NASA CR-122516

FINAL REPORT

FABRICATION AND TEST OF EIGHT SETS OF STRAP III FLIGHT HARDWARE

Prepared For

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

F72-03

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PREFACE

All activities on this program were performed in accordance with the cost plus fixed fee Contract NAS 5-11664 between National Aeronautics and Space Administration, Goddard Space Flight Center (NASA/GSFC) and Ball Brothers Research Corporation (BBRC). The program was initiated on 23 March 1969. Contract award was a result of BBRC Proposal 645, dated 30 August 1968, and prepared in response to a competitive NASA/GSFC RFP 720-94382-260, dated 23 July 1968.

This program had one major objective, to produce eight sets of reliable flight hardware at a cost that was compatible to the typical sounding rocket mission. The flight hardware includes the Attitude Control System (ACS), the pneumatics system components and a Fine Guidance Error Sensor (FGES) star tracker.

As an aid to achieve the program objectives, the contract included some design and drawing preparation effort for both the ACS and the FGES and fabrication of Aerospace Ground Equipment (AGE) for the ACS system. A small part of the design and drawing update activity was directed specifically towards improving system performance and reliability.

The program objectives were met in nearly all respects, especially for the ACS and the pneumatics. The FGES easily met all but three out of more than twenty major specification requirements. The deviations were minor in nature and could be eliminated in the future by more stringent specifications on phototubes, some minor redesign to increase the electronics dynamic range and some change of certain circuit compensation methods.

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Many of the improvement recommendations for the ACS and pneumatics that were generated on this program were incorporated before or during the two follow-on hardware fabrication programs that were initiated before this report was written. These improvements included a screening program to upgrade the piece part reliability of the ACS system, modifications to the system to upgrade the performance and/or its capabilities, and value engineering improvements to reduce system fabrication and test time. Because the design of the present ACS is at least five to seven years old, considerable effort is now being expended by NASA/GSFC and independently at BBRC to replace the present system with an entirely new system employing updated state of the art components. The new system will have much better accuracy, capability and reliability than the existing system. Because of these developments, no significant recommendations are included in this report to upgrade the present system.

We recommend incorporating the changes mentioned above (to eliminate the minor deviations experienced in the FGES) before any additional FGES units are built in the future.

Before any upgrading of the present FGES is attempted we also recommend that an evaluation be made of the intended use of the FGES. The emphasis of the investigation should be placed on identifying the most important operating parameters and the tradeoffs that can be made to improve those parameters.

ACKNOWLEDGMENTS

I want to acknowledge the efforts of all of the individuals too numerous to name who were associated with this program, both at BBRC and at NASA/GSFC. Without their devoted efforts the success of this program and the writing of this report would not have been possible.

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Section 1
INTRODUCTION

This report cannot stand on its own without a brief mention of the history of the STRAP III (STRAP is the acronym for Stellar Tracking Rocket Attitude Positioning) system prior to the initiation of the subject program.

The STRAP III Attitude Control System (ACS) is an outgrowth of a development effort that was begun in the early 1960s. The objective of that development was to produce a stable three-axis platform for sounding rocket experiments that was not dependent on a specific celestial target for its position reference. The basic sensors were gyroscopes which provided an inertial reference during the flight. As the experiments became more sophisticated and the scientific investigation concentrated on single celestial objects, the ACS was updated to use a fine sensor in conjunction with the gyroscope platform to greatly improve the pointing accuracy.

At the initiation of this program, the STRAP III was the latest version of this ACS system.

After several STRAP III development models had been built and flown, GSFC solicited proposals to fabricate and test these units in quantities required to meet their experiment or support requirements. The objective of this solicitation was to take advantage of industry's experience in developing processes and procedures to reduce the fabrication and test costs of the unit by applying production and value engineering.

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The following activities were included in the original contract:

- Fabricate and test, including complete three-axis air bearing tests, eight complete STRAP III packages.
- Procure and fabricate all pneumatics components necessary for eight systems. Tests are limited to the pneumatics valves.
- Prepare and obtain the GSFC Technical Officer's approval for all necessary test and acceptance procedures including electronics and pneumatics both functional and environmental.
- Prepare the drawings which are missing on drawing diagram B27-1220.
- Fabricate and test one set of Aerospace Ground Equipment (AGE) which includes the launch and calibration panel and all module testers.
- Conduct final acceptance test to demonstrate the system operational capability.
- Incorporate the Liaison Engineering Action (LEA) items into the original drawings so that the drawings will reflect the "as-built" configuration.

- Perform a design study to improve limit cycle performance on dim stellar targets.

- Provide design and production effort to lower the output impedance of the T/M conditioning circuits.

- Provide documentary photography in accordance with GSFC Specification S-253-P-4.

The contract was later modified to include the following effort:

- Design, fabricate, test, and deliver eight Fine Guidance Error Sensors (FGES) in accordance with Aerobee FGES Specification A6000-4, dated 10 July 1969.

- Make the following changes to the STRAP III System:

  (1) Modify caging circuit in common, universal and fine module.

  (2) Modify reference and power ground of the threshold detector circuits in fine and universal modules.

  (3) Relocate roll position signal clipping from the RSP to universal module.

  (4) Replace the tracker position and rate signal chopper with balanced modulator.

  (5) Add slave-roll position telemetry circuit to the common module.

(6) Prepare printed circuit (PC) board assembly drawings for the AC-DC power supply.

(7) Update schematics and modify printed wiring masters to incorporate the above changes.

(8) Design a welded module, Time Delay.

(9) Fabricate two additional Launch and Calibration Consoles (LCC) and three sets of LCC cables.

Except for the FGES, all of the modifications to the subject contract were minor when compared to the original contract scope. Because the FGES was a major contract scope change, competitive bids were solicited from prospective star tracker manufacturers. Five vendors were asked to bid and response was received from three (including BBRC). BBRC acted as the proposal administrator in behalf of NASA/GSFC.

Since BBRC was a competitor, a separate organization prepared and submitted a proposal to the BBRC evaluation group using the same ground rules extended to the other competitors. No direct internal communications were permitted between the BBRC proposal and evaluation teams unless the content was transmitted to the other competitors.

After a thorough review of the proposals the evaluation team concluded the BBRC proposal was the most competitive, both in cost and technical approach. The conclusions were transmitted to GSFC for further review. At the end of their review, GSFC agreed with the BBRC recommendation and authorized the necessary program funds.

1.1 PROGRAM OBJECTIVES AND PHILOSOPHY

The major objective of the program was to produce eight sets of STRAP III flight hardware at a cost that was compatible to the objectives of the sounding rocket program. The contract included several activities to aid in the achievement of the primary objective. Included in these activities were the new drawing preparation, fabrication of the AGE, preparation of test procedures, and the final drawing update to reflect the as-built configuration.

The starting point of the program for the ACS and pneumatics was considerably different from the FGES; thus, although they were covered by the same contract, the programs were treated quite differently. All of the existing ACS and pneumatics GSFC drawings were furnished to BBRC at the onset of the program. The new design and drawing activity was limited to some circuit improvements and the preparation of production quality assembly drawings which were unavailable. Since the system concept and most of the hardware design was established by the GSFC-furnished drawings, the fabrication and test of the ACS and pneumatics was based on a build-to-print philosophy. In other words, BBRC assumed the GSFC design was capable of meeting the operational criteria imposed by their specification.

The FGES program was undertaken with a completely different philosophy. No GSFC design for the FGES was available. The FGES program concept was to convert the existing BBRC star tracker into a unit that meets all the requirements of the NASA/GSFC "Fine Guidance Error Sensor Specification," A6000-4, dated 10 July 1969.

The primary objectives of the program were met and the resulting flight hardware meets the basic GSFC requirements. Minor deviations to the FGES specifications were accepted by GSFC. These deviations are discussed in Sections 2.0 and 5.0.

1.2 SUMMARY OF REPORT CONTENT

This report is intended to describe briefly the hardware built and document the history of the subject program. Since most of the design for both the ACS and the star tracker actually occurred before this contract (in-house at GSFC for the STRAP III ACS and in-house at BBRC for the FGES), discussion of the design is limited to those items which were pursued as part of this program. A general description of both the ACS and the FGES is included to acquaint the reader with the concept and operation of the system.

The report is divded into seven major sections:

- Introduction
- Description of Operation
- Design
- Manufacturing
- Test
- Conclusions and Recommendations
- New Technology

Each section reviews the program activities applicable to the subject contract with emphasis on the general approach, problems encountered and solved, and end results.

Section 2
SYSTEM DESCRIPTION AND OPERATION

2.1 STRAP III ACS DESCRIPTION AND OPERATION

The Stellar Tracking Rocket Attitude Positioning system (STRAP III) Attitude Control System (ACS) is a cold gas reaction jet system developed to provide three-axis orientation of sounding rocket payloads. It was designed to be used as either an inertial system using gyroscopes for coarse attitude control or a fine pointing system using a star tracker or other fine pointing sensor. The performanace characteristics of the STRAP III system are summarized in Table 2-1.

STRAP III was originally designed for use on the Aerobee 150, a sounding rocket used extensively as a research vehicle to carry various scientific payloads into space. The 15-inch diameter, 30-foot long (with payload attached) Aerobee, propelled by a solid booster and a liquid-fueled sustainer, carries a 300-pound payload through a ballistic trajectory with a peak altitude of 100 miles. This system has since been adapted for use on several other vehicles including the Aerobee 170, Aerobee 350, Black Brant VC and the STRYPI. These vehicles provide greater altitude and/or payload weight capability.

During the five or more minutes the rocket sustainer and payload is above the atmosphere, scientific observations and measurements are made without atmospheric distortion. The STRAP III control system functions during this period to orient the scientific instrument towards the target or phenomenon of interest. Typical payload objectives range from upper atmospheric studies to observations of the spectral distribution of the energy from stars, planets, and X-ray sources.

