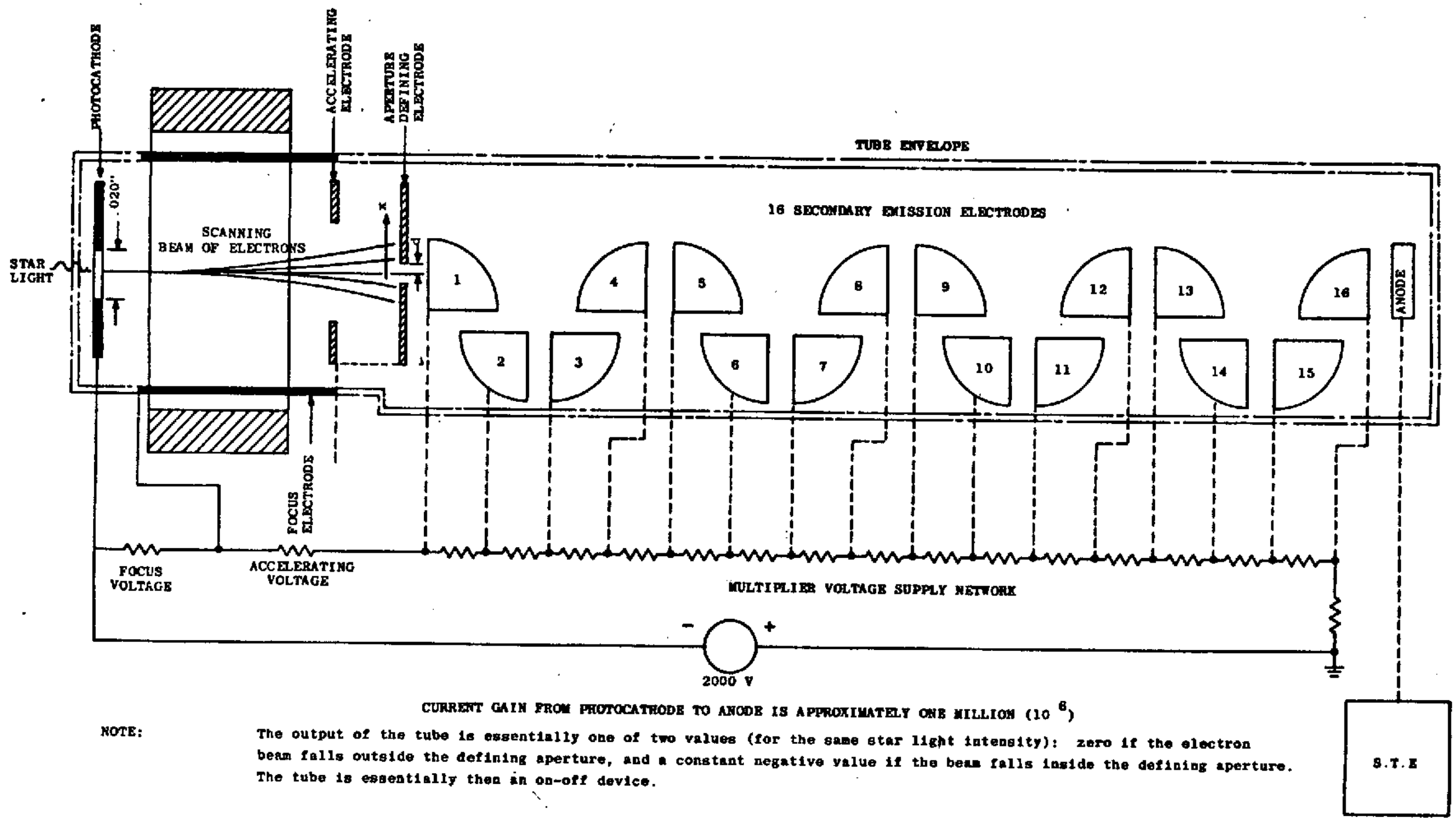
2.3.1.4 Lens Housing

The lens housing of the star tracker objective is made of beryllium. The housing is vented so that the air in the air space can be bled off, thus eliminating unnecessary stress upon the optical elements when the ambient becomes the hard vacuum of space. From thermal analysis it has been shown that the lens assembly will have a temperature excursion in space operation of slightly greater than $100^{o}$F.

2.3.2 Detector

The detector provides the main system transducer which converts the optical information of the star's position to a workable electronic signal.

This is accomplished by an external magnetic coil and the three main sections of the tube; the photocathode, the electron lens system (of which the aperture is an integral part) and the dynode multiplier. (See Figure 2.3.2-1). In operation, illumination from the star being tracked is imaged onto the photoemissive cathode driving off electrons which are accelerated toward the aperture. During this interval two things occur. First, the electron lens system converges the electrons and focuses




CURRENT GAIN FROM PHOTOCATHODE TO ANODE IS APPROXIMATELY ONE MILLION ($10^6$)

NOTE: The output of the tube is essentially one of two values (for the same star light intensity): zero if the electron beam falls outside the defining aperture, and a constant negative value if the beam falls inside the defining aperture. The tube is essentially then an on-off device.

STAR TRACKER DETECTOR

FIGURE 2.3.2-1

them onto an aperture located in the electrostatic image plane of the tube. Second, the external magnetic coil, mounted around this section, systematically deflects the electron image across the aperture. The electrons gaining entrance through the aperture are increased by dynode multiplication thus forming an "on" signal. The electrons which are swept onto the plate containing the aperture do not enter the multiplier, hence an "off" signal is produced during this interval. The information on the position of the star being tracked is contained in the wave train of the on-off pulses. It should be noted that this type of modulation scheme is devoid of moving parts, thus improving the reliability of the system.

The particular detector used for the A.T.M. Star Tracker is a ruggedized image dissector photomultiplier (ITT FW143).

The tube employs an S-20 (tri-alkali)photoemissive cathode. The S-20 was chosen because of its high quantum efficiency and low dark current. It is especially suited for tracking Canopus since its spectral content peaks at approximately the same wavelength as the spectral distribution of Canopus, 4200 angstroms. The cathode response in the blue end of the spectrum assists in providing a high efficiency for tracking blue stars such as Achernar, while maintaining sufficient sensitivity for acquisition and track of Alpha Crux.

The electrostatic lens system employed in the proposed detector consists of a focusing ring deposited internally on the neck of the tube envelope and a square aperture.

The focusing feature increases resolution by reducing the size of the electron image that is deflected across the aperture.

In the plane of the electrostatic lens is an aperture, 0.014 inches on a side. Due to the geometry of the tube, the accelerating potential, and the focusing dynamics, the aperture is projected onto the photocathode with a magnification factor of 1.4. This area, 0.020 inches, and the optical focal length, 6.833 inches, produces an instantaneous field of view of 10 arc minutes. The limited cathode area reduces the equivalent noise input by minimizing collected thermionic emission, at the same time maintaining high collection efficiency. A reduction of dark noise by a factor of 36 is realized in using the ten minute field of view as opposed to a 1 degree IFOV system with no loss to signal current.

Beyond the aperture is the multiplier section consisting of 16 dynodes each of which exhibits secondary electron emission characteristics of approximately 2.5. The 16 stages thus produces an overall electron gain of approximately 2.5 million.

The anode, situtated beyond the multiplier, collects the electrons and thus serves as the signal electrode.

Bendix has measured the dynamic characteristics of a tube using a small (14 arc minute square) field of view in conjunction with an external magnetic coil. The purpose of the test was to locate the deflected star electron image and thus determine the linearity characteristics of the tube coil combination. The results of scanning the electron beam over a field of view of $2^o \times 2^o$ verified performance requirements.

2.3.3 Sun Shade

The sun shade has been tested successfully to within $40^o$ of the sun at the GE solar impingement-vacuum test chamber at Valley Forge. Computer studies performed by Bendix have confirmed an allowable earth light impingement down to $5^o$ (no adequate earth simulator exists). Bendix has also determined mathematically (by computer) that vehicle obstruction effects are less than the effect of the earth.

2.3.4 Sensors

The Bendix Corporation has designed, developed and fabricated for ATM use, two types of sensors, for the purpose of providing the star tracker photomultiplier tubes with protection from direct earth and sun illumination. Each type of sensors was individually designed to operate at specific sun and earth angles over a wide range of temperature variations to match their related trigger electronics. These sensors have been tested and qualified for ATM.

In order to provide a redundant protective system for the star tracker, the sun and earth sensors each have separate trigger electronics and have the capability of reading to both, the sun and the earth.

For calibrating and testing these sensors, Bendix has developed an earth albedo simulator and a $3000^oK$ two degrees beam spread tungsten sun that has an energy output equivalent to zero space sun.

Earth Sensor

The earth sensor is a photovoltaic device consisting of three voltaic cells arranged in such a way to achieve maximum sensitivity. This photovoltaic device provides a signal which will trigger when the angle of the optical axis to the earth's zenith is $5^{\circ}$ maximum. The reflected sunlight from the earth's albedo enters through an objective lens and produces an image of the earth's horizon. When the earth first comes into the field of view, the first cell becomes operative and yields a positive output. As the earth comes more and more in the field of view, the second and third cells provide an opposing negative signal to the first cell. The output of all three cells is voltaic and is fed into a high impedance circuit. Since the photovoltaic device is required to operate over a significantly large temperature ranges, a thermistor is used to adjust the sensor temperature coefficient to that of the related earth trigger.

Specifications for the earth sensor and trigger electronics are as follows:

| | |
|---|---|
| Temperature: | $\pm 1^{\circ}$ trigger angle $+25^{\circ}C$ to $-75^{\circ}C$ |
| Rotational Symmetry: | $\pm 1^{\circ}$ |
| Sensor Output Voltage: | -200 mv $+25^{\circ}C$ |
| Trigger Angle: | $5^{\circ}$ maximum with 35 Albedo |

The earth sensor will not activate prematurely to the sun at an angle greater than $45^{\circ}$.

Sun Sensor

The sun sensor is identical in construction and operation to that of the earth sensor. Like the earth sensor it serves as a protective device. It protects the photomultiplier tube from damage when the angle between the sun rays and the optical axis is $45^\circ$. A feature of the sun sensor is the use of an internal resistive network that prevents the sun sensor from activating prematurely against the earth at an angle greater than $5^\circ$.

Specifications for the sun sensor and related trigger electronics are as follows:

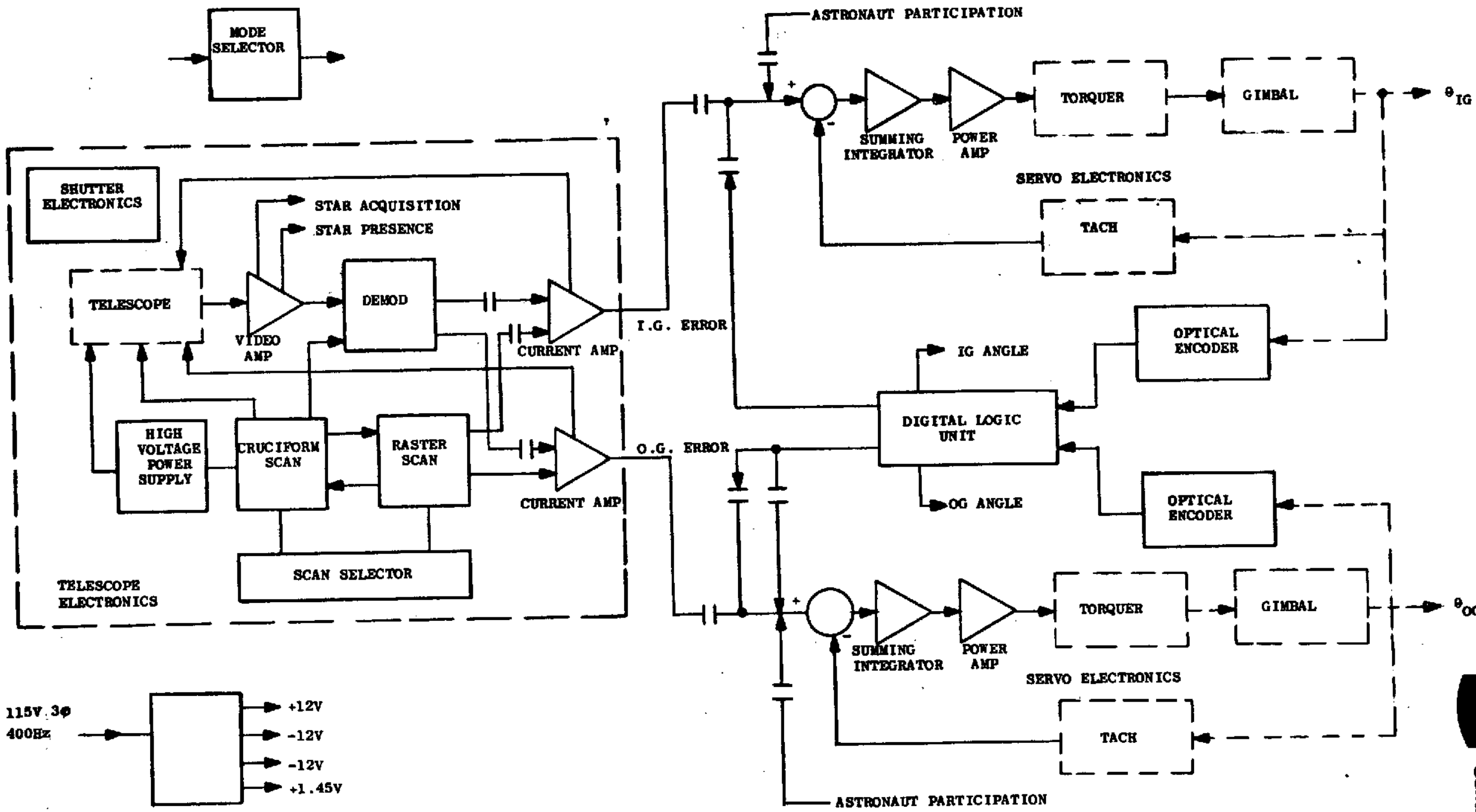
| | |
|---|---|
| Temperature | $\pm 1^\circ$ trigger angle $+25^\circ C$ to $-75^\circ C$ |
| Rotational Symmetry: | $\pm 1^\circ$ trigger angle |
| Sensor Output Voltage: | $-200$ mv at $+25^\circ C$ |
| Trigger Angle: | $45^\circ$ maximum |

## 2.4 Electronics

### 2.4.1 Introduction

The electronics unit used with the Star Tracker is shown in Figure 2.4.1-1 and may be divided into the following functional sections: (1) Mode Selector, (2) Telescope Electronics, (3) Servo Electronics, (4) Digital Logic Unit, and (5) Power Supplies.

The Mode Selector acts as an interface between the Star Tracker and the ATM input command discretes. This unit transforms the voltage level of the input commands to one compatible with the microcircuits used in the Star Tracker electronics, and also logically combines the input commands with a Star Presence signal to produce command signals to which the tracker electronics can respond directly.




BLOCK DIAGRAM, ATM STAR TRACKER ELECTRONICS
FIGURE 2.4.1-1

The Telescope Electronics supply error signals to the servo electronics proportional to the angle between the star line and the optical axis of the telescope, and also generate a Star Presence signal when the proper magnitude star is within the field-of-view of the telescope. The Telescope Electronics consist of the following sub-units: (a) Video Amplifier, (b) High Voltage Power Supply, (c) Raster Scan Electronics, (d) Cruciform Scan Electronics, (e) Demodulator, (f) Scan Selector, and (g) Shutter Electronics.

The Servo Electronics receive analog command signals from Telescope Electronics, the Digital Logic Unit, and the astronaut's Hand Controller, and supply the gimbal torque motors with properly scaled and compensated drive signals.

The Digital Logic Unit (DLU) contains the electronics required to perform a fine and coarse two-axis gimbal search, and the electronics required to hold the gimbals stationary. The DLU also provides the ATM digital computer with the required inner and outer gimbal position information.

The power supplies generate ±12 VDC, +5VDC and +1.45 VDC regulated voltages.

Each of the functional units mentioned above is described in more detail in the following sections.

### 2.4.2 Mode Selector Electronics

The Mode Selector constitutes the interface between the ATM system and the Star Tracker, and logically operates on the external input commands to produce command signals to which the Star Tracker can respond directly.

The Mode Selector receives the following inputs:

From Digital Computer

1. Automatic Mode
2. Shutter-Closed/Hold

From Control and Display Panel

1. Manual Command
2. Automatic Mode
3. Shutter Closed/Hold

From Telescope Electronics

1. End Search Pulse: A 200 m sec. pulse which indicates search is ending and the telescope electronics is switching to the track mode.
2. Star Presence
3. Shutter Closed

The Mode Selector provides the system with the following control signals.

1. Manual Command: This command activates relays in the servo loops and in the output interface.
2. Track Command: This command activates relays in the servo loops.
3. Search Command: This output notifies the DLU when the search mode is selected.
4. Output Gimbal Search Command: This command energizes a relay in the outer gimbal servo loop when the Search mode is selected.
5. Inner Gimbal Search/Hold Command: This command operates a relay in the inner gimbal servo loop when either the Search or Hold mode is selected.

6. Hold Command: This command notifies the DLU when the Hold mode is selected.
7. Outer Gimbal Hold Command: This command operates a relay in the outer-gimbal servo loop when the Hold mode is selected.
8. Automatic Mode Indication: This output energizes a relay in the output interface when the Automatic mode is selected.
9. Shutter-Close Command: This command is fed to the Shutter Electronics when the Shutter-Close/Hold mode is selected.

The operation of the Mode Selector is summarized in Figure 2.4.2-1, and the circuit diagram is shown in Figure 2.4.2-2.

## 2.4.3 Telescope Electronics

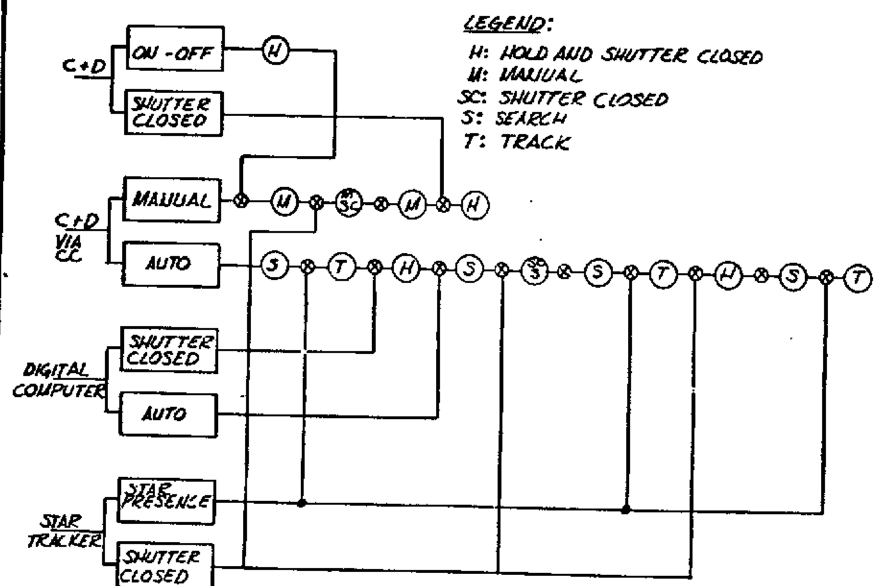
### 2.4.3.1 General Description

The telescope electronics supply the two-axis analog error information required by the servo electronics, and a Star Presence signal which indicates when the desired star is within the field-of-view of the telescope. The Star Tracker is characterized by two fields-of-view, a one degree acquisition field and a 10 arc minute track field. The first of these, the acquisition field, is operative only during the time the star search is being conducted. The second field, the tracking field, is smaller than the first and is operative after the star is operative after the star has been acquired. The telescope electronics described in this section provide this dual field capability.

A block diagram of the Telescope Electronics is shown in

| PART NO. |
|---|
| |

| MF | ZONE | LTR | REVISIONS DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|---|




MODE SELECTION

| COMMAND | RESULTS |
|---|---|
| ON: C AND D | SHUTTER CLOSED AND HOLD. |
| MANUAL: C AND D VIA CC | MANUAL MODE; OVERRIDES ANY PREVIOUS COMMAND. |
| AUTO: C AND D VIA CC | SEARCH MODE; OVERRIDES MANUAL COMMAND. |
| STAR PRESENCE: STAR TRACKER | SYSTEM SWITCHES FROM SEARCH TO TRACK MODE; DOES NOT OVERRIDE MANUAL MODE. |
| SHUTTER CLOSED: D.C. | SHUTTER CLOSED AND HOLD; WILL NOT OVERRIDE MANUAL MODE. |
| AUTO D.C. | SAME AS AUTO FROM C+D EXCEPT WILL NOT OVERRIDE MANUAL MODE. |
| SHUTTER CLOSED: C AND D | SHUTTER CLOSED AND HOLD; OVERRIDES ANY PREVIOUS COMMAND. |
| SHUTTER CLOSED: STAR TRACKER | SHUTTER CLOSES AND SYSTEM REMAINS IN PREVIOUS MODE EXCEPT WHEN IN TRACK MODE IN WHICH CASE THE SYSTEM GOES INTO HOLD MODE. |
| DIGITAL COMPUTER DISCONNECT: | MODE SELECTOR DISREGARDS DIGITAL COMPUTER INPUTS. |

PREPARED BY NAVIGATION AND CONTROL DIVISION OF THE BENDIX CORPORATION FOR GEORGE C. MARSHALL SPACE FLIGHT CENTER NASA, HUNTSVILLE, ALABAMA

*—INDICATES SUBASSEMBLY
†—VENDOR ITEM – SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING

—LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103

UNLESS OTHERWISE SPECIFIED
—DIMENSIONS ARE IN INCHES
—TOLERANCES ON DECIMALS
2 PLACE ± .03 | 3 PLACE ± .005 | 4 PLACE ± .0005

HARDNESS

FINISH

MATERIAL

DR | 26 FEB 69
CHK | 13 MAR 69
ENGR | 13 MAR 69
T.D.
MET
REL
APPD | 13 MAR 69

CONTRACT NO.

APPROVAL

APPROVAL

PART REF

ORIGINALLY DESIGNED FOR 2126108

THE BENDIX CORPORATION — NAVIGATION & CONTROL DIVISION, TETERBORO, NEW JERSEY, U.S.A.

MODE SELECTION

SIZE C | CODE IDENT NO. 19315 | 2125965

SCALE | SHEET 1 OF 1

☐ DO NOT MARK PART NO.
☐ MARK PART NO. AS SPECIFIED

ATMST/SX 1-12A

Bendix Navigation & Control Division



FIGURE 2.4.2-1

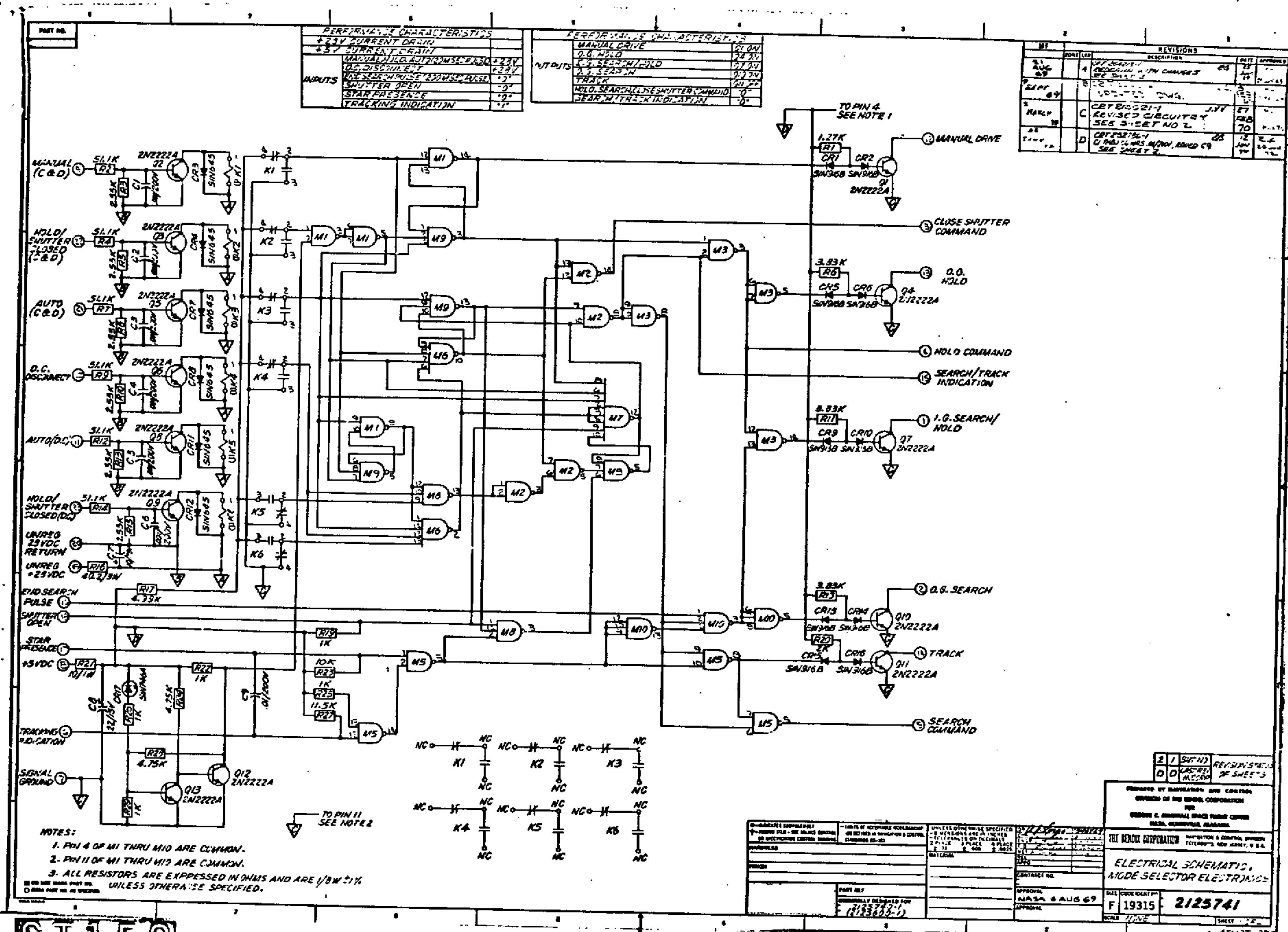

PERFORMANCE CHARACTERISTICS
+23V CURRENT DRAIN
+5V CURRENT DRAIN
INPUTS
SHUTTER OPEN
STAR PRESENCE
TRACKING INDICATION
OUTPUTS
MANUAL DRIVE
TRACK
REVISIONS
CBT 8/0021-1 REVISED CIRCUITRY SEE SHEET NO 2
TO PIN 4 SEE NOTE 1
MANUAL (C&D)
HOLD/ SHUTTER CLOSED (C&D)
AUTO (C&D)
O.C. DISCONNECT
AUTO/DC
HOLD/ SHUTTER CLOSED(DC)
UNREG 23VDC RETURN
UNREG +23VDC
END SEARCH PULSE
SHUTTER OPEN
STAR PRESENCE
+5VDC
TRACKING INDICATION
SIGNAL GROUND
MANUAL DRIVE
CLOSE SHUTTER COMMAND
O.G. HOLD
HOLD COMMAND
SEARCH/TRACK INDICATION
I.G. SEARCH/ HOLD
O.G. SEARCH
TRACK
SEARCH COMMAND
TO PIN 11 SEE NOTE 2
NOTES:
1. PIN 4 OF M1 THRU M10 ARE COMMON.
2. PIN 11 OF M1 THRU M10 ARE COMMON.
3. ALL RESISTORS ARE EXPRESSED IN OHMS AND ARE 1/8W ±1% UNLESS OTHERWISE SPECIFIED.
THE BENDIX CORPORATION
ELECTRICAL SCHEMATIC, MODE SELECTOR ELECTRONICS
NASA 6 AUG 69
F 19315 2125741

FIGURE 2.4.2-2

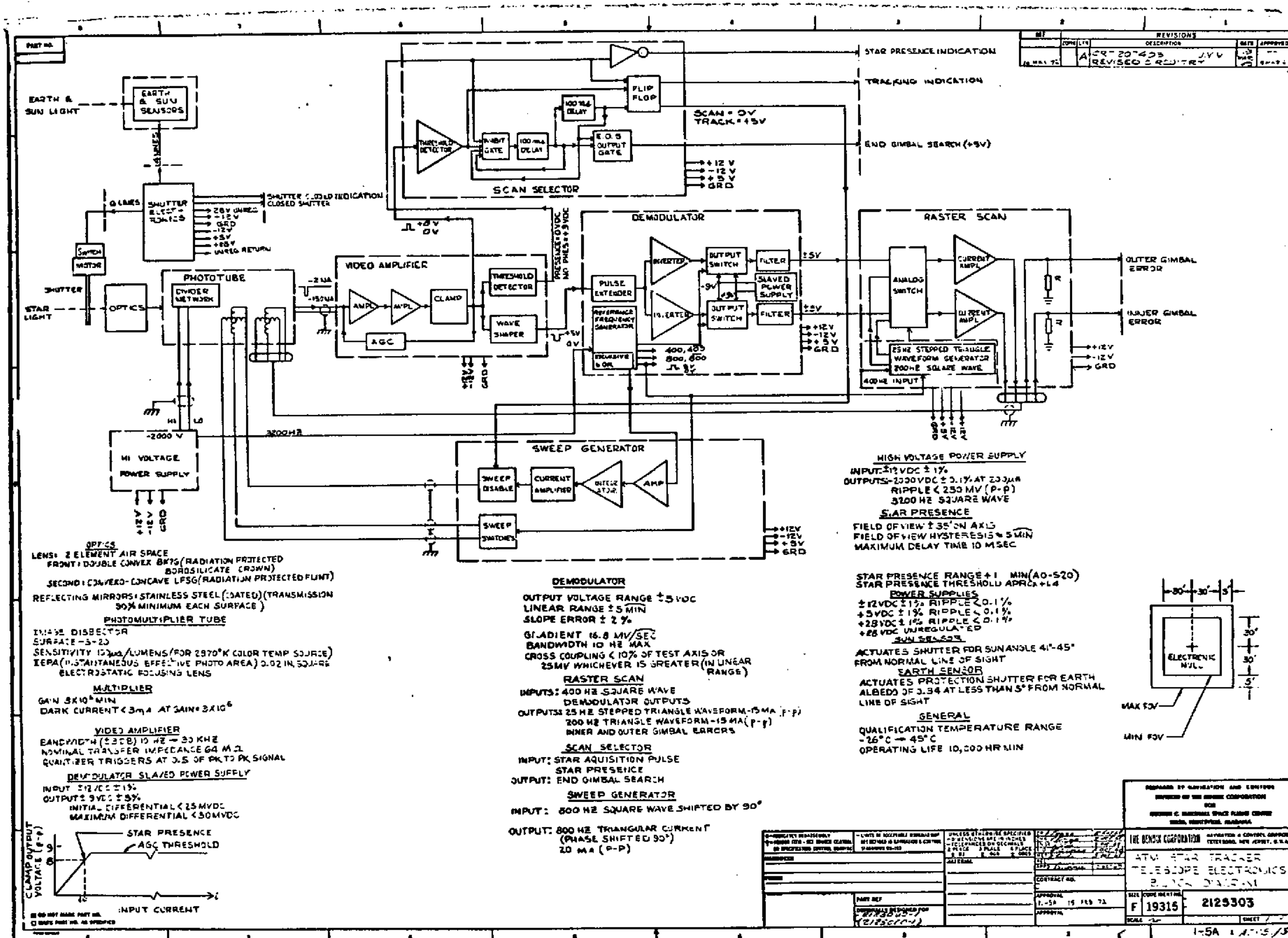
Figure 2.4.3-1. Included on the diagram are the performance characteristics of the several functional units comprising the electronics.

In the Search mode of operation the Raster Scan Electronics produce the waveforms required to electronically scan the one degree acquisition field. The scan pattern produced by these waveforms consists of a linear sweep of the 10 arc minute instantaneous field-of-view along one axis followed by a stepped motion along the other. When a star of proper magnitude enters the one degree field a "Star Acquisition" pulse is generated by the Video Amplifier.

This pulse is accepted by the Scan Selector which, in turn, generates an "End Search" pulse which terminates the mechanical gimbal search, and, after a small time delay, switches the system from the raster to the cruciform scan. A star presence signal is then generated and the system switches to the track mode of operation.

In the Track mode the output signal from the Video Amplifier is a modulated function of star position relative to the instantaneous field-of-view of the telescope and is sent to the Demodulator for further processing. The Demodulator gates this video signal with reference signals derived from the 3200 Hz clock to produce a DC error signal proportional to the misalignment angle between the star line and the center of the instantaneous field-of-view of the telescope.

The output signals from the Demodulator are sent to the




Bendix Navigation & Control Division

ST155

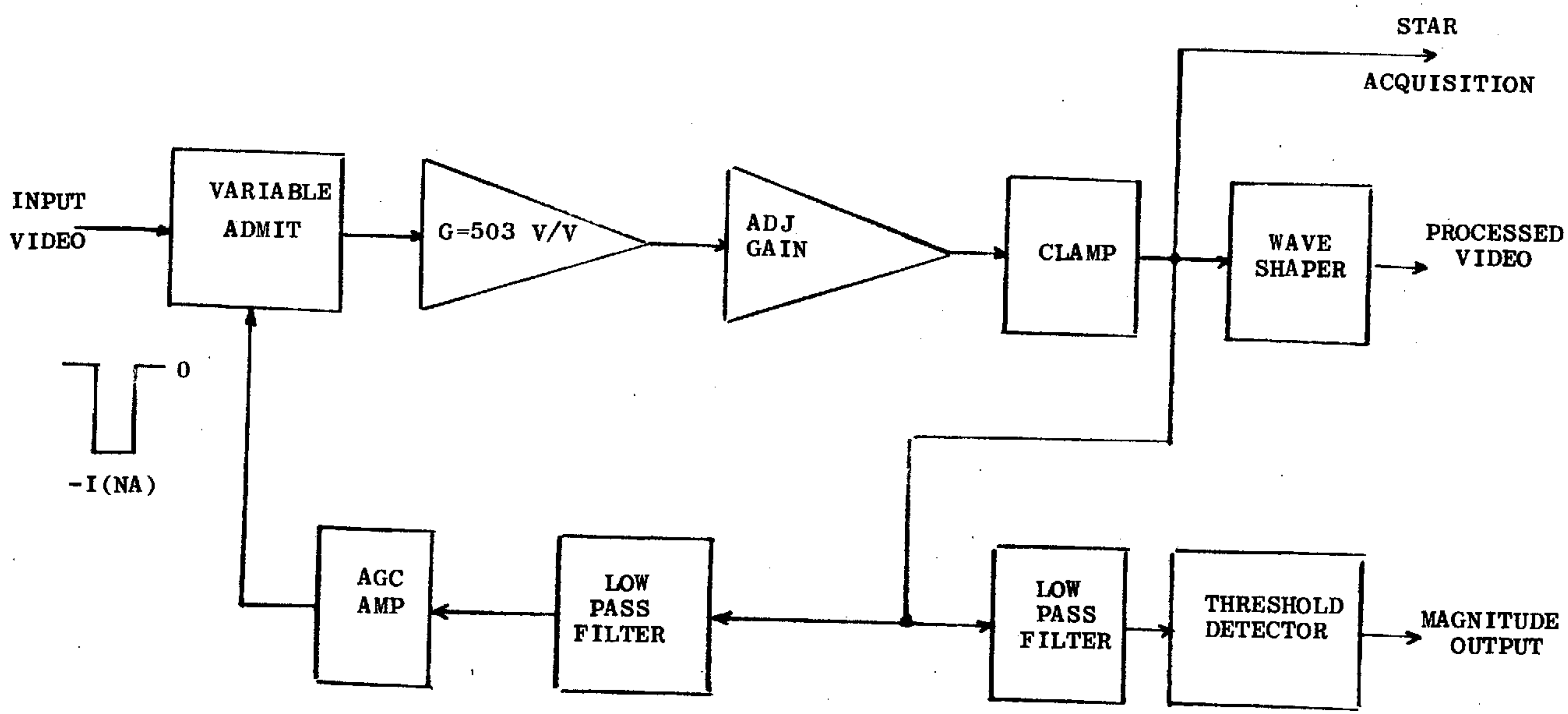
FIGURE 2.4.3-1

current amplifiers of the Raster Scan Electronics. These amplifiers drive the deflection coils so as to reduce the demodulator output signals to zero, which results in the star line being brought into coincidence with the axis of the instantaneous field-of-view of the telescope. The resultant deflection coil currents are thus proportional to the star line/optical axis misalignment angle and therefore represent the analog error signals required by the servo electronics. Thus, in the Track mode, the telescope electronics form an all-electronic tracking loop, independent of the gimbal servo loops, in which the instantaneous field-of-view of the telescope is brought into coincidence with the star line.

A more detailed description of the units making up the telescope electronics is given in the following sections.

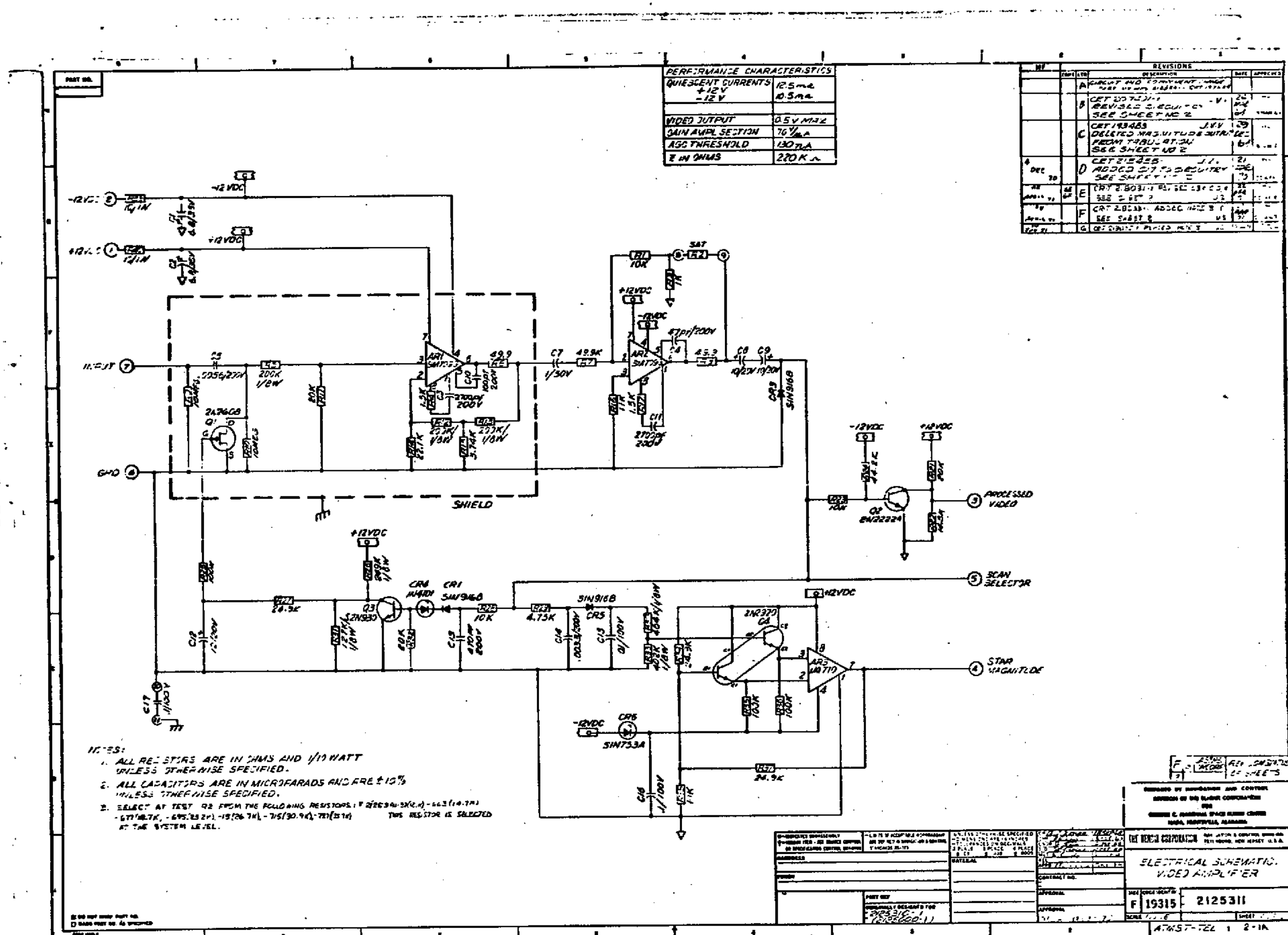
2.4.3.2 Video Amplifier

The Video Amplifier receives current pulses from the photomultiplier tube and processes these signals to form the Star Acquisition signal, the Star Presence Signal, and the modulated star-position error signals. The first two processed signals are used by the Scan Selector to determine the scan mode of operation, and the error signals are used by the demodulator to generate the DC signals required by the output current amplifiers in the Track Mode. In addition, the Star Presence signal is used to control the overall tracker mode of operation. A block diagram of the Video Amplifier is shown in Figure 2.4.3-2, and a circuit schematic in Figure 2.4.3-3.




VIDEO AMPLIFIER BLOCK DIAGRAM

FIGURE 2.4.3-2


PERFORMANCE CHARACTERISTICS
QUIESCENT CURRENTS +12V 12.5ma
-12V 10.5ma
VIDEO OUTPUT 0.5V MAX
GAIN AMPL SECTION
AGC THRESHOLD
Z IN OHMS 220K
REVISIONS
INPUT
GND
SHIELD
PROCESSED VIDEO
SCAN SELECTOR
STAR MAGNITUDE
+12VDC
-12VDC
NOTES:
1. ALL RESISTORS ARE IN OHMS AND 1/10 WATT UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS ARE IN MICROFARADS AND ARE ±10% UNLESS OTHERWISE SPECIFIED.
3. SELECT AT TEST R2 FROM THE FOLLOWING RESISTORS. THIS RESISTOR IS SELECTED AT THE SYSTEM LEVEL.
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ELECTRICAL SCHEMATIC VIDEO AMPLIFIER
F 19315 2125311

FIGURE 2.4.3-3

Basically, the Video Amplifier consists of a variable admittance input branch coupled to a high-input-impedance non-inverting fixed-gain stage of 503 V/V. The second stage is an adjustable gain stage used to tailor the phototube to the system. The gain of this stage is adjusted so that the magnitude threshold detector triggers for the threshold star.

The output of the second stage is clamped to -0.5V for comparison to the magnitude threshold detector, scan selector, threshold detector, processed video output waveshaper and the AGC amplifier.

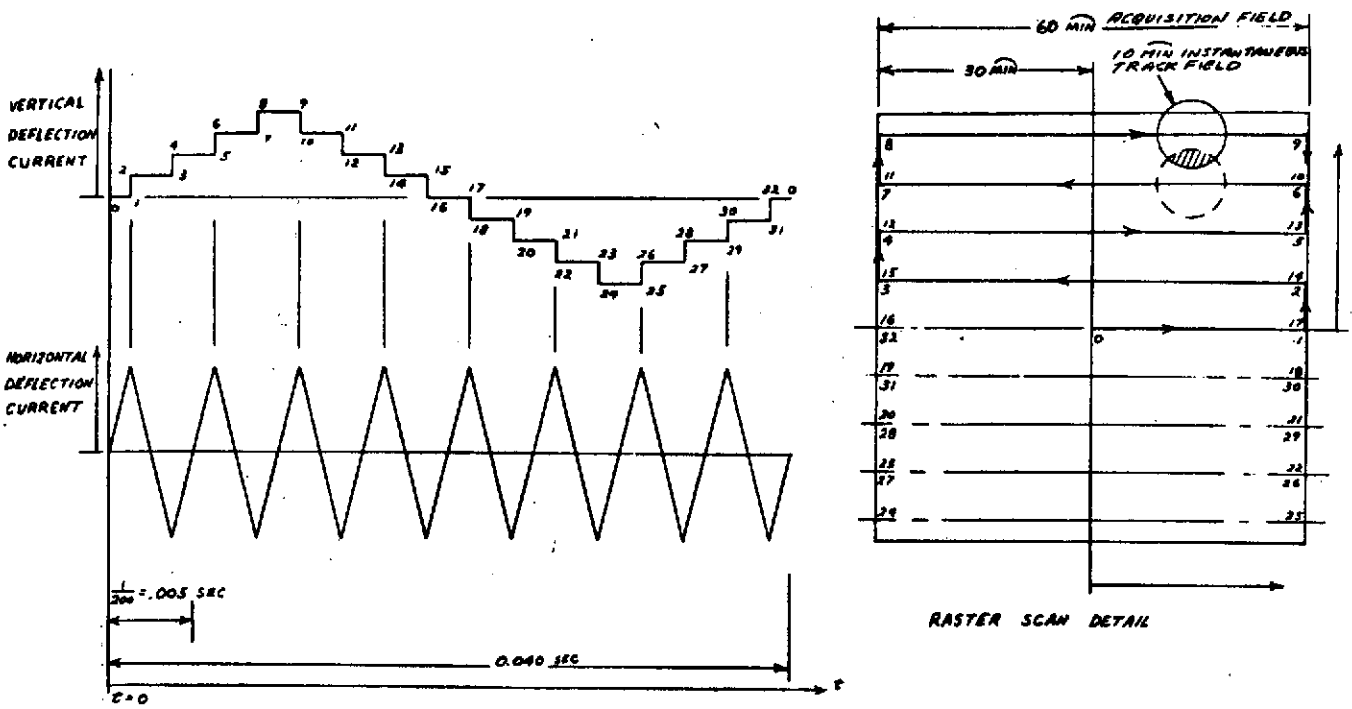
The processed video turns on at approximately one half of the peak-to-peak value of the threshold star.

The AGC amplifier is set to turn on at a leverl 23% above the level at which the magnitude detector turns on. The AGC amplifier controls the variable admittance input stage of the amplifier. The variable admittance stage consists of a current divider network in which one branch of the divider is a 10 meg resistor in parallel with a field-effect transistor, whose drain-to-source admittance is controlled by the AGC amplifier.

The low pass filters at the input to the magnitude detector and AGC amplifier are for filtering any high frequency spikes contained in the signal.

### 2.4.3.3 Raster Scan Electronics

The Raster Scan Electronics provide the waveforms required to electrically scan the one degree acquisition




RASTER SCAN SEARCH PATTERN

FIGURE 2.4.3-4

field in the Search mode of operation, and provide the output current amplifiers required to close the electronic tracking loop in the Track mode of operation. The electronic scan of the one degree acquisition field is accomplished by applying a linear 200 Hz triangular current waveform to the horizontal deflection coils and a synchronized 25 Hz stepped triangular current waveform to the vertical deflection coils. The resulting search pattern is illustrated in Figure 2.4.3-4 and shows the one-degree field to be completely scanned every 20 milliseconds.

The Raster Scan Electronics consists primarily of a stepped triangular waveform generator, an analog switch assembly, and a pair of output current amplifiers, and is shown in Figures 2.4.3-5 and 2.4.3-6. The stepped triangular waveform generator (Figure 2.4.3-5) utilizes a five-stage gated parallel counter which produces the binary sequence 4 5 6 7 8 9 10 11 12 11 10 9 8 7 6 5 4 3 ....... The output of the counter controls the states of four digital switches which in turn supply weighted currents to the operational amplifier. The output of the amplifier is the desired stepped 25 Hz triangular waveform.

The linear 200 Hz triangular waveform is obtained by using amplifier AR2 (Figure 2.4.3-6) to integrate the 200 Hz square wave produced by the triangular waveform generator. The analog switch assembly allows the search-mode waveforms to be connected to the output current amplifiers in the Search Mode of operation, and the appropriate Demodulator signals in the Track mode of operation.

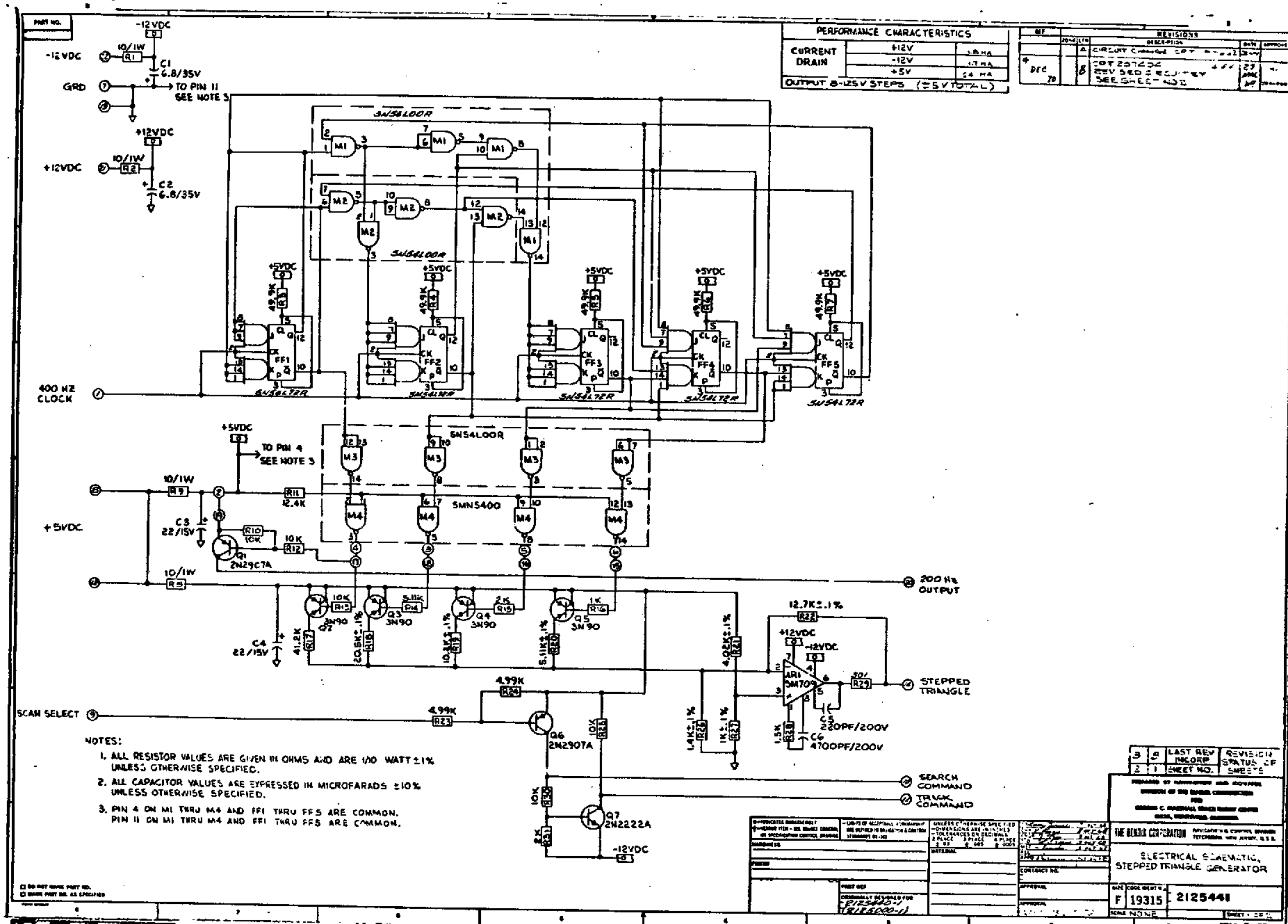



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FIGURE 2.4.3-5

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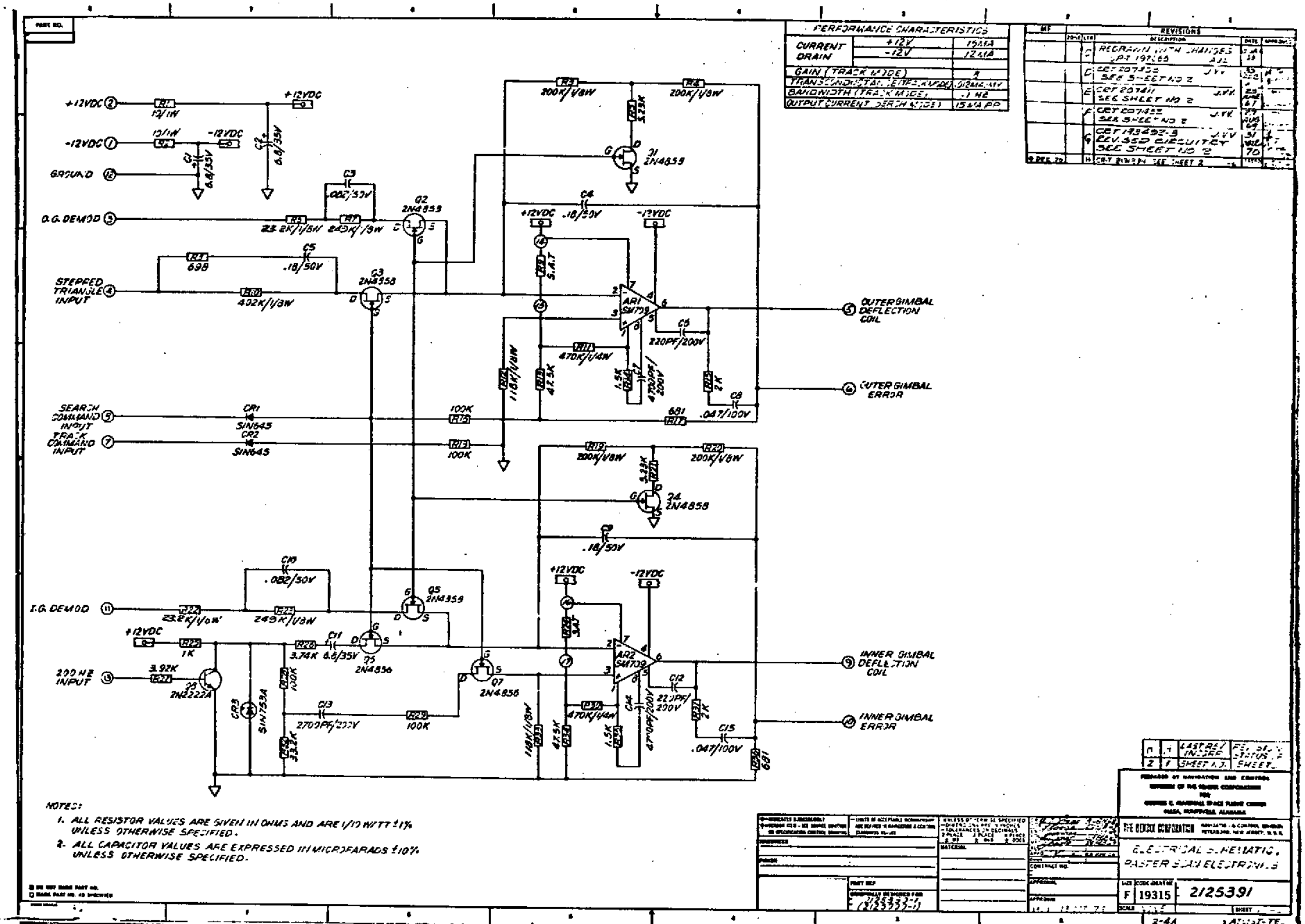


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FIGURE 2.4.3-6

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The output current amplifiers are used to provide the deflection coil with a high-impedance drive source. Each amplifier consists of an SM709G operational amplifier with appropriate RC networks. In the Track mode, the outputs of these amplifiers comprise the required tracker error signals.

2.4.3.4 Sweep Generator

The Sweep Generator produces the cruciform scan pattern required in the Track mode of operation, and is shown in the schematic in Figure 2.4.3-7. In operation, the 800 Hz $\underline{/\ 90^{o}}$ waveform is accepted by a buffer circuit which drives two temperature-compensated zener diodes. The resultant square wave is fed to an integrator to produce a triangular voltage waveform which is converted to a triangular current signal by the current amplifier. This current is alternately fed to the two deflection coils by means of analog switches which are driven by the 400 Hz input.

2.4.3.5 Demodulator

The Demodulator receives processed video signals from the Video Amplifier and converts them into two-axis analog error signals for use by the output current amplifiers. A schematic of the Demodulator is shown in Figure 2.4.3-8. The demodulator contains four basic sections: a pulse extender, the inner-gimbal error circuitry, the outer-gimbal error circuitry, and a regulated voltage source. The inner and output gimbal error circuitry are identical, except for their reference inputs.

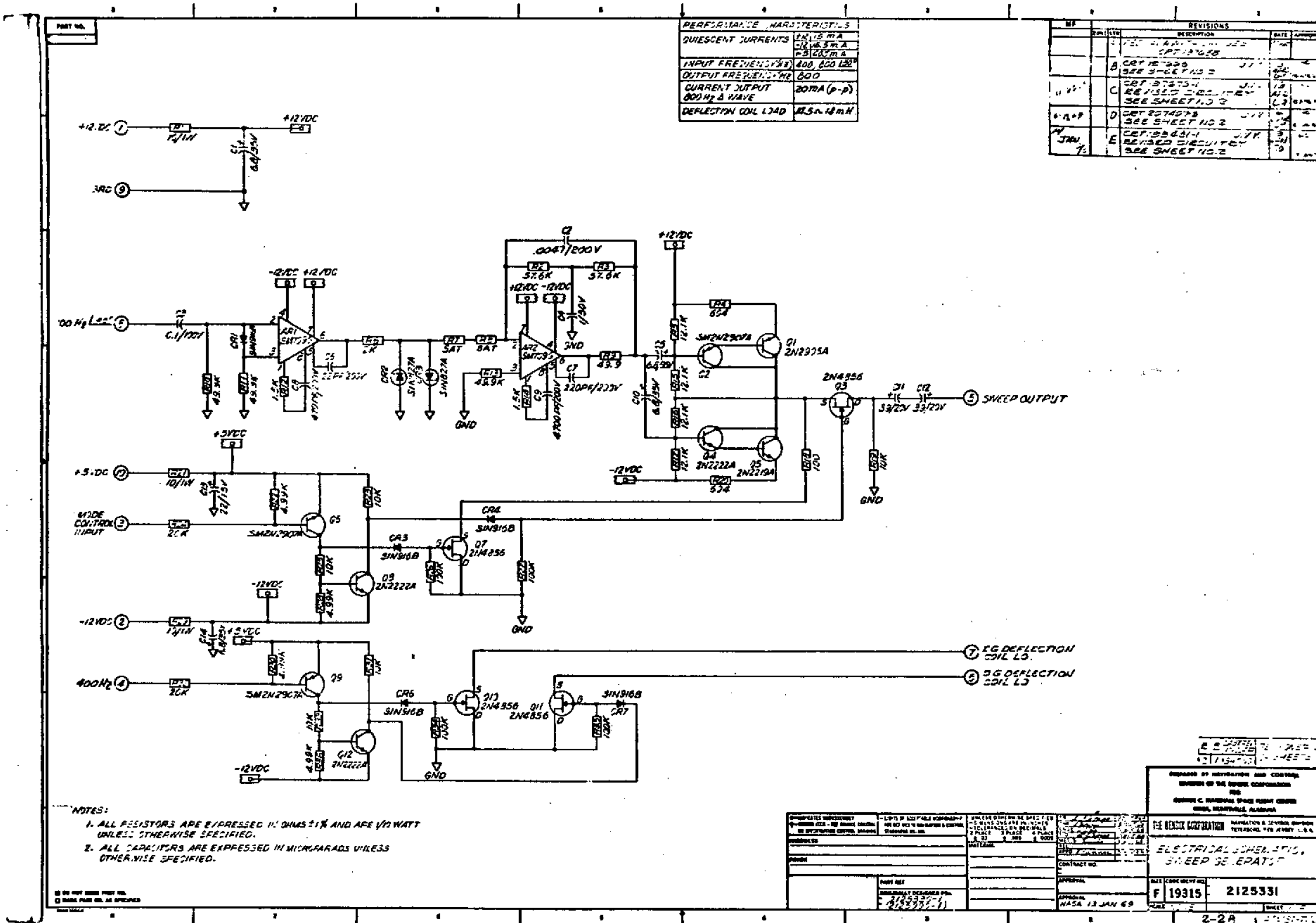


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FIGURE 2.4.3-7

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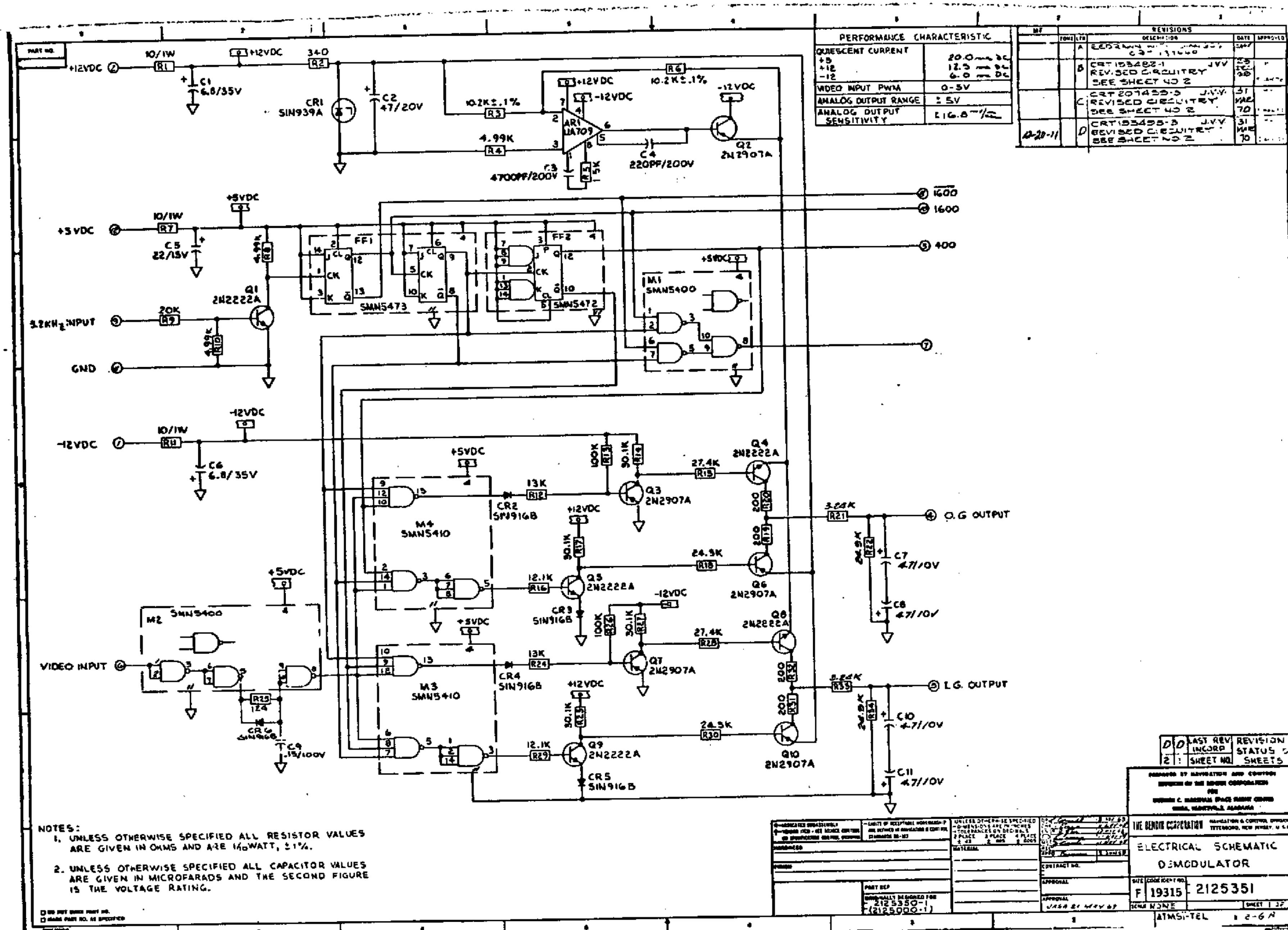


FIGURE 2.4.3-8

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The Demodulator operates in the following manner. The demodulator gates receive the pulse extender output, process the information, and feed it to the output switches. The supply voltages for the switches come from a special regulated supply in which both voltages track, thereby causing the absolute value of the two voltages to remain the same. The outputs of the switches are summed, filtered, and fed to the output current drivers.

2.4.3.6 Scan Selector

The Scan Selector determines which of the two scans, raster or cruciform, is to be used, and is shown in the schematic of Figure 2.4.3-9.

The threshold detector output is at a high level whenever the Star Acquisition input is above a preset threshold level (7 volts). The threshold detector output triggers one-shot AR2 through the input nand gate provided the gate is not inhibited. If there is a Star Presence signal or if the circuit is already in the "end-search" state, the input gate is inhibited and Star Acquisition pulses do not get through to AR2. The output of one-shot AR2 stays high for approximately 100 ms after it is triggered. When the output switches to low, one-shot AR3 is triggered. When a Star-Acquisition pulse is received while one-shot AR3 is on, the output flip-flop changes stage, providing a signal to switch the system to the cruciform scan (Track) mode of operation. If the Star Presence signal is lost after the one-shot AR3 output terminates, the output flip-flop switches again, returning the system to the raster scan (Search) mode of operation.

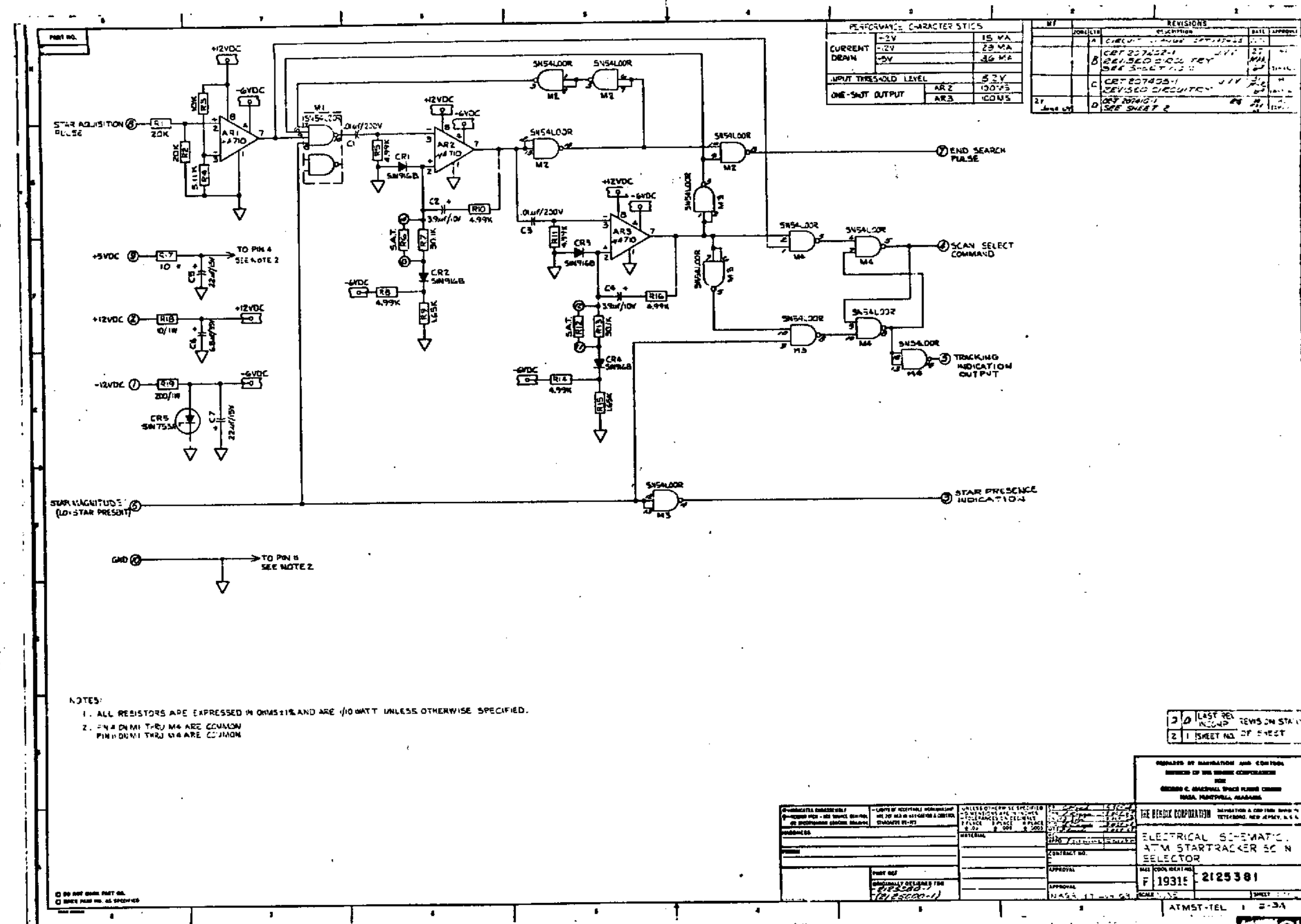


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FIGURE 2.4.3-9

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2.4.3.7 High Voltage Power Supply

The High-Voltage Power Supply is powered from the +12 volt regulated power supply. The circuit provides a -2000V output to the 10 megohm resistive divider chain which supplies the phototube bias. In addition, the circuit provides the clock pulses for the remainder of the telescope electronics. The circuit schematic appears in Figure 2.4.3-10.

Figure 2.4.3-11 is the circuit block diagram. Section A is the equivalent of the SIN827A reference diode. Section B is the remainder of the power supply and regulator. $A_2$ represents the DC-to-DC converter which supplies -2000V from a +10V input. The DC-to-DC converter also supplies the system clock pulses. $\beta$ is a voltage divider ratio determined by the load and the S.A.T. resistors (R10 and R11). $A_1$ represents the two 709 amplifiers and the following transistor stage.

The load current returns through R10 and R11 where it produces a voltage which tends to bring the AR1 amplifier input to ground potential. The voltage at the AR1 input is the circuit error voltage. AR1 amplifies the error signal and also serves as a high-input-impedance buffer, drawing very little current from the high-voltage return. The AR2 amplifier provides additional gain and frequency compensation to stabilize the regulator loop. Q4 provides a phase inversion and drives the control transistor, Q1. Q1 controls the voltage to the DC-to-DC converter which completes the regulator loop.