Table 2-1

SUMMARY OF STRAP III PERFORMANCE CHARACTERISTICS

POINTING PERFORMANCE CHARACTERISTICS	
COARSE MODE	
Pointing Accuracy from launch to first programmed attitude in P,Y&R	≤ ±3°, 3σ, Typical ≤ ±1.5°
Drift Rate	6 - 10 deg/hr
Stabilization Time	
Initial Roll ± 180° Pitch and Yaw ± 10°	20 sec (Acceleration of 5 deg/sec^2) 5 sec (Acceleration of 2 deg/sec^2)
Limit Cycle Amplitude	±0.25°
Limit Cycle Rate	0.125 deg/sec
Telemetry Position Error Monitor Accuracy	0.1 deg
FINE MODE	
Pointing Accuracy Using Star Tracker	±1 arc min
Limit Cycle Amplitude (using FGES Star Tracker)	
> +1 magnitude stars < +1, > +4 magnitude stars	±10 arc sec ±20 arc sec
Limit Cycle Rates	40 arc sec/sec maximum (+ 2 magnitude star)
INTERMEDIATE MODE	
Pointing Accuracy	±1 arc min
Limit Cycle Amplitude	±1 arc min
Limit Cycle Rate	3 arc min/sec
RSP PERFORMANCE	
Angular Freedom of Motion	Roll - Full Freedom P&Y - ±85°
Cage Accuracy	< 0.2°
Cage Time From Any Position	P&Y - 20 sec Roll - 36 sec
Error Caused by Uncage	< 0.1°
Time for Uncage Warm-Up Time	< 20 ms < 4 min
MANEUVER PERFORMANCE (Assuming Aerobee Pneumatics Described Below)	
Maneuver Rates, R, P or Y (One axis at a time)	5 deg/sec Minimum
Maneuver Accuracy	1% maneuver angle or 0.25° whichever is greater
Programmable Fixed Maneuver Rates	
Number Rates	8 Selectable

PNEUMATICS CHARACTERISTICS (Aerobee 150/170)	
Nozzle Expansion Ratio	~ 10:1
Acceleration	
Despin Roll (Couple Balanced to ±5%) Pitch and Yaw - Coarse Pitch and Yaw - Fine	60 to 75 deg/sec^2 5.0 to 8.0 deg/sec^2 2.0 to 3.5 deg/sec^2 0.1 to 0.2 deg/sec^2
Transducer Readout Accuracy	±2%, 10 ms to 63% of pressure step input
PHYSICAL CHARACTERISTICS	
Weight	
ACS w/o skin section 10-inch skin section Pneumatics (Aerobee 150/170)	43.5 lb 5.7 lb 25.0 lb
Size and Shape	
ACS	Fits into 15 in. diameter 10 in. long cylinder
Pneumatics	Fits into the forward and aft sections of Aerobee sustainer
OPERATION ENVIRONMENTAL CONDITIONS	
Preflight	
Temperature Humidity	0 to +50°C 0 to 100%
Flight	
Acceleration - 3 axes	10 g's ± 1 g
Vibration	
Thrust Axis	
Sine Mode	10-60 Hz, 1.5 g's 60-160 Hz, 3.0 g's 160-2000 Hz, 5.0 g's 4 octaves/min
Random Mode	20-2000 Hz, 7.0 g-rms 10 sec duration
Lateral	
Sine Mode	10-60 Hz, 3.6 in/sec 60-250 Hz, 3.5 g's 250-2000 Hz, 5.0 g's 4 octaves/min
Random Mode	20-2000 Hz, 10.0 g-rms 10 sec/axis
Shock	30 g's peak sine shaped pulse 11 ± 2 ms 3-axes

STRAP III was designed to perform the following tasks:

- Despin the rocket from a maximum of three revolutions per second.
- Stabilize the rocket in all three axes (roll, pitch, and yaw) to the prelaunch orientation.
- Correct the launch time delays, prelaunch tower tilts, and gyroscope drifts. This amounts to orienting the rocket to the launch-site local vertical of a preselected sidereal time.
- Cause the rocket to reorient from the preselected sidereal time to a new orientation (the first target).
- Hold on the first target as long as required, then move to a second target.
- Continue to maneuver, hold, maneuver, hold, etc., until atmospheric disturbance torques overpower the control system and reentry begins.

Note that the above functions must be accomplished rather quickly, since the total usable pointing time is approximately five minutes. The STRAP control system points the rocket at the first target within 1.5 to 2 minutes after liftoff.

By use of the cold gas reaction jets, the control system despins, orients, and continuously aligns the rocket body with the null position of the rocket attitude sensors. The gas supply for all the reaction jets is the helium pressurization gas which remains in the Aerobee 150/170 sustainer fuel, oxidizer, and pressurization tanks after burnout. (All other vehicle payloads require a self-contained pneumatics system.) A typical STRAP III Aerobee 150/170 payload configuration is shown in Fig. 2-1.

The STRAP III ACS system major assemblies are shown in Fig. 2-2 and in its final assembly. The ACS as shown contains all the necessary electronics to operate in the inertial mode plus all of the interface circuitry making it compatible to a fine sensor. The control electronics assembly (CEA) module list and a description of the module functions is listed in Table 2-2.

The three-axis rate gyroscope package (RGP) shown in the right foreground in Fig. 2-2 (the RGP is missing in the photo on the left in Fig. 2-2) is used to provide damping necessary for system stability.

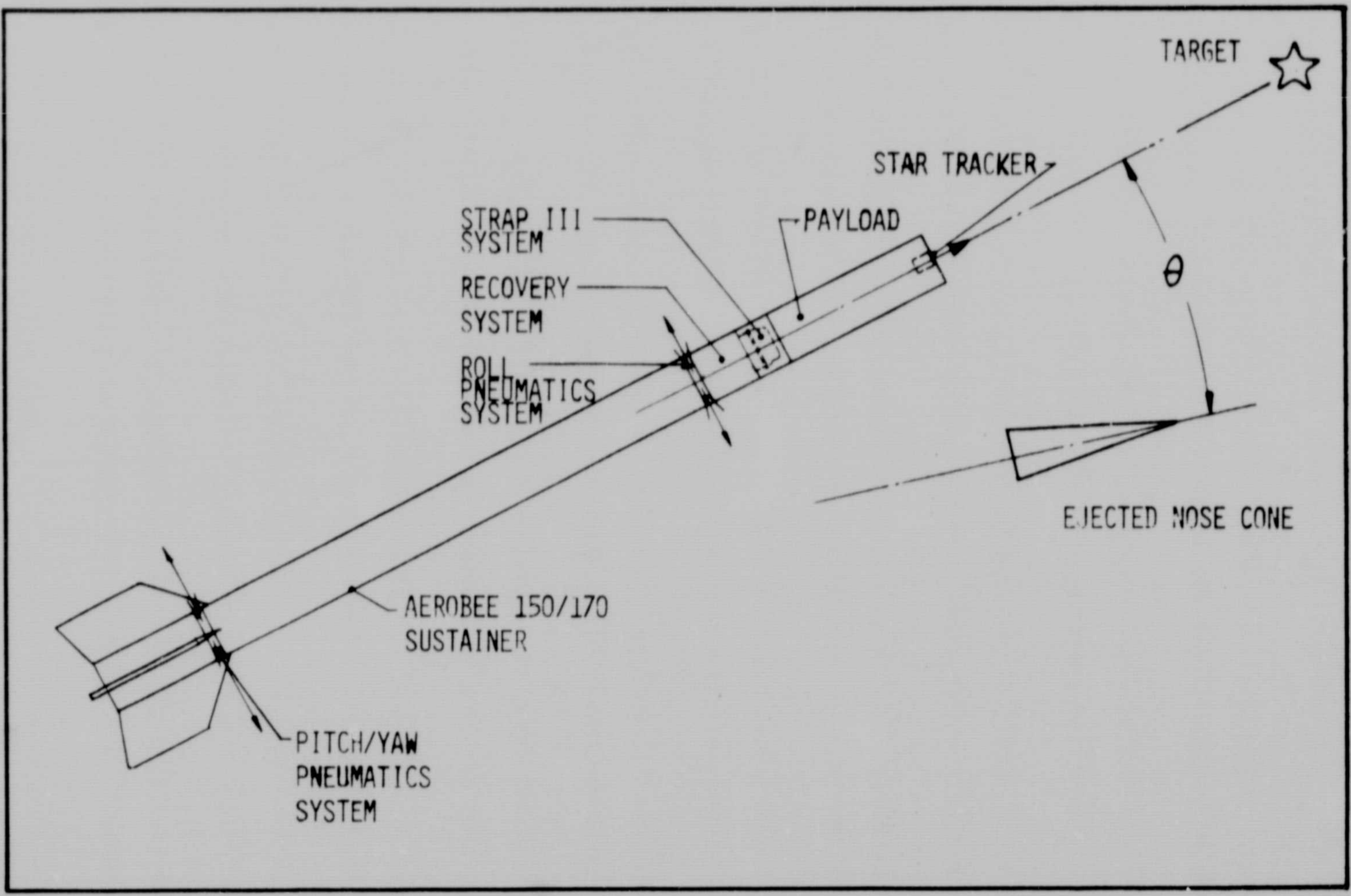


Fig. 2-1 Typical STRAP III System Configuration for Aerobee 150 and 170

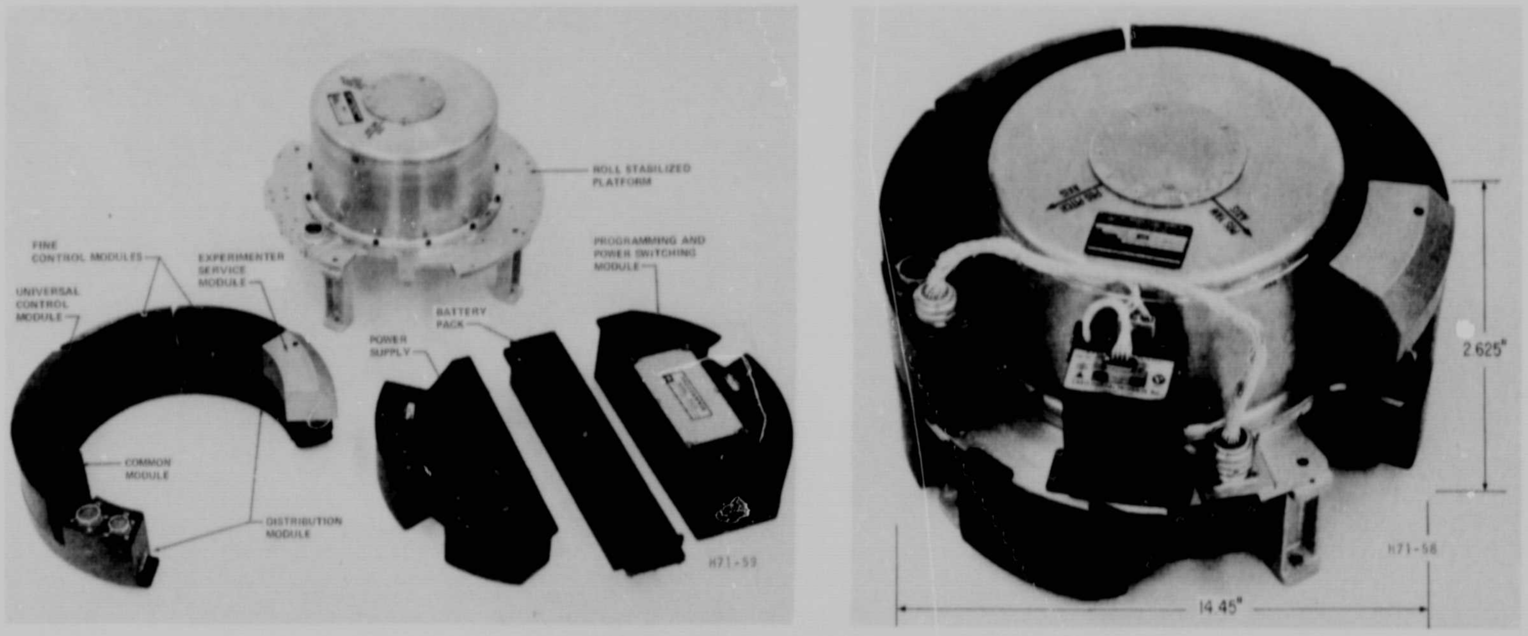


Fig. 2-2 STRAP III System Major Assemblies (Left) and Assembled (Right)

The coarse attitude sensors are two-axis free gyroscopes mounted on a roll stabilized platform (RSP). The platform isolates the gyroscopes from the high vehicle roll rate during powered flight and thereby eliminates pitch and yaw precessional drift caused by unidirectional roll motion. The RSP is shown fully assembled in Fig. 2-2. A view with the cover removed is shown in Fig. 2-3. Fig. 2-4 is a RSP gimbal diagram.

Pointing at preselected targets is accomplished by precessing the free gyroscope gimbals at a fixed rate for a preset time (using electrical torquers internal to the free gyroscope), thus causing a position gyroscope error. Since the system is "null seeking," the rocket follows the moving gyroscope gimbal.