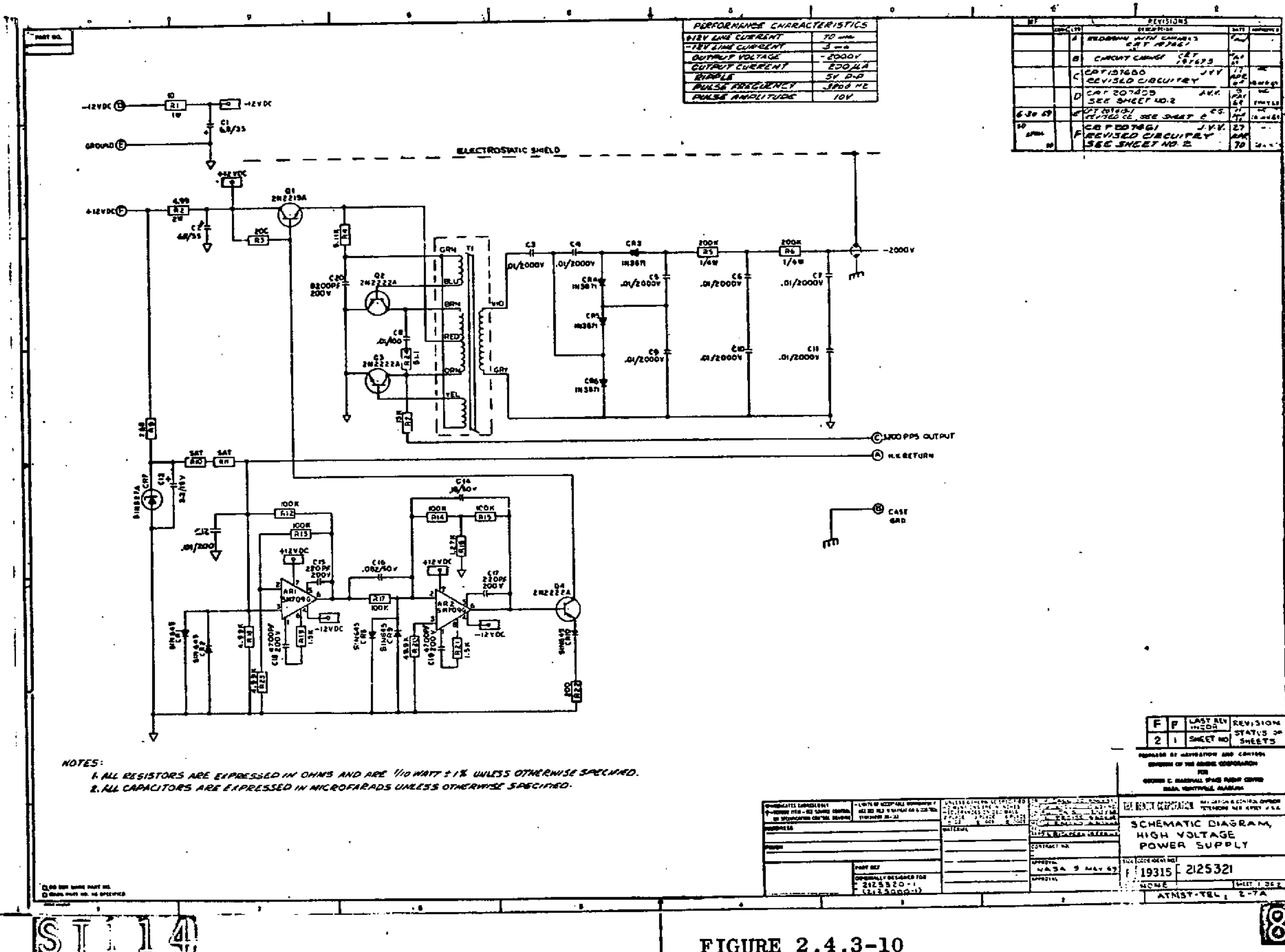
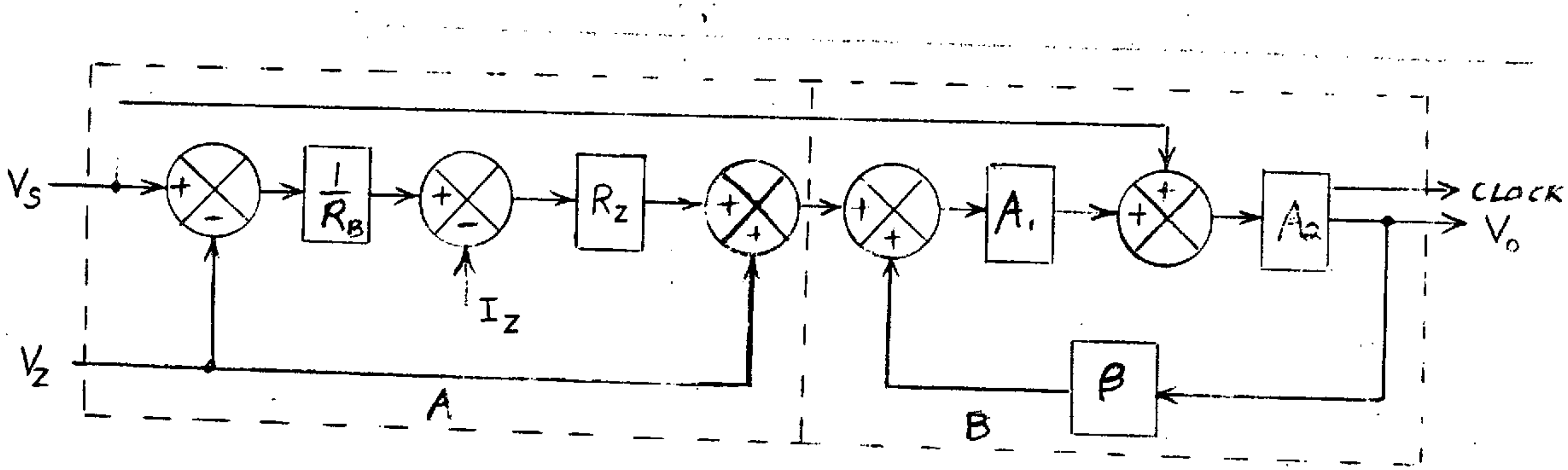



FIGURE 2.4.3-10




$V_S$ = 12 Volt Line Voltage

$V_Z$ = 6.2V, Nominal Zener Reference Voltage

$I_Z$ = 7.5Ma, Nominal Zener Current

$R_B$ = 768$\Omega$ Zener Bias Resistor

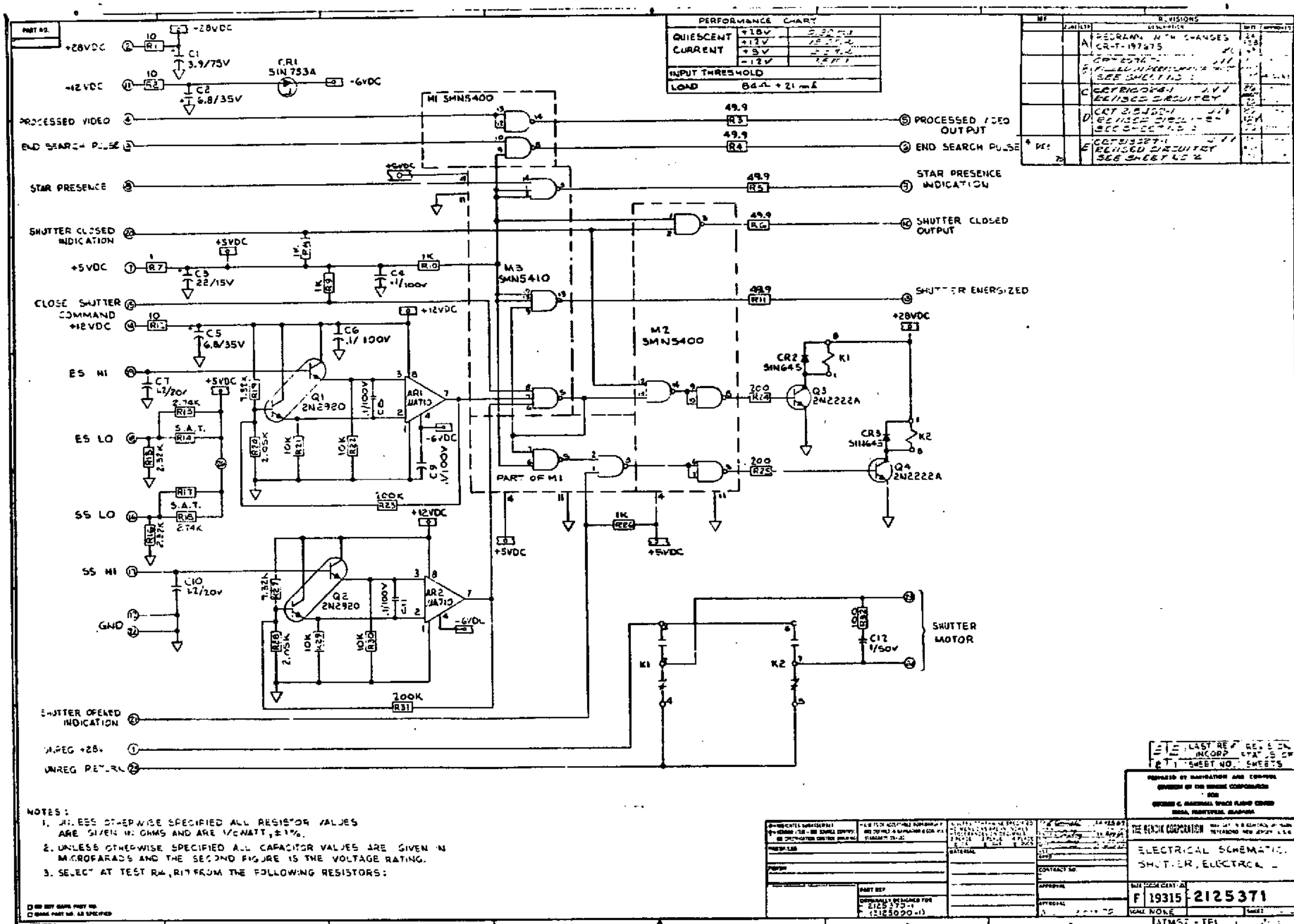
$R_Z$ = 10$\Omega$, Zener Dynamic Impedance

$A_1$ = (21)(-80.7)(-.9) = +1525, DC Gain of the two 709 Amplifiers and the following Transistor Stage

$A_2$ = -200, DC to DC Converter Gain (DC)

$$\beta = \frac{31 \times 10^3}{10.03 \times 10^6} = 3.09 \times 10^{-3}, \text{ Voltage Divider, } \frac{R10 + R11}{R_L + R10 + R11}$$

FIGURE 2.4.3-11

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SI127

FIGURE 2.4.3-12

High loop gain minimizes output changes due to gain and offset variations. The high gain of $A_1$ minimizes output changes due to line voltage variations. CR7 is a temperature compensated reference diode which provides a stable reference voltage.

### 2.4.3.8 Shutter Electronics

The Shutter Electronics receives command inputs from the Earth and Sun Sensors, and from the Mode Selector, and appropriately controls the shutter. A schematic of the Shutter Electronics is shown in Figure 2.4.3-12.

## 2.4.4 Servo Electronics

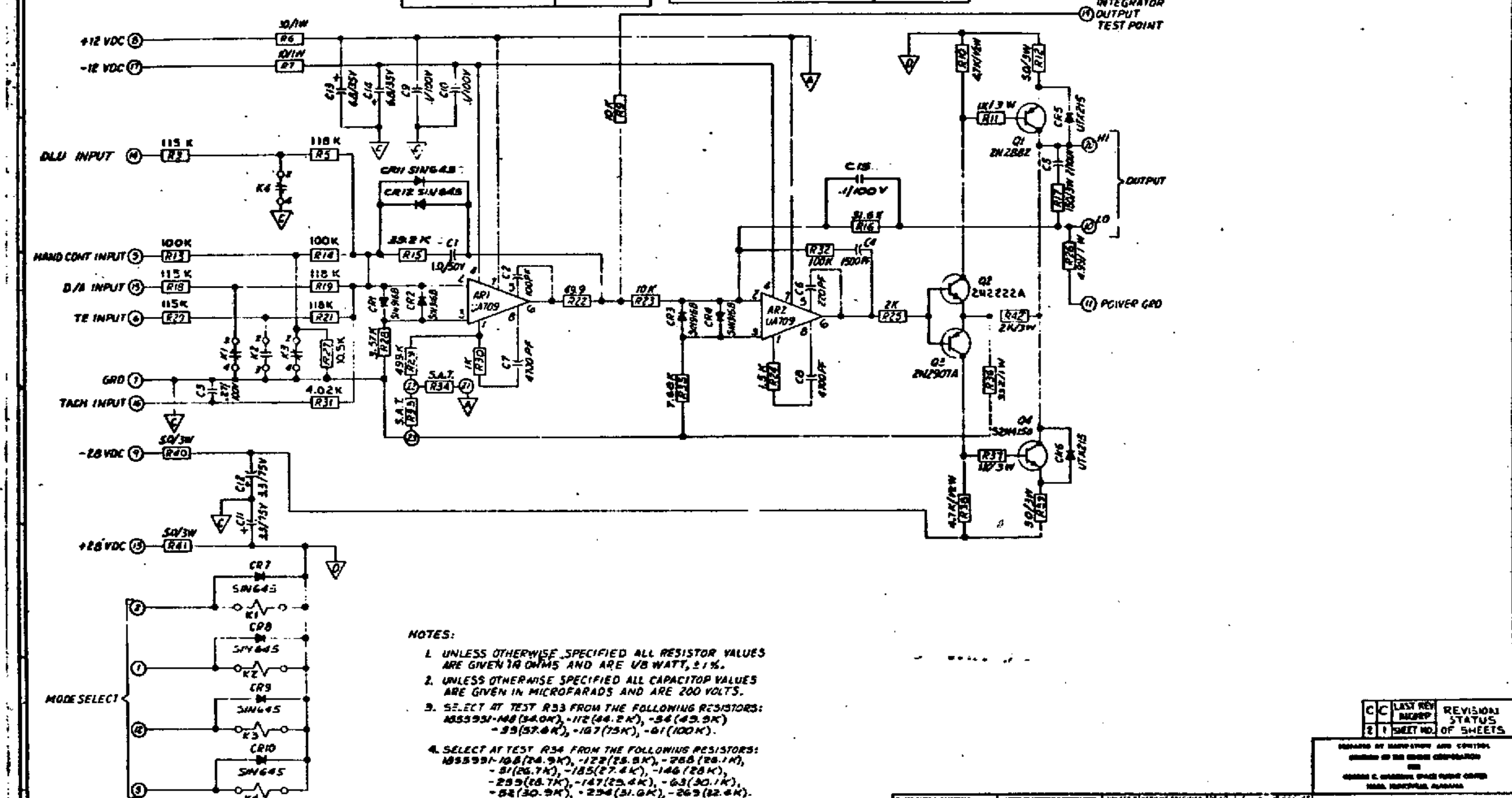
### 2.4.4.1 General Description

The servo electronics consist of a dual-channel servo amplifier to provide drive signals to the Star Tracker's gimbal torque motors, and of switching circuits to enable the system modes of operation: Track, Hold, Search and Manual. A schematic of the servo amplifier along with the switching relays, is shown in Figures 2.4.4-1 and 2.4.4-2 for the inner gimbal and outer gimbal, respectively. Each amplifier channel is seen to consist of an operational amplifier to provide the necessary compensation and voltage gain, and a power amplifier to provide the power gain required to drive the gimbal DC torque motors.

The servo amplifier is designed to operate in four modes of operation: Track, Hold, Manual and Search. In the Track mode the servo amplifiers receive analog error signals from the telescope electronics and convert them to command signals for the appropriate gimbal torquers.

| PERFORMANCE CHARACTERISTICS | | |
|---|---|---|
| CURRENT DRAIN (TYP) | NULL | FULL LOAD |
| +28VDC (128 Ω LOAD) | 0 | 215 MA |
| -28VDC (128 Ω LOAD) | 0 | 215 MA |
| +12 VDC | 2.1MA | 2.5 MA |
| -12 VDC | 2.1MA | 2.5 MA |
| POWER STAGE GAIN V/V | .633 x ZL | |
| POWER STAGE GAIN I/V | .633 | |

| | |
|---|---|
| OUTPUT OFFSET | 400 MV MAX |
| POWER STAGE BAND WIDTH | HZ |
| OUTPUT SATURATION | 27 V |
| POWER STAGE OUTPUT IMPEDANCE | OVER 50KΩ @ DC |
| TRANSFER FUNCTION TE INPUT | |
| TRANSFER FUNCTION TACH INPUT | |




NOTES:

1. UNLESS OTHERWISE SPECIFIED ALL RESISTOR VALUES ARE GIVEN IN OHMS AND ARE 1/8 WATT, ±1%.
2. UNLESS OTHERWISE SPECIFIED ALL CAPACITOR VALUES ARE GIVEN IN MICROFARADS AND ARE 200 VOLTS.
3. SELECT AT TEST R33 FROM THE FOLLOWING RESISTORS: 1855991-148 (34.0K), -112 (44.2K), -34 (49.9K) -39 (57.6K), -187 (75K), -61 (100K).
4. SELECT AT TEST R34 FROM THE FOLLOWING RESISTORS: 1855991-108 (24.9K), -122 (25.5K), -288 (26.1K), -51 (26.7K), -185 (27.4K), -146 (28K), -259 (28.7K), -147 (29.4K), -63 (30.1K), -52 (30.9K), -254 (31.6K), -269 (32.4K).

ELECTRICAL SCHEMATIC INNER GIMBAL AMPL

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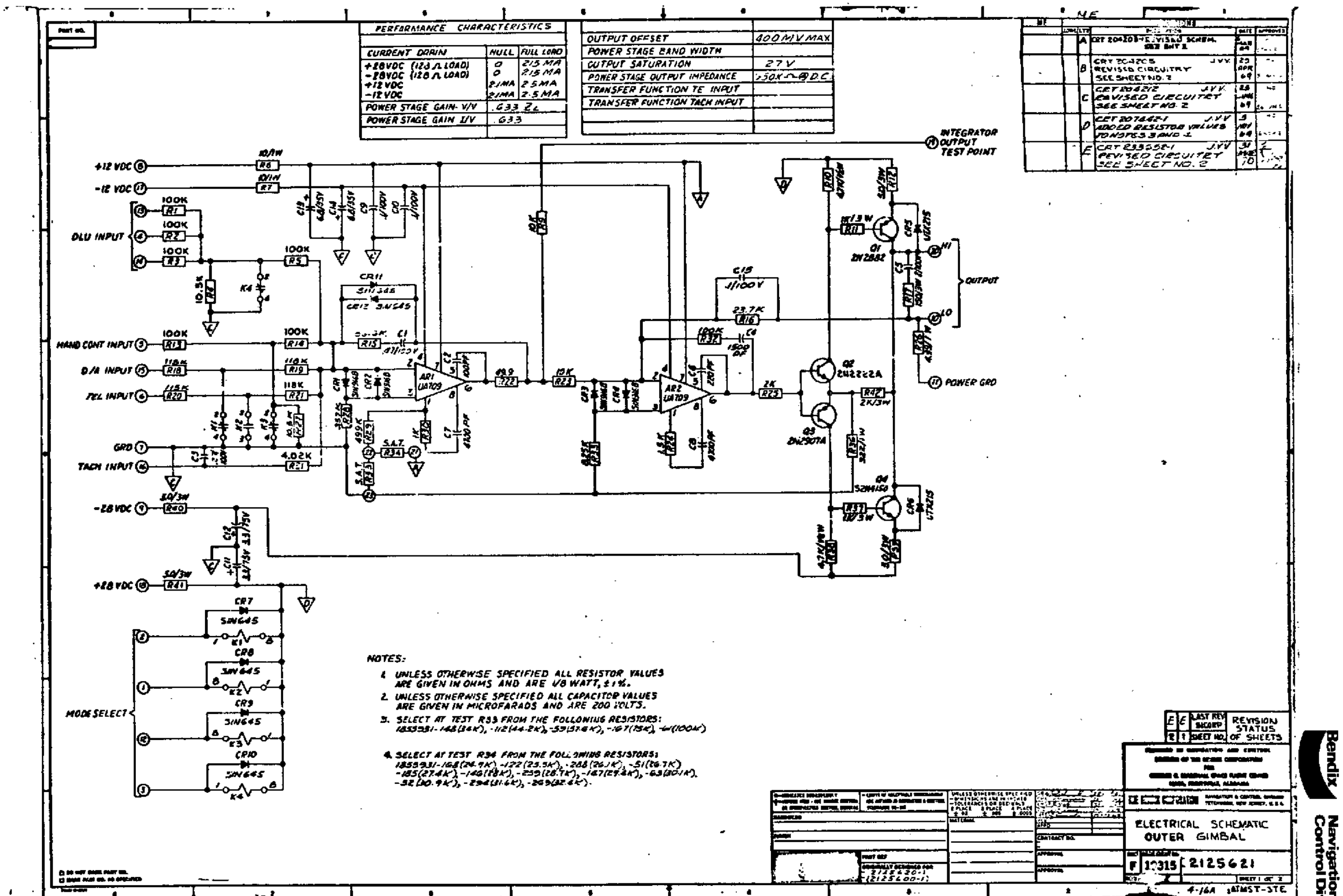
FIGURE 2.4.4-1


PERFORMANCE CHARACTERISTICS
CURRENT DRAIN NULL FULL LOAD
+28VDC (128 Ω LOAD) 0 215 MA
-28VDC (128 Ω LOAD) 0 215 MA
+12 VDC 2.1MA 2.5MA
-12 VDC 2.1MA 2.5MA
POWER STAGE GAIN V/V .633 ZL
POWER STAGE GAIN I/V .633
OUTPUT OFFSET 400 MV MAX
POWER STAGE BAND WIDTH
OUTPUT SATURATION 27 V
POWER STAGE OUTPUT IMPEDANCE
TRANSFER FUNCTION TE INPUT
TRANSFER FUNCTION TACH INPUT
INTEGRATOR OUTPUT TEST POINT
+12 VDC
-12 VDC
DLU INPUT
HAND CONT INPUT
D/A INPUT
TEL INPUT
GRD
TACH INPUT
-28 VDC
+28 VDC
MODE SELECT
OUTPUT
POWER GRD
NOTES:
1. UNLESS OTHERWISE SPECIFIED ALL RESISTOR VALUES ARE GIVEN IN OHMS AND ARE 1/8 WATT, ±1%.
2. UNLESS OTHERWISE SPECIFIED ALL CAPACITOR VALUES ARE GIVEN IN MICROFARADS AND ARE 200 VOLTS.
3. SELECT AT TEST R33 FROM THE FOLLOWING RESISTORS:
4. SELECT AT TEST R34 FROM THE FOLLOWING RESISTORS:
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2125621
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FIGURE 2.4.4-2

In the Hold mode the servo amplifier receives error signals from the D/A converters located in the Digital Logic Unit (DLU). These error signals are proportional to the difference between the commanded "hold" positions and the actual gimbal positions (as indicated by the optical encoders), and the servo amplifier drives the gimbal torquers so as to reduce the errors to zero.

In manual operation, the astronaut's hand controller is connected directly to the rate-loop inputs of both channels. In search operation, the inner gimbal amplifier receives an error signal from the D/A Converter which is proportional to the difference between the programmed search angle and the actual inner-gimbal angle. This error signal is driven to zero by appropriately driving the inner-gimbal torque motor. The outer-gimbal amplifier, in the search mode, accepts an analog signal directly into its rate loop. This signal is controlled by the DLU in accordance with the programmed search pattern, and is scaled to produce a gimbal rate of one deg/sec.

### 2.4.5 Digital Logic Unit

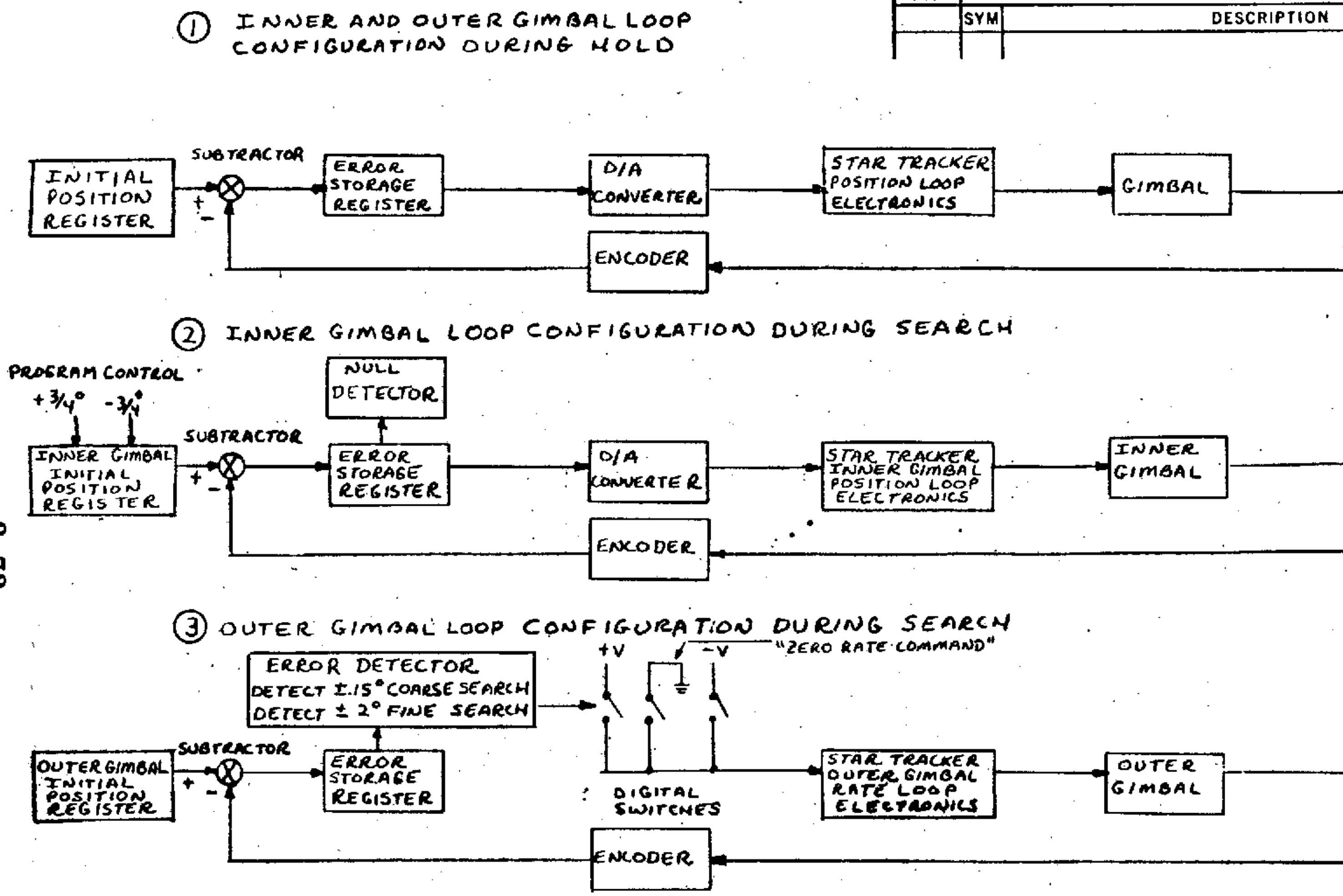
The Digital Logic Unit (DLU) contains the electronics required to perform a fine and coarse two-axis gimbal search, and the electronics required to hold the gimbals in a fixed position. In addition, the DLU provides the ATM Digital Computer, the Control and Display Panel, and Telemetry with inner and outer gimbal position information.

In particular, the DLU performs the following operations:

1. Holds the Star Tracker gimbals in their last position when a "Hold" command is received from the ATM/Tracker interface circuitry.
2. Conducts a fine and coarse two-axis gimbal search when a "Search" command is received from the ATM/Tracker interface circuitry.
3. Supplies the ATM Digital Computer with inner and outer gimbal position information, in serial binary form, (MSB first), upon command.
4. Supplies the Control and Display Panel with inner and outer gimbal position information in parallel binary-coded-decimal form.
5. Supplies Telemetry with inner and outer gimbal position information in parallel binary form.

A simplified block diagram showing the DLU/Servo Loop configurations for the Hold and Search modes of operation is shown in Figure 2.4.5-1. In the Hold mode the inner and outer gimbal loops are identical. In operation the initial gimbal positions are stored and from them are subtracted the actual gimbal positions which are obtained from the gimbal mounted digital encoders. The resulting digital error signals are stored in the "Error Storage Registers" and are converted to DC analog signals by the "D/A Converters". These signals are fed to the Star Tracker's gimbal electronics which drive the error signals to null.

In the Search mode, the inner and outer gimbal loops have different configurations. Reference to Figure 2.4.5-1 shows that the outer gimbal search motion is achieved by driving the outer gimbal rate loop at a




| MF | REVISIONS | | | |
|---|---|---|---|---|
| | SYM | DESCRIPTION | DATE | APPROVAL |
| | | | | |

FIGURE 2.4.5-1

| THE Bendix CORPORATION | ECLIPSE - PIONEER DIVISION TETERBORO, NEW JERSEY, U.S.A. | |
|---|---|---|
| CODE IDENT NO. 19315 | SIZE B | DLU BLOCK DIAGRAM (SIMPLIFIED) |
| SCALE | WT | SHEET |

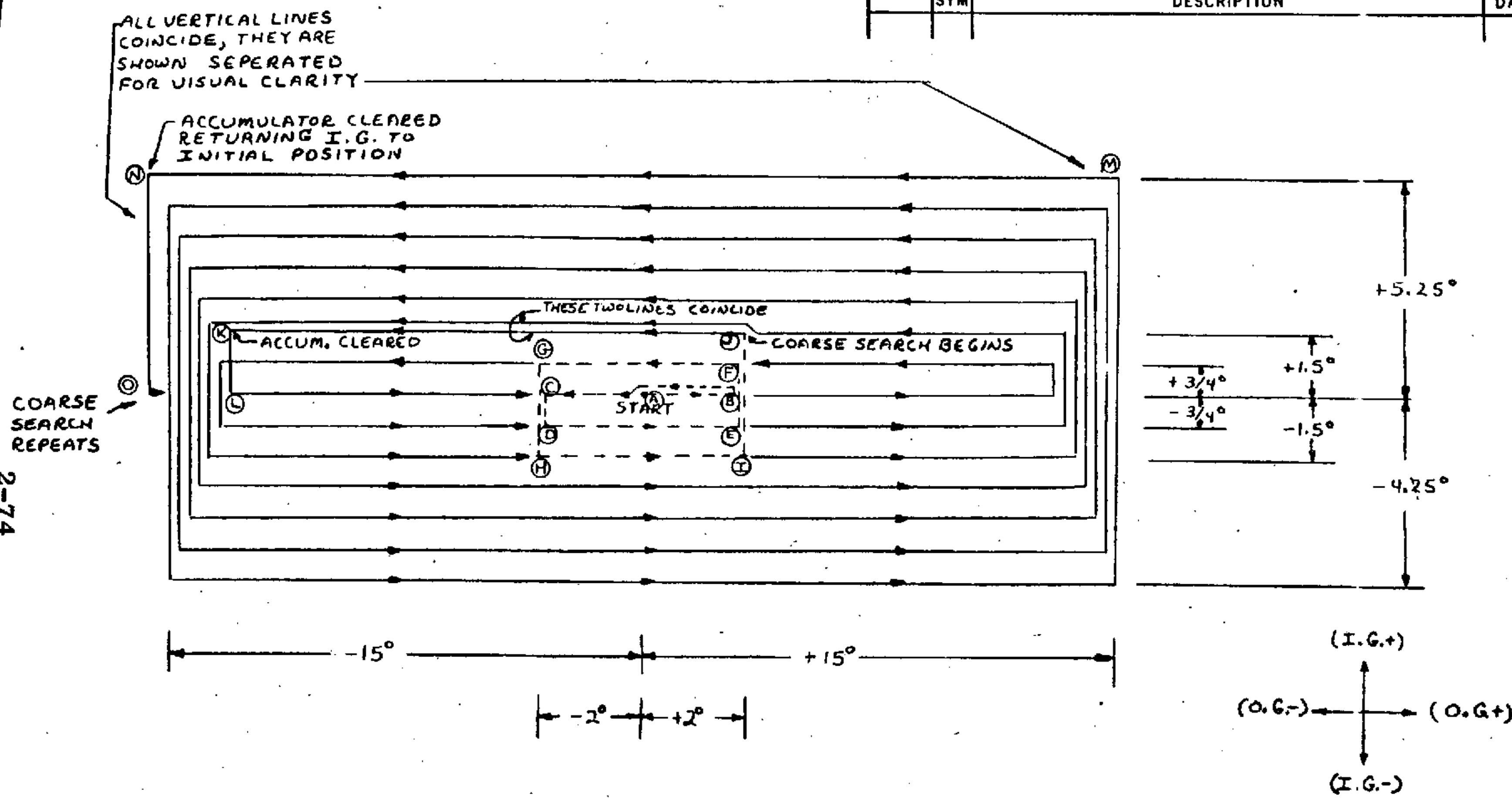
constant speed. At the start of the search operation the outer gimbal position is stored in the "Outer Gimbal Initial Position Register", and thereafter the new outer gimbal position is subtracted from it. The results of the subtraction are stored in the "Error Storage Register" and are examined by the "Error Detector" which determines when the extremities of the search pattern have been reached. When this occurs the drive signal is removed from the outer gimbal rate loop and inner gimbal motion is initiated.

The inner gimbal servo loop configuration during the Search mode is the same as in the Hold mode, with the exception that the "Initial Position Register" word is periodically incrmented in $\pm 3/4$ degree steps. In addition, a "Null Detector" has been added to determine when the inner gimbal has reached the newly commanded position. At this time, inner gimbal motion ceases and outer gimbal motion is resumed.

Search Pattern Description

When the Search Command is received from the Mode Selector, the DLU electronics cause the gimbal search pattern shown in Figure 2.4.5-2 to be generated. Examination of this figure shows the two-axis search to be conducted in two modes: a fine mode (dashed lines) in which a $\pm 2.5$ degree by $\pm 2$ degree area, centered about the starting position, is searched, followed by a coarse mode in which an angle of +15.5 degrees about the outer gimbal starting position and +5.75 and -4.75 degrees about the inner gimbal starting position is searched. After the coarse search is ended, the inner gimbal is

| MF | REVISIONS | | | |
|---|---|---|---|---|
| | SYM | DESCRIPTION | DATE | APPROVAL |
| | | | | |




NOTE: DASHED LINES INDICATE FINE SEARCH
SOLID LINES INDICATE COARSE SEARCH

FIGURE 2.4.5-2

| THE Bendix CORPORATION | ECLIPSE - PIONEER DIVISION TETERBORO, NEW JERSEY, U.S.A. | |
|---|---|---|
| CODE IDENT NO. 19315 | SIZE B | TWO AXIS GIMBAL SEARCH DIAGRAM |
| SCALE | WT | SHEET |

returned to its initial position and the coarse search pattern only is repeated.

The general sweep pattern is achieved by rotating the outer gimbal at a fixed rate, while holding the inner gimbal, and then holding the outer gimbal while indexing the inner gimbal by a multiple of $\pm 3/4$ degree. Thus, the search pattern is characterized by a series of 4 degree or 30 degree sweeps around the outer gimbal axis with each sweep being separated by 3/4 degree of inner gimbal motion. Since the acquisition field-of-view of the telescope is one degree, the star will always be found during one of the outer gimbal sweeps, and hence, the outer gimbal sweep speed should be as uniform as possible. To accomplish this, the outer gimbal is driven by a one deg/sec command applied directly to its rate loop, with the gimbal encoder being used only to determine when the proper angle ($\pm 2$ degrees or $\pm 15$ degrees from the initial angle) has been reached. The inner gimbal is indexed the required 3/4 degree angle by means of its position loop, since uniformity of speed is unimportant along this axis.

Block Diagram Description

A simplified block diagram of the Digital Logic Unit is shown in Figure 2.4.5-3. A brief description of each block appearing in Figure 2.4.5-3 follows.

Block No. 1 Clock

The Clock unit generates the basic 10 KHz square wave signal required by the Programmer (Block 2).

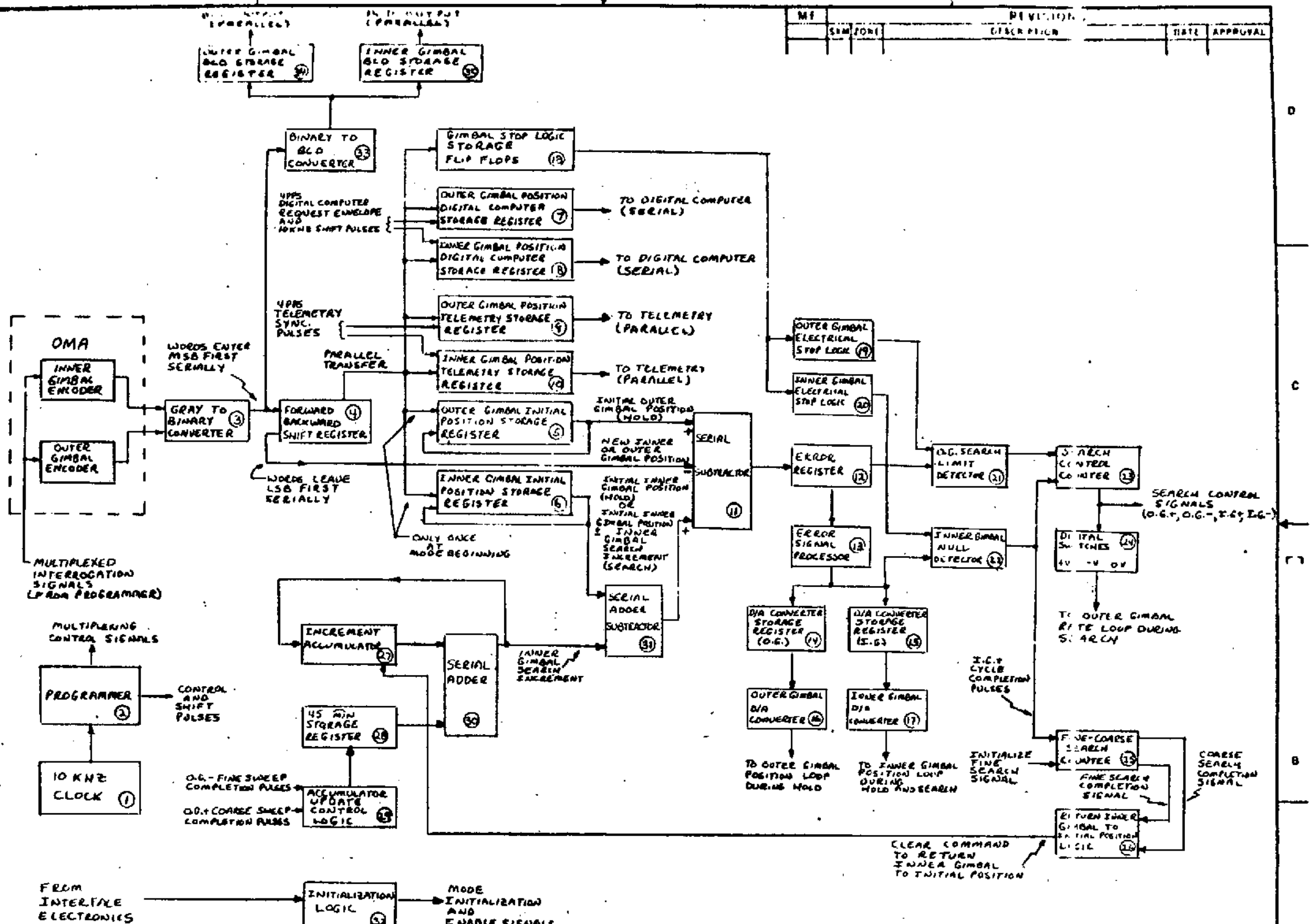



FIGURE 2.4.5-3

THE Bendix CORPORATION ECLIPSE - PIONEER DIVISION TETERBORO, NEW JERSEY, U.S.A

| CODE IDENT NO. | SIZE | |
|---|---|---|
| 19315 | C | STAR TRACKER |
| SCALE | WT | SHEET |

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Block No. 2 Programmer
The Programmer unit generates the time-multiplexing envelopes, individual timing pulses, and 10 KHz shift-pulse bursts required to control the sequential operation of the DLU. The unit itself consists of a five-stage synchronous Gray-code counter designed to divide by a factor of 22, a cascaded two-stage synchronous Gray-code counter designed to divide by a factor of four, and associated gating circuitry. Each program cycle thus consists of 88 cycles of the 10 KHz clock.

Block 3 Gray to Binary Converter
The Gray-to-Binary Converter converts the multiplexed serial Gray-coded outputs of the gimbal encoders, MSB first, to a serial binary word. The converter implements a common Gray-to-Binary conversion rule whereby the most significant binary digit is the same as the corresponding Gray-code digit, and each successive binary digit is complemented if the corresponding Gray-code digit is a "1" or is left as is if the corresponding Gray-code digit is a zero.