Table 2-2

CEA MODULE LIST AND DESCRIPTION

Power Supply. Draws direct current from the batteries and supplies power to portions of the system. Outputs include 400-Hz square-wave ac at 36, 26, and 16 volts rms and regulated dc at +26, +15, -15, and -26 volts. Maximum power output is 200 volt-amperes ac and 30 watts dc. The power supply also contains the power relay to transfer the system from external 28 V supply to battery operations and relays to turn the tracker on and off remotely.

Programming and Power Switching Module. Contains the relays necessary to switch ac torquing power (both for caging and maneuvers) to the free gyroscopes and the programming matrix and timer. The timer provides 24 separate 28-V output pulses (10 msec) which enable/disable the various timed functions necessary for a flight. The programming matrix is a 24 x 24 diode matrix which routes the 24 timer output pulses to various latching relay coils (up to 12 two-coil latching relays can be used), depending on which diodes are connected. It also contains the gyro torquing current regulator and relay logic to provide up to 6 different torquing rates (relays controlled from matrix).

Common Logic Module. Contains slave roll caging amplifier and performs all basic system logic functions as follows: 1) Solenoid control valve enable/disable; 2) Sense the completion of the despin phase, disable the despin valve, and initiate stabilization to launch attitude; 3) Advance the timer when stabilization to gyro nulls is complete; 4) Enable the fine sensor to acquire the target; 5) Sense the conditions necessary to transfer control to the fine sensor, and initiate the thrust reduction necessary for fine control.

Distribution Module. Serves as the wiring harness to distribute all electrical signals and power to all portions of the system, as well as the conditioned telemetry signals, valve actuation signals, and external sensor inputs and outputs.

Universal Control Module. Contains circuits identical to the fine control module, except for control and logic circuits pertaining to the fine sensor. When fine pointing is not required, three of these modules are used to make an inertial attitude control system (IACS). For fine pointing this module is used on roll only.

Fine Control Module. Contains the control logic, sensor error signal mixing and processing, and solenoid valve drivers for one axis of fine control. The inputs to this module are error signals from the gyros (both rate and position) and the error signal from the star tracker. The outputs are commands to the solenoid valves, conditioned telemetry signals, and certain logic signals necessary to facilitate transfer to star tracker operation. This module also contains the caging amplifier for its respective gyro gimbal. This module is used in pitch or yaw only.

Experiment Service Module. Contains a group of relays to provide the scientific experiment with output commands synchronized with the occurrence of certain events in the ACS system. Ejects the nose tip, turns on the experiment, and provides experiment gain changes when the system is pointing at the various targets. Normally this module is is custom wired for each flight.

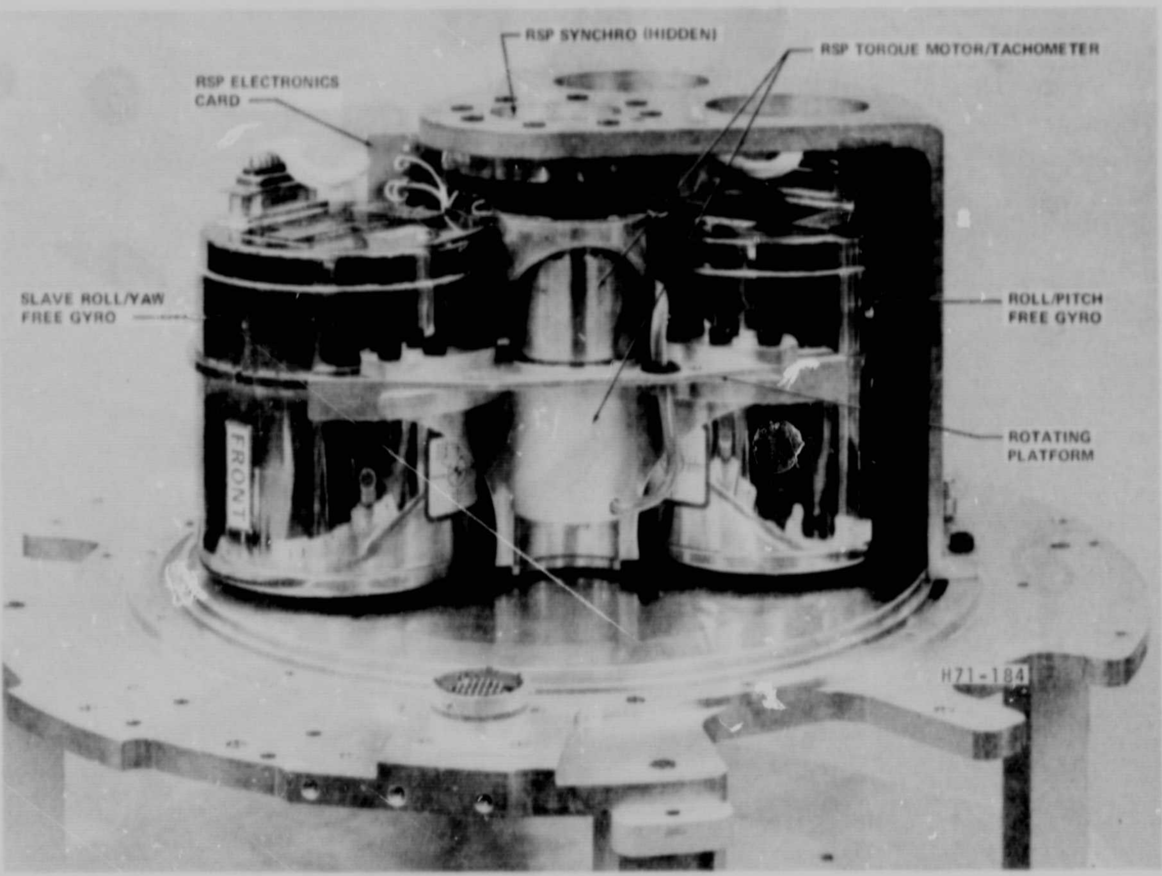


Fig. 2-3 RSP with Cover Removed

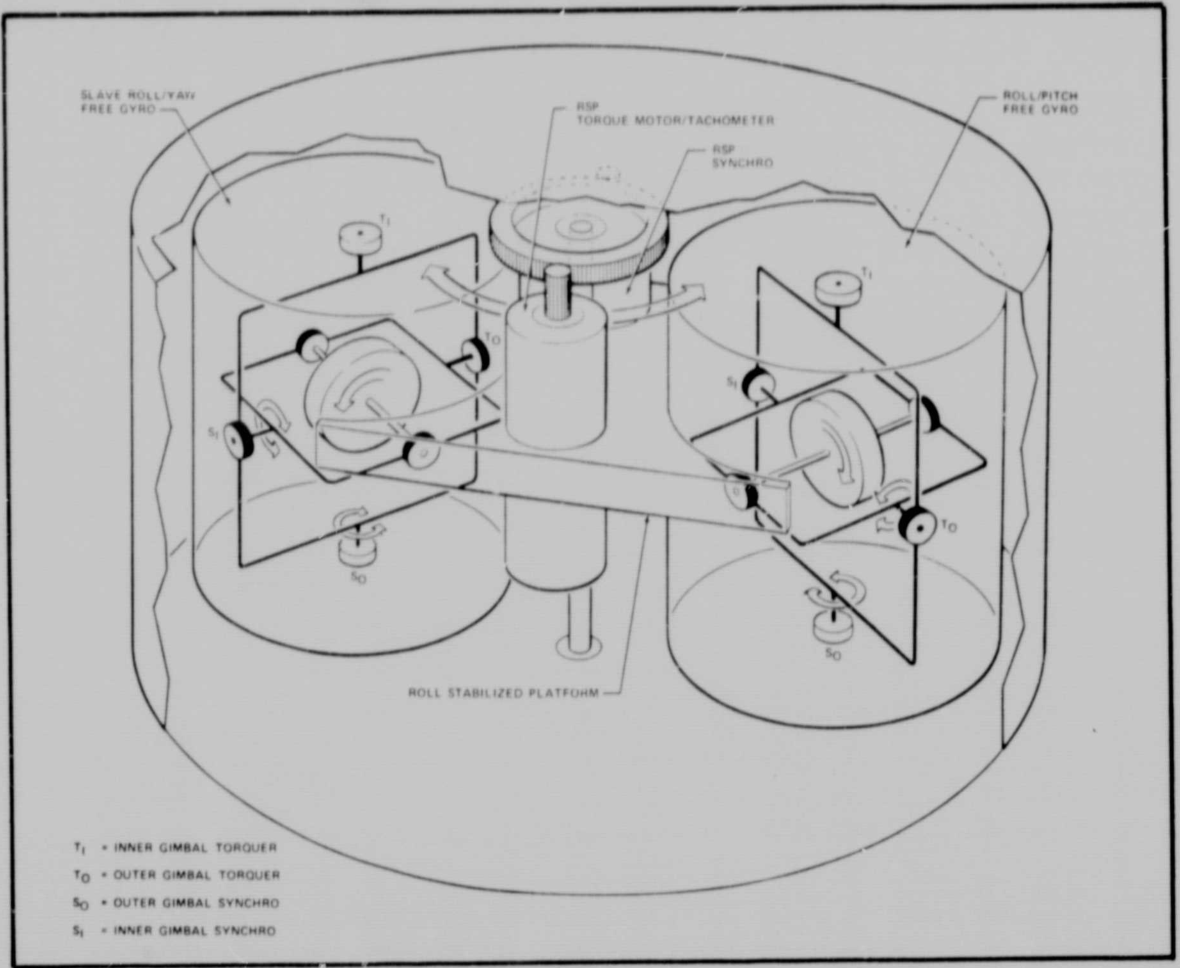


Fig. 2-4 RSP Gimbal Diagram

Gyroscope torquing intervals are controlled by a 23-interval sequence timer. Three intervals of the timer used to control the initial gyroscope torquing are remotely adjustable through the umbilical cable to compensate for gyroscope drifts, launch tower tilts, and actual launch time deviations from the sidereal time for which the fixed maneuvers are calculated. The complex matrix calculations necessary to resolve all the variables (time, tower tilt, etc.) into three remote coordinate adjust Euler maneuvers (roll, pitch, and yaw) are performed by a digital computer.

Through the use of its 20 preset intervals, the timer is also used to initiate system maneuvers (gyroscope torques), enable fine tracking, and maneuver to new targets. Some of the 20 preset intervals can also be used to start coordinated payload command functions such as nose-cone ejections, control of experiments, gains, etc.

The three modes of operation for the STRAP III system using a fine sensor are summarized in Table 2-3. Figure 2-5 is a simplified block diagram of the STRAP III control logic depicting the primary gain changes and system switching modes. The entire system logic is shown in Fig. 2-6 including the caging and maneuver logic. A step-by-step time sequence of a normal STRAP III mission is given in Table 2-4 (note that all relay references in Table 2-4 are shown in Fig. 2-6).

Excerpts from the flight telemetry record of the first successful STRAP III mission are shown in Fig. 2-7. These excerpts show typical performance for initial acquisition and fine tracking performance.