Block No. 4 Forward-Backward Shift Register
The Forward-Backward Shift Register accepts binary-coded serial information from the Gray-to-Binary Converter (Block 2), MSB first, stores the information for a time, and then shifts it, LSB first, through the Subtractor unit of Block 11. During the interval in which the word is stored, it is parallel transferred to the Digital Computer and Telemetry Storage Registers (Blocks 7-10), to the Gimbal Stop-Logic, Storage Flip-Flops (Block 18) and, at the start of a Search or Hold

operation, to the Inner and Outer Gimbal Initial Position Registers (Blocks 5,6).

Block No. 5, 6 Initial Position Storage Registers
The Initial Position Storage Registers store the gimbal positions which are present at the start of a Hold or Search operation. These registers are thus updated only when a Hold or Search operation is first initiated; and, thereafter the contents of these registers serve as the reference angles required in the Hold and Search modes. When the Initial Position Registers are updated, the new information is received from the Forward Backward Shift Register, Block 4, in parallel form. The output of each of the Initial Position Registers is serial, and depending on the mode of operation, is passed through one of the subtractor units (Blocks 11, 31).

Blocks Nos. 7, 8 Digital Computer Storage Registers
The Digital Computer Storage Registers receive new gimbal position information once each program cycle, in parallel form, from the Forward-Backward Shift Register (Block 4). This information is then read out asynchronously by the Digital Computer, in serial form, at a rate of four 10 KHz readouts per second. Suitable gating is provided to prevent the storage registers from being updated during the time in which the information is being serially transferred to the Digital Computer.

Blocks 9, 10 Telemetry Storage Registers
The Telemetry Storage Registers are updated by a parallel transfer of information from the Forward-Backward Register at a rate of four updates per second. Each update is initiated by a 4 pps 278 μsec sync pulse from telemetry,

and the information words are made available to telemetry in a parallel format.

Block 11 Serial Subtractor

The Serial Subtractor unit of Block 11 subtracts the most recent encoder position word, received serially from the Forward-Backward Shift Register (Block 4), from the commanded position word. The commanded position word is the initial position, (obtained serially from the Initial Position Registers, Blocks 5,6), when the system is in the Hold mode of operation. When the system is in the Search mode, the commanded position word is the initial position for the outer gimbal portion of the program cycle, and is the initial position plus or minus a predetermined angle increment (generated by Blocks 27-31) for the inner gimbal portion of the program cycle.

Block 12 Error Register

The Error Register receives, in serial form, the results of the subtraction performed by the Subtractor unit of Block 11, and stores the error word.

Block 13 Error Signal Processor

The Error Signal Processor examines the 15-bit word in The Error Register (Block 12) for sign, and for magnitude in excess of the D/A Converter's $\pm 64$ increment output swing, and appropriately sets the 7-bit D/A Converter Storage Registers (Blocks 14, 15). The Processor thus operates on the 15-bit word in the Error Register to produce a 7-bit word (1 sign bit and 6 magnitude bits) which is subsequently stored in one of the D/A Converter Storage Registers. This 7-bit word has the following characteristics:

a. The MSB (i.e. the sign bit) is the same as the MSB of the unprocessed error word.

b. For non-saturated errors (i.e. errors smaller in magnitude than 64 increments), the remaining 6 bits are the same as the last 6 bits of the unprocessed word.

c. For saturated errors of positive polarity (+64 increments or larger) the remaining 6 bits are all "logical ones".

d. For saturated errors of negative polarity (-64 increments or smaller) the remaining 6 bits are all "logical zeros".

Blocks 14, 15 D/A Converter Storage Registers

The D/A Converter Storage Registers store the processed error signals and make them available to the D/A Converters on a continuous basis. These registers accept multiplexed parallel inputs from the Error Signal Processor (Block 13) and send parallel outputs to the D/A Converters.

Blocks 16, 17 D/A Converters

The D/A Converters convert the processed digital error signals to analog voltage signals which are used to drive the gimbal servo loops. Each D/A Converter unit consists of a microcircuit operational amplifier with an associated binary-weighted-resistor input network.

Block 18 Gimbal Stop Logic Storage Flip Flops

The Gimbal Stop Logic Storage Flip-Flops store the seven most significant bits of the gimbal readout angle. The outputs of these flip-flops are sent to the Gimbal Stop Logic Electronics (Blocks 19, 20).

Block 19 Outer Gimbal Stop Logic
The Outer Gimbal Stop Logic detects when the outer gimbal angle reaches $+87.467^{\circ}$ or $-87.475^{\circ}$. When either of these angles are reached a signal is sent to the Search Limit Detector, (Block 21) terminating the outer gimbal sweep and initiating the next I.G. incrementation.

Block 20 - Inner Gimbal Stop Logic
The Inner Gimbal Stop Logic detects when the inner gimbal angle reaches +40.533 degrees or -40.54 degrees. When either of these angles are reached a signal is sent to the Inner Gimbal Null Detector, (Block 22), terminating the inner gimbal motion and initiating the next outer gimbal sweep.

Block 21 - Outer Gimbal Search Limit Detector
The Outer Gimbal Search Limit Detector is used in the Search mode to determine when the limits of the required outer-gimbal motion have been reached. In the Fine Search mode these limits are set at +2.0 degrees and -2.0083 degrees from the initial position, and in the Coarse Search mode these limits are set at +15.0 degrees and -15.0083 degrees from the initial position. When these limits have been reached a signal is generated which is used to advance the Search Control Counter (Block 23).

Block 22 Inner Gimbal Null Detector
The Inner Gimbal Null Detector is used in the Search mode to determine when the inner gimbal has completed its travel to a newly commanded position. When the

inner gimbal comes within 1.5 arc min. of the commanded position the Null Detector produces an output signal which is used to advance the state of the Search Control Counter (Block 23).

Block 23 Search Control Counter
The Search Control Counter is used in the Search mode to determine which gimbal is to be rotated and in which direction. The sequence of gimbal motion, as commanded by this counter, is: OG (+) IG (+) OG (-) IG (-) OG (+)...

The counter itself is a two stage synchronous Gray counter and it is advanced each time a signal is received from the Outer Gimbal Search Limit Detector, or the Inner Gimbal Null Detector.

Block 24 Digital Switches
The Digital Switches insert a positive drive command, a negative drive command, or a zero drive command, into the outer-gimbal rate loop during the Search mode of operation. The positive drive signal is inserted when the Search Control Counter (Block 23) commands OG (+), the negative drive signal when OG (-), is commanded, and the zero drive signal when IG (+) or IG (-) is commanded.

Block 25 Fine/Coarse Search Counter
The Fine/Coarse Search Counter is used to determine when the fine gimbal search is completed and when the coarse gimbal search is completed. The counter itself consists of a three stage synchronous binary counter

which counts the number of IG (+) weeeps. When 2 IG (+) sweeps have been counted the fine search ends, the inner gimbal is returned to its initial position and the coarse search begins. When 7 additional IG (+) sweeps have been counted the coarse search ends, the inner gimbal is returned to its initial position, and the coarse search repeats.

Block 26 Return LG to Initial Position
The Return Inner Gimbal to Initial Position logic receives fine and coarse search completion signals from the Fine/Coarse Search Counter (Block 25), and in response, issues a signal which clears the Increment Accumulator (Block 27). This results in the inner gimbal being returned to its initial position, which allows the next search pattern to be started.

Block 27 Increment Accumulator
The Increment Accumulator contains the commanded angle, relative to the initial inner gimbal angle, to which the inner gimbal is to be positioned during the Search mode. This angle is generated by adding 45 arc minute increments to the original Accumulator number (initially zero) each time the inner gimbal is to be moved a new distance from the starting point. This addition is made each time an OG (-) sweep is completed when the coarse search is in progress, and is controlled by the Accumulator Update Control Logic (Block 29).

Block 28 45 Arc Minute Storage Register
The 45 Arc Minute Storage Register stores a digital word with a weight of 45 arc minutes. This number is

added to the Increment Accumulator (Block 27) at the appropriate time as determined by the Accumulator Update Control Logic (Block 29).

Block 29 Accumulator Update Control Logic
The Accumulator Update Control Logic causes 45 arc minute increments to be added to the Increment Accumulator (Block 27) each time the inner gimbal is to be moved a new distance from its starting point. This addition is caused to occur each time an OG (-) sweep is completed when the fine search is in progress, and each time an OG (+) sweep is completed when the coarse search is in progress.

Block 30 Serial Adder
The Serial Adder of Block 30 performs the addition in which 45 arc minute increments are added to the contents of the Increment Accumulator (Block 27). The results of the addition are stored in the Increment Accumulator.

Block 31 Serial Adder/Subtractor
The Adder Subtractor Unit adds (or subtracts) the contents of the Increment Accumulator (Block 27) to (from) the contents of the Inner Gimbal Initial Position Register (Block 6). The result of this addition (or subtraction) is the angle to which the inner gimbal is commanded during the search mode. The addition operation takes place when and IG (+) or OG (-) sweep is in progress, and the subtraction takes place when an IG (-) or OG (+) sweep is in progress.

Block 32 Initialization Logic
The Initialization Logic detects when a Hold or Search operation is first commanded and appropriately prepares the DLU to perform the desired operation. In particular, at the start of both modes, the Initial Position Registers (Blocks 5,6) are updated. In addition, at the start of the Search mode, the Search Control Counter (Block 23) is cleared, the Increment Accumulator (Block 27) is cleared, and the Fine/Coarse Search Counter (Block 25) is cleared and set to implement the fine search.

Block 33 Binary to BCD Converter
The Binary-to-BCD Converter is used to convert the serial binary-coded gimbal position information, available at the output of the Gray-to-Binary Converter (Block 3), into binary-coded decimal form with a resolution of 1.0 arc minute. The actual output of the Converter consists of sign information in the form of two 28 volt discretes, and magnitude information in the form of a four-digit binary-coded-decimal number.

The binary-to-BCD conversion is accomplished by shifting the binary number, most-significant bit first, into a specially-gated shift register which counts in BCD form. If the binary number is negative it is complemented before being passed through the converter.

Blocks 34, 35 BCD Storage Registers
The BCD Storage Registers store the inner and outer gimbal binary-coded decimal words and make them available to the PCS Control and Display Panel on a continuous basis.

## 2.4.6 Power Supplies

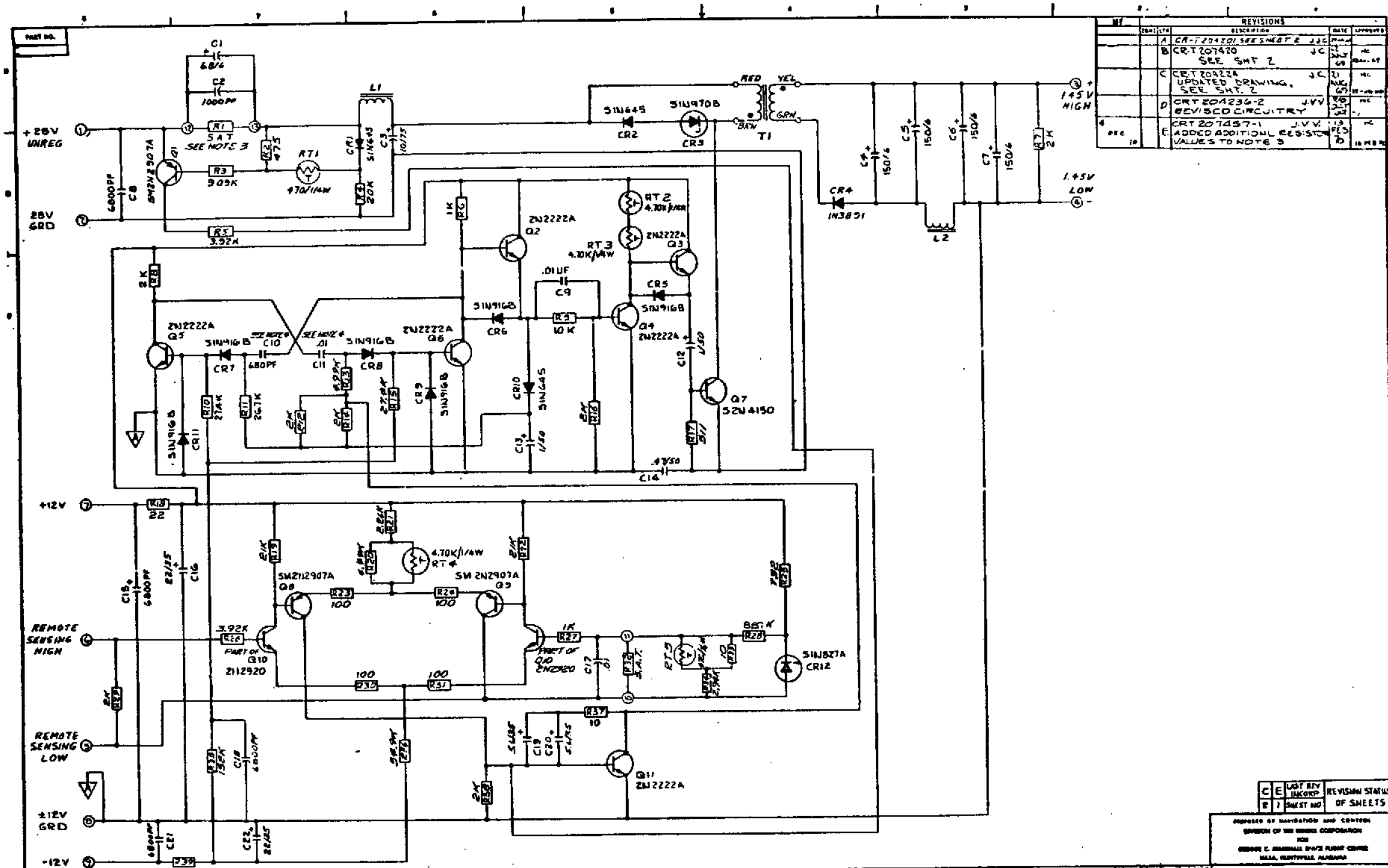
### 2.4.6.1 Encoder Power Supply (+1.45 VDC)

The 1.45 VDC supply drives the encoder lamps, whose intensity must be accurately controlled. A schematic of this supply is shown in Figure 2.4.6-1, and switching regulation techniques are used because of the high power loss inherent in series regulation at this low voltage level. In response to load or input line variations, the duty cycle of the pulses from the power switch to the transformer is varied to maintain the output constant.

In operation, the output voltage is compared at Q10 with a fractional part of the reference voltage from CR12. The difference voltage is amplified by Q10, Q8, Q9 and Q11, causing the collector voltage of Q11 to vary as a function of the output voltage. Since the timing network C11 and R13 is connected to Q11, the cutoff time of multivibrator transistor Q6 also varies as the output voltage. The on time remains fixed at 17 microseconds since R11 is returned to a fixed voltage.

Thermistor RT5 compensates for changes in output voltage due to temperature variations by adjusting the reference voltage. RT4 compensates for beta changes of Q11 due to temperature variations by adjusting the drive to Q11. R37, C19, C20 prevent oscillation of linear amplifier Q11.

Q2 serves a threefold purpose of isolating the multivibrator from the following stages, supplying bias to the timing networks, and providing positive-starting of the multivibrator.




NOTES:

1. ALL RESISTORS ARE EXPRESSED IN OHMS ±1% AND ARE 1/8 WATT, UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS ARE EXPRESSED IN MICROFARADS ±10% AND 20JV, UNLESS OTHERWISE SPECIFIED.
3. SELECT AT TEST R1 FROM THE FOLLOWING RESISTORS: 2125411-7 (2.21), -11 (2.26), -13 (2.32), -15 (2.37) & -17 (2.43), -21 (1.74), -23 (2.0)
4. C10 & C11 MUST HAVE BX CHARACTERISTIC.
5. SELECT AT TEST R32 FROM THE FOLLOWING RESISTORS: 1855931-169 (121K), -191 (71.5K), -57 (54.9K), -116 (48.7K), -149 (35.7K), -269 (32.4K), -51 (26.7K), -270 (23.2K), -88 (20.5K), -133 (18.7K) & -131 (17.4K).

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FIGURE 2.4.6-1

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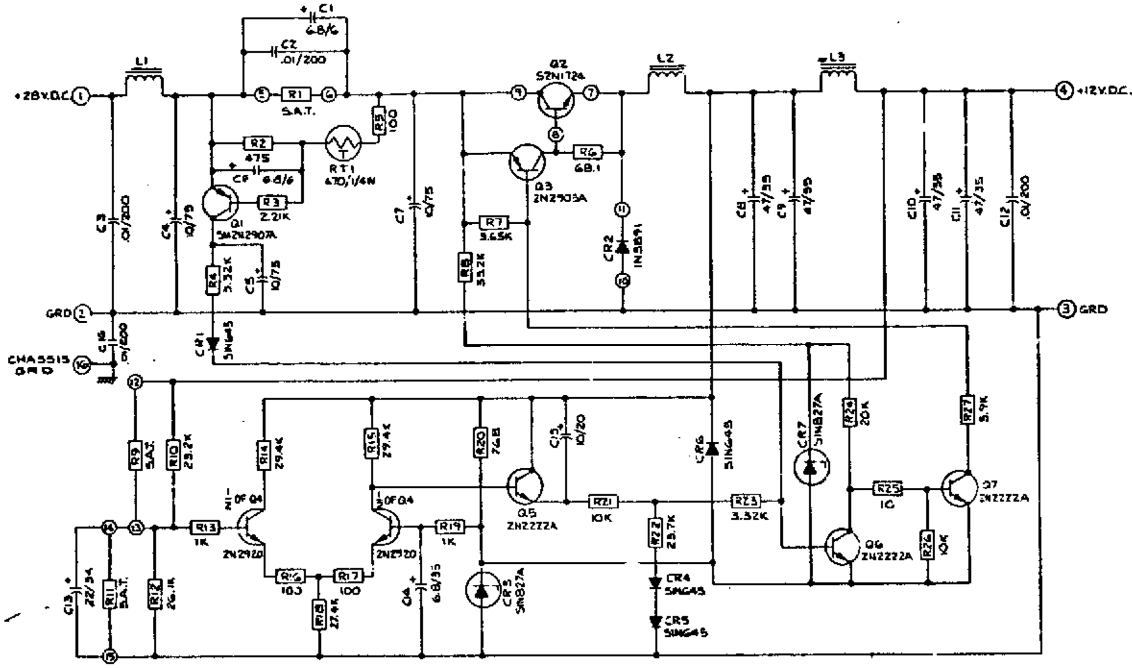
Q4 inverts the oscillator pulse to drive power switch Q7. Q3 turns off as the pulse goes in the negative direction, thereby increasing efficiency. RT2 and RT3 provide increased drive at low temperatures to offset loss of beta. Q7 alternately pulses primary of T1 on and off with a duty cycle proportional to the output voltage. The secondary voltage swings around an average value determined by the duty cycle, and is rectified, filtered, and supplied to the load.

2.4.6.2 DC Power Supplies

The DC power supplies produce the regulator ±12 VDC, and +5VDC voltages required by the system. These supplies are conventional in design and are shown in Figures 2.4.6-2, 2.4.6-3 and 2.4.6-4.

| PERFORMANCE | CHARACTERISTICS |
|---|---|
| INPUT VOLTAGE | +22VDC TO +32VDC |
| OUTPUT VOLTAGE | +12VDC ±1% |
| INPUT CURRENT @ 28V | 165 MA |
| LOAD CURRENT @ 38.1 Ω | 325 MA |
| RIPPLE | 3 MV P-P |
| EFFICIENCY | 85 % |

| MF | ZONE | LTR | REVISIONS DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|---|
| | | A | CRT 20742 J.V.V. REVISED CIRCUITRY SEE SHEET NO. 2 | 3 JULY 69 | |
| | | B | CRT 20718 J.V.V. SEE SHEET NO. 2 | 25 | |
| | | C | CRT 21847 J.V.V. REVISED CIRCUITRY SEE SHEET NO. 2 | 2 MAR 70 | |




NOTES:

1. ALL RESISTOR VALUES ARE IN OHMS AND ARE ±1%, 1/8 WATT RATING UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITOR VALUES ARE IN MICROFARADS ±10% AND THE SECOND FIGURE INDICATES VOLTAGE.
3. SELECT AT TEST R1 FROM THE FOLLOWING 2125411 TYPE RESISTORS: -21(1.74Ω), -23(2Ω), -25(2.49Ω), -5(3.01Ω)
4. SELECT AT TEST R9 FROM THE FOLLOWING 1855931 TYPE RESISTORS: -88(20.5K), -90(21.0K), -44(21.5K), -50(22.1K), -198(22.6K), -270(23.2K), -202(23.7K), -145(24.3K), -48(24.9K), -122(25.5K), -288(26.1K).
5. SELECT AT TEST R11 FROM THE FOLLOWING 1855931 TYPE RESISTORS: -202(23.7K), -145(24.3K), -48(24.9K), -122(25.5K), -288(26.1K), -51(26.7K), -185(27.4K), -142(28.0K), -259(28.7K).

| C | C | LAST REV LTR | REVISION STATUS |
|---|---|---|---|
| 2 | 1 | SHEET NO | OF SHEETS |

PREPARED BY NAVIGATION AND CONTROL DIVISION OF THE BENDIX CORPORATION FOR GEORGE C. MARSHALL SPACE FLIGHT CENTER NASA, HUNTSVILLE, ALABAMA

THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO, NEW JERSEY, U.S.A.

ELECTRICAL SCHEMATIC POWER SUPPLY +12V.D.C.

| SIZE | CODE IDENT NO. | |
|---|---|---|
| F | 19315 | 2125781 |
| SCALE NONE | | SHEET 1 OF 2 |

NASA 10 NOV 69

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Bendix Navigation & Control Division

ST 104

FIGURE 2.4.6-2

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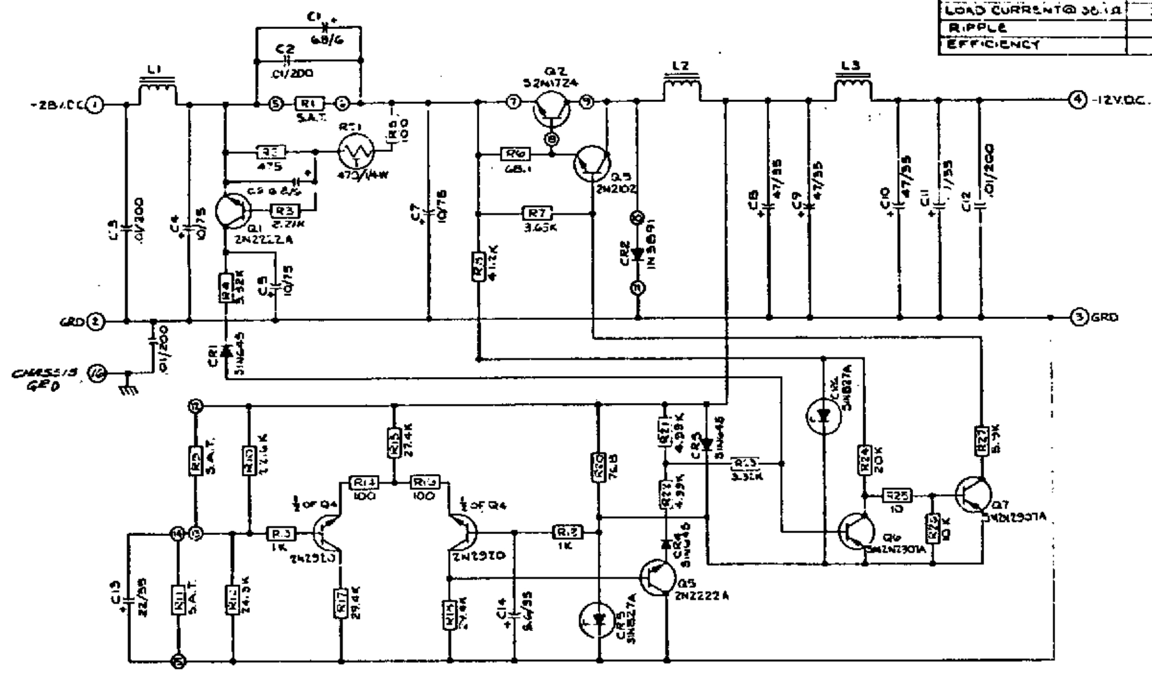
| PERFORMANCE CHARACTERISTICS | |
|---|---|
| INPUT VOLTAGE | -22VDC TO -32VDC |
| OUTPUT VOLTAGE | -12VDC ±1% |
| INPUT CURRENT@25V | 151 ma |
| LOAD CURRENT@ 36.1Ω | 305 ma |
| RIPPLE | 5 mv P-P |
| EFFICIENCY | 84% |

| LTR | REVISIONS DESCRIPTION | DATE |
|---|---|---|
| A | CRT 20745 REVISED CIRCUITRY SEE SHEET NO 2 | |
| B | SEE SHEET 2 | |
| C | CRT 21547 REVISED CIRCUITRY SEE SHEET NO 2 | 2 NOV 73 |
| D | CRT 21947-3 ADDED RESISTOR VALUES TO NOTES 4 AND 5 | 22 NOV 73 |




NOTES:

1. ALL RESISTOR VALUES ARE IN OHMS AND ARE ±1%, 1/8 WATT RATING UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITOR VALUES ARE IN MICROFARADS, ±10% AND THE SECOND FIGURE INDICATES VOLTAGE
3. SELECT AT TEST R1 FROM THE FOLLOWING 2125411 TYPE RESISTORS: -2 (1.74-), -23 (2K), -25 (2.49K), -5 (3.01K)
4. SELECT AT TEST R9 FROM THE FOLLOWING 655P3 TYPE RESISTORS: -47 (22.1K), -99 (22.5K), -70 (22.6K), -144 (22.8K), -50 (22.1K), -198 (22.6K), -270 (23.2K), -202 (23.7K), -45 (24.3K), -58 (24.9K), -122 (25.5K), -285 (26.1K), -51 (26.7K) (D)
5. SELECT AT TEST R11 FROM THE FOLLOWING 655P3 TYPE RESISTORS: -50 (22.1K), -98 (22.6K), -270 (23.2K), -202 (23.7K), -145 (24.3K), -58 (24.9K), -122 (25.5K), -285 (26.1K), -5 (26.7K), -155 (27.4K)

C D LAST REV. INCORP. REVISION STATUS OF SHEETS
2 1 SHEET NO.

PREPARED BY NAVIGATION AND CONTROL DIVISION OF THE BENDIX CORPORATION FOR GEORGE C. MARSHALL SPACE FLIGHT CENTER NASA, HUNTSVILLE, ALABAMA

THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO, NEW JERSEY U.S.A.

ELECTRICAL SCHEMATIC POWER SUPPLY -12VDC

SIZE F CODE IDENT NO 19315 2125651

SCALE NONE SHEET

4-3A

FIGURE 2.4.6-3

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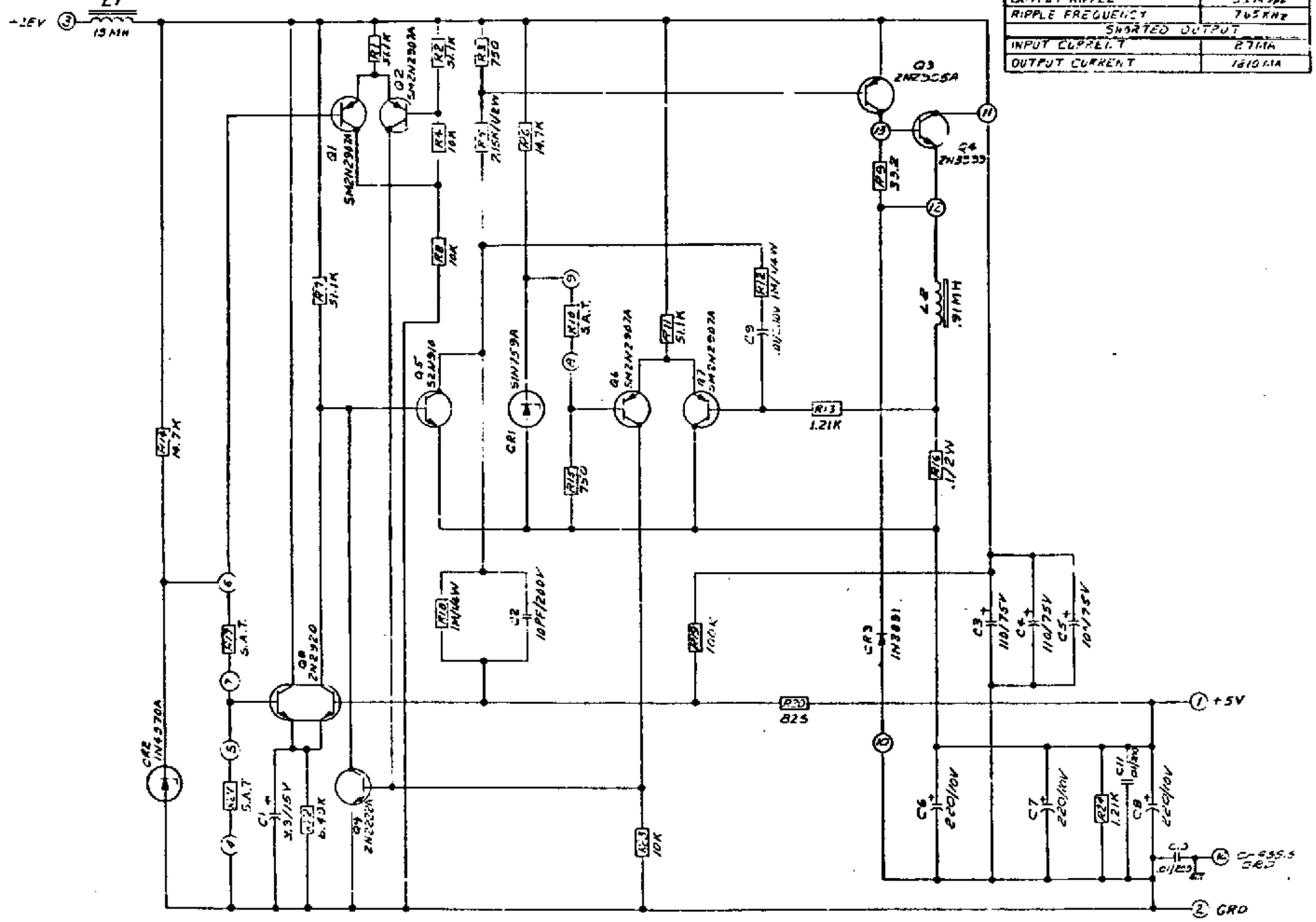
| PERFORMANCE CHARACTERISTICS | |
|---|---|
| INPUT VOLTAGE | 28V |
| VOLTAGE REGULATION @ 1555 MA OUTPUT CURRENT | |
| INPUT CURRENT | 350 MA |
| OUTPUT VOLTAGE | 5V |
| EFFICIENCY | 76.5% |
| OUTPUT RIPPLE | 39 MVpp |
| RIPPLE FREQUENCY | 765 KHz |
| SHORTED OUTPUT | |
| INPUT CURRENT | 27 MA |
| OUTPUT CURRENT | 1610 MA |



NOTES:
1. ALL RESISTORS ARE EXPRESSED IN OHMS, ±1% AND ARE 1/8 WATT, UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS ARE EXPRESSED IN MICROFARADS, ±10% UNLESS OTHERWISE SPECIFIED.
3. SELECT AT TEST R10 FROM THE FOLLOWING RESISTORS: 1855931-55(51.1K), -116(48.7K), -114(46.4K), -112(44.2K), -111(42.2K), -172(40.2K), -150(39.3K), -123(36.5K), -223(34.8K).
4. SELECT AT TEST R17 FROM THE FOLLOWING RESISTORS: 1855931-134(2.21K), -175(2.26K), -311(2.32K), -312(2.31K), -156(2.43K), -193(2.49K).
5. SELECT AT TEST R21 FROM THE FOLLOWING RESISTORS: 1855931-275(2.87K), -271(8.87K), -45(10.0K), -289(11.3K), -246(12.7K).

THE BENDIX CORPORATION

ELECTRICAL SCHEMATIC 5 VDC POWER SUPPLY

F 19315 2125771

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FIGURE 2.4.6-3

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## 2.5 MECHANICAL DESIGN

### 2.5.1 DESIGN PHILOSOPHY

In view of the large temperature range to which the OMA is subjected, as well as launch shock and vibration, the mechanical design has been aimed at developing maximum mechanical stability. First, it may be seen that structural symmetry has been employed widely. Also, materials with similar coefficients of expansion are used throughout. Truss rib designs were chosen to afford maximum resistance to deflection, and gimbal pivot bearings have been configured to contribute to maximum gimbal rigidity. Improved stability through the folded optical path has been realized through the use of a pair of wedge reflecting mirrors which are rotated for adjustment and securely locked in position. The design philosophy of each element will be discussed in the description of each subassembly.

### 2.5.2 STRUCTURAL CONSIDERATIONS

In order to provide a light-weight alloy of moderate cost with a coefficient of expansion matching stainless steel, (about $8.4 \times 10^{-6}$ in/in/$^{o}$F), a vanadium-aluminum-silicon casting alloy was selected for the frame, gimbal, and telescope housing. This alloy, Reynolds A-390 is termed hyper-eutectic in that it contains 19 percent silicone, 12 percent in solution and the remainder distributed throughout the matrix. Its unusual stability is traded for somewhat difficult machinability and reduced tensile properties. The cross-ribbed pattern employed in the frame and gimbal affords a marked increase in resistance to structural deflection over that of other candidate rib patterns. This is particularly useful as in this case where a three-point mount in a plane below the c.g. is called upon to survive launch loads and resist deformation.

Each raw casting is solution heat-treated at 900°F and artifically aged at 350°F to develop maximum properties. Each part is penetrant inspected and x-rayed to assure integrity. Before final machining, stability is improved by subjecting the part to a number of cycles wherein it is alternately heated and chilled over the expected temperature range.

The particular stainless alloy which matches the coefficient of expansion of Vanasil is grade 309, one of the less common grades of 18-8. It is used rather widely throughout the tracker.

To afford maximum gimbal rigidity and avoid sliding fit hangup, both bearing pairs in both gimbal pivots are securely preloaded and neither is floated. This only becomes feasible with a close match of coefficients as described.

## 2.5.3 DESCRIPTION OF MECHANICAL DETAILS

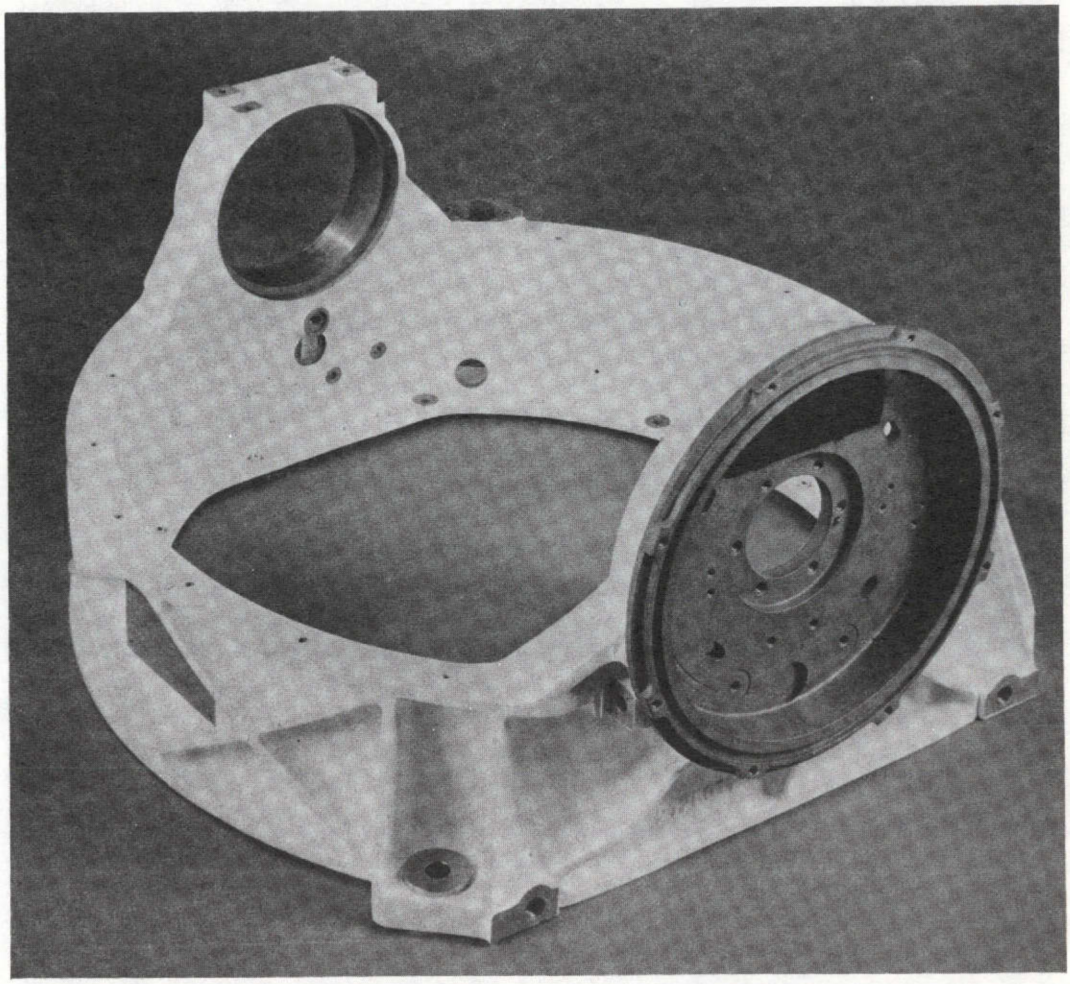
A modular concept has been followed throughout the OMA design. Major elements in the assembly consist of the frame, gimbal, inner and outer torquer pivots, inner and outer encoders and pivots, and the telescope assembly.