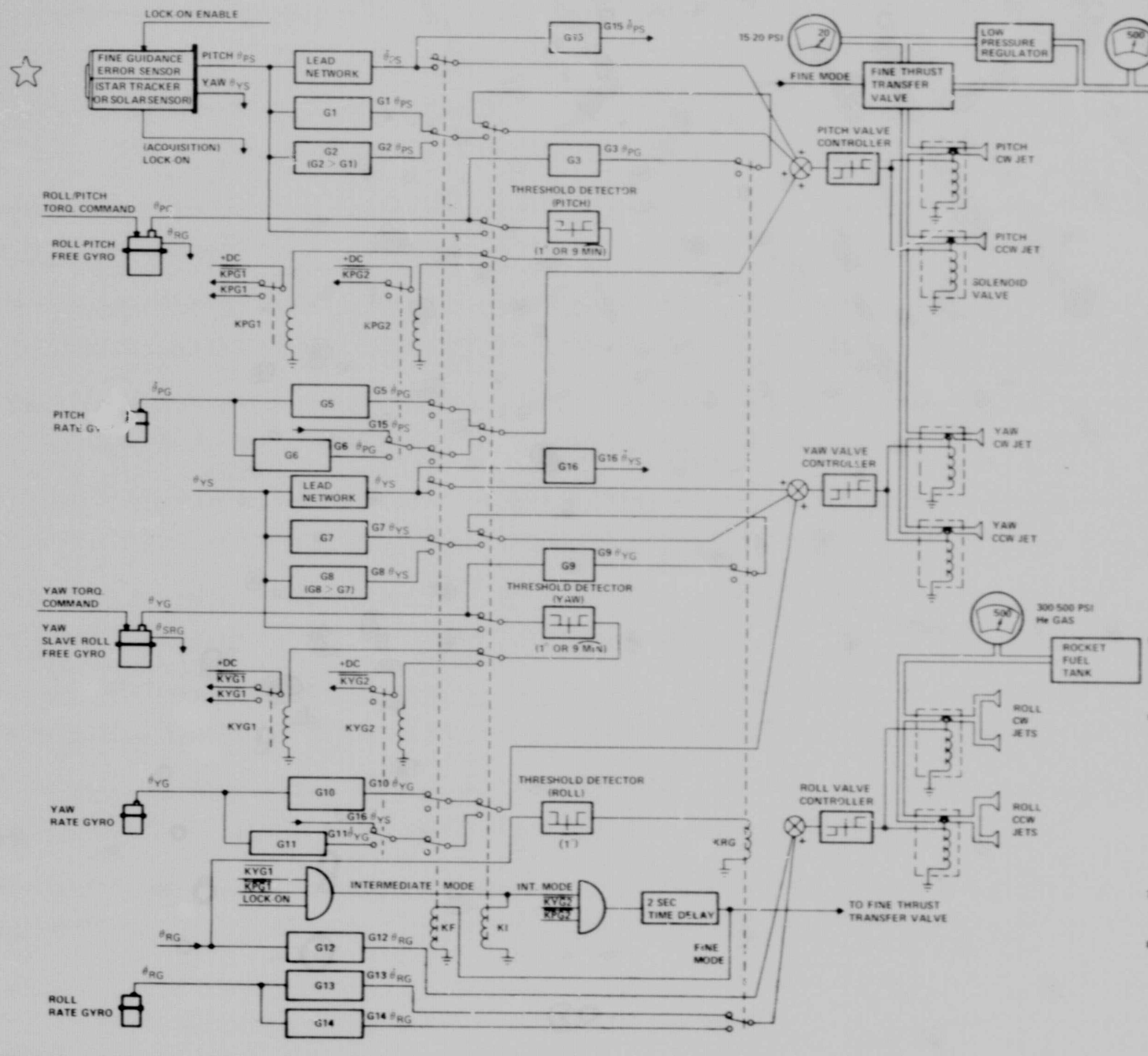
Table 2-3

SUMMARY OF STRAP MODES OF OPERATION

Coarse or Inertially Referenced Mode. The system is controlled by coarse thrust in all axes, using the free gyros as attitude sensors and rate gyros for damping. All rocket maneuvering is done in this mode by precessing the free gyros as necessary. Normal limit-cycle amplitudes are ±1/8° at body rates of 1/8°/sec or lower. In some cases only the coarse mode is used. The system is capable of providing up to eight different precession rates, which can be used to provide experiment scans and various rates in any axis.

Intermediate Mode. When the inertially referenced mode has maneuvered and stabilized the payload observation axis to within a degree or less of the stellar target, the STRAP system activates the star tracker. The star tracker searches its field of view and selects and acquires a target, and sends a lock-on confirmation signal back to the control logic. The control logic then discards the pitch and yaw position gyro error signals and allows the jets to orient the rocket body until a star tracker signal null is obtained (still using the coarse thrusters and rate gyro damping). When the control system has aligned the payload to the star tracker null and has held both axes within about 9 arc minutes of the star tracker null for 2.5 seconds, a logic signal is generated which initiates the fine mode of operation. A second, or intermediate II, mode occurs when either the pitch or the yaw axis (but not both) is within 9 arc minutes of null. This mode lessens the effects of rate gyro null offsets. The rate gyros are switched out of the control loops in pitch and yaw during the fine mode, and rate information is derived from the star tracker output signal using an active lead network. If the system were allowed to maintain the intermediate mode of operation by inhibiting fine mode transfer, it would maintain a limit cycle of about ±1 arc minute about the star tracker null with body rates of about 2 arc min/sec. In the intermediate mode, as in all modes of system operation, roll axis control is maintained by use of the position and rate gyroscope sensors.

Fine Mode. When the intermediate conditions described above are satisfied, the system transfers to fine mode operation. At this point the pitch and yaw star tracker position and rate signal gains are increased. Also at this point the thrust and hence acceleration is reduced (by pneumatically transferring the pitch and yaw thrusters to a lower working pressure) from a coarse value of about 3.5°/sec^2 to about 0.15°/sec^2. Since the intermediate mode holds the aforementioned 9 arc minute threshold for a preset time delay (normally 2 to 3 seconds) before permitting fine mode transfer, the system is assured of relatively low residual body rates and positional errors for the fine jet controllers to take out. Therefore, capture and stabilization into the final limit cycle (approximately ±10 arc seconds amplitude) usually occurs within 1-3 seconds after initiation. The pitch and yaw gyro gimbals are also caged as soon as the system is turned over to fine control.

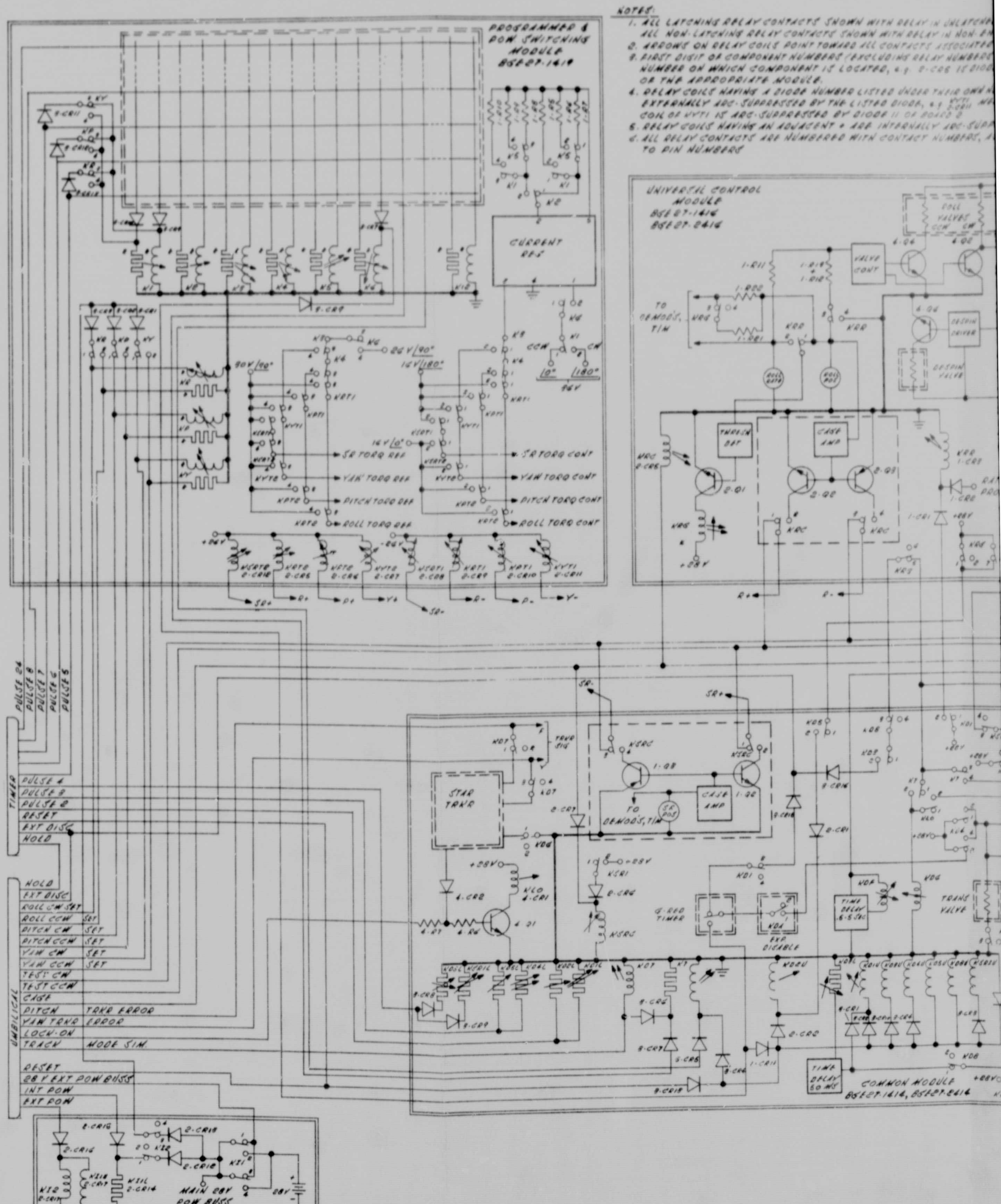


NOTES:

1. SLAVE ROLL IS CAGED TO ITS CASE NULL TO KEEP THE YAW SENSING AXIS ORTHOGONAL TO THE PITCH SENSING AXIS.
2. ROCKET DESPIN AND GYRO ERECTION LOGIC CIRCUITRY ARE NOT SHOWN ON THIS DIAGRAM.
3. MANEUVERS ARE ACCOMPLISHED BY TORQUING (PRECESSING) THE DESIRED GIMBAL AXIS OF THE FREE GYRO AT A FIXED ANGULAR RATE FOR A PRESELECTED TIME. THE ROCKET BODY FOLLOWS THE PRECESSING GYRO GIMBAL.
4. KRR IS ENERGIZED WHEN ROLL AXIS FREE GYRO ERROR IS GREATER THAN ONE DEGREE. IT CAUSES PITCH AND YAW TO CONTROL ON BODY RATE ONLY WHEN IN THE COARSE MODE OF OPERATION.
5. KI IS ENERGIZED WHEN THE STAR TRACKER IS LOCKED ON, AND THE ROCKET BODY IS WITHIN ONE DEGREE OF THE FREE GYRO NULL IN PITCH AND YAW.
6. KF IS ENERGIZED ONLY WHEN KI IS ENERGIZED, AND THE ROCKET BODY IS WITHIN 9 ARC-MINUTES OF THE STAR TRACKER BORESIGHT NULL AXIS IN PITCH AND YAW. THE TIME DELAY IS INSERTED TO ENSURE THAT THE SYSTEM IS HOLDING THE 9 ARC-MINUTE THRESHOLD BEFORE TRANSFERRING TO HIGH TRACKER GAIN AND LOW THRUST AND THAT THE BODY RATES ARE LOW ENOUGH TO ENABLE A CAPTURE WITH LOW THRUST IN A REASONABLE TIME (UNDER 5 SEC).
7. PITCH AND YAW FREE GYROS ARE CAGED TO THE BODY WHEN THE SYSTEM IS IN THE FINE MODE.
8. VALVE CONTROLLERS ARE PULSE FREQUENCY TYPE — i.e., VALVE ACTUATION FREQUENCY INCREASES WITH INCREASE IN ERROR SIGNAL INPUT.

Fig. 2-5 STRAP III Control Logic Block Diagram

FOLDOUT FRAME



NOTES:

1. ALL LATCHING RELAY CONTACTS SHOWN WITH RELAY IN UNLATCHE
ALL NON-LATCHING RELAY CONTACTS SHOWN WITH RELAY IN NON-EN
2. ARROWS ON RELAY COILS POINT TOWARD ALL CONTACTS ASSOCIATED
3. FIRST DIGIT OF COMPONENT NUMBERS (EXCLUDING RELAY NUMBERS
NUMBER ON WHICH COMPONENT IS LOCATED, e.g. 2-CR6 IS DIOD
OF THE APPROPRIATE MODULE.
4. RELAY COILS HAVING A DIODE NUMBER LISTED UNDER THEIR OWN N
EXTERNALLY ARC-SUPPRESSED BY THE LISTED DIODE, e.g. KYT1 2-CR11 NE
COIL OF KYT1 IS ARC-SUPPRESSED BY DIODE 11 OF BOARD 2
5. RELAY COILS HAVING AN ADJACENT • ARE INTERNALLY ARC-SUP
6. ALL RELAY CONTACTS ARE NUMBERED WITH CONTACT NUMBERS, A
TO PIN NUMBERS

Fig. 2-6 STRAP III Logic Diagram

OWN WITH RELAY IN UNLATCHED STATE;
SHOWN WITH RELAY IN NON-ENERGIZED STATE.
ARD ALL CONTACTS ASSOCIATED WITH THE RELAY.
S (EXCLUDING RELAY NUMBERS) IS BERC BOARD
LOCATED, e.g. 2-CR6 IS DIODE #6 ON BOARD 2

BER LISTED UNDER THEIR OWN NUMBER ARE
E LISTED DIODE, e.g. $\frac{K}{2\text{-}CR11}$ MEANS THE
Y DIODE 11 OF BOARD 2
* ARE INTERNALLY ARC-SUPPRESSED.
D WITH CONTACT NUMBERS, AS OPPOSED

7. ALL COMPONENTS ENCLOSED IN DOUBLE-DOTTED LINES ARE PHYSICALLY LOCATED IN A PART OF THE ROCKET REMOVED FROM ANY OF THE MODULES SHOWN.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL
A	ADDED TIE PT. [illegible] & ROLL POS. MOVED ANODE OF 2-CR16 FROM [illegible] TO [illegible]. MOVED +28V FROM [illegible] TO [illegible]. ADDED LABEL TO PROG. & POW. SW. MOD. MODS: "REDUNDANCY", "ROLL LOCKOUT DISABLE" RESULTANT ARROW CHANGES & ADDITIONS. UPDATE OF SCHEM. NOS., RELABELLING OF COMP'S FOR S/N 109-119.	9/24/71	

FOLDOUT FRAME

2

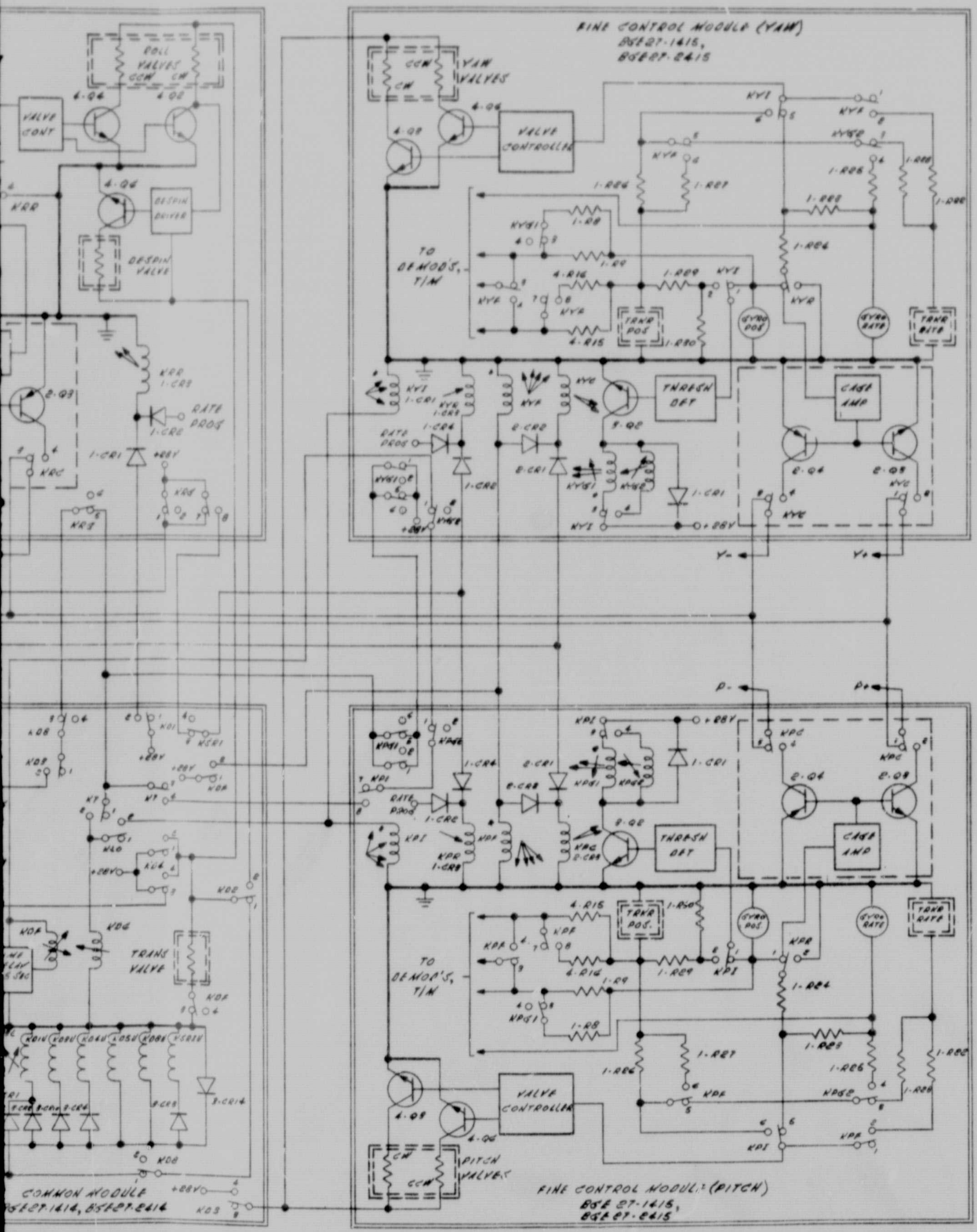


Table 2-4
STRAP III LOGIC OPERATIONS

	System Event/Mode of Operation	Description of Event or Mode	Control Relay Functions
1.	Pre-Launch Operation	Ground control transfers power to internal battery, cages gyros, and resets system to its "zero" state.	KI1L is latched for internal power operation. All gyro caging relays, KRC, KSRC, KYC, and KPC are energized.
2.	Rocket Thrust Phase	G-Reduction Timer applies 28 vdc to Common Logic reset circuits, and to the Programming and Power Switching Module, to disconnect gyro torquing reference signals. Gyros uncaged.	All Common Logic latching relays (8) are held in unlatched state. K6 of the Programming and Power Switching Module is held unlatched. Caging relays are de-energized.
3.	ACS Start	At rocket burn-out G-Reduction Timer removes 28 vdc from reset circuits and applies it to Sequence Timer external discrete line, commanding pulse 2. Despin mode is set up but not activated. The roll threshold detector senses roll rate. Roll valves are controlled by roll rate only.	KD1L latches: (1) energizes KRR of the roll module to set up despin mode; and (2) turns off external discrete signal. KD2L latches: connects despin valve circuit to roll/transfer valve enable line. KRR is energized: (1) switches roll rate gyro signal to threshold detector; and (2) turns off roll position signal to roll valve circuit. KRG is energized for roll rate >2.5°/sec (CW): (1) energizes KPR and KYR, and (2) reduces gain on roll position T/M. KPR turns off pitch gyro position signal. KYR turns off yaw gyro position signal.
4.	Despin Mode	Pulse 3 occurs in time sequence and activates roll/transfer valve enable line. Despin of the rocket to <2.5°/sec (CW) occurs at high deceleration level of about 75°/sec². Both the despin valve and the roll CW valve are energized.	KD4L latches: (1) activates the roll/transfer valve enable line; and (2) drops 28 vdc from the G-Reduction Timer circuit to disable the external discrete signal that produced pulse 2. KD5L latches and connects the rate threshold logic circuit (relay KRG) for unlatching KD2L at completion of despin.
5.	Despin Complete, Begin Erection in Roll	At CW spin reduction to <2.5°/sec, the roll despin mode is turned off and roll erection begins. Roll valves are controlled by position and rate signals. The rocket acquires the inertial roll position it had in the launch tower at the time the gyros were uncaged (assuming no gyro errors). Pitch and yaw axes are under rate gyro control only until roll erection to the ±1° error range is achieved.	KRG is de-energized: (1) unlatches KD2L, which then unlatches KD1L, which in turn de-energizes KRR; (2) de-energizes KPR and KYR (momentarily); and (3) raises gain on roll position T/M (momentarily). KD2L unlatches: (1) drops despin valve power and initiates a 50 ms delay to latch KD3 (this function AND-gated with KD8L unlatch state); and (2) applies power to unlatch KD1L (through KD8L in unlatched state also). KD1L unlatches and de-energizes KRR. KRR is de-energized: (1) switches roll position gyro signal to threshold detector, which energizes KRG again for $\|\epsilon_R\| >1°$, which in turn energizes KPR and KYR again, turning off pitch and yaw position control. KRG also reduces roll position T/M gain. KD3 latches and activates the pitch/yaw valve enable line.
6.	Pitch/Yaw Erection	When $\|\epsilon_R\| <1°$ pitch and yaw position gyro signals control their respective valve circuits, which were on rate gyro control only during roll erection. The rocket acquires its inertial pitch/yaw attitude before launch, at the time the gyros were uncaged (assuming no gyro errors). When roll, pitch and yaw position errors are in the ±1° range, an external discrete Sequence Timer command is generated and causes pulse 4 to occur.	KRG is de-energized for $\|\epsilon_R\| <1°$: (1) allows KPR and KYR to drop, turning on pitch and yaw position control; (2) increases roll position T/M gain; and (3) sets up a logic AND function to generate an external discrete signal at full erection and command timer pulse 4. This AND function has 5 relay inputs: ● KRG de-energized ($\|\epsilon_R\| <1°$) ● KPG1de-energized ($\|\epsilon_p\| <1°$) ● KYG1de-energized ($\|\epsilon_Y\| <1°$) ● KD3L latched (pitch/yaw enabled) ● KD8L unlatched (pulse 4 not yet generated)
7.	Cage Slave Roll	When $\|\epsilon_R\|$, $\|\epsilon_p\|$, and $\|\epsilon_Y\|$ are all less than 1° simultaneously, pulse 4 is commanded to latch the slave-roll (SR) gyro caging circuit. The SR gimbal nulls, with the yaw sensing axis positioned 90° from the pitch sensing axis. This SR cage condition holds for the rest of the flight sequence.	K8DL latches and turns off the external discrete command that produced pulse 4. KSRIL latches and cages the slave-roll (SR) gyro gimbal by energizing KSRC. KSRC closes the SR cage loop by switching the position signal to the caging amplifier input, and by connecting the SR torquer relay coils to the caging amplifier output.