### 2.5.3.1 FRAME

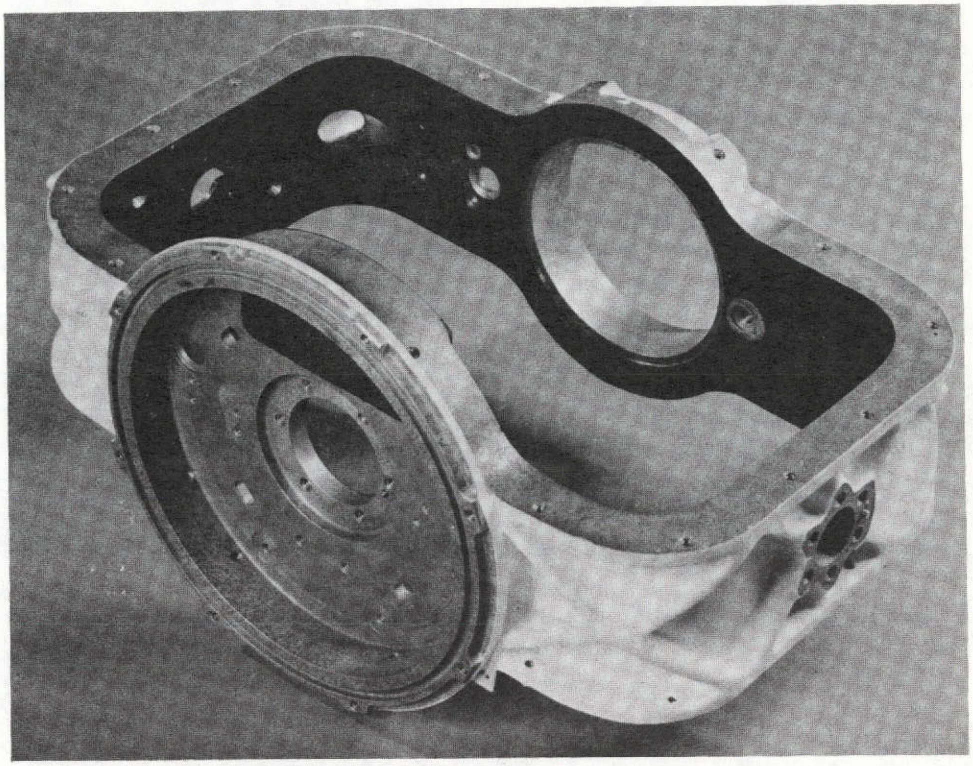
The Frame is the structural chassis which supports the entire tracker and by which the assembly is mounted on the vehicle rack. The frame pivot bores are line-bored accurately with respect to the plane of the mounting feet and also the pad which receives an alignment reference mirror. The hole pattern in the bushed mounting feet is transferred to the feet by means of a drill jig fixture which has been precisely positioned with respect to the pivot axis by clamping against an alignment bar and lateral locating pin. Holes in the spacecraft support rack are transfer-drilled from an identical fixture. Mounting bosses for an elapsed time indicator, gimbal stop, and nameplate are provided in the machined casting, Figure 2.5.3.1-1.

### 2.5.3.2 GIMBAL

Materials and construction of the gimbal is similar to that of the frame. Pivot bores are held to a high degree of orthogonality to benefit pointing accuracy. The upper and lower flanges are machined to receive pairs of covers which serve the primary purpose of thermal control but also afford structural support to the gimbal. As for the gimbal as well as the frame, bores and tapped holes are provided with liners and inserts. In the majority of cases, threaded inserts are of the helical coil type and commonly include a deformed-coil self-locking feature to secure mating screws. Figure 2.5.3.2-1 depicts a completed gimbal.



FRAME MACHINED - ENCODER END
2125010-1
FIGURE 2.5.3.1-1



GIMBAL MACHINED - ENCODER END
2125051-1
FIGURE 2.5.3.2-1

2.5.3.3 TELESCOPE HOUSING

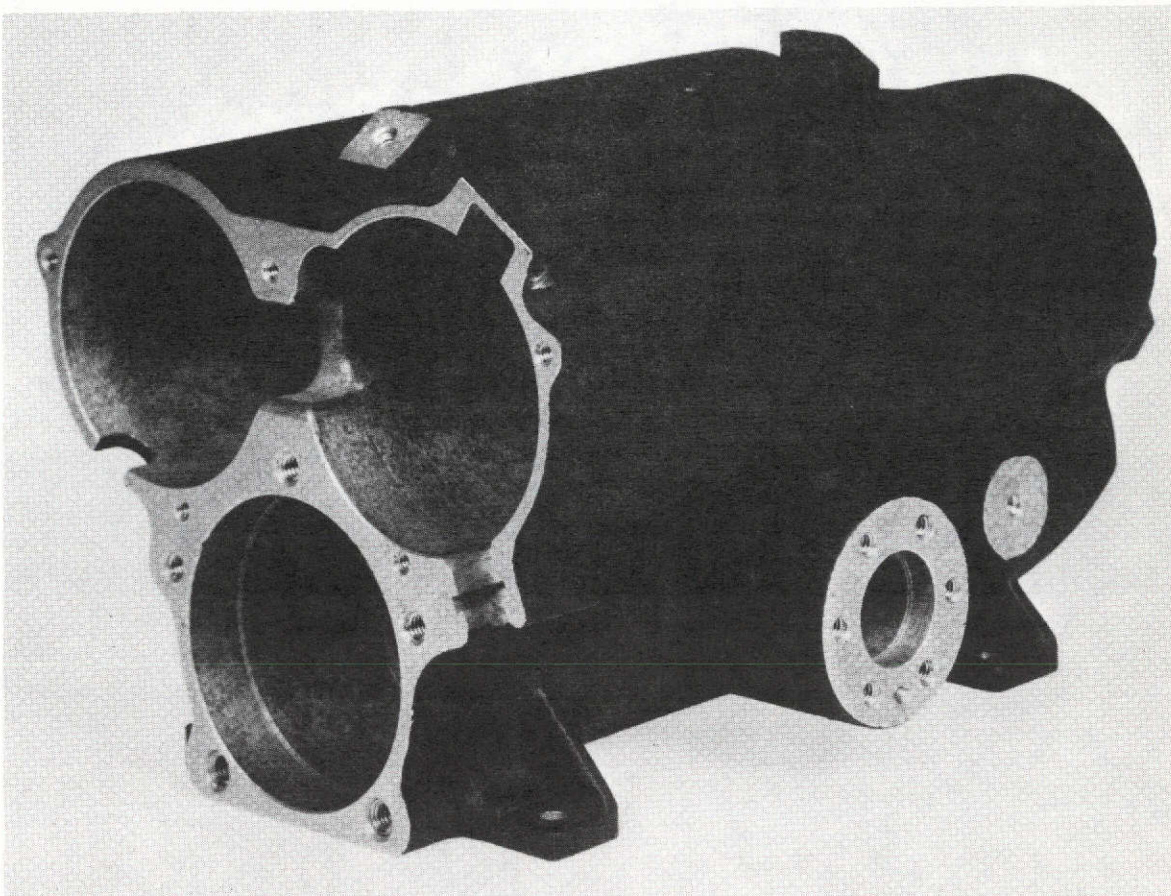
Adhering to the principle of uniform materials, the telescope housing is also constructed of A-390. Resembling a cluster of three cylindrical elements, the three bores of the housing contain the lens assembly, photomultiplier tube, and high-voltage power supply, respectively, Figure 2.5.3.3-1.

2.5.3.4 OPTICS

The lens assembly consists of a coated aplanatic air-spaced doublet lens mounted within a tube assembly which is threaded to afford initial focusing. A pair of aluminized and coated metal wedge mirrors fold the optical path 180 degrees. These mirrors are rotated to position the focal point in the center of the Cathode target. Geometric symmetry and close matching of materials properties combine with careful design to insure a very stable optical system which is insensitive to environmental changes.

2.5.3.5 PHOTOTUBE

The photomultiplier tube assembly consists of the tube proper, a toroidal magnetic sweep yoke, and an external set of nested shielding cans. The high voltage photocathode lead resides within a tunnel in the shield and the entire assembly is potted by a vacuum process which assures elimination of internal voids which contribute to arcing problems. Locating the high voltage power



TELESCOPE HOUSING
FIGURE 2.5.3.3-1

supply adjacent to the tube assembly minimizes lead length for this same purpose.

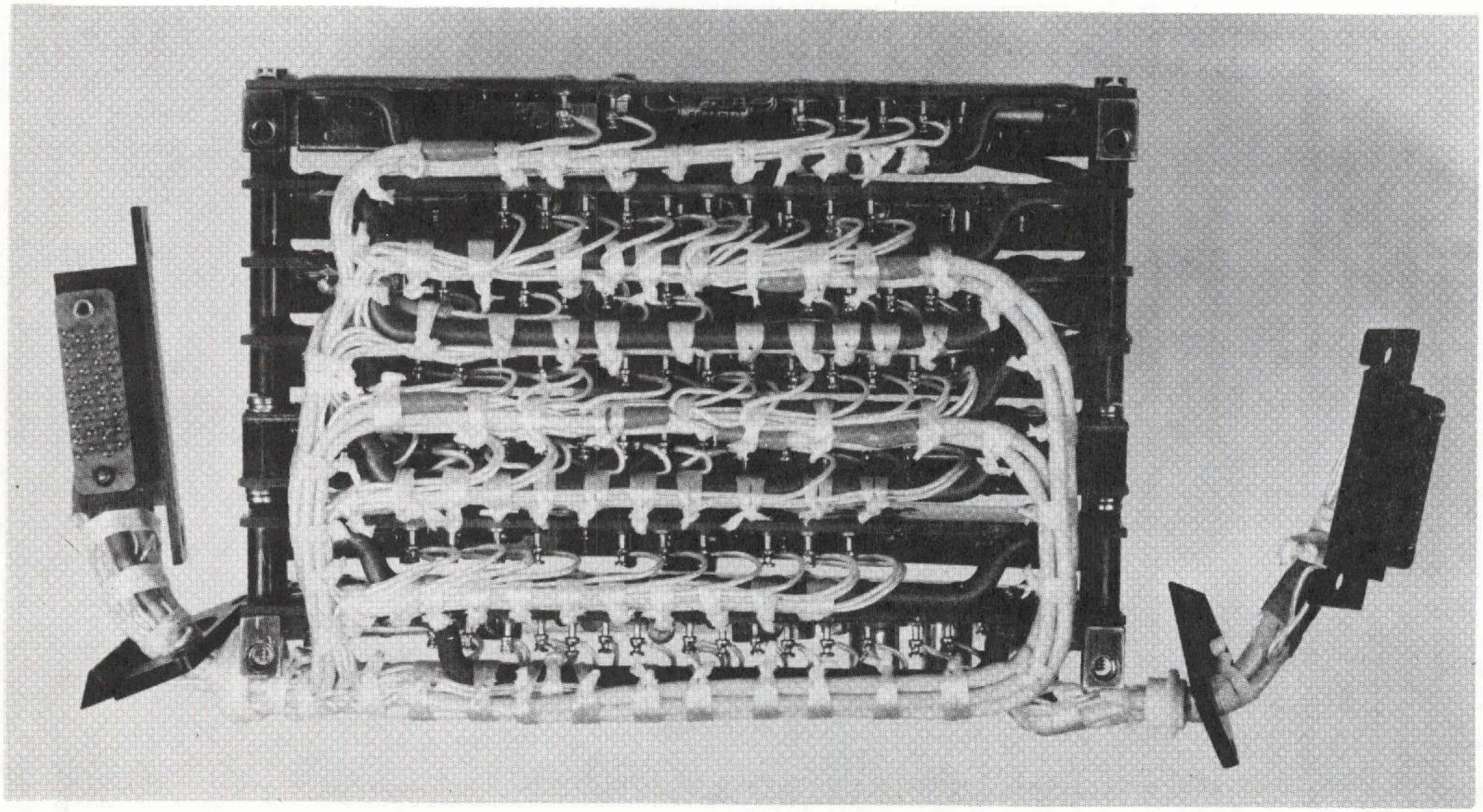
### 2.5.3.6 ELECTRONICS

Processing signal circuitry and shutter control logic is packaged in a modular Telescope Electronics Assembly attached to the telescope housing by means of four screws. Two connector plugs facilitate installation, Figure 2.5.3.6-1. The unit consists of an array of printed circuit component boards contained within an aluminum housing. In addition to shutter command circuitry, the assembly contains the video amplifier, scan selector, sweep generator, demodulator, and raster scan logic. A pair of terminal boards mounted adjacent to the telescope pivot servo provides a junction for the Electronics Assembly mating connector.

A circular aluminum shroud mounted on four standoffs assists in the maintenance of acceptable operating temperatures.

### 2.5.3.7 SUN SHADE AND SHUTTER

In order to permit tracking a guide star within 39 degrees of the sun line and 5 degrees of earth reflection, a carefully designed sun shade is extended beyond the lens along the optical axis and affords sunlight attenuation of the order of $1 \times 10^{-11}$. The assembly consists of a machined aluminum tube about 2.5 inches in diameter and 14 inches long containing black optical baffles. A sun sensor and an earth sensor are mounted adjacent to the open entry of the tube. A hinged



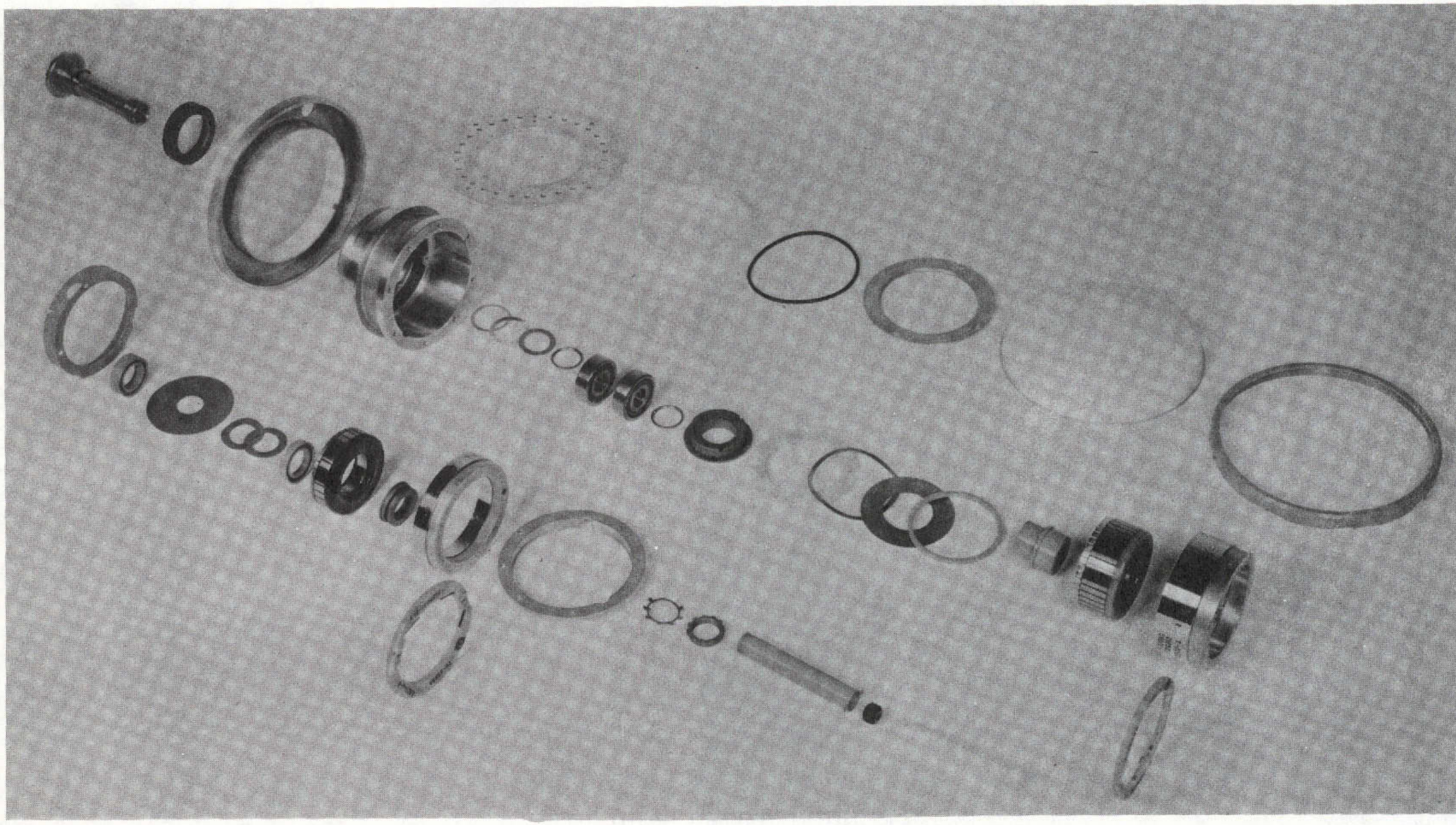
TELESCOPE ELECTRONICS ASSEMBLY
FIGURE 2.5.3.6-1

shutter-door provides closure of the tube against contamination and damaging high-intensity stray light upon manual or sensor command. The shutter is spring-loaded to open, a steel tape wrapped around a drum returning the door to closed position as required. Pull-force is exerted on the tape by means of a jackscrew and nut driven by a dc torque motor. A pair of hermetically sealed snap-action switches control drive travel and signal door position. Positive non-jamming mechanical stops are provided at each end of the nut excursion. A spring element in series with the tape maintains tension on the link with the door in closed position. Actuating time to fully close is about 600 milliseconds.

Dry-film lubrication is used on the jackscrew and bearings throughout. Ball bearings are equipped with TFE, glass, $M_0S_2$ composition separators. The motor is thermally isolated from the shade and covered by a shroud for protection against temperature extremes. A stable encapsulating resin and tantalum-moly brushes control outgassing and commutator wear to a low level. The shade is thermally isolated from the telescope by an epoxy-fiberglass spacer. Attachment is by five capscrews and an electrical connector completes the circuitry to the telescope electronics module.

2.5.3.8 GIMBAL TORQUER PIVOTS

Modular Torquer Pivots containing mostly common parts are used to support one end each of the gimbal and telescope respectively. The pivot consists of a housing, shaft, bearings, torque motor, rate tachometer, flex leads, terminal board and cover, Figure 2.5.3.8-1.

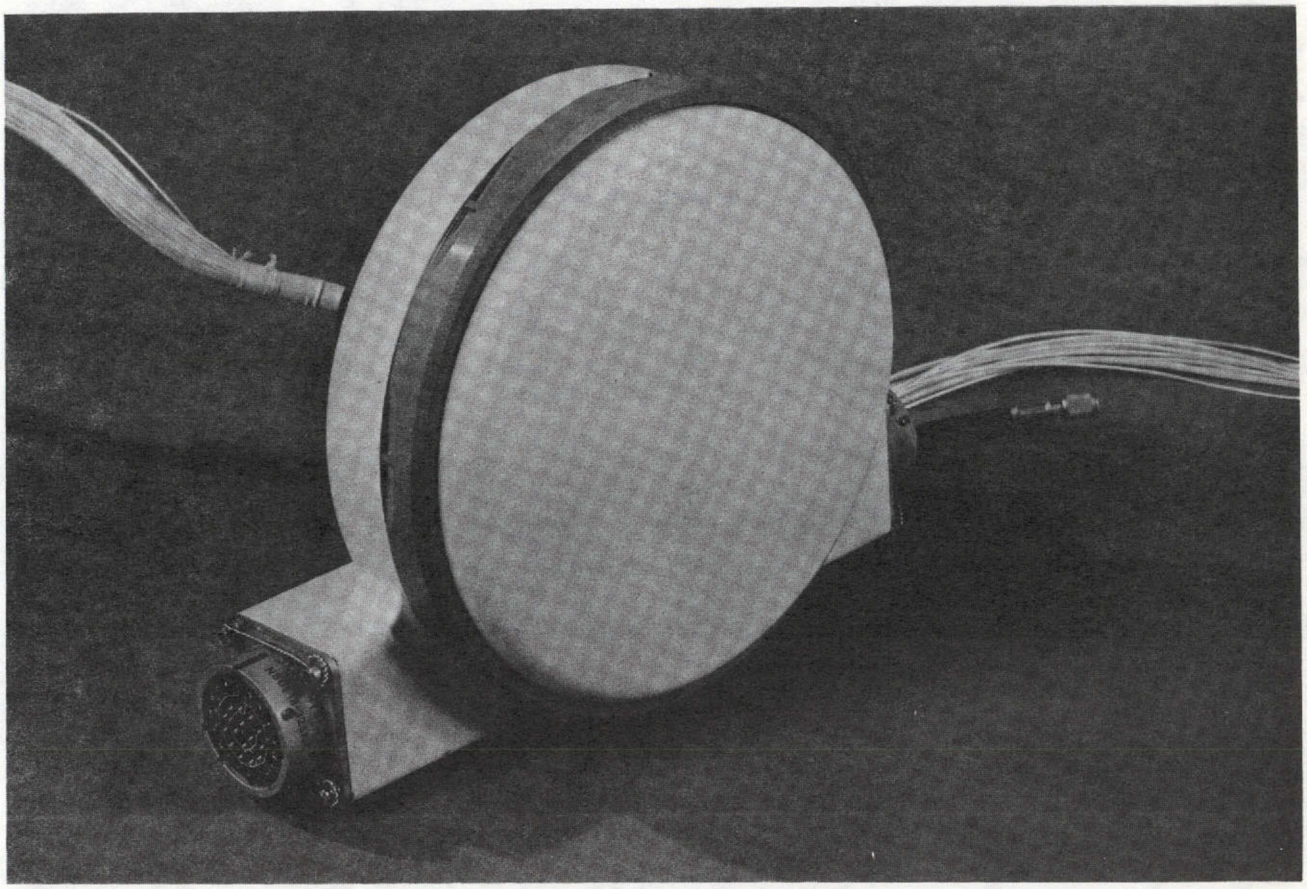


TORQUER PIVOT MODULE (INNER)
2125170-1
FIGURE 2.5.3.8-1

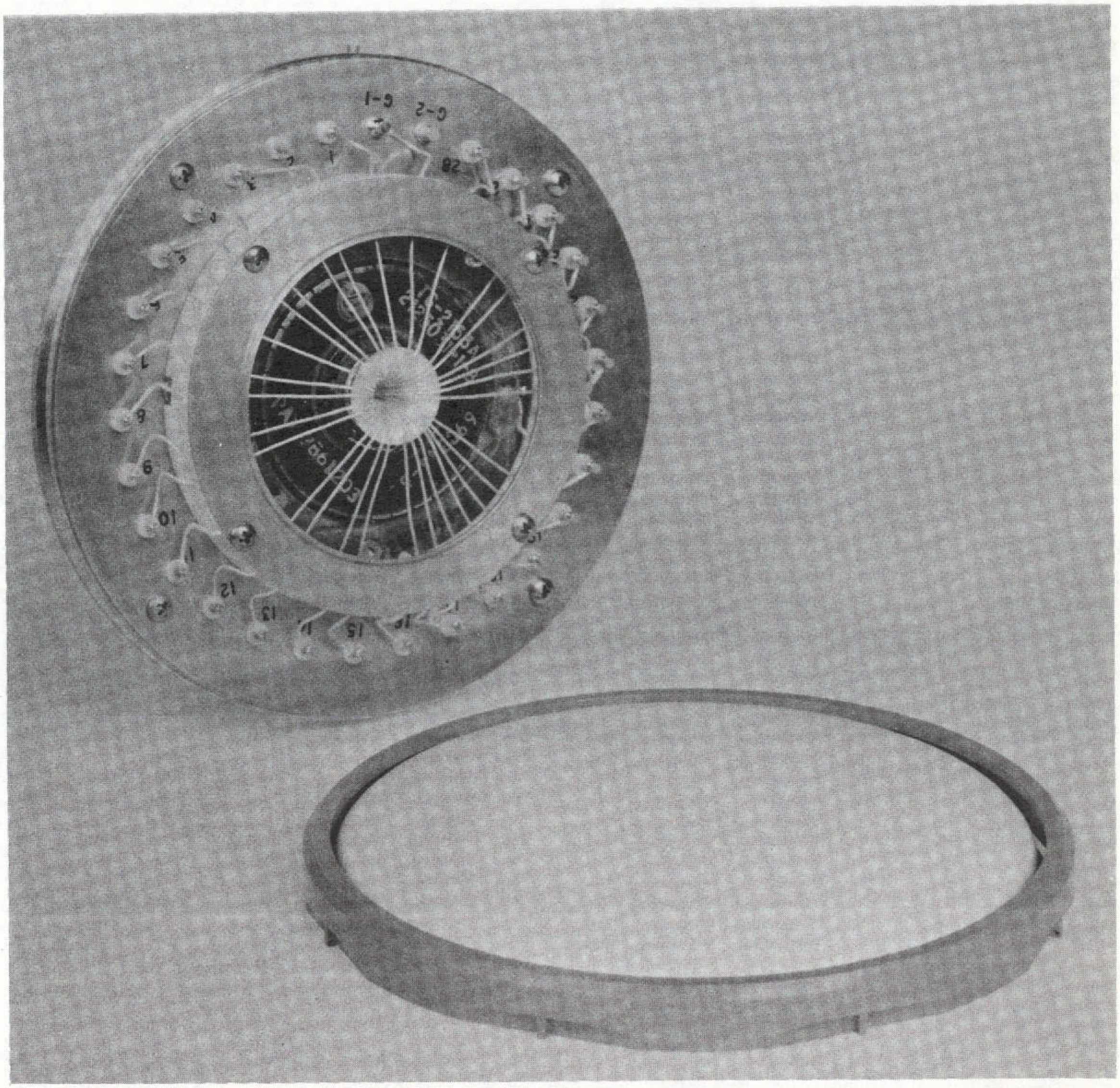
The housing is turned from aluminum alloy barstock and contains a corrosion resistant steel bearing liner and threaded inserts. A pair of 440 C preloaded angular contact ball bearings accurately pivots the shaft on which the motor and tachometer rotor adapters are mounted. An iron alloy shield disc minimizes magnetic field coupling between the motor and tachometer. To insure positive clamping force under worst cold temperature conditions, a BeCu wavy washer is included in series with the retaining nut and locking tab washer.

Within the hollow pivot shaft is contained a flex lead assembly for the purpose of conducting circuitry from gimbal to gimbal without the use of slip rings. The leads are TFE insulated silver alloy, gripped by a Viton grommet at the base of TFE bellmouth tube liner. Leads flex in torsion mainly and are clamped at the periphery of the fanout in a slotted teflon retainer disk, finally terminating at individual feed-throughs in the pivot terminal disk. Leads soldered to the backside of the feedthroughs terminate either in the electrical connectors (outer), Figure 2.5.3.8-1 or interconnect with the other torquer pivot, Figure 2.5.3.8-2.

Motors and tachometers are of permanent magnet pancake configuration employing a wound rotor encapsulated with approved resin. The tantalum-moly composition brushes used were selected for superior life when operating in a vacuum environment. Attachment of the torquer pivot shaft to gimbal is by means of a threaded ring and flange, torque being delivered through a captive pin



OUTER PIVOT TORQUER
2125180-1
FIGURE 2.5.3.8-1



INNER TORQUER PIVOT
ATM ST - OMA 2125170-1
FIGURE 2.5.3.8-2

in the flange. The torquer housing body contains a pilot diameter, locating pin, and a threaded ring means of retention. To insure interchangeability, each assembly is constructed such that a close tolerance dimension is held between the locating flanges on the housing and the shaft.

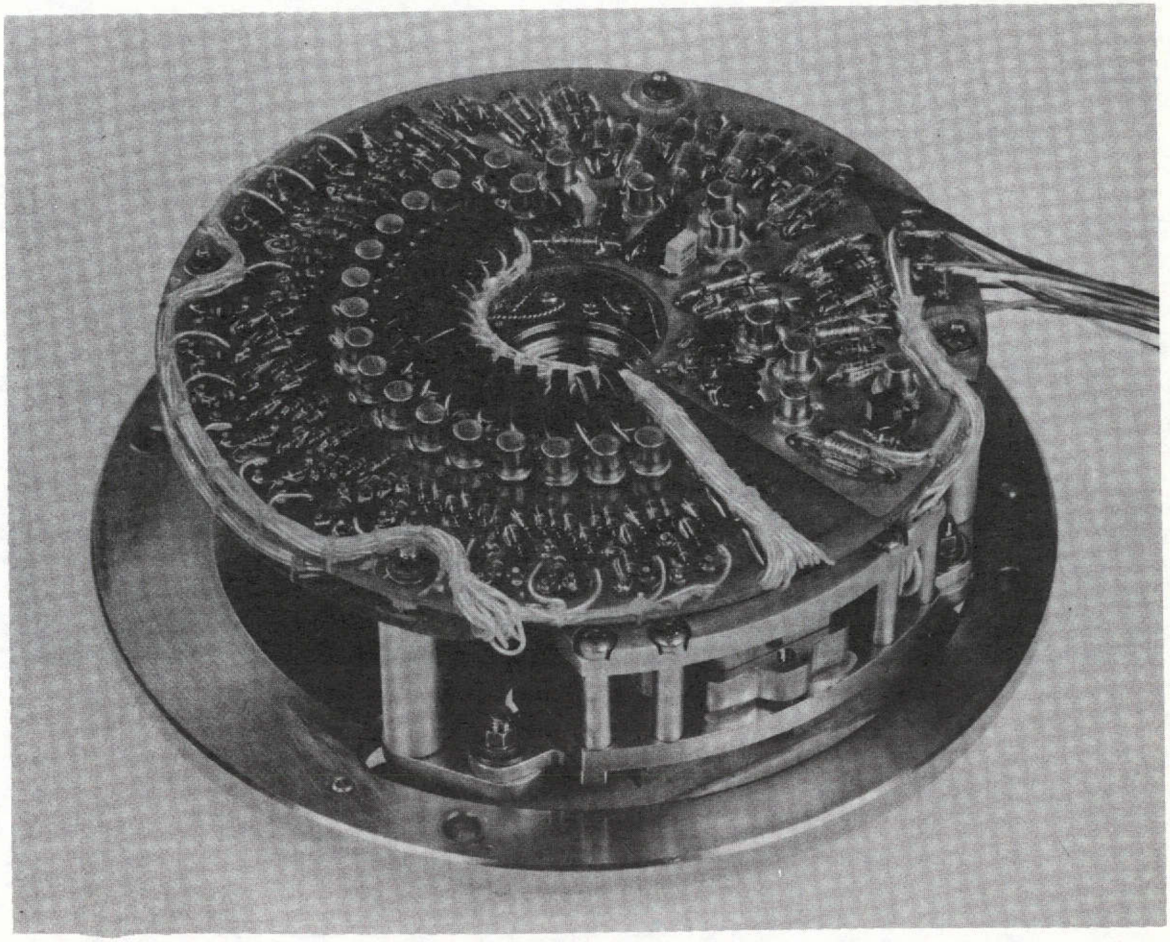
## 2.5.3.9 ENCODER PIVOT

The function of supporting the gimbal or telescope on the encoder side is not shared by the encoder assembly but rather by a separate pair of trunnion bearings. This is done so as to relieve the optical disk hub from forces generated during launch. The trunnion is comprised of a flanged shaft, a pair of angular contact ball bearings identical to those in the torquer pivot, a housing liner, and associated threaded rings, nuts, and tab washers. Rotational coupling between the pivot shaft and the encoder disk hub is by means of a metal bellows.

The pivot shaft is hollow-bored for insertion of a porous lubricant reservoir, vapors being conducted to the region of the bearings via a drilled passage. A threaded hole in the end of the shaft accepts an optical alignment tool consisting of an adjustable mirror. The mirror is adjusted in conjunction with an autocollimator to define the actual gimbal axis.

## 2.5.3.10 ENCODER ASSEMBLY

The function of the Optical Encoders is to provide gimbal angle information to the digital electronics in the form of 16 bit serial gray code. The assembly, Figure 2.5.3.10-1 consists of a hub, mounting plate, angular



OPTICAL SHAFT ENCODER
FIGURE 2.5.3.10-1

contact bearing pair, coded optical disk, light source readout array, and a pair of printed circuit component boards. The optical disk contains a code pattern consisting of alternate transparent and opaque segments arranged in concentric annular rings. The disk is precisely centered on the highly accurate hub which has been ground after assembly to control runout of the disk mounting face. The light source consists of a high-rel tungsten filament lamp, its beam focused by a truncated cylindrical lens. The beam, 100 microinches wide is focused on the disk. Photocells form a detector array on the opposite side of the disk, the signals from which are amplified, compared to a reference level, and digitized. The resulting angle information is unique for each position of the gimbal.

Structural parts of the assembly are constructed largely of 309 stainless steel, with selected parts of 6 Al 4V titanium and 400 series cres steel to compensate for certain thermal gradients. The 440 C bearings are preloaded in the DB configuration for maximum shaft stability. Molecular seals minimize contamination of bearings and lubricant escape. A pair of opposing adjustment screws are used to position the encoder mounting plate with respect to the structure during the zero-adjust procedure, after which the plate-mounting capscrews are tightened and the adjust screws secured. Figure 2.5.3.10-2 shows an encoder hub mounted on a work plate.

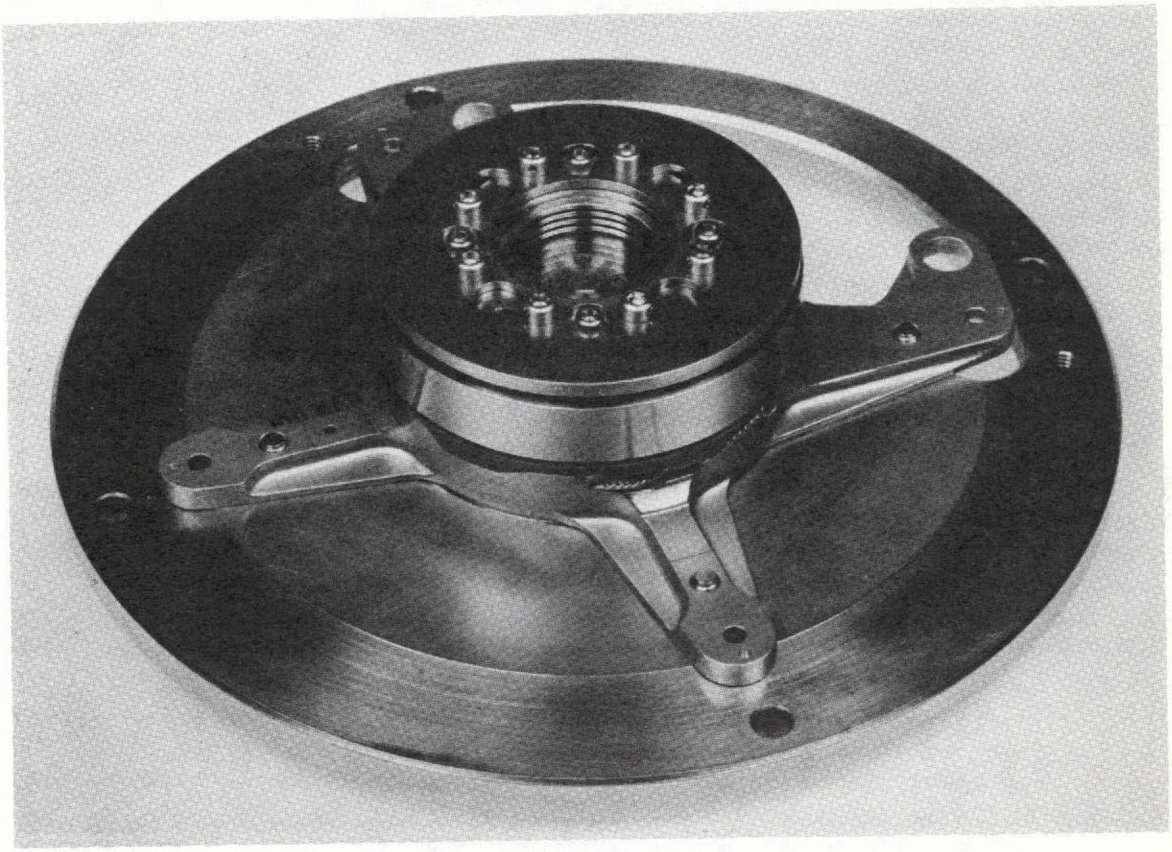


FIGURE 2.5.3.10-2

## 2.5.4 LUBRICATION

To provide long-term reliable lubrication with the smooth performance required for a precision optical device, a system employing a fluorosilicone oil is used. The viscosity of this class of oils is least sensitive to large temperature variations. Porous "Nylasint" ball separators have a controlled void, 20 percent by volume, which is vacuum impregnated with the oil. Additional lube storage is contained in a similar supplementary "reservoir" pad in proximity to the bearings. The mechanism by which the oil reaches the ball zone is one in which a vapor-pressure equilibrium is achieved within the pivot cavity. Transport is molecular in nature and varies with temperature. Undesirable flooding is avoided as is the somewhat higher attendant torques associated with the use of channeling grease.