	System Event/Mode of Operation	Description of Event o
8.	Target Acquisition to Inertial References	Pulses 5, 6, 7, and 8 oc preset times and cause p roll, pitch, and yaw gim displacements, respectiv The rocket body moves to the error signals caused gimbal displacements, an thus acquire any pre-pla inertial position relati the erection position. (Position maneuvers in o control axes are require acquiring a target).
9.	Track Mode On	The programmer generates track mode enable signal is AND-gated with the ta acquisition logic signal ertial acquisition), to vate the tracker. A tar lock-on signal from the tracker will now command mediate Mode.
10.	Intermediate Mode (IM)	The following descriptio applies to either the pi the yaw axis: In IM the valves are con by tracker position (at gain) and gyro rate. Th threshold detector discri nates the tracker positi error and switches when <9 arc minutes. When th error level is reached, gyro rate signal is turn and the tracker rate sig (electronic derivative s of tracker position) is on. When the 9 arc minu error level is reached i axes simultaneously, a l signal is generated that switches the system into Mode. A few-second time lay is employed after po thresholds of 9 arc minu are reached, and before Mode is commanded. With delay, fine acquisition reduced thrust will not to contend with large bo rates that exist at the the fine mode position th olds are met. (Fine acqu tion to limit cycle occu less than 5 seconds.)
11.	Fine Mode (FM)	The following description applies to either the pi or the yaw control axis: In FM the valves are controlled by tracker positi (at high gain) and track rate. Valve thrust is reduced to about 1/35 of th IM thrust level. The pos tion gyro gimbal is cage establish an accurate in position reference for t first target. The system limit cycle is about ±7. seconds, centered on the tracker electrical null. (assumes no system elect offset or drift)
12.	Second Target	Pulses 9, 10, 11, and 12 cause roll, pitch, and ya gimbal displacements, and mand rocket maneuvers in quiring a second target i manner similar to that fo first target acquisition, item 8. This operation c begin only if a "Track Mo Off" signal is received f the programmer before, or the start of, the first g torquing interval.

FOLDOUT FRAME 2

Table 2-4

STRAP III LOGIC OPERATIONS

ent or Mode	Control Relay Functions
nsfers power y, cages system to its	KI1L is latched for internal power operation. All gyro caging relays, KRC, KSRC, KYC, and KPC are energized.
applies 28 c reset cir- Programming g Module, to rquing refer- os uncaged.	All Common Logic latching relays (8) are held in unlatched state. K6 of the Programming and Power Switching Module is held unlatched. Caging relays are de-energized.
G-Reduction vdc from reset es it to Se- rnal discrete pulse 2. De- p but not ll threshold ll rate. ntrolled by	KD1L latches: (1) energizes KRR of the roll module to set up despin mode; and (2) turns off external discrete signal. KD2L latches: connects despin valve circuit to roll/transfer valve enable line. KRR is energized: (1) switches roll rate gyro signal to threshold detector; and (2) turns off roll position signal to roll valve circuit. KRG is energized for roll rate >2.5°/sec (CW): (1) energizes KPR and KYR; and (2) reduces gain on roll position T/M. KPR turns off pitch gyro position signal. KYR turns off yaw gyro position signal.
time sequence /transfer ket to <2.5°/ high decel- about 75°/sec². alve and the energized.	KD4L latches: (1) activates the roll/transfer valve enable line; and (2) drops 28 vdc from the G-Reduction Timer circuit to disable the external discrete signal that produced pulse 2. KD5L latches and connects the rate threshold logic circuit (relay KRG) for unlatching KD2L at completion of despin.
ion to <2.5°/ pin mode is ll erection ves are con- on and rate ket acquires position it tower at the re uncaged errors). s are under only until the ±1° hieved.	KRG is de-energized: (1) unlatches KD2L, which then unlatches KD1L, which in turn de-energizes KRR; (2) de-energizes KPR and KYR (momentarily); and (3) raises gain on roll position T/M (momentarily). KD2L unlatches: (1) drops despin valve power and initiates a 50 ms delay to latch KD3 (this function AND-gated with KD8L unlatch state); and (2) applies power to unlatch KD1L (through KD8L in unlatched state also). KD1L unlatches and de-energizes KRR. KRR is de-energized: (1) switches roll position gyro signal to threshold detector, which energizes KRG again for $\lvert\epsilon_R\rvert > 1°$, which in turn energizes KPR and KYR again, turning off pitch and yaw position control. KRG also reduces roll position T/M gain. KD3 latches and activates the pitch/yaw valve enable line.
ch and yaw nals control valve cir- on rate during roll ket acquires /yaw atti- , at the e uncaged errors). nd yaw e in the rnal dis- er command auses	KRG is de-energized for $\lvert\epsilon_R\rvert < 1°$: (1) allows KPR and KYR to drop, turning on pitch and yaw position control; (2) increases roll position T/M gain; and (3) sets up a logic AND function to generate an external discrete signal at full erection and command timer pulse 4. This AND function has 5 relay inputs: • KRG de-energized ($\lvert\epsilon_R\rvert < 1°$) • KPG1 de-energized ($\lvert\epsilon_P\rvert < 1°$) • KYG1 de-energized ($\lvert\epsilon_Y\rvert < 1°$) • KD3L latched (pitch/yaw enabled) • KD8L unlatched (pulse 4 not yet generated)
nd $\lvert\epsilon_Y\rvert$ are imultaneously, ed to latch) gyro s, with the ositioned sensing condition of the	K8DL latches and turns off the external discrete command that produced pulse 4. KSR1L latches and cages the slave-roll (SR) gyro gimbal by energizing KSRC. KSRC closes the SR cage loop by switching the position signal to the caging amplifier input, and by connecting the SR torquer relay coils to the caging amplifier output.

	System Event/Mode of Operation	Description of Event or Mode	Control Relay Functions
8.	Target Acquisition to Inertial References	Pulses 5, 6, 7, and 8 occur at preset times and cause precise roll, pitch, and yaw gimbal displacements, respectively. The rocket body moves to null the error signals caused by the gimbal displacements, and can thus acquire any pre-planned inertial position relative to the erection position. (Position maneuvers in only 2 control axes are required in acquiring a target).	The same threshold logic relays used to detect erection errors of less than 1° are used again here to detect that acquisition errors to the target inertial references have been reduced to 1°. These relays are KRG (roll), KPG1 (pitch), and KYG1 (yaw).
9.	Track Mode On	The programmer generates a track mode enable signal which is AND-gated with the target acquisition logic signal (inertial acquisition), to activate the tracker. A target lock-on signal from the tracker will now command Intermediate Mode.	KRG is de-energized when the roll error from target inertial roll reference is less than 1°. This condition enables pitch and yaw to acquire the target, by dropping KPR and KYR relays, and switching on pitch and yaw position signals. KPG1 and KYG1 relays de-energize for pitch/yaw errors of less than 1° and produce a 28 vdc acquisition logic signal. They also increase gyro position T/M gain. K7L is latched by a "track mode on" signal. The acquisition logic 28 vdc is gated through K7L (latched) to energize KD6, which activates the tracker (slew control function). A lock-on signal from the tracker energizes KL0 which switches the KD6 control 28 vdc signal to KPI and KYI, the Intermediate Mode pitch/yaw control relays.
10.	Intermediate Mode (IM)	The following description applies to either the pitch or the yaw axis: In IM the valves are controlled by tracker position (at low gain) and gyro rate. The threshold detector discriminates the tracker position error and switches when $\lvert\epsilon_{P,Y}\rvert$ <9 arc minutes. When this error level is reached, the gyro rate signal is turned off and the tracker rate signal (electronic derivative signal of tracker position) is turned on. When the 9 arc minute error level is reached in both axes simultaneously, a logic signal is generated that switches the system into Fine Mode. A few-second time delay is employed after position thresholds of 9 arc minutes are reached, and before Fine Mode is commanded. With the delay, fine acquisition on reduced thrust will not have to contend with large body rates that exist at the moment the fine mode position thresholds are met. (Fine acquisition to limit cycle occurs in less than 5 seconds.)	The following function applies primarily to the pitch axis, to simplify relay notation: KPI is energized: (1) turns off gyro position; (2) turns on low-gain tracker position; (3) switches the threshold detector input to tracker position, with discrimination level scaled for ±9 arc minutes; and (4) switches threshold circuit output from KPG1 to KPG2, to set up a logic AND-gate for switch to Fine Mode. (see below) KPG2 connects the gyro rate signal to the valve control circuit when $\lvert\epsilon_P\rvert$ >9 arc minutes (through KPF and KPI closed contacts). As soon as the ±9 arc minute pitch threshold is sensed, KPG2 switches gyro rate off and tracker rate on. The command logic signal for Fine Mode is derived from 6 inputs, AND-gated into a 2-3 second time delay, which then energizes the system logic relay for Fine Mode, KDF. The 6 inputs are as follows: • KYG1 de-energized (yaw in IM) • KPG1 de-energized (pitch in IM) • K7L latched (track mode on) • KPI energized (pitch in IM) • KPG2 de-energized ($\lvert\epsilon_P\rvert$ <9 arc min) • KYG2 de-energized ($\lvert\epsilon_Y\rvert$ <9 arc min)
11.	Fine Mode (FM)	The following description applies to either the pitch or the yaw control axis: In FM the valves are controlled by tracker position (at high gain) and tracker rate. Valve thrust is reduced to about 1/35 of the IM thrust level. The position gyro gimbal is caged to establish an accurate inertial position reference for the first target. The system limit cycle is about ±7.5 arc seconds, centered on the tracker electrical null. (assumes no system electrical offset or drift)	The following function applies primarily to the pitch axis, to simplify relay motation: KDF is energized: (1) opens the transfer valve circuit; (2) energizes FM control relays, KPF and KYF; and (3) energizes cage relays KPC and KYC. KPF increases both tracker position and tracker rate signal gains into the valve controller, in FM. KPC closes the pitch gimbal cage loop by connecting the gyro position signal to the caging amplifier input, and by connecting the pitch torquer relay coils to the caging amplifier output. The loop nulls the gyro position error signal at the on-target pitch attitude of the rocket.
12.	Second Target	Pulses 9, 10, 11, and 12 can cause roll, pitch, and yaw gimbal displacements, and command rocket maneuvers in acquiring a second target in a manner similar to that for first target acquisition, item 8. This operation can begin only if a "Track Mode Off" signal is received from the programmer before, or at the start of, the first gimbal torquing interval.	K7L unlatches when "Track Mode Off" signal is received: (1) fine, intermediate, and cage relays in the pitch and yaw control modules drop (KPF, KYF, KPI, KYI, KPC, KYC); (2) common logic relays KDF, KL0, and KD6 drop; (3) all coarse position threshold relays, KRG (roll), KPG1 (pitch), and KYG1 (yaw) energize when their respective gyro position errors exceed 1°