Escape of lubricant from the confined cavity is effectively controlled by three means. First, a teflon face-seal element is provided on each of the four rotating pivot shafts. A tempered BeCu spring maintains seal contact with a mating stainless steel washer. In addition to this rubbing contact seal, molecular seals sometimes termed labyrinth seals flank both sides of each bearing cavity being designed for minimum radial clearances and maximum axial length. Tests conducted have verified the approach and agree well with theoretical calculations of vapor loss. Thirdly, migration of lube over the surfaces of parts in the escape path is minimized by application of a dry oleophobic coating with a selected "surface energy" level.

## 2.5.5 THERMAL CONTROL

### 2.5.5.1 REQUIREMENTS

Certain components within the OMA may be damaged or permanently degraded if subjected to temperature extremes beyond design limitations. Furthermore, in order to meet performance specifications, even tighter temperature control must be exerted. These means are employed to influence tracker temperature: insulation, application of heater power, and passive methods involving surface finishes.

### 2.5.5.2 INSULATION

Where low thermal conductivity must be maintained across an interface requiring structural integrity a wafer or spacer of a rigid plastic or other selected material is used. For example, to prevent escape of thermal energy from the telescope housing to the sunshade, a spacer of rigid filled epoxy-fiberglass is clamped between the shade flange and its mounting pad on the housing and again between the shutter drive motor and its mounting pad on the shade.

On the other hand, decidedly more efficient insulating effect is realized from the use of multi-layer aluminized Mylar as is used between the Encoder Cover sandwich shells and in the frame belly pan cover where structural support is not of primary concern.

2.5.5.3 ELECTRIC HEATERS

Resistance heaters and thermal snap-switches are mounted in the telescope and the gimbal and frame encoder chambers totalling 20 watts. These elements are switched in and out by a redundant array of four disc-type hermetically sealed snap switches.

2.5.5.4 THERMAL CONTROL FINISHES

By choosing a finish with a preferred ratio of solar absorptivity to thermal emmissivity, a surface may be made to accept or reject BTU. Selected finishes have, therefore, been applied per this principle. In general, inside surfaces, or those not in the sun view, are painted with Cat-a-lac epoxy black paint. Surfaces external are painted with Pyromark white, a silicone resin based paint.

2.5.6 WIRING

A pair of PV type 32 pin bayonet-latch connectors are located on the outer torquer pivot housing accommodating all OMA power and signal circuits. Each torquer pivot is wired as a subassembly module ready for installation. Hookup is accomplished by trimming the leads to proper length and soldering to pertinent terminals in the next assembly. Wire bundles are securely laced to tie bars provided. Encoders likewise are prewired and tested at the subassembly level as is the telescope. As mentioned earlier, the Telescope Electronics Assembly provides two rectangular miniature connectors at the telescope interface junction.

Wire used throughout is silver alloy with transparent teflon insulation. In particular, flex leads are 30 AWG with 19 x 42 stranding.

## 2.5.7 ALIGNMENT REFERENCE

To assist in location of the optical axis and for check-out of alignment with respect to vehicle, a reflective reference is attached to the OMA frame on the torquer pivot end. The device may be viewed from the zenith direction and a position normal to the same. A pair of cross-hair scribe lines are used to locate the optical axis zenith, dimensions from the axis to each reference line being recorded in the data package accompanying each tracker. A smaller reflective element attached to the cylindrical sun shade is provided for test procedure purposes.

# SECTION 3

## 3.0 SYSTEM TEST EQUIPMENT

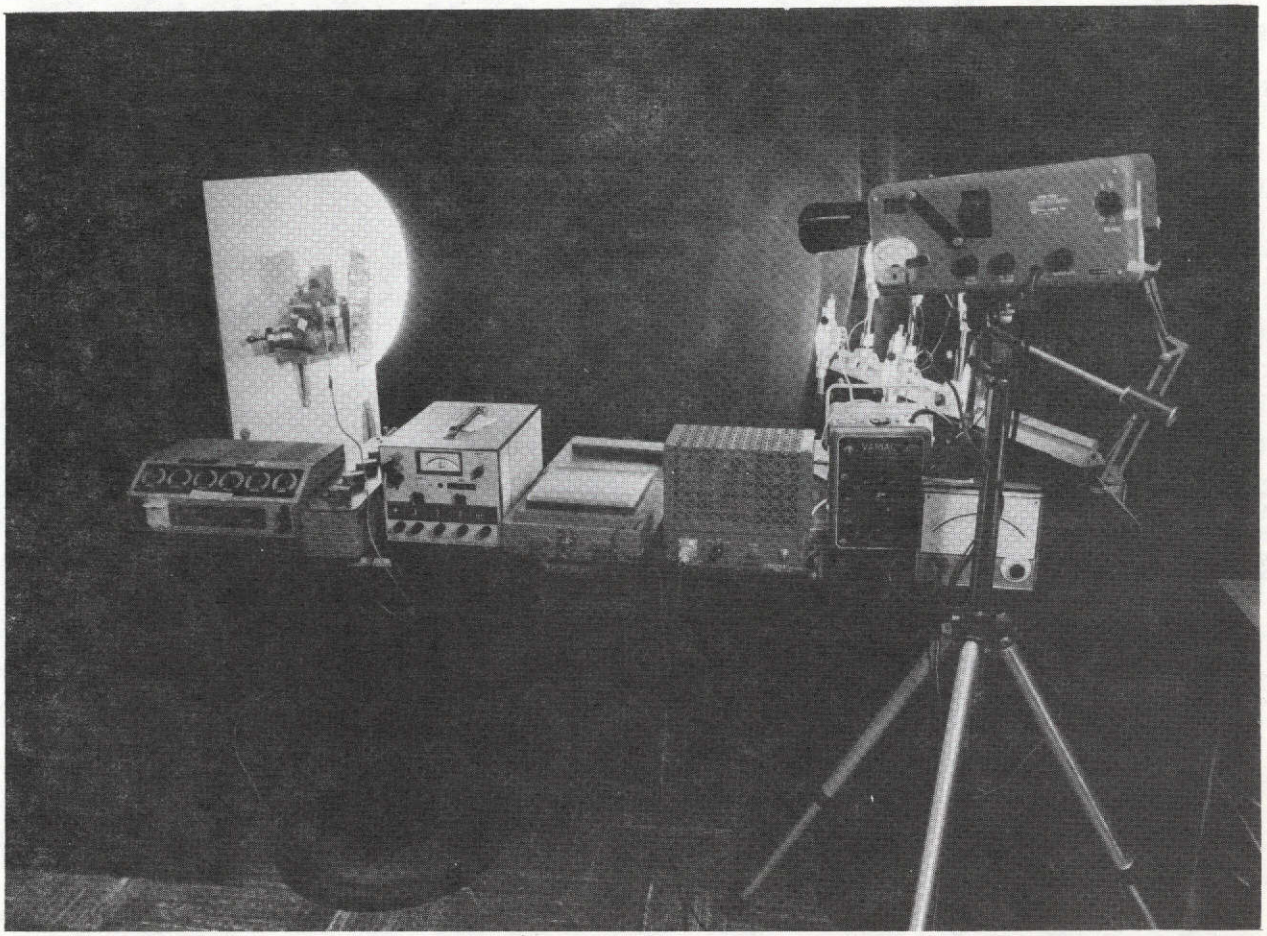
Two identical dark rooms are equipped with seismic blocks and Diffraction Ltd. star simulators. The star simulators can be accurately moved through 120 degree arc corresponding to IG rotation. The optical-mechanical assembly (OMA) is also mounted on an optical-mechanical table and can be rotated through a 180 degree arc. This corresponds to OG rotation. The tables are position accurate to 5 arc seconds and they are aligned perpendicular to eac other to within 3 arc seconds with the aid of two autocollimators and an optical master. The combined effect of the two tables is to accurately locate the simulated star anywhere within the range of gimbal movement of the star tracker. The electrical test console simulates the spacecraft signals and loads. Extensive monitoring and readout devices are available. In addition, a minimum of eight channels of Sanborn strip chart oscillograph recording provides a permanent record of the star tracker performance.

Figure 3-1 shows the earth albedo simulation utilizing a Spectra Prichard photometer.

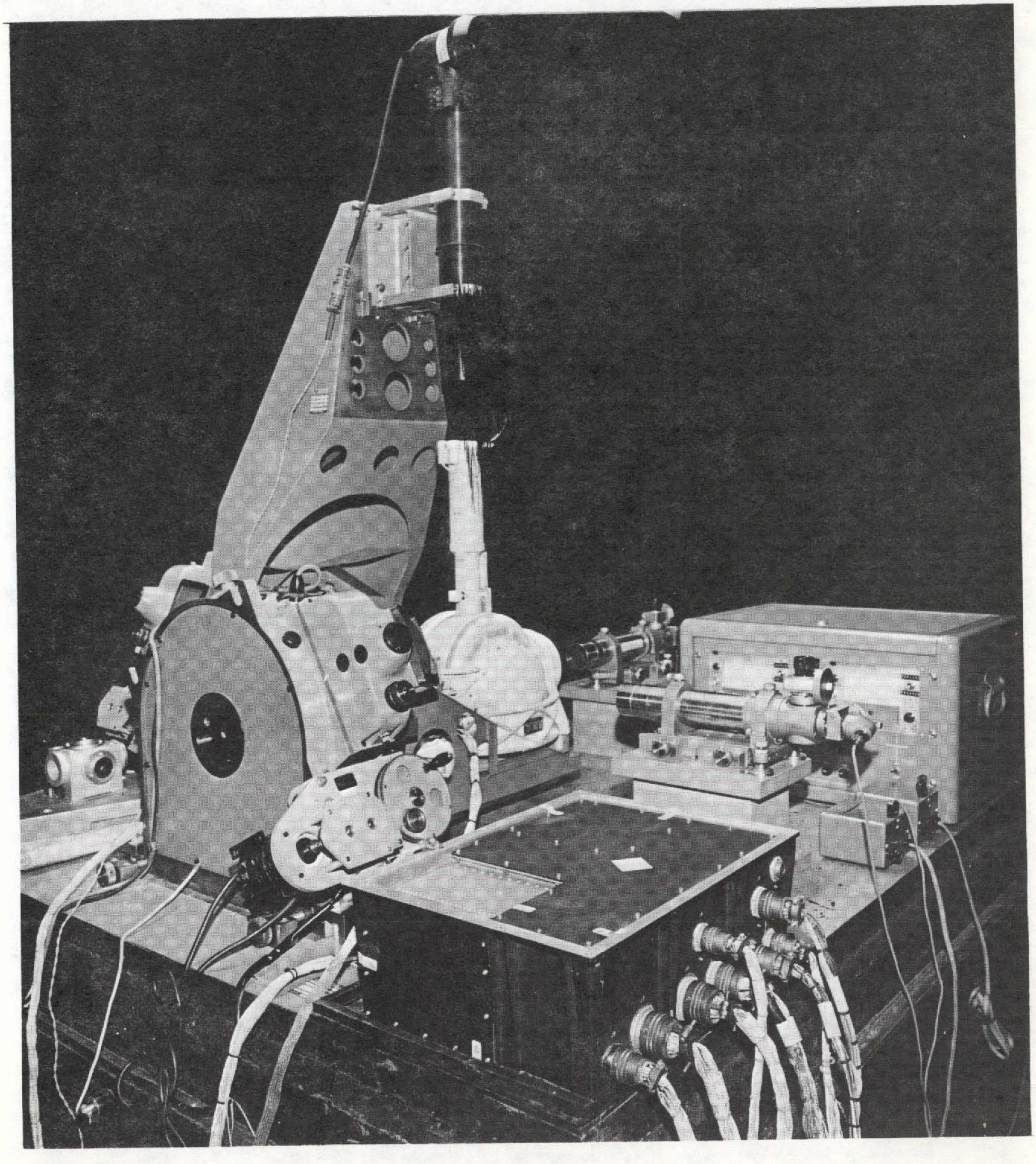
### 3.1 Alignment of Final Functional Test Stand

Qualification and Acceptance Function Testing of the ATM system are performed on the Final Functional Test stand, shown in Figure 3-2.

The star tracker OMA is mounted on the mounting bracket and plate on the optical rotary table with the outer gimbal axis parallel to and coincident with the axis



EARTH ALBEDO SIMULATOR
FIGURE 3-1



ATM FINAL ALIGNMENT ROTATING TEST SET UP
FIGURE 3-2

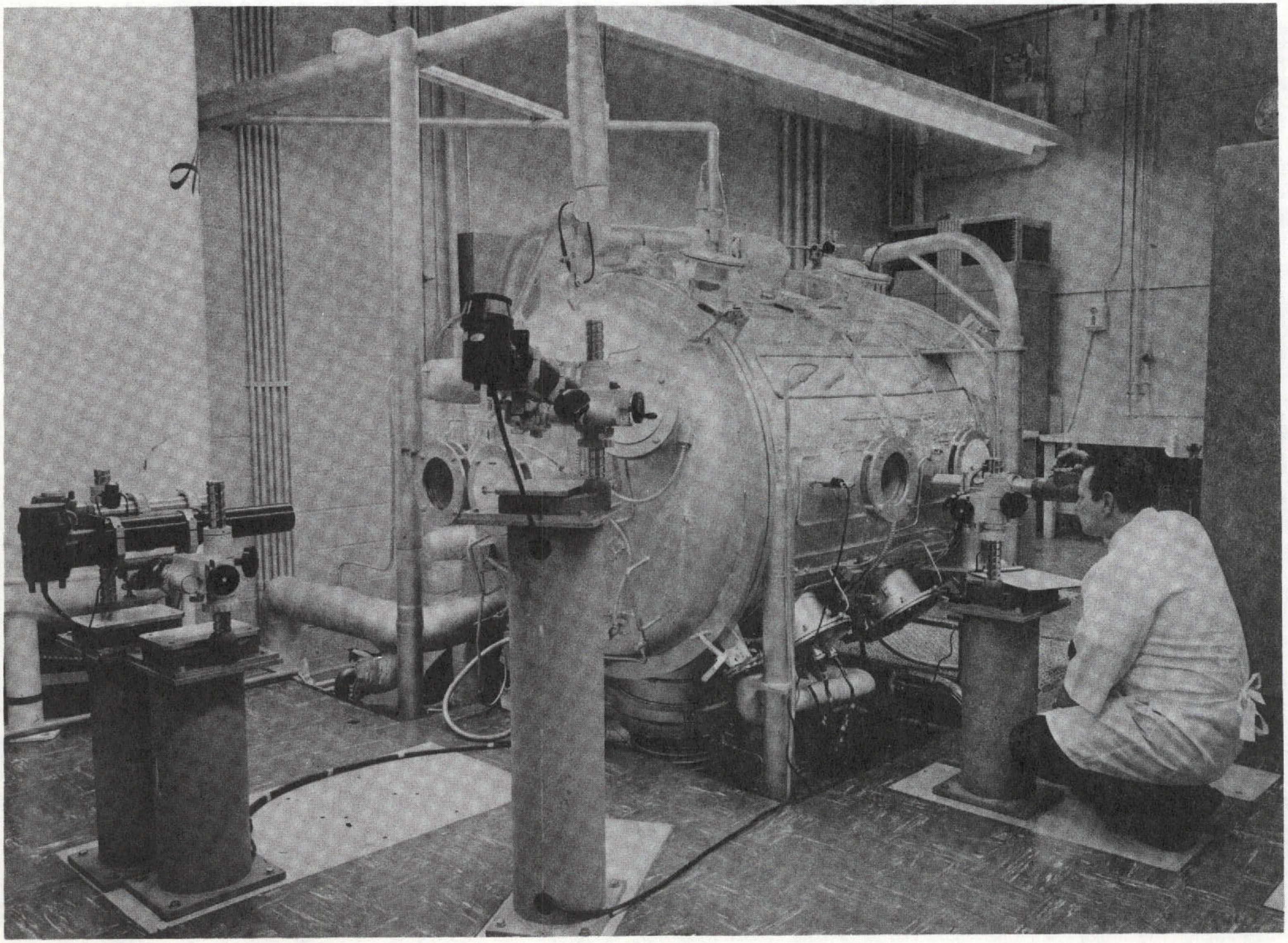
of rotation of the rotary table. The axis of rotation of the star simulator rotary table is oriented orthogonal to and approximately intersecting the axis of rotation of the OMA rotary table. The collimated beam of the simulated star, at the zero setting of its rotary table, is orthogonal to both axes of rotation and approximately intersects their point of intersection. Both rotary tables are capable of manual movement and may be positioned to any fixed angle within the required range of travel. They are both capable of arc second readout accuracy. The drive system is capable of providing rates from 0 to 1.5$^o$/sec.

Of particular interest is the thermal-vacuum chamber expecially built for testing star trackers, Figure 3-3.

It has a working area 5 ft. long x 3 ft. diameter, which is divided into two sections by a bulkhead. Dual environmental controls allow simultaneous testing with two different temperature profiles. The chamber is constructed with optical quality windows used for external star references and for monitoring the platen position. It may be operated at temperatures from -300$^o$F to +350$^o$F and pressures from sea level down to 1 x $10^{-9}$mm Hg.

3.2 Star Tracker Alignment and Test Equipment

The Star Tracker Optical Mechanical Assembly is subjected to optical alignment and inspection at numerous stages of its manufacture, including a final assembly inspection. The optical axis is aligned perpendicular



THERMAL VACUUM TEST FACILITY
FIGURE 3-3

to the plane of the rotational axes with a 3 sigma accuracy of 15 arc-seconds. Inner and outer gimbal axis orthogonality is limited to 10 arc-seconds, 3 sigma. The three-point mounting configuration (two two-axis pad) is machined and lapped until the planes described by the pads are parallel to the outer gimbal axis to within 15 arc-seconds, 3 sigma.

## 3.3 Final Check Out Console (130F751)

### 3.3.1 Uses of the F.C.O.

The electrical Final Checkout Console 130F751 is used to perform final exceptance testing and qualification testing of Star Tracker System for the Apollo Telescope Mount (ATM). The Star Tracker consists of an Optical Mechanical Assembly (OMA) 2125000-1 and a Star Tracker Electronic Box (STE) 2125600-1.

The FCO supplies and measures all necessary excitations and signals to the star tracker including 0-6 VDC supply for simulated star.

The FCO has readout capability for all star tracker performance tests.

### 3.3.2 Test Configurations

#### 3.3.2.1 Ambient Condition Testing

The 130F751 FCO is used with the 130E226 Mechanical Test Station and the Star Tracker dark room (Bendix Facility) to perform ambient testing.

3.3.2.2 Thermal Vacuum Testing

Use 130F751, Thermal Vacuum Cables No. 1938554 and Thermal Vacuum Chamber (Bendix Facility) to perform thermal vacuum testing.

3.3.2.3 Hot/Cold Testing at Ambient Pressure

Use 130F751 FCO with cables and Hot/Cold Chamber (Bendix Facility) cable No. 1938555.

3.3.2.4 Solar Impingement Test

Use 130F751 FCO with Solar Impingement cables No. 1938556 and Solar Impingement Mounting Fixture Testing is done at GE, Valley Forge Facility.

3.3.2.5 Electromagnetic Compatibility Testing

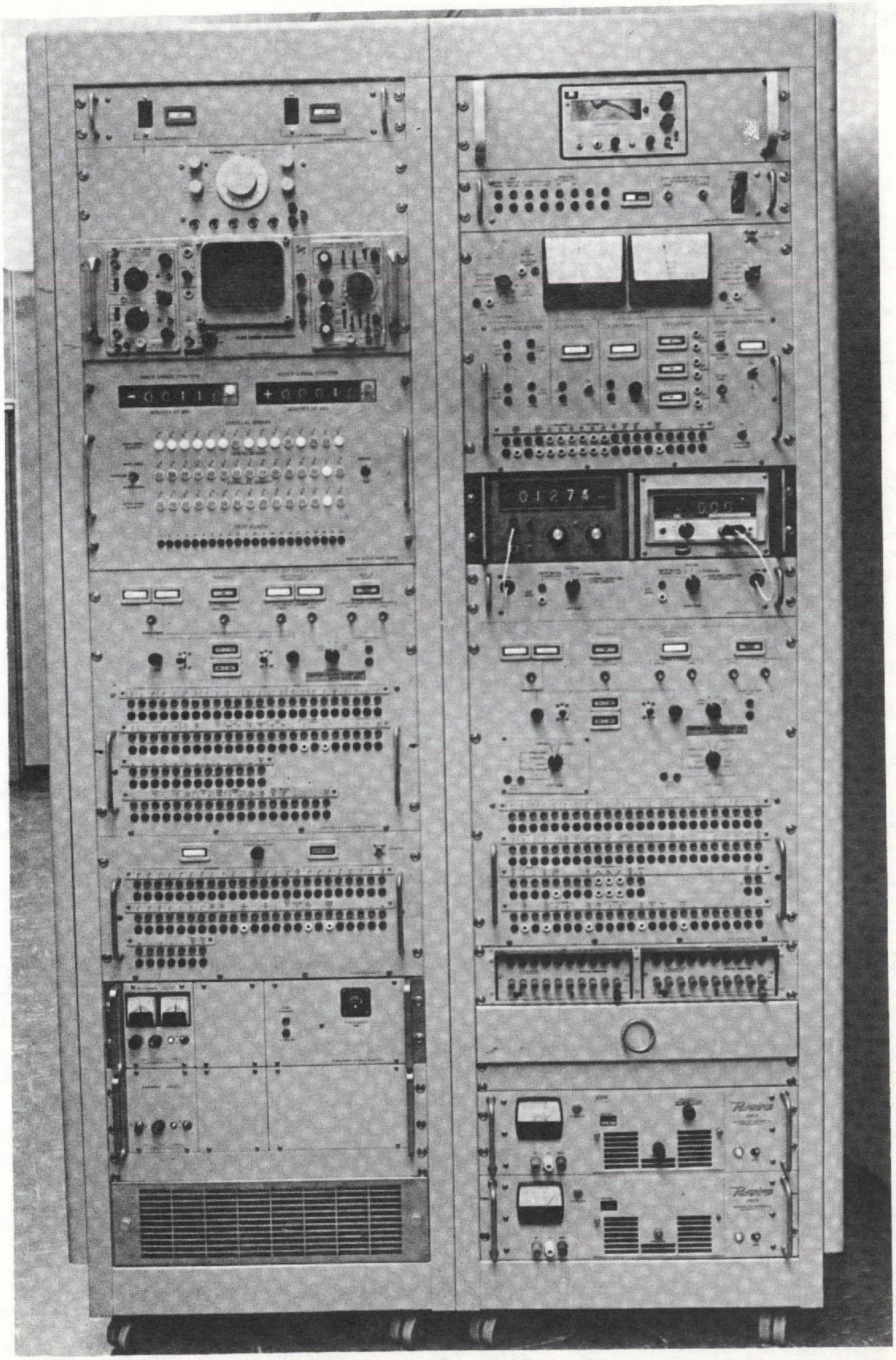
Use 130F751 FCO with EMC cables No. 1938557. Test is performed in shielded rooms. (Loki Building - Bendix Facility).

3.3.2.6 Acoustic Noise Testing

Use 130F751 FCO with No. 1938558 cables.

3.3.3 Test Stand Description - See Figures 3.3.3-1 and 3.3.3-2.

3.3.3.1 Power Breaker Panel 1938472 contains two 15A breakers and controls 115V 60 Hz power to two independent plug molds inside console.



ATM STAR TRACKER FINAL TEST STAND CONSOLE
FIGURE 3.3.3-1

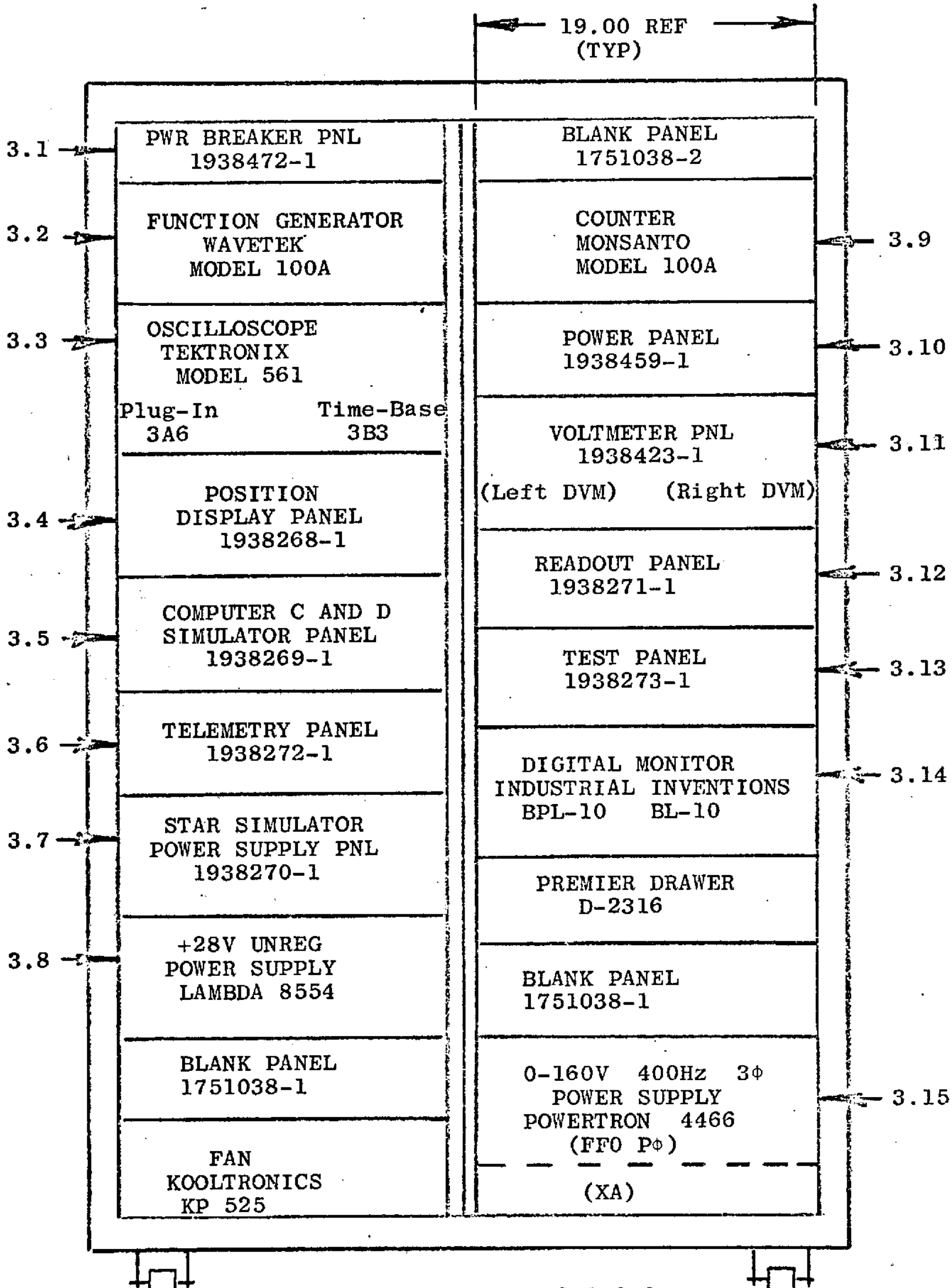

19.00 REF
(TYP)
3.1
PWR BREAKER PNL
1938472-1
3.2
FUNCTION GENERATOR
WAVETEK
MODEL 100A
3.3
OSCILLOSCOPE
TEKTRONIX
MODEL 561
Plug-In
3A6
Time-Base
3B3
3.4
POSITION
DISPLAY PANEL
1938268-1
3.5
COMPUTER C AND D
SIMULATOR PANEL
1938269-1
3.6
TELEMETRY PANEL
1938272-1
3.7
STAR SIMULATOR
POWER SUPPLY PNL
1938270-1
3.8
+28V UNREG
POWER SUPPLY
LAMBDA 8554
BLANK PANEL
1751038-1
FAN
KOOLTRONICS
KP 525
BLANK PANEL
1751038-2
COUNTER
MONSANTO
MODEL 100A
3.9
POWER PANEL
1938459-1
3.10
VOLTMETER PNL
1938423-1
(Left DVM)
(Right DVM)
3.11
READOUT PANEL
1938271-1
3.12
TEST PANEL
1938273-1
3.13
DIGITAL MONITOR
INDUSTRIAL INVENTIONS
BPL-10 BL-10
3.14
PREMIER DRAWER
D-2316
BLANK PANEL
1751038-1
0-160V 400Hz 3Φ
POWER SUPPLY
POWERTRON 4466
(FFO PΦ)
3.15
(XA)

FIGURE 3.3.3-2

3.3.3.2 Function Generator; Wavetek Model 100A can be patched into "Function Generator Input" on the Computer, C and D Panel 1738269 or into the "Function Generator Input" on the Test Panel 1938273 to perform servo loop frequency response tests.

3.3.3.3 Oscilloscope - Tektronix Model 561 mainframe with a 3A6 (Dual Channel, 10 MHz) plug-in and a 3B3 (Delay Sweep-Time Base) plug-in. For all test points using red (hi) and black (lo), use a properly adjusted Tektronix 10:1 probe on red (hi) jack only. For signals not referenced to ground (lower jack not black), use scope in its differential mode, (use two 10:1 probes and place 3A6 mode switch to "Added".)

3.3.3.4 Position Display Panel 1938261

3.3.3.4.1 Outputs from Display Panel to STE

The Position Display Panel provides Inner and Outer gimbal Interrogate Commands (to J4-K, J4-L) and ATM DC Clock Pulses (to J4-M). The above signals are derived from a crystal oscillator and are used to shift out serial binary information from the STE IG and OG Binary Storage Registers.

3.3.3.4.2 Inputs to Display Panel from STE

Inner Gimbal position (J5-A through J5-R) is displayed on individual Bit Lights marked "Inner Gimbal Telemetry-Parallel Binary."

Outer Gimbal position (J5-T through J5-K) is displayed on individual Bit Lights marked "Outer Gimbal Telemetry - Parallel Binary."

Serial Binary Position Signal

Inner Gimbal Serial Binary Signals (J4-G) are shifted into a register and displayed on Bit Lights when the toggle switch marked "Computer" is switched to "Inner Gimbal."

Outer Gimbal Serial Binary Signals (j4-H) are shifted into a register and are displayed on Bit Lights when the toggle switched marked "Computer" is switched to "Outer Gimbal."

Parallel Binary Coded Decimal Output from STE

The IG parallel BCD signals (J6-S through J6-F) and the OG parallel BCD signals (J6-A through J6-R) are decoded and displayed with nixie tubes.

Logic is used in the Position Display Panel to display the position to an accuracy of 0.5 minutes of arc. For example; +3999.5 minutes of arc. Test points numbered 1-22 monitor points internal to the Display Panel and are not normally used.

3.3.3.5 Computer - C and D Panel 1938269

All pins from the STE connectors J4 ATM/DC and J6 ATM Distributor are brought to test jacks along the lower half of the panel. A series protective resistor

(Type 2.2K) is used to prevent damage to the Star Tracker should any of the test points be accidentally shorted.

Status is displayed by lighted indicators.

Commands are initiated with toggle switches. Hand controller signals are simulated in the following manner: Set Readout Panel to "Comp- C and D Hand Contro." Use Hand Controller adj Knob to preset any input between 0 to 5 volts as read on the digital voltmeter. Move the Hand Controller switch upward (spring return), the preset voltage will now be applied to the Hand Controller Input (e.g., J6-t to J6-u). A lighted indicator simultaneously appears showing polarity of input. The opposite polarity is obtained by moving level downward (spring return).

In the neutral position, zero volts is applied to the Hand Controller Inputs.

3.3.3.6 Telemetry Panel 1938272

All pins on the STE connector J5 are brought to front panel jacks with protective series resistors.

The Telemetry Panel generates a 278 microsec strobe pulse four times a second to interrogate the STE Telemetry Storage Registers.

Connect the Monsanto Counter to the BNC input labeled "Counter" and rotate "Telemetry Strobe Pulse Adj" until 278 microsecond pulses are obtained.

3.3.3.7 Star Power Supply 1938270

The Star Power Supply feeds a Diffraction Limited simulated star source. Rotate Readout Panel (1938271) selector switch to "Star Current" setting. Increase the current until the proper star magnitude is reached as per attached calibration chart - Lamp Current vs. Star Magnitude.

3.3.3.8 Unregulated +28V Power Supply

Provides +28V unregulated power. No adjustments are made on this panel. The power supply is to be normally on; unregulated 28V power to the Star Tracker is controlled on the "Power Panel".

3.3.3.9 Counter

Monsanto Model 100A is used to adjust the telemetry sample pulse, perform the AC power frequency variation test as well as a general purpose counter/timer.

3.3.3.10 Power Panel 1938459

The Power Panel monitors and controls AC and DC excitation to the Star Tracker.

Description of indicators and controls:

1. The two wattmeters marked M1 and M2 measure the Star Tracker power consumption from the 115V 400Hz 3Φ lines. The Two Wattmeter Method is used and the total wattage is the sum of the two readings.

2. The BNC output marked "J5 Counter" provides a 10V 400Hz signal suitable for triggering the counter. A step down transformer from the 115V line is used.

3. Two rotary switches marked Left and Right DVM allow monitoring of AC and DC voltages and currents on the two DVM's.

4. Box on panel marked "Alternate Power" - If $\pm$28VDC excitation instead of 115V 3$\Phi$ power is desired, two external power supplies (28V at 2 amp minimum) can be connected to the four jacks enabled "Ext P/S No. 1" and "Ext P/S No. 2" with polarities as shown. Place right hand toggle switch to "Alt DC Power." Current shunts are provided. 0.1V corresponds to 1A.

5. Box on panel marked "Heater" - when toggle switch is thrown ON +28VDC power is supplied to the Star Tracker Heaters, the "Heater On" indicator will light. A current shunt is provided, 0.1V corresponds to 1A.

6. Box marked "+28V Unreg."

   "+28V unreg" indicator is lighted when the +28V P/S is energized. Monitor "+28V P/S" on left DVM. Use "Adj" knob to set +28VDC. A current shut is provided 0.1V corresponds to 1A.

7. Box Marked "115V 400Hz"

   Indicators $\Phi_A$, $\Phi_B$, and $\Phi_C$ will light if 3$\Phi$ power supplies are on and "400Hz 3$\Phi$ Breaker" is ON. Three current transformers with precision loads labeled "$\Phi_A$ curr, $\Phi_B$ curr, and $\Phi_C$ curr" provide a voltage isolated from the 115V 3$\Phi$ such that 1 VAC corresponds to 0.1 amperes.

8. Box marked "Star Tracker Power"

   Place toggle switch to Primary Path." This applies unreg. +28VDC via pins J3-B to J3-A. 115V 3$\Phi$ is applied via J3-E, J3-F, J3-G.

   In the "Redundant Path" position unreg. +28VDC is applied via pins J3-D to J3-C. 115V 3$\Phi$ is applied via J5-H, J3-J, J3-K.

   The toggle switch marked "Alt. DC Power"/"AC Power" applies external $\pm$28V power supplies to J3-M, J3-L, J3-N and disconnects 115V 3$\Phi$ excitation in the "Alt DC Power" position. 3$\Phi$ power is applied and the external supplies are disconnected in the "AC Power" position. When the toggle switch labeled "Star Track Pwr" is switched to ON the Star Tracker system will be energized. (115V 3$\Phi$ and 28V unreg. is applied simultaneously.) The indicator "Star Track Pwr On" will light.

9. All pins from STE connector J3-ATM power distributor are brought to front panel jacks through protective series resistors (Typ. 2.2K)

3.3.3.11 Voltmeter Panel 1938423

The voltmeter panel mounts two digital voltmeters to allow simultaneous monitoring of both gimbals. The left DVM is a Fairchild Mod 7000 (4 digit 0.02% Acc on DC, with autorange and AC plug-in option. The right DVM is a Systron Donner Mod 9000 (3 digit 0.2% Acc on DC and OHMS scales.)

3.3.3.1.2 Readout Panel 1938271

The readout panel channels signals from the various panels to the digital voltmeters. Two level switching is used. For example, to monitor the IG tach output on the Test Panel, the "Left DVM" selector switch on the readout panel must be in the "Test Panel" position and the "Left DVM" selector switch on the Test Panel must be placed into the "IG Tach" position.

3.3.3.13 Test Panel 1938273

All pins from the STE connectors J7 and J8 are brought to test jacks through series protective resistors (Typ. 2.2K) Star Tracker status is displayed on lighted indicators. Analog voltages from the Star Tracker can be channeled to the left and right digital voltmeters.

The hand controller set-up is identical to the Computer - C and D Panel.

### 3.3.3.14 Logic Monitor Panel

The Logic Monitor Panel provides twenty independent lamp drivers and lamps. The lamps light when an input signal is more than 0.9 volts above reference. The input impedance is 1 megohm and inputs up to +40 volts are permissible.