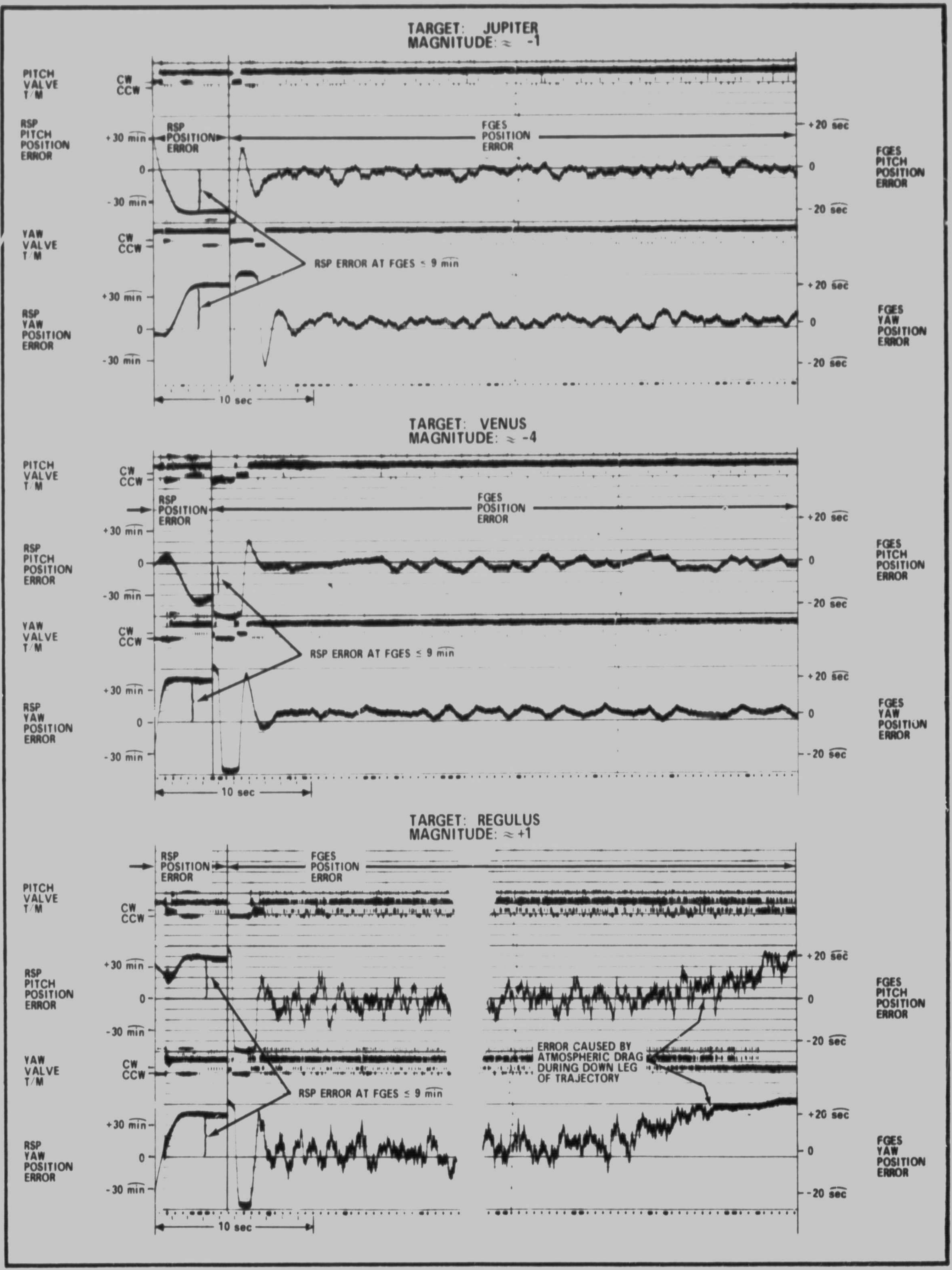


Fig. 2-7 Flight Telemetry Data of STRAP III Fine Tracking Performance

2.2 FINE GUIDANCE ERROR SENSOR DESCRIPTION AND OPERATION

The FGES Star Tracker, shown in Fig. 2-8, is used to provide analog error signals to the STRAP III attitude control system. It acquires the brightest target in its 8-degree diameter field of view (FOV) and tracks this target, providing signals proportional to the angular distance of the target from null or from externally supplied offset pointing commands. It is often used to acquire and track several targets during one mission.

As indicated in the introduction, the objective of the Star Tracker program was to obtain a tracker that meets the requirements of the NASA/GSFC "Fine Guidance Error Sensor Specification," A6000-4, dated 10 July 1969. Table 2-5 compares the most pertinent performance requirements specified in A6000-4 with the corresponding parameters of the BBRC tracker (A6000-4 is included in Appendix A). The data for the comparison were gathered from the test results of the first eight flight model Star Trackers built under Contract NAS5-11664.

Fig. 2-8 Fine Guidance Error Sensor

Table 2-5
COMPARISON OF TRACKER PERFORMANCE AND A6000-4 REQUIREMENTS

Performance Parameter	BBRC Tracker Performance	A6000-4 Specified Performance
<u>Acquisition Mode</u>		
Search pattern	8.2°x8.2° Raster	None
Minimum active FOV	8° diameter circle	8° diameter circle
Search frame time	0.3 seconds	None
Acquisition of A_{0V} star of magnitude m in search time T with a probability of 80%.		
For m = 0, T = ...	0.6 second,...........	1 second
For m = +4, T = ...	1.2 seconds,..........	1 second
The above acquisition to be accomplished with competing star conditions listed in GSFC Spec A6000-4	Conditions met except m = 0 when -1 is specified.	(See A6000-4 Appendix A)
<u>Track Mode</u>		
Track pattern	1°x1° cross scan	
Track period (time of two axis track scan)	20 msec	
Output phase shift in response to a 5-Hz input motion.	≤45°	45°
Output signal random noise (n) when tracking a 3.0 magnitude A0V star	9< n< 14 arc sec rms (depending upon individual tube sensitivity)	n< 10 arc sec rms
Output signal gain	5.0 ± 0.25 mV/arc sec	5.0 ± 0.25 mV/arc sec
Saturation of output signal:		
Voltage level	5.4 ± 0.6 V	5.4 ± 0.6 V
Angle of saturation	18 ± 2 arc min	18 ± 2 arc min
Axis Orthogonality (cross coupling)	±4 arc min in 4° of cross axis rotation	±4 arc min in 4° of cross axis motion

Table 2-5 (Cont.)

Performance Parameter	BBRC Tracker Performance	A6000-4 Specified Performance
Offset point mode		
Nominal gain	2 volts/deg	
Range	±4° in each axis	±4° in each axis
Range of null adjustment	±6 arc min	±2 arc min
Null Stability		
Maximum null error	1 arc min	1 arc min
Null error resulting from the following:		
Environmental effects		45 arc sec rss
Temperature	<30 arc sec	
Vibration	<30 arc sec	
Earth's magnetic field	<10 arc sec	<10 arc sec
Target Magnitude variations -1 to +3	6 to 18 arc sec	<6 arc sec
-1 to +4	0.2 to 22 arc sec	<12 arc sec
Power supply variations	<10 arc sec	<10 arc sec
Target position in acquisition field	<5 arc sec	<10 arc sec

In its present configuration, the Star Tracker meets all of the requirements of the specification consistently, except for the output noise (n) when tracking +3.0 and +4.0 magnitude A_{OV} stars and the ability to track stars over the range of -1 to +4 magnitude. The first eight Star Trackers displayed greater than specification values in null shift over the star magnitude range and null error when the star presence output occurs, however, both of these characteristics can be improved by expending more effort during test. GSFC considered the cost increase vs performance improvement was not justified during this program, therefore, all the units were approved as built.

The largest deviation in the noise output while pointing at a +3 magnitude star was 50 percent on two Star Trackers. Five units exceeded the noise requirement by 2 to 25 percent. One unit met all of the specification noise limits. In all cases, the noise characteristics were a direct function of the phototube gain and photocathode characteristics. Noise characteristics could have been improved by specifying better phototube gain and cathode characteristics; however, the cost impact would have been greater than could have been justified for the performance improvement.

An inability to track stars over the magnitude range is primarily a dynamic range limitation in the video circuit.

The basic function of the Star Tracker is to provide two axis analog error signals proportional to the angular error between the target and the tracker reference planes whenever the target is within the defined tracker FOV.

This is accomplished by using a field scanning image dissector type phototube with a small 24 arc-minute by 24 arc-minute instantaneous FOV. The instantaneous FOV is electronically swept to accomplish the following functions.

1. Search/Acquisition. Search the FOV for target stars. Select the brightest star in the 8-degree diameter circular FOV.

2. Track Mode. Reduce the scan to a 1-degree, two-axis cross pattern, centered about the target star, which is capable of following motions of the target throughout the FOV and provide high gain, high precision, analog error signals when the target star is near the null region of the tracker.

Acquisition is accomplished by scanning the small instantaneous FOV (aperture) in a left-to-right and right-to-left raster pattern through the entire FOV, as shown in Fig. 2-9. A scan through the entire FOV is called a frame or search frame. When the aperture passes over a star, a signal pulse is obtained and stored. If any succeeding signal pulse is larger than the stored value, the larger value is stored. This is continued until the entire FOV has been scanned. The search raster is then repeated, only this time the star signal pulses are compared with the largest value obtained on the first frame. If a near match occurs, the search scan is stopped and the track mode is enabled.

When the position of the brightest star has been obtained, the crossed sweep track pattern (see Fig. 2-9) is centered on the star location. The track servo loop is then closed and the track pattern follows the target image to maintain track anywhere in the FOV. The output signal amplifier gain and saturation regions are deliberately adjusted to obtain a constant signal for all pointing angles larger than about 18 arc-minutes from null. For smaller angles the output signal gain is 5 mv/arc-sec.