### 3.3.3.15 AC Power Supply

Two 250 watt AC power supplies, connected in an open delta configuration, provide 115V 400Hz 3$\phi$ excitation to the Star Tracker. The output voltage is variable from 0 to 160 volts and the frequency is variable from 390 to 410 Hz.

Power supplies are to be normally on; AC power to the tracker is controlled on the "Power Panel".

# SECTION 4

## 4.0 QUALIFICATION PROGRAM

The serial number 0003 ATM Star Tracker System, which contains an Optical Mechanical Assembly Bendix Navigation and Control Division Type Number 2125000-3 (NASA 50M22145) and a Star Tracker Electronics package BNCD Type Number 2125800-1, (NASA 50M22146) was successfully qualification tested to BNCD GQTP document 2124424. The qualification tests were performed over the time interval from July, 1971 to January, 1972.

A list of the qualification tests the ATM Star Tracker was subjected to along with the applicable test procedure section numbers, are listed in Table 4.1 titled "Qualification Tests Performed". A summary of the functional test data recorded prior to, during, and after the total qualification test is listed in Table 4.2 titled, "Summary of the Results of the Functional Tests Performed During Qualification Testing". The intent of the qualification test was to subject the ATM Star Tracker, which was built to production drawing and representative of the product configuration baseline, to tests which would demonstrate that the unit conformed to the contractual design requirements.

## TABLE 4.1
## QUALIFICATION TESTS PERFORMED

Star Tracker Package consisting of:

Optical Mechanical Assembly BNC Type No. 2125000-3

Star Tracker Electronics BNC Type No. 2125800-1

Test Procedure: BNC Document No. 2124424 (GQTP)

| TEST | TEST PROCEDURE PARAGRAPH |
|---|---|
| Examination of Product | 4.2.1 |
| Full Functional (Initial) | 4.2.2 |
| Electromagnetic Interference | 4.2.10 |
| Thermal Shock | 4.2.7 |
| High and Low Temperature | 4.2.4 |
| Full Functional (Post High and Low Temp.) | 4.2.2 |
| Vibration | 4.2.9 |
| Acceleration | 4.2.8 |
| Acoustical Noise | 4.2.6 |
| Thermal Vacuum | 4.2.5 |
| Circuit Transients | 4.2.11 |
| Full Functional (Final) | 4.2.2 |
| Outgassing | 4.2.3 |

| | SPECIFICATION REQUIREMENTS | INITIAL FULL FUNCTIONAL (1-2) PERFORMED 7/13/71 | ELECTROMAGNETIC INTERFERENCE (1-3) PERFORMED 7/20-8/19/71 FUNCTIONAL TEST (F.T.) PERFORMED 8/3/71 | THERMAL SHOCK (1-4) PERFORMED 8/10-8/12/71 F.T. PERFORMED 8/13/71 | HIGH AND LOW TEMPERATURE (1-5) PERFORMED 8/30-9/4/71 F.T. PERFORMED 9/8/71 | FULL FUNCTIONAL (1-6) PERFORMED 10/11/71 | VIBRATION (1-7) PERFORMED 10/12/71 F.T. PERFORMED 10/13/71 | ACCELERATION (1-8) PERFORMED 10/14-10/25/71 F.T. PERFORMED 10/15/71 | F.T. PERFORMED 10/26/71 | ACOUSTICAL NOISE (1-9) PERFORMED 10/18/71 F.T. PERFORMED 10/19/71 | THERMAL-VACUUM (1-10) PERFORMED 11/3-11/10/71 F.T. PERFORMED 11/3/71 (REDUCED F.T.) (ROOM TEMP) | F.T. PERFORMED 11/4/71 (REDUCED F.T.) (LOW TEMP) | F.T. PERFORMED 11/5/71 (REDUCED F.T.) (HIGH TEMP) | F.T. PERFORMED 11/8/71 (REDUCED F.T.) (ROOM TEMP) | F.T. PERFORMED (11/17/71) | CIRCUIT TRANSIENTS (1-14) PERFORMED 11/23/71 AND 1/10/72 F.T. PERFORMED 11/24/71 (SAME AS FINAL FUNCTIONAL 11/24/71) | FINAL FULL FUNCTIONAL (1-12) PERFORMED 11/24/71 | OUTGASSING (1-13) PERFORMED 12/71 AT MSFC F.T. PERFORMED 12/14/71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. POWER (WATTS) MODES | 30 ± 4 (20 - 38) | | | | | | | | | | | | | | | | | |
| HOLD | | 25.7 | 25.6 | 25.6 | 25.9 | 26.1 | 26.6 | 25.5 | 25.1 | 25.2 | 3.63 | 26.6 | 24.1 | 25.2 | 26.1 | 26.9 | 24.9 | 25.1 |
| AUTO | | 25.6 | 26.2 | 26.5 | 26.0 | 25.4 | 25.8 | 23.6 | 26.5 | 23.8 | 25.2 | 26.7 | 24.2 | 24.8 | 25.0 | 25.4 | 25.4 | 24.8 |
| NO STAR PRESENCE | | 24.6 | 24.0 | 23.7 | 26.4 | 23.8 | 23.6 | 23.4 | 23.3 | 23.8 | 23.6 | 25.3 | 23.1 | 23.5 | 23.6 | 24.0 | 24.0 | 23.7 |
| STAR PRESENCE | | 26.0 | 25.9 | 23.7 | 26.1 | 26.9 | 25.5 | 26.7 | 25.5 | 23.3 | 26.8 | 27.1 | 24.2 | 23.6 | 25.3 | 25.4 | 23.4 | 26.0 |
| MANUAL | | | | | | | | | | | | | | | | | | |
| 2. STAR THRESHOLD (MAGNITUDES) | +1.19 ± 0.1 (+1.09 to +1.29) | +1.09 | +1.17 | +1.15 | +1.25 | +1.19 | +1.09 | +1.20 | +1.23 | +1.22 | +1.17 | +1.25 | +1.15 | +1.15 | +1.20 | +1.13 | +1.12 | +1.16 |
| 3. STAR PRESENCE FIELD OF VIEW (DEGREES, MIN AND SEC) STAR: | 1 deg ± 5 min (55 - 65 MIN) | | | | | | | | | | | | | | | | | |
| ALPHA CRUX I.G. | | 1°03'30" | 1°03'22" | 1°03'43" | 1°04'08" | 1°01'43" | 1°03'15" | 1°05'28" | 1°03'30" | 1°03'36" | 62' | 60' | 60' | 56' | 1°03'00" | 1°02'33" | 1°02'55" | 1°03'40" |
| O.G. | | 0°55'30" | 0°55'32" | 0°55'53" | 0°53'53" | 0°56'00" | 0°54'34" | 0°53'38" | 0°58'25" | 0°55'42" | 53' | 53' | 53' | 53' | 0°58'42" | 0°55'33" | 0°55'35" | 0°55'20" |
| CANOPUS I.G. | | 1°06'00" | 1°06'[illegible]" | 1°07'03" | 1°01'51" | 1°05'40" | 1°06'43" | 1°06'34" | 1°07'14" | 1°07'30" | — | — | — | — | 1°01'00" | 1°06'33" | 1°06'35" | 1°06'36" |
| O.G. | | 0°57'30" | 0°57'[illegible]" | 0°58'13" | 0°58'11" | 0°57'40" | 0°58'38" | 0°57'22" | 0°57'56" | 0°57'43" | — | — | — | — | 0°57'30" | 0°57'30" | 0°57'20" | 0°57'50" |
| 4. GIMBAL ACCURACY (MIN, RMS) STAR: | 0.5 min RMS MAXIMUM | | | | | | | | | | | | | | | | | |
| ALPHA CRUX I.G. | | 0.5 | 0.4 | 0.5 | 0.2 | 0.5 | 0.2 | 0.3 | 0.4 | 0.4 | — | — | — | — | 0.3 | 0.2 | 0.2 | 0.2 |
| O.G. | | 0.3 | 0.3 | 0.5 | 0.3 | 0.3 | 0.7 | 0.5 | 0.4 | 0.3 | — | — | — | — | 0.7 | 0.7 | 0.7 | 0.2 |
| CANOPUS I.G. | | 0.4 | 0.4 | 0.6 | 0.3 | 0.3 | 0.5 | 0.2 | 0.4 | 0.4 | — | — | — | — | 0.3 | 0.2 | 0.3 | 0.3 |
| O.G. | | 0.3 | 0.3 | 0.6 | 0.3 | 0.2 | 0.6 | 0.3 | 0.3 | 0.4 | — | — | — | — | 0.7 | 0.8 | 0.6 | 0.3 |
| ACHERNAR I.G. | | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.5 | 0.2 | 0.4 | 0.4 | — | — | — | — | 0.3 | 0.2 | 0.3 | 0.2 |
| O.G. | | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 | 0.6 | 0.2 | 0.3 | 0.3 | — | — | — | — | 0.7 | 0.8 | 0.6 | 0.3 |
| 5. ZENITH POSITION READOUT (SEC MIN) I.G. | — | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | -0000.5 | 0000.0 | +0000.5 | 0000.0 | 0000.0 | 0000.0 | 0000.0 |
| O.G. | | 0000.0 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | -0000.5 | 0000.0 | 0000.0 | 0000.0 | 0000.0 | +0000.5 | 0000.0 | 0000.0 | -0000.5 | -0000.5 | -0000.5 | 0000.0 |

TABLE 4-1
SUMMARY OF THE RESULTS OF THE FUNCTIONAL TESTS PERFORMED DURING QUALIFICATION TESTING



FOLDOUT FRAME 1

FOLDOUT FRAME 2

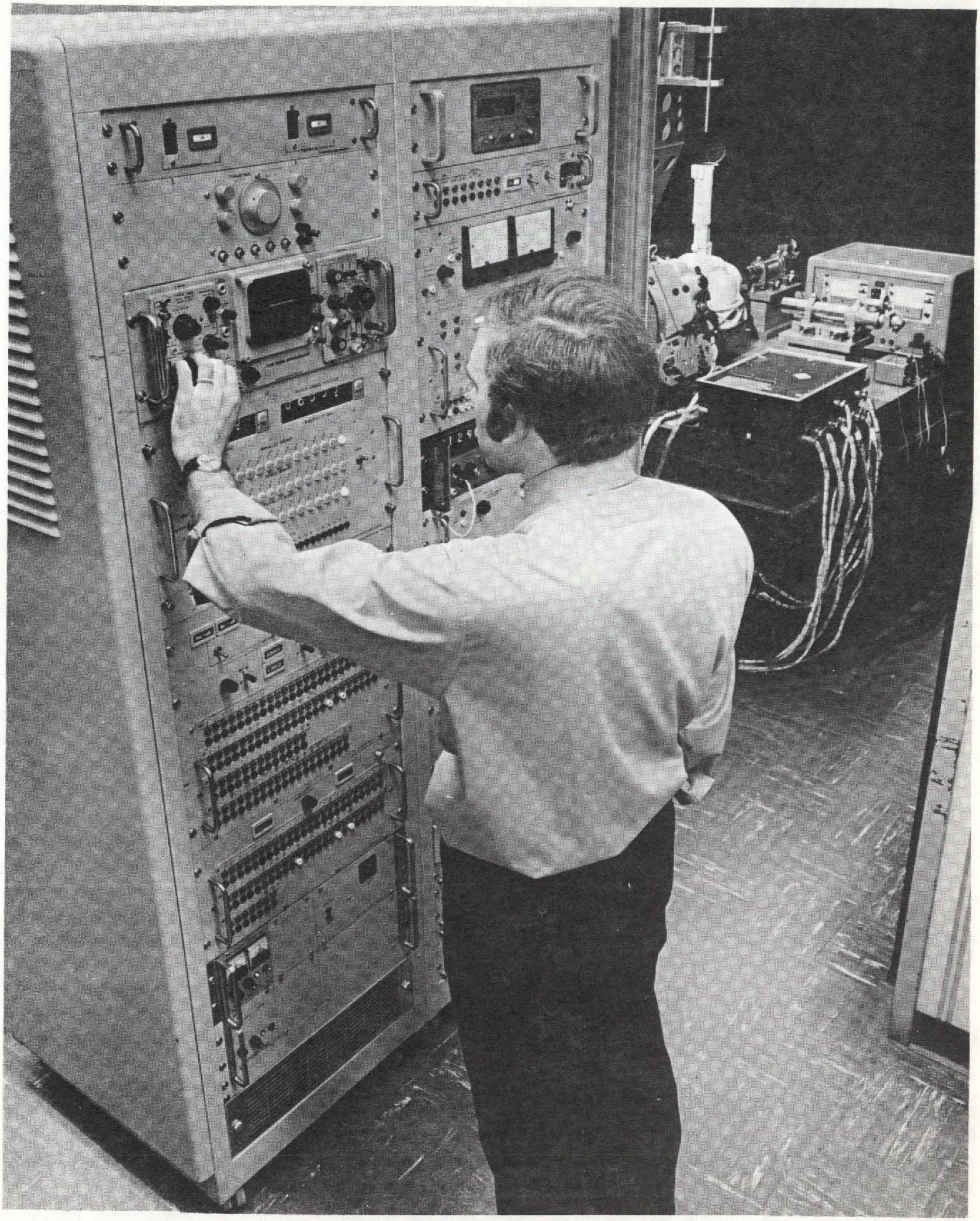
The results of the various tests are as follows:

1) The optical mechanical assembly and the star tracker electronics package were mechanically and electrically inspected per 2124424 (GQTP) 4.2.1 and were found satisfactory.

2) The star tracker was next subjected to the initial full functional test per 2124424 (GQTP) 4.2.2. Except for the star threshold level, the results of the test were within specified limits and the tracker operation was satisfactory. The minimum allowable star threshold sensitivity has a magnitude of +1.09. The measured tracker star threshold sensitivity was +1.08. The star standard calibration was then checked, found to be slightly out of calibration, and the source of the out of specification condition determined to be due to this condition. The actual star threshold value was then determined to be +1.09 magnitudes. It was concluded that the star tracker had successfully met its performance specification. Figure 4-1 illustrates the full functional testing configuration.

3) The star tracker was subjected to the electromagnetic interference test per GQTP 2124424 paragraph 4.2.10.

   The unit passed the susceptibility portion of the test but had some minor non-conformances to the conducted and radiated portions of the EMI requirements. MSFC approved these deviations.



ATM STAR TRACKER FINAL FUNCTIONAL TEST
FIGURE 4-1

Following the EMI test, a functional test was performed on the system. There was no evidence of damage or deterioration to the system due to the EMI testing, with the results of the post EMI functional test within the specified limits.

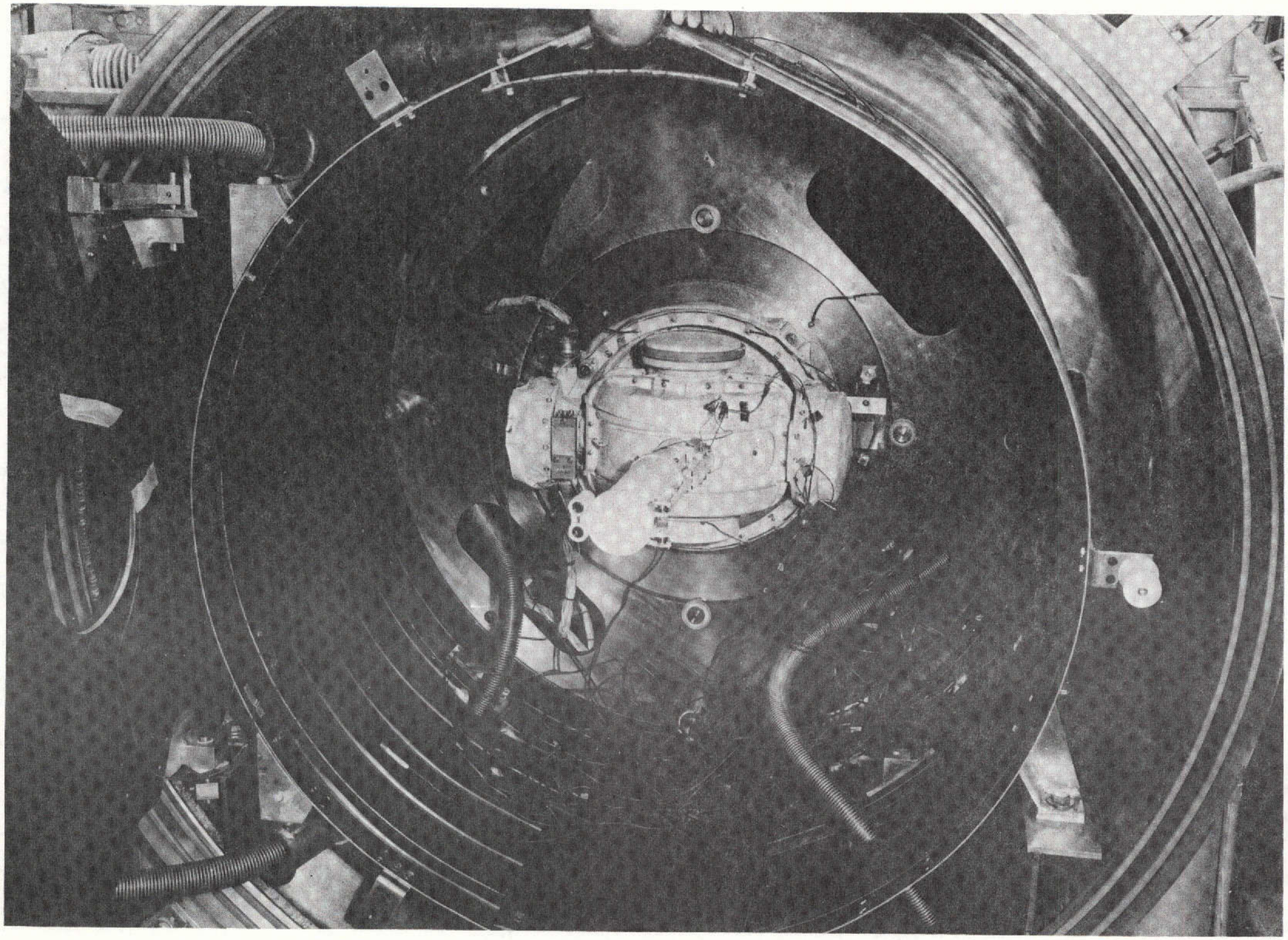
4) The star tracker was subjected to the thermal shock per 2124424 (GQTP) 4.2.7. Following the exposure, inspection revealed no evidence of damage, operation was satisfactory, and function test results were within specified limits.

5) The star tracker was subjected to the high and low temperature test per 2124424 (GQTP) 4.2.4. Operation was satisfactory throughout, results were within specified limits, and there was no evidence of damage or deterioration as a result of the test.

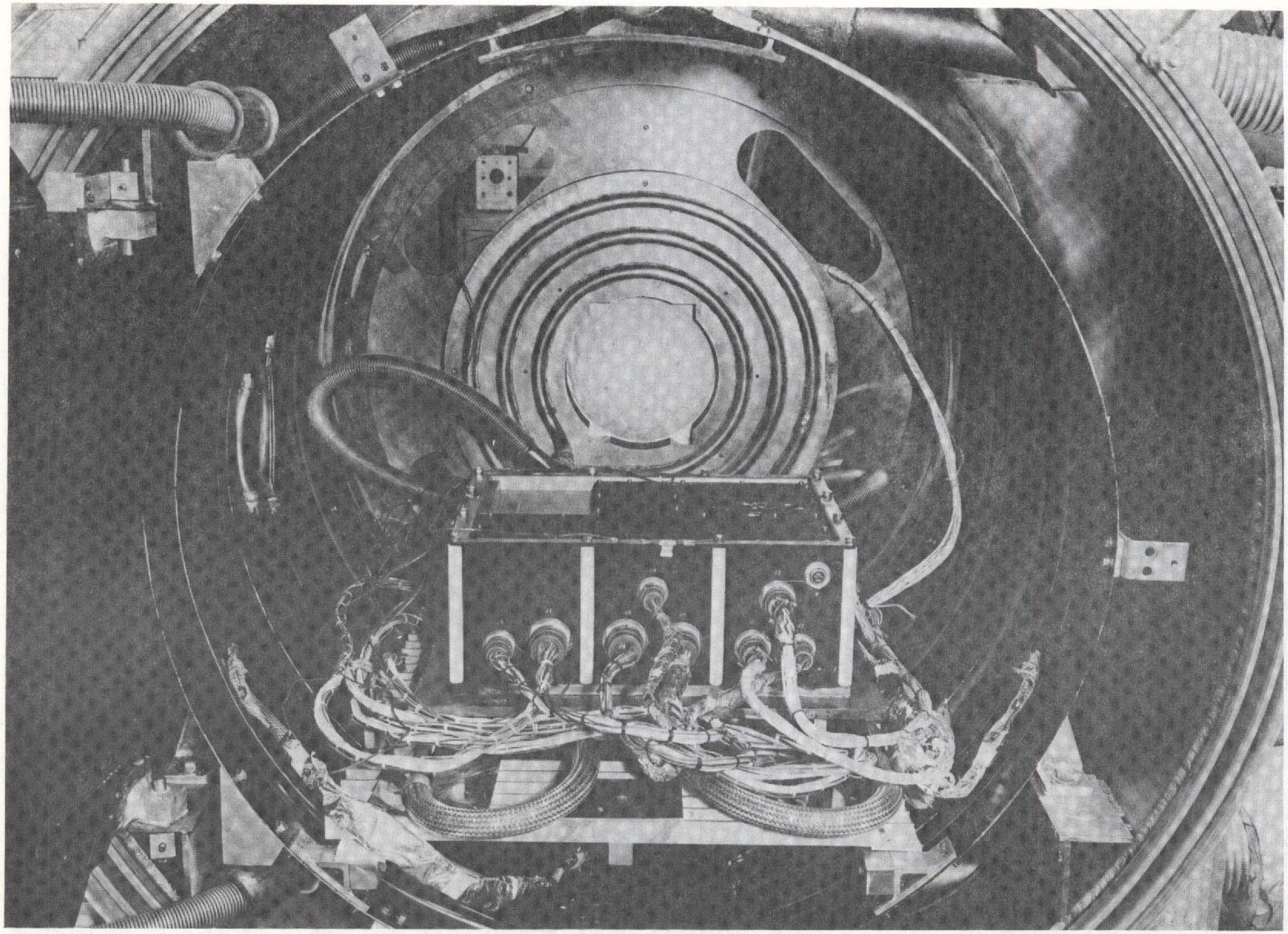
   Following the high and low temperature exposures the units were functionally tested with the results within specified limits.

   Figures 4-2 through 4-4 illustrate the thermal facuum test configuration for the OMA and STE.

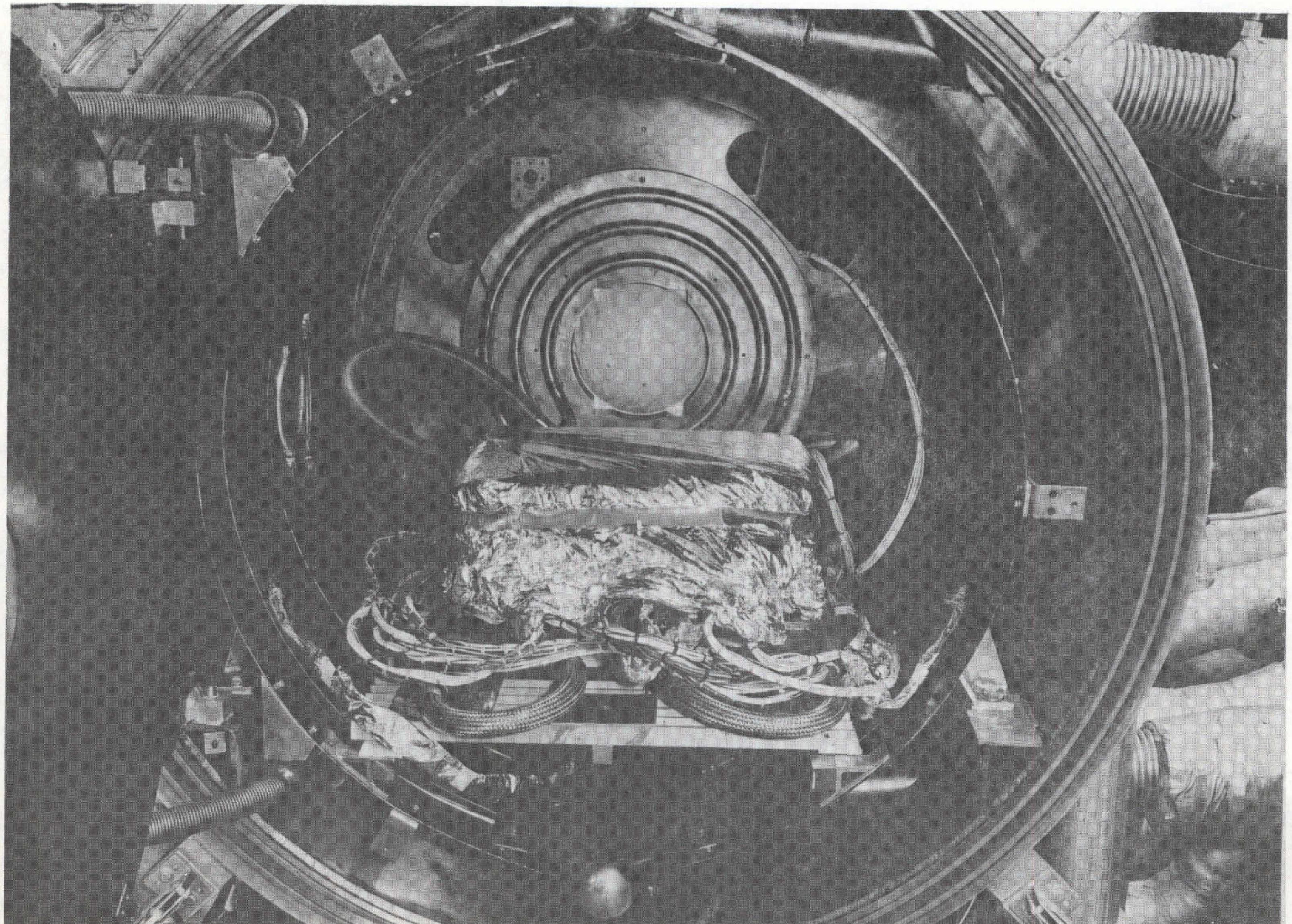
6) In late September 1971, the Qualification Star Tracker serial number 0003 was modified, incorporating additional restraint to the phototube assembly and improving the shutter drive mechanism. These modifications were incorporated into the flight hardware at the same time. The modifications were coordinated with, and approved by NASA/MSFC personnel.



OPTICAL MECHANICAL ASSEMBLY MOUNTED IN
THERMAL VACUUM CHAMBER
FIGURE 4-2



STAR TRACKER ELECTRONICS SHOWN MOUNTED IN
THERMAL VACUUM CHAMBER
FIGURE 4-3



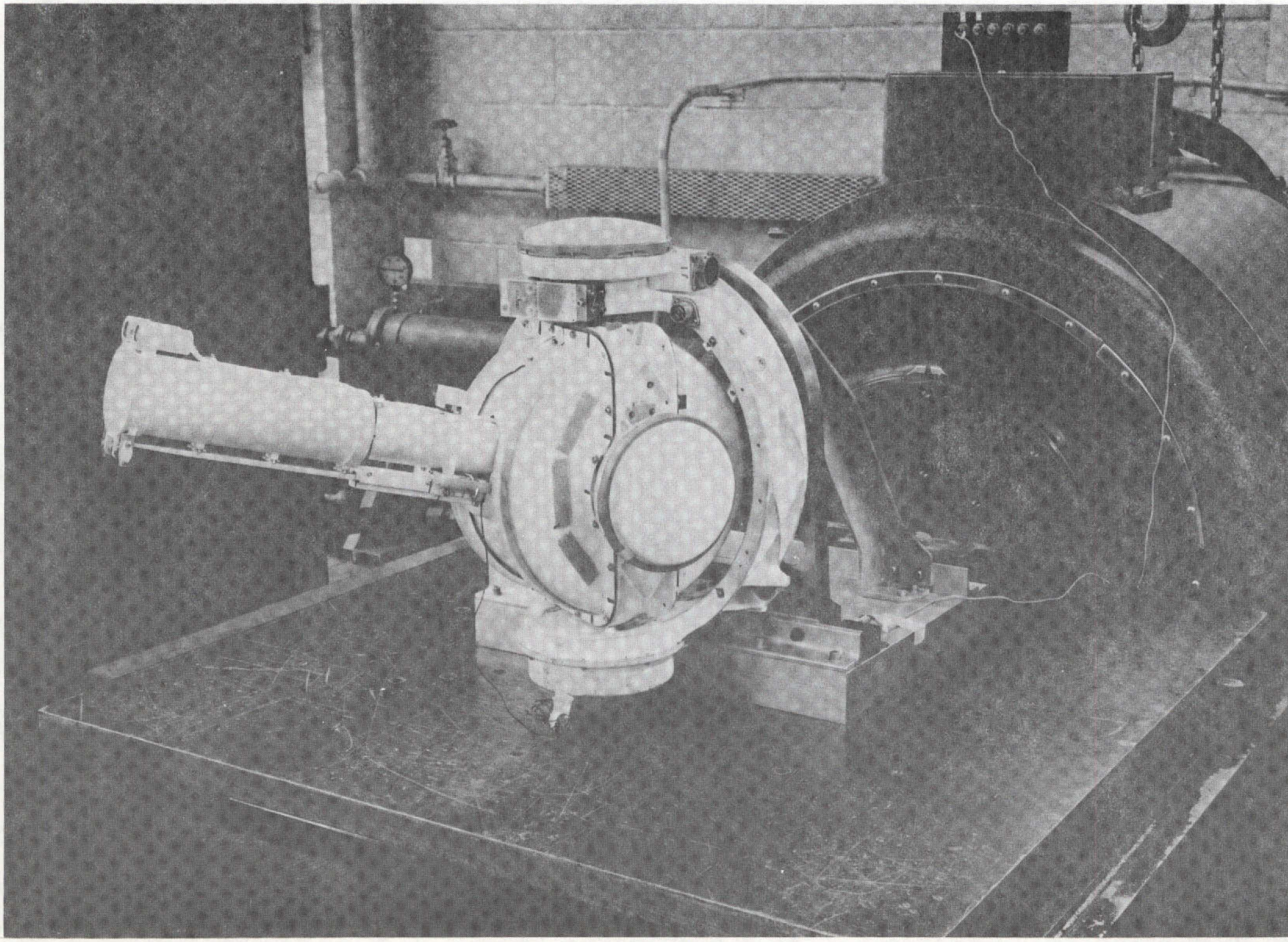
STAR TRACKER ELECTRONICS WITH THERMAL
BLANKET MOUNTED IN THERMAL VACUUM CHAMBER
FIGURE 4-4

Qualification testing was resumed beginning with this full functional test, performed per 2124424 (GQTP) 4.2.2. Operation was satisfactory throughout the test and the results were within specified limits.

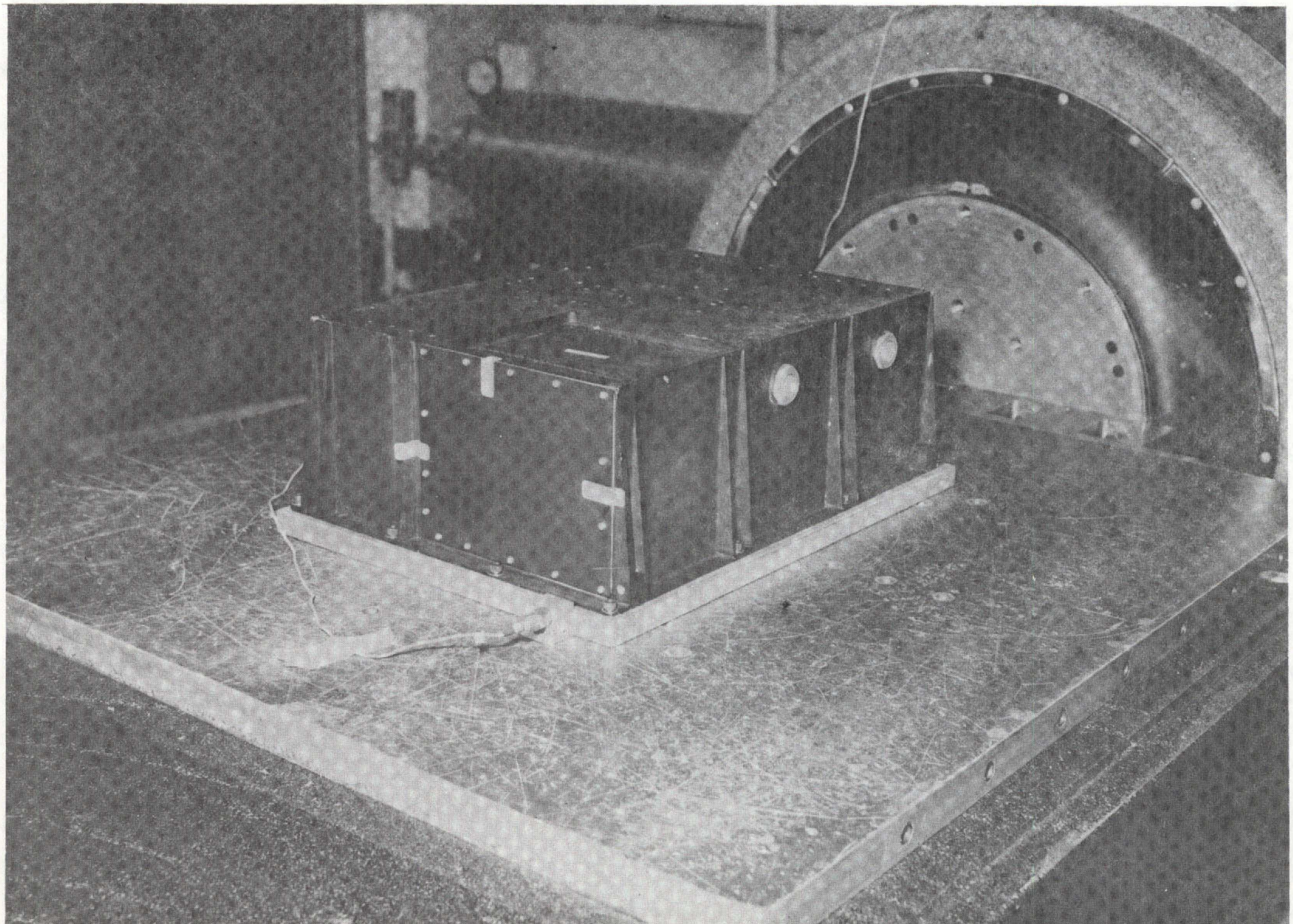
7) The star tracker was subjected to the vibration test per 2124424 (GQTP) 4.2.9. Following the exposure, inspection revealed no evidence of damage, operation was satisfactory, and function test results were within specified limits.

   Figures 4-5 and 4-6 illustrate the vibration test set-up for the OMA and STE respectively.

8) The star tracker was subjected to the acceleration test per 2124424 (GTQP) 4.2.8. The tests were performed in two parts: A partial exposure in which the OMA and STE were accelerated along the flight axis and in both directions in each transverse axis, and second, a final exposure in which the units were accelerated in the negative direction along the flight axis. Functional tests were performed following the partial exposures and again following the final exposure. Inspections after the tests disclosed no evidence of damage, operation was satisfactory, and the functional test results were within specified limits.



OPTICAL MECHANICAL ASSEMBLY MOUNTED
ON VIBRATION EQUIPMENT
FIGURE 4-5



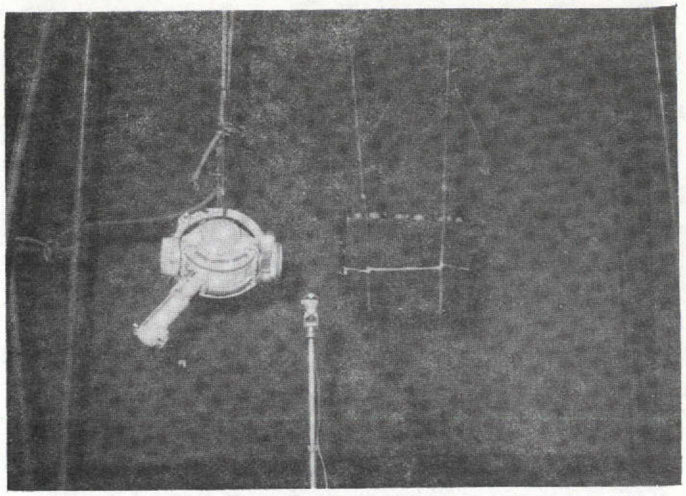
STAR TRACKER ELECTRONICS MOUNTED ON
VIBRATION EQUIPMENT
FIGURE 4-6

9) The star tracker was subjected to the acoustical noise test per 2124424 (GQTP) 4.2.6. Following the exposure, inspection revealed no evidence of damage, operation was satisfactory, and functional test results were within specified limits.

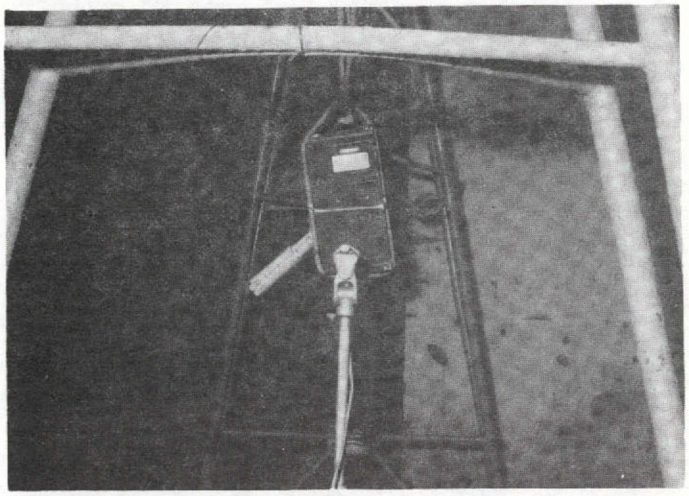
Figure 4-7 is a photograph of the OMA in the acoustical test chamber.

10) The star tracker was subjected to the thermal vacuum test per (GQTP) 2124424 paragraph 4.2.5.

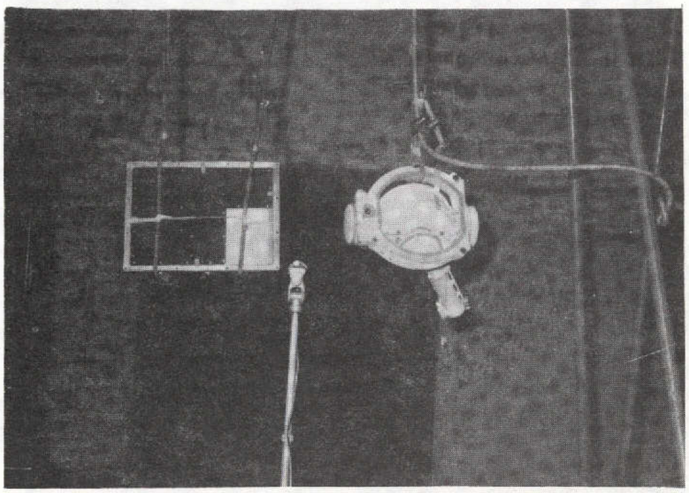
During the cold case test, paragraph 4.2.5.2.2b, the STE platen temperature was maintained as specified with the star tracker electronics not energized. However, when the star tracker electronics were energized, the STE platen temperature could not be reduced to a value which would bring the STE down to its specified value of $-15 \pm 3.6^{\circ}F$. Due to this limited low temperature capability of the thermal equipment, the low temperature functional test was begun with the STE at -8 degrees F and completed with the electronics at -3 degrees F. In the worst case then the STE was 8 degrees above the specification limit with the average somewhat less. The thermal vacuum test was continued from this point, with the concurrence of MSFC personnel, with the feeling that the basic intent of the specification had been met, and the knowledge that the unit had yet to go through a more severe thermal-facuum life test. A successful life test was later performed with equipment that maintained the qualification



RUN NO. 1



RUN NO. 2



RUN NO. 3

STAR TRACKER AT ACOUSTICAL NOISE FACILITY
FIGURE 4-7

test cold case environment for 4 days - not a two hour soak plus test time. Additionally, during the cold case and hot case exposures, the telescope movement about the inner gimbal axis was checked throughout its full range but the movement about the outer gimbal axis was checked through a limited range to preclude interference between the telescope and test chamber.

Both during and after the thermal-vacuum test exposure, functional tests were performed on the tracker system. The functional tests were performed according to the qualification test procedure.

It should be noted that the gimbal accuracy data taken as part of the functional test performed after the thermal-vacuum exposure did not meet the specification limit. For all three stars, the outer gimbal accuracy error was 0.7 minutes RMS and should have been 0.5 minutes RMS or less. It was determined from subsequent testing of other star trackers, that the probable cause of this error was a telescope lens shift. This lens holding mechanism was improved and incorporated into the follow-on trackers.

11) The star tracker was subjected to the circuit transient test per GQTP 2124424 paragraph 4.2.11.

The circuit transients generated by the tracker and its response to transients were within the specification limits.

A functional test was performed after the initial transient test when the tracker's response to external circuit transients was observed. This test was noted as the final functional test. The results of this test were acceptable as explained in the final functional test, next paragraph. No functional test was performed after the portion of the circuit transient test in which the transients generated by the tracker system were observed. None was considered necessary as this was considered normal star tracker operating procedure.

12) The star tracker was subjected to a full functional test per GQTP 2124424 paragraph 4.2.2 following the completion of the qualification environmental tests.

The data indicates that the unit met the specification limits except for the gimbal accuracy test. In this case the results are similar to the results obtained in the previous function test performed at the conclusion of the thermal-vacuum test. That is, the system gimbal accuracy has not changed from the previous functional test, and for all three stars, the O.G. axis has between 0.6 and 0.7 minutes RMS of error (specification value being 0.5 minutes RMS error or less). The cause of this error being a telescope lens shift which occurred in the thermal vacuum test and discussed in that paragraph.

13) The star tracker was subjected to outgassing tests per GQTP 2124424 paragraph 4.2.3 by NASA at the George C. Marshall Space Flight Center in December 1971.

The Navigation and Control Division was infomred by MSFC technical personnel that the test results were satisfactory.

Following the outgassing test, the star tracker was returned to BNCD where a reduced functional test was performed. These tests were per GTSP 2124427, sections 4.3.1, 4.3, 4.3, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10 reduced, 4.11 and 5.12. The results of the test within specified limits, indicating that no damage or deterioration to the unit's performance occurred due to subjecting the hardware to the outgassing test.

In summary then with the exception of the low temperature portion of the thermal vacuum exposure, the Star Tracker system was successfully subjected to the environment portions of the qualification test. Due to thermal vacuum chamber limitations, the electronics package was tested at about five degrees F above the specified cold temperature limit; the test was accepted by MSFC. The Star Tracker System operation during the environmental exposures was satisfactory, and except in the case of electromagnetic interference, results were within specified limits. During the electromagnetic interference tests, generated and conducted interference in excess of permissible limits was measured. Increases in the permissible levels of interference were requested and granted by MSFC.

Functional operation of the Star Tracker System was satisfactory after each environmental exposure except for the slight increase in outer gimbal accuracy error noted after thermal vacuum testing. Subsequent testing on other Star Tracker Systems has pointed to a loose telescope lens holding mechanism as the cause of this error.

The Star Tracker System completed its qualification testing program without any functional damage or deterioration to the unit.

The Guidance Systems Division concluded that the Star Tracker, (the Optical Mechanical Assembly and the Star Tracker Electronics) conformed to the contractual design requirements as demonstrated by the satisfactory completion of the qualification test, and recommended that the star tracker be accepted as qualified hardware.

# SECTION 5

## 5.0 RELIABILITY

During the course of theprogram a Failure Mode Effects and Criticality Analysis (FMECA) was performed on the ATM tracker in accordance with NASA Reliability Publication 250-1.

### 5.1 Summary of Results

Criticality Number, $C_R = (\lambda_{N_1} t + \lambda_{N_2} t_m) 10^6 = 172{,}680$

Reliability Index, $R(t) = e^{-(\lambda_{N_1} t + \lambda_{N_2} t_m)} = 0.842$

MTBF, $1/\lambda_T$ = 10,417 Hours

Failure Rate (TOTAL)**, $\lambda_T$# = 96.0 PPMH*

Failure Rate (NET)***, $\lambda_N = \lambda_{N_1} + \lambda_{N_2}$# = 47.8

Factored Mission Time (T)Δ = 3,600 Hours

Total Mission Time ($t_m$) = 5,760 Hours

A detailed listing of individual block failure rates and criticality numbers is included in Sections 6 and 7, respectively of the original FMECA report.

<u>Notes and Definitions:</u>

$N_1$ = Failure Rate (net) of items that are operational during a time period equivalent to $t \approx 47.6$ PPMH.

$N_2$ = Failure Rate (net) of items that are operational during the total mission time ($t_m$) $\approx 0.24$ PPMH.

\# Includes equivalent failure rate of redundant items.

Δ Refer to Page 7-2 of the original FMECA report.

* Failure Rate (Total) unadjusted for redundancy:

123.4 PPMH

** Sum of Block Failure Rates (TOTAL):

$$\lambda_T = \sum_{\substack{Y=1\\X=1}}^{\substack{X=n_2\\Y=n_1}} [\, F_{(Y)} \,]_{(X)}$$

*** Sum of Block Failure Rates (NET):

$$\lambda_N = \sum_{\substack{Y=1\\X=1}}^{\substack{X=n_2\\Y=n_1}} [\, \beta c_{(Y)} \, F_{(Y)} \,] \, (X)$$

Where F is equal to the failure rate associated with block failure effect (Y), $n_1$ is equal to the number of failure effects (Y) of Block X; $n_2$ is equal to the number of blocks in the ATM Star Tracker, and $\beta c$ is the Beta Factor applied to F, which is described on Page 4-9 of the original FMECA report.

# APPENDIX I

## HISTORICAL SUMMARY OF PROGRAM

The following is a brief summary of the program. More detailed historical notes may be found in the monthly progress reports.

September 1968 - Program start - Program control procedures set up. Star tracker vehicle interface definition near completion. Optical encoder specifications released. Test equipment requirements established.

October 1968 - Interface definition basically completed. System block diagrams and descriptive layouts submitted. Optical encoder order released. Gimble casting drawing released. Telescope schematics and casting drawings nearing completion. Basic digital logic unit (DLU) design completed. Started design concept phase of final acceptance test equipment.

November 1968 - Design review conducted at NASA MSFC on November 20, preliminary design review conducted at Bendix November 26, and encoder design review conducted at Baldwin. Telescope casting drawing released.

December 1968 - Interface requirements defined in new design areas. Continuation of sunshade shutter and encoder design. Design of mode selector module initiated. Many telescope detail assembly drawings released. Sun and earth sensor drawings started. Test equipment workmanship standard approval received from NASA.

January 1969 - With the exception of a few drawings, telescope electronic drawings have been completed. Star tracker electronics (STE) "floor plan" and outline completed and submitted to NASA for review. Acceptance Test Plan and Final Check reviewed at NASA-Bendix. Telescope casting pattern and frame and machining drawings completed. Purchase orders released for all commercial test equipment used in final checkout consoles except for the wattmeter and power supplies (DC).

February 1969 - Pin functions between the vehicle and the star tracker electronics (STE) and the STE and the optical mechanical assembly (OMA) defined. Shade-shutter concept finalized. Engineering model encoder tested successfully. An engineering model of the sun sensor was constructed. Initial gimbal housing and telescope housings have been cast. Initial outgassing test on wet-lube bearings successfully completed. Heater power requirements determined. Additional schematic diagrams released.

March 1969 - Updated layout and block diagram drawings submitted to NASA for review. Preliminary thermal analysis for heaters completed. Telescope and gimbal castings were heat-treated. Sun shade shutter-sensor layout completed. Encoder mounting assembly parts were completed. Drawing revisions for heater implementation were completed. Several test specifications and printed circuit boards were completed. Shutter electronic schematic and mode selector design were completed. Servo loop layouts were completed. Mode selector, input interface and ac to dc converter design completed. All final acceptance test equipment commercial test instruments are on order. Design of in-process test equipment almost complete. Fabrication on most test equipment completed or started.

April 1969 - Stress and thermal problems at the star tracker mounting bracket interface defined. Two sets of encoder electronic circuit boards were completed. Machining of telescope casting about 25 percent complete. Two gimbal castings released for machining. All telescope electronics printed circuit boards completed. Ac to dc converter testing successfully completed. Two test stand panels (final acceptance test equipment) were submitted to NASA for design approval. Modification of existing Bendix telescope module test stand started. Fabrication of telescope electrical test station completed. Fabrication of encoder electrical test station interconnect cables completed. Telescope test fixture fabricated. Encoder test fixture completed.

May 1969 - Design review conducted at NASA MSFC on May 8. Encoder mounting assemblies completed and shipped to Baldwin. Phototubes for flight 1 and 2 systems received. All Bendix final acceptance test stand panels approved by NASA.

June 1969 - Tube and HVPS modules completed and assembly of tube HVPS assembly started. Three telescope housings machined and ready for painting. Vibration analysis finalized and documented. The three ATM Star Tracker Final Check-out Consoles were released to fabrication. The following in-process test equipment has been completed. Telescope Module Test Station, Telescope System Electronics Test Station, Encoder Electrical Test Station, Telescope Test Fixture, Motor and Tachometer Test Fixtures, and Encoder Test Fixture.

July 1969 - Critical Design Review conducted at NASA MFSC on July 22. Preliminary Acceptance Test Procedure completed and submitted for review. Earth sensor prototype built. Four encoder hub assemblies shipped to Baldwin. All mechanical design drawings released. All Telescope Electronics Assembly drawings released. Vibration and thermal stress analysis completed. Thermal model of Optical Mechanical Assembly (OMA) completed and documented.

August 1969 - Adaption of star simulator computer program completed. Procedures for earth and sun sensor testing completed. Studies of proposed phototube and pivot life tests completed. Telescope electronics completed and under test. All STE drawings released to production. OMA frame thermal interface defined. Analysis of STE circuit boards completed.

September 1969 - Qualification and acceptance testing of the prototype encoders successfully completed. Star standard received from Goodard Space Flight Center (GSFC).

Three telescope housings completed. Prototype gimbal machined. Telescope electronics successfully tested over temperature range. Inner and outer loop amplifier cards built and tested. Three FCO electronic consoles, without intercept boxes are 95 percent assembled. Intercept box and associated cable design has begun. The STE module test stand is completed. The STE system test stand is 80 percent completed. Mechanical test stands are complete except for the end stop microswitches. Master Test Fixture and Telescope Alignment Fixture 75 percent complete. Vibration and Thermal Vacuum fixture design completed. Fabrication of fixtures started.

October 1969 - Encoder-frame compatability tests for both the Vanasil frame and A390 frame completed. Prototype gimbal ready for OMA assembly. Final test completed on three final acceptance test stands. Some STE modules for prototype completed.

November 1969 - Five optical shaft encoders have passed their acceptance test and have been delivered to Bendix. Prototype gimbal assembly buildup proceeding satisfactorily and telescope assembly is being prepared for installation. Lube-life rig ready to be assembled. Test equipment checkout on three final acceptance test stands completed.

December 1969 - Five additional optical shaft encoders ready for acceptance test. Prototype gimbal assembly buildup and telescope testing progressing satisfactorily. Lube-life rig approaching final assembly. Phototype sunshade and shutter mechanism completed and checked out.

| | |
|---|---|
| January 1970 | - Prototype telescope electronics bench tested and adjusted. Prototype STE and OMA married and tested extensively by engineering. Five additional optical shaft encoders successfully passed acceptance tests Life-lube rig assembled. (See Figure A-1). One 130F751 ATM Final Checkout Console checked out with prototype star tracker. Three OMA intercept boxes received and are being checked out. |
| February 1970 | - Prototype ATM Star Tracker engineering tests approaching completion. ATM Star Tracker gimbal servo loops modified. Tachometer and torquer magnetic cross talk problem eliminated. |
| March 1970 | - ATM Star Tracker electronic tracking loops modified to increase response. Shutter motor drive electronics and mechanism modified to prevent relay arcing and to provide smoother travel for shutter. ATM Star Tracker Final Checkout Console 130F751 SN1 ready for checkout with Star Tracker system and correlation tests with SN3 test stand. ATM Star Tracker Final Checkout Console SN3 in Star Tracker final test area completely checked out with the Star Tracker System. |
| April 1970 | - ATM Star Tracker prototype acceptance tested and delivered. ATM Star Trackers SN2 and SN3 sub-assemblies being tested. OMA life lube rig completed and delivered. ATM Star Tracker FCO Console 130F75-1 -1 SN1 tested, inspected and shipped to MFSC. Started to update SN2. |

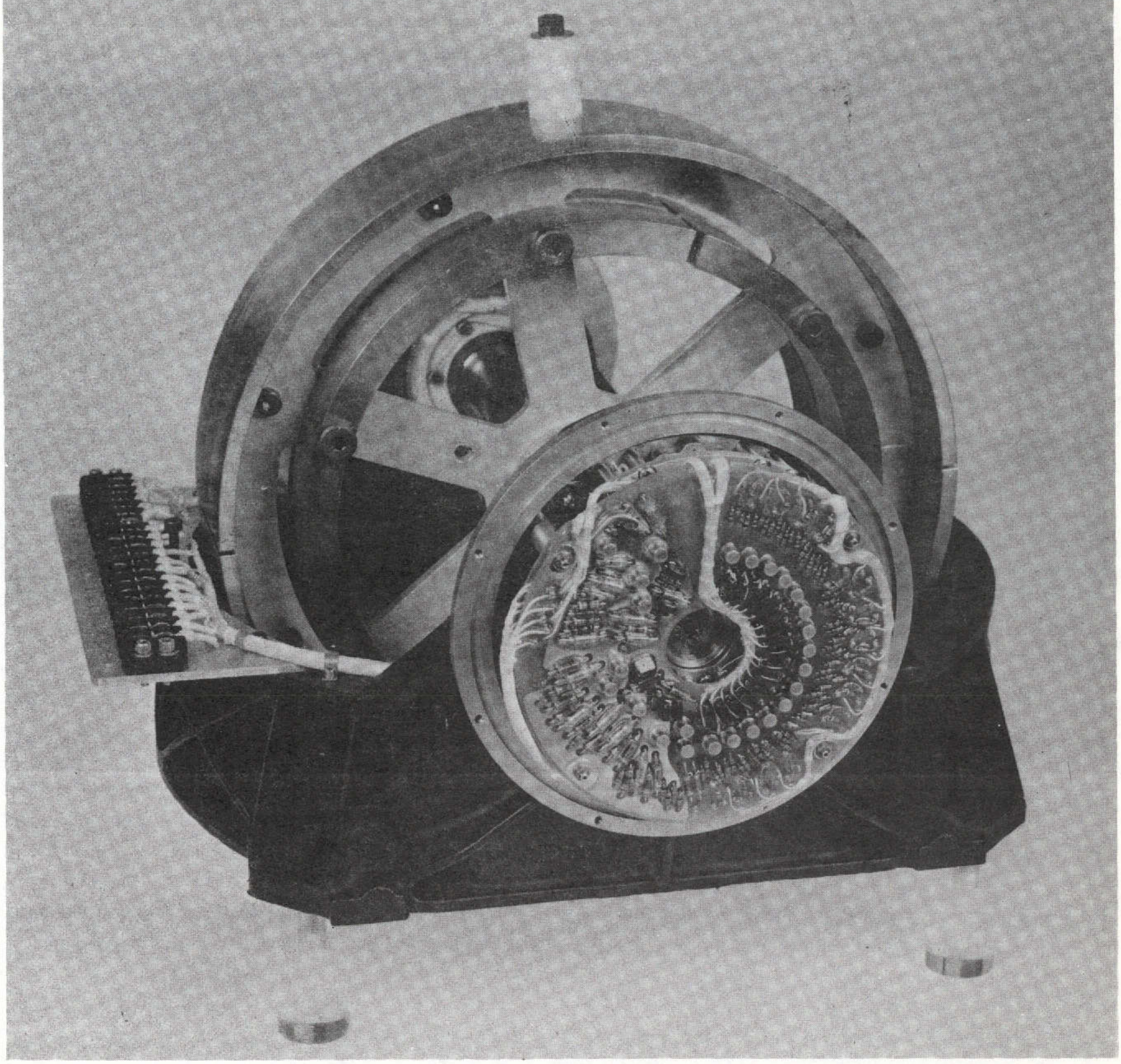


FIGURE A-1

May 1970 - ATM Star Tracker SN2 and SN3 subassembly testing near completion. Variable dark current problem isolated and identified. Shutter mechanism undergoing redesign. Star Tracker FCO Console 130F751-1 SN2 updated. Three sets of log books for FCO consoles completed.

June 1970 - ATM Star Tracker SN4 undergoing manufacturing checkout calibration and alignment. Tube HVPS design finalized (with respect to high voltage design). Telescope internal pressure tests completed. Telescope electronics and STE for system number four completed. Solar impingement cables (used to interface the Star tracker system with the General Electric solar impingement chamber) designed and fabricated.

July 1970 - ATM Star Tracker SN2 ready for manufacturing checkout calibration and alignment. SN2 tube HVPS assembled and installed in OMA. Shutter life lube rig completed. All three ATM Star Tracker FCO consoles now operational.

August 1970 - Manual mode altered to eliminate response to structural 170 Hz resonance. Telescope electronics video amplifier altered to eliminate threshold problem. Hold mode changed to eliminate a 10 Hz oscillation. Telescope shade motor drive circuitry modified to eliminate relay arc over.

September 1970 - ATM Star Tracker SN2 system being prepared for manufacturing checkout calibration and alignment. Telescope shade motor drive circuitry modified to eliminate transients generated by the motor.

October 1970 - Redesigned phototube undergoing installation. ATM Star Tracker SN3 system being prepared for manufacturing checkout calibration and alignment. Telescope shade mechanical drive modified to prevent shade from opening during launch vibration. Shutter close command logic altered to prevent incorrect updating of the DLU upon entering the hold mode. ATM Star Tracker SN2 system acceptance test completed.

November 1970 - ATM Star Tracker SN3 system completed manufacturing checkout calibration and alignment and is undergoing acceptance test. ATM Star Tracker SN4 ready for manufacturing checkout calibration and alignment.

December 1970 - ATM Star Tracker SN3 system completed acceptance testing and is being prepared for qualification testing. ATM Star Tracker SN4 system completed first stage of manufacturing checkout, calibration, and alignment.

January 1971 - ATM Star Tracker SN4 OMA and STE system checkout calibration, and alignment completed. Methode connector rework completed for SN3 and SN5 STE.

February 1971 - ATM Star Tracker SN4 system acceptance test completed and shipped to NASA. ATM Star Tracker SN3 system transformer changed, connector and encoder bellows reworked and final gimbal alignment completed. The system is ready for qualification test. ATM Star

| | |
|---|---|
| | Tracker SN5 system ready for system checkout alignment and calibration. |
| March 1971 | - ATM Star Tracker SN3 OMA gimbal alignment completed. SN3 system qualification test program started. |
| April 1971 | - Corrected misalignment of field-scribe line of deflection coil. Vendor agreed to replace coils having misaligned field-scribe lines. |
| May 1971 | - Tube-HVPS for qual system SN3 has completed third stage potting. Tube - HVPS for system SN5 has been completed. |
| June 1971 | - Build and thermal vacuum testing for SN3 tube-HVPS completed. Final build of SN3 OMA and optical axis alignment completed. Final temperature testing of SN5 earth sensor completed. |
| July 1971 | - ATM Star Tracker SN3 assembled aligned and acceptance tested. Qualification testing of SN3 started. ATM Star Tracker SN5 system checkout and alignment started. SN6 sun sensor completed. |
| August 1971 | - Qualification test of ATM Star Tracker SN3 in progress. Alignment of ATM Star Tracker SN5 interrupted due to misalignment of gimbal orthogonality. Misalignment corrected. Thermal vacuum testing of ATM Star Tracker SN6 tube HVPS terminated due to arcing caused by broken lead. Tube lead repaired. |
| September and October 1971 | - Qualification test of ATM Star Tracker SN3 in progress. Build and test of ATM Star Tracker SN3 replacement tube - HVPS completed. Acceptance testing of ATM Star Tracker SN5 completed. |

| | | |
|---|---|---|
| November and December 1971 | - | Qualification test of ATM Star Tracker SN3 completed. ATM Star Tracker SN5 shipped to MSFC but subsequently returned to Bendix for modifications. Primary build and alignment of ATM Star Tracker SN6 completed. ATM Star Tracker SN4 exposed to 2 weeks of low temperature vacuum without problems. |
| January and February 1972 | - | ATM Star Tracker SN5 modified, tested and reshipped to MSFC. ATM Star Tracker SN6 built and under test. Low temperature tests completed on ATM Star Tracker SN4. The unit was shipped to MSFC. |
| June, July and August 1972 | - | OMA SN0003 14 day life test completed. Unit shipped to MSFC. OMA SN0004 returned to Bendix and updating to latest configuration started. OMA SN0005 repaired at Bendix and shipped to MSFC. |
| September Through December 1972 | - | Star simulator recalibrated at Houston Manned Space Flight Center. ATM Star Tracker SN6 retested and found to be within specifications. ATM Star Tracker SN4 retrofit completed. |
| January Through March 1973 | - | Intermittent oscillation experienced in SN006 STE. Problem trouble shooting performed. Failure traced to Initial Position register card by test and analyses. Cause of failure confirmed by x-ray of microstick which showed broken lead (ground). |
| April Through June 1973 | - | Rebuild and retrofit of SN4 completed required because of vamistor resistor replacement. Acceptance testing completed. Unit flown aboard Skylab vehicle. |
| July Through September 1973 | - | Rework of SN5 OMA initiated. Spare cards manufacture in progress. |

| | |
|---|---|
| October Through December 1973 | - Rework of SN5 OMA completed. |
| January Through February 1974 | - System SN6 successfully passed acceptance test. |

# APPENDIX II

II-0 DESIGN CHANGES

II-1 ANGLE OF GIMBAL TRAVEL

Angle of gimbal travel change from $\pm$ 80 to $\pm$ 85 to $\pm$ 87 degrees.

II-2 TELESCOPE ELECTRONICS CHASSIS

Chassis for telescope electronics revised to provide an environmental seal and add a separate connector for disengaging sensor signals.

II-3 INCREASED TORQUE

A requirement for increased torque has necessitated a change in the torquer motor. A type T2201 torquer with a dc resistance of 127 ohms was used to deliver 30 ounce-inches of torque.

II-4 THRESHOLD LEVEL

The threshold level of the video amplifier was lowered to include the new target star $\alpha$-CRUS.

A. White Paint Substitute

Pyromark white thermal control paint had been approved for use on the OMA wherever 4-13G is specified. This coating was applied and vacuum-baked at Bendix.

II-5 BLACK PAINT SUBSTITUTE

Optical black paint 3M-101C10 substituted for Parson's Black.

II-6 INTERFACE PROBLEM

Digital logic unit (DLU) interface and conditioning card redesigned to avoid potential interface problem between the DLU and mode selector logic.

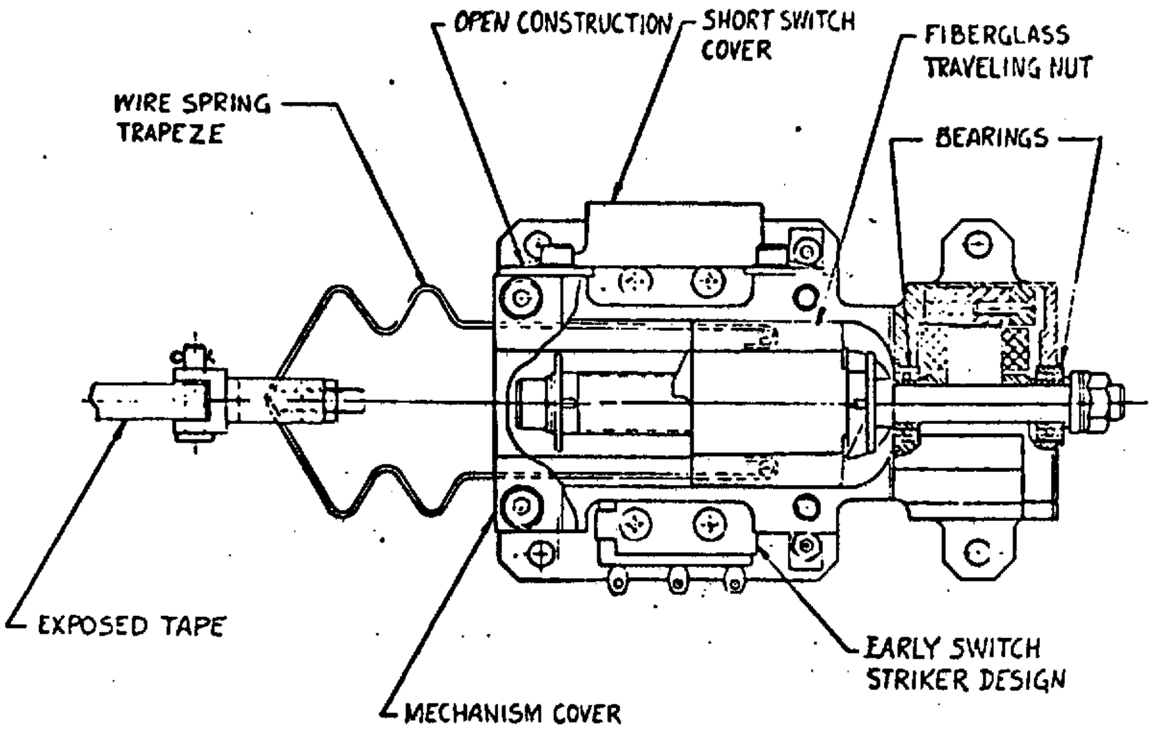
II-7 BANDWIDTH INCREASE

The bandwidth of theelectronic tracking loop, which centers the instantaneous field of view on the star line of sight was increased from 50 radians to 150 radians to improve response. Prior to redesign, the star was lost during the acquisition cycle due to the failure of the instantaneous field to properly follow up the line of sight.

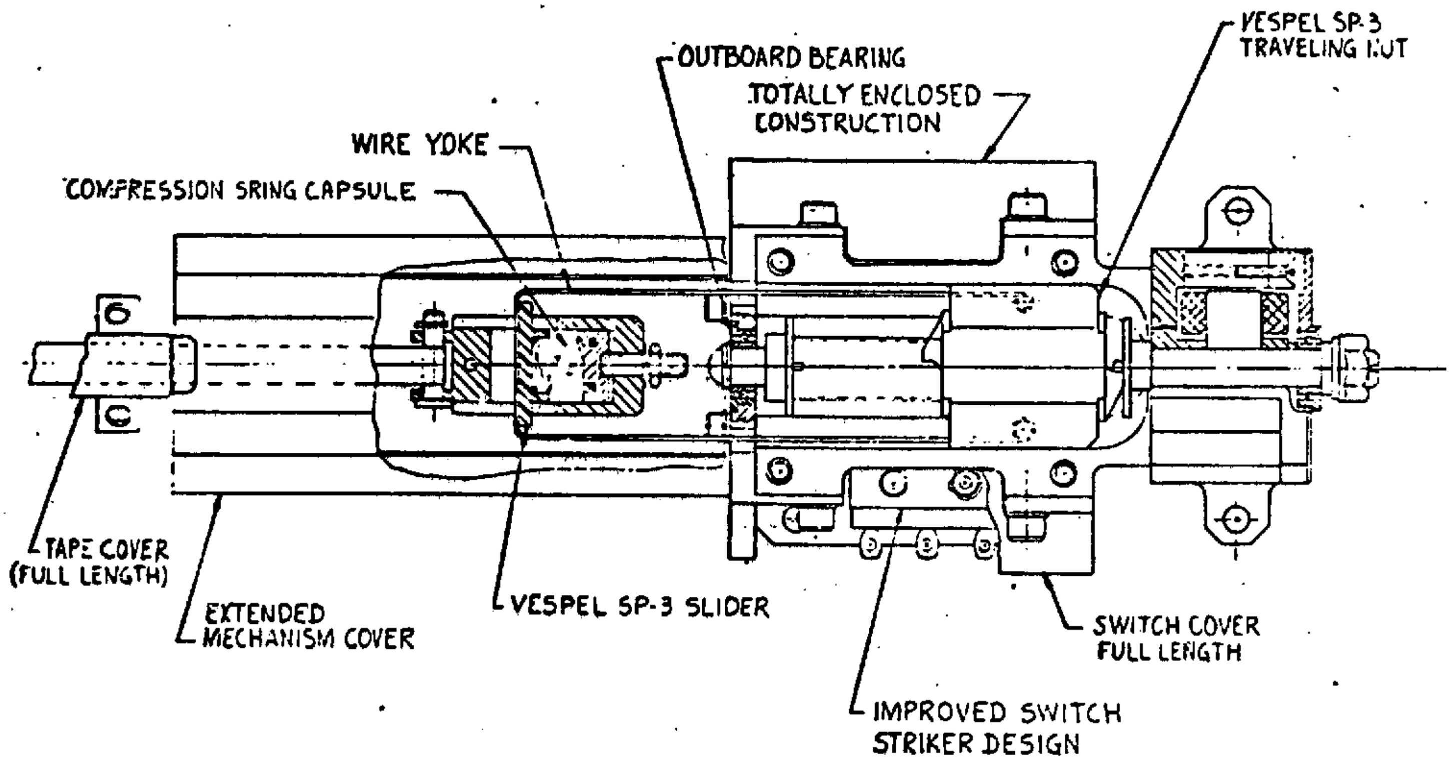
II-8 SUNSHADE AND SHUTTER MECHANISM

The shutter mechanisms were fitted with covers to completely shroud all operating parts including the tape. As part of the modification, one jackscrew bearing was relocated to reduce the possibility of shaft runout. Refer to Figures II-1 through II-3.

Shutter Test Rig was rebuilt with new 32 threads per inch jackscrew and nut combination, new spring, and retainers. A new larger dia. shaft was fabricated and installed at shutter end. This new design provided a greater mechanical advantage thus allowing a greater force to be applied at the shutter without increase of power. Test rig was subjected to high and low level random vibration test and shutter remained closed.

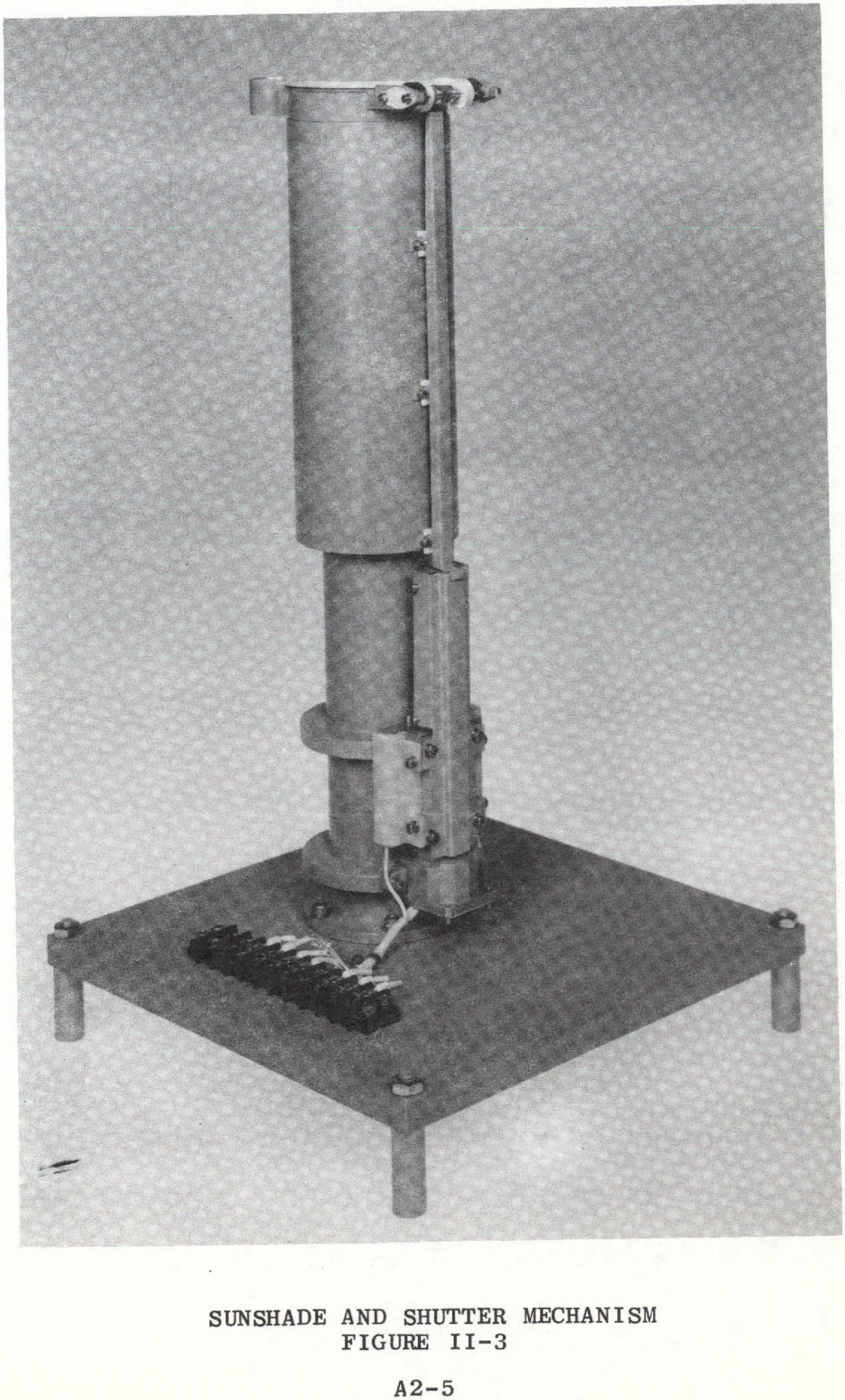



ORIGINAL SHUTTER MECHANISM
FIGURE II-1




REVISED SHUTTER MECHANISM

FIGURE II-2



SUNSHADE AND SHUTTER MECHANISM
FIGURE II-3