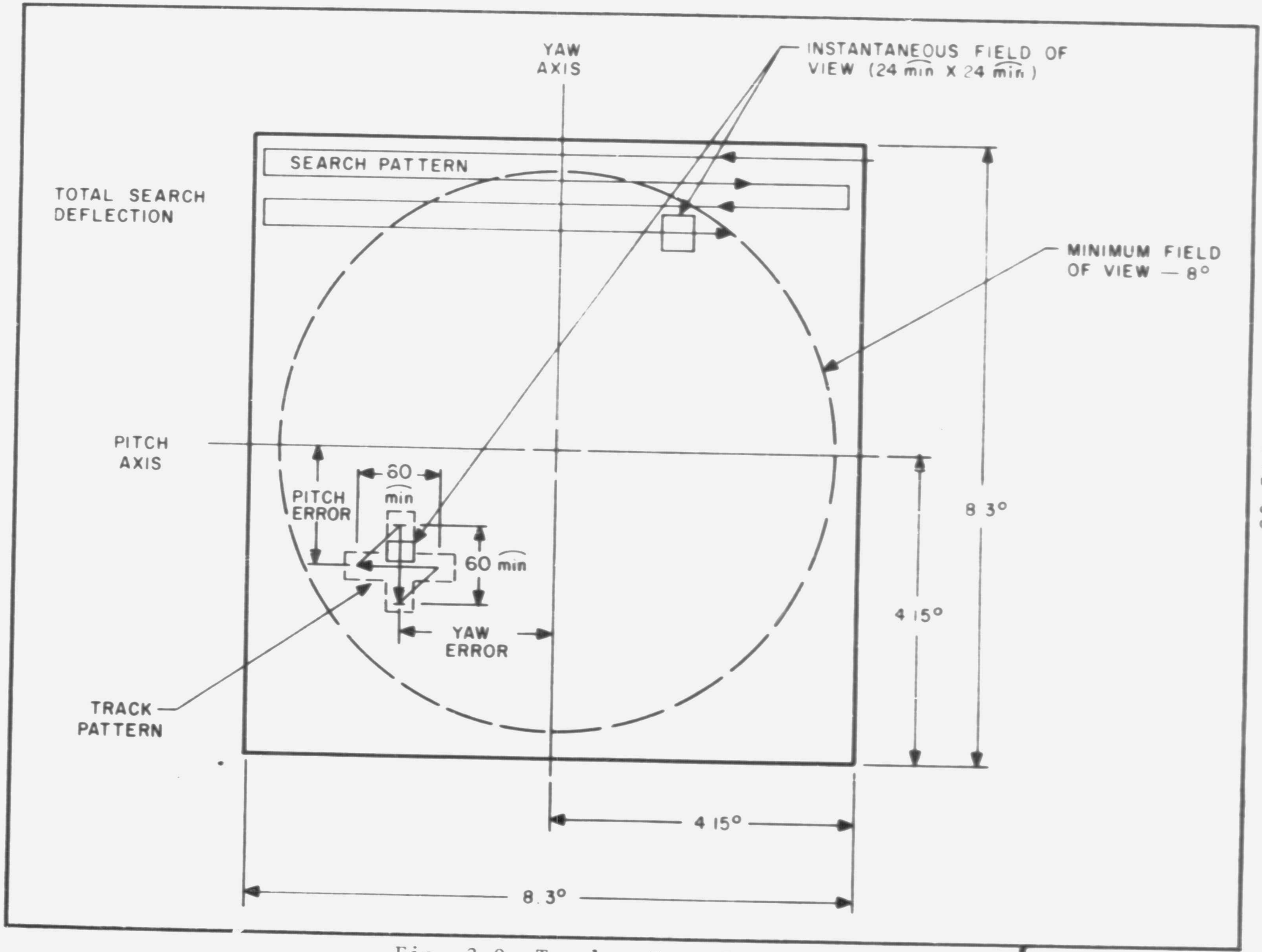


Fig. 2-9 Tracker Scan Geometry

Section 3
DESIGN ACTIVITIES

3.1 STRAP III SYSTEM

Design activities for the STRAP III system were limited to circuit improvements, drawing preparation and update, and a study to determine ways to improve the dim target pointing performance.

A summary of each of these efforts is given in Sections 3.1.1 through 3.1.3.

3.1.1 STRAP Circuit Improvements

Modulators and Demodulators. STRAP III control electronics are basically AC coupled from the input to the valve controller operating with a basic carrier frequency of 400 Hz. Since the two-axis free gyroscopes and the three-axis rate gyroscope outputs are varying amplitude, 400 Hz square waves, the signals can be used directly without further processing. Outputs from the FGES Star Tracker are DC voltages portional to the error angle; thus, a modulator is required to produce an AC signal compatible with the control electronics. The modulators used previously in the STRAP system were half-wave (unbalanced) modulators. This type of modulator has shortcomings in producing a good modulated signal because phase shift is induced by the capacitor coupling. The old modulators also use transformers which reduce the overall circuit reliability. The old and new modulators are shown in Figs. 3-1 and 3-2, respectively. Output waveforms of the two circuits are shown in Figs. 3-3 and 3-4 with a 50 Hz input signal (inputs frequencies to the STRAP system are never this high but this frequency was chosen to emphasize the improvement in circuit characteristics).

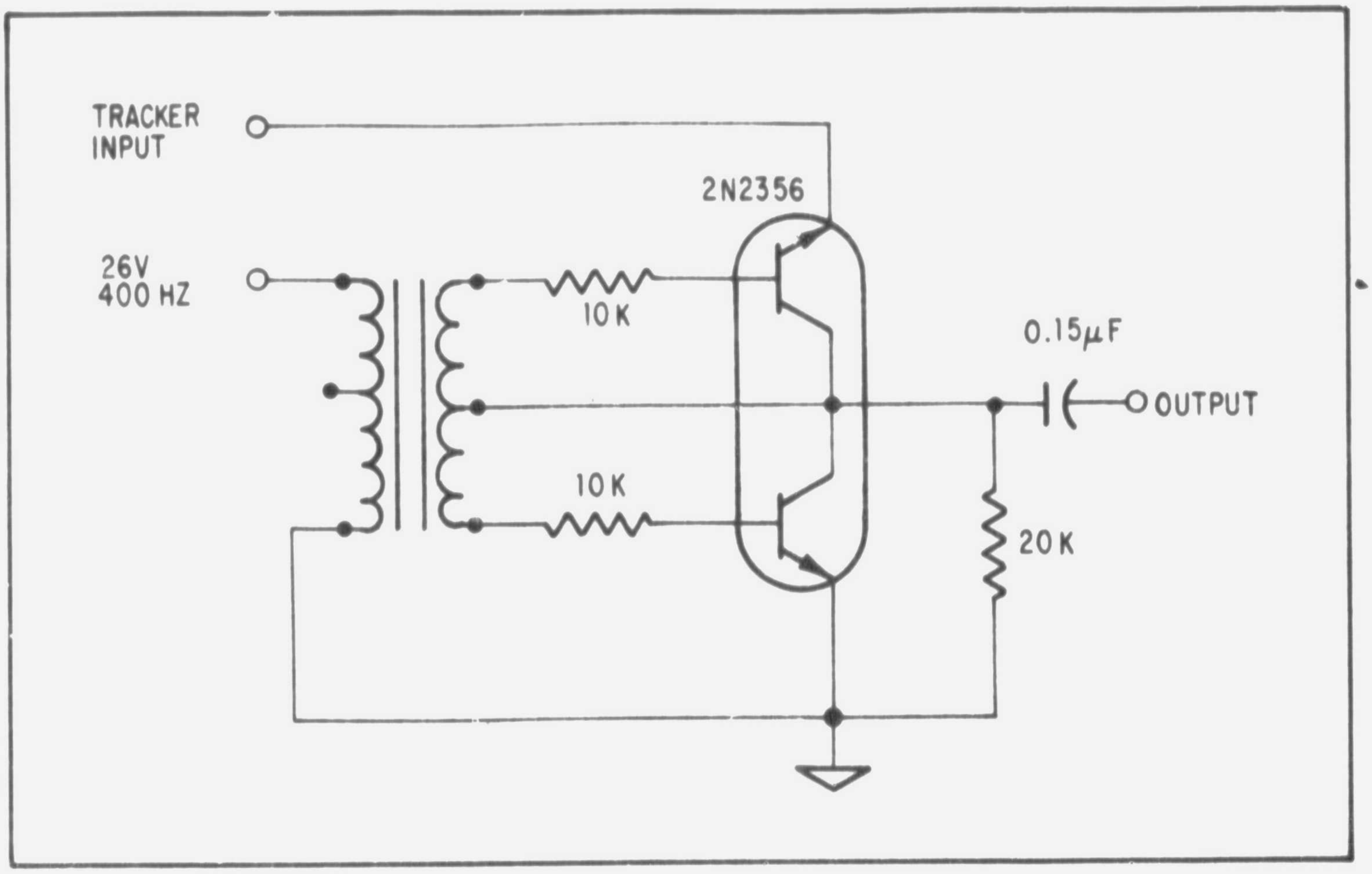


Fig. 3-1 Unbalanced Modulator

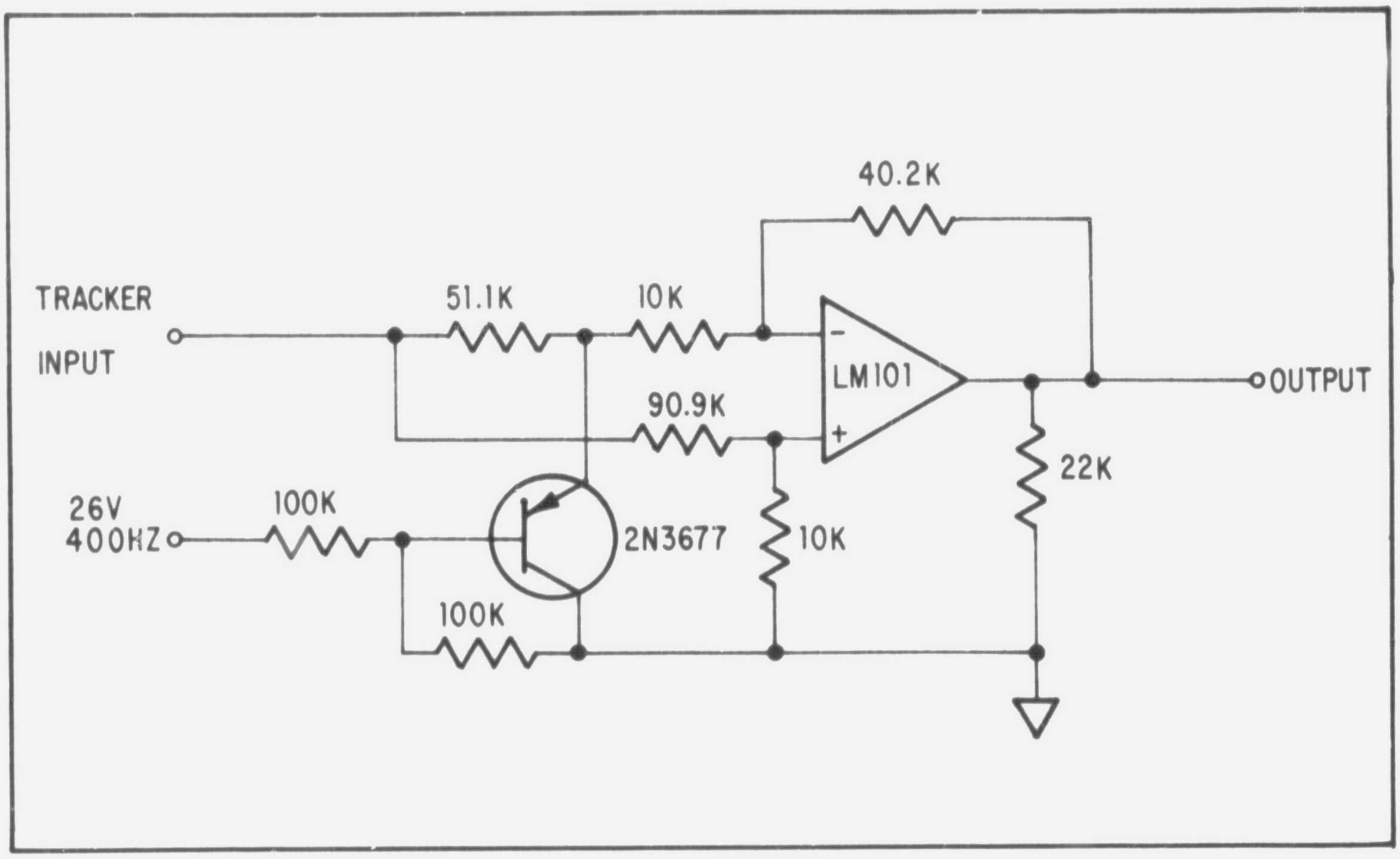


Fig. 3-2 Balanced Modulator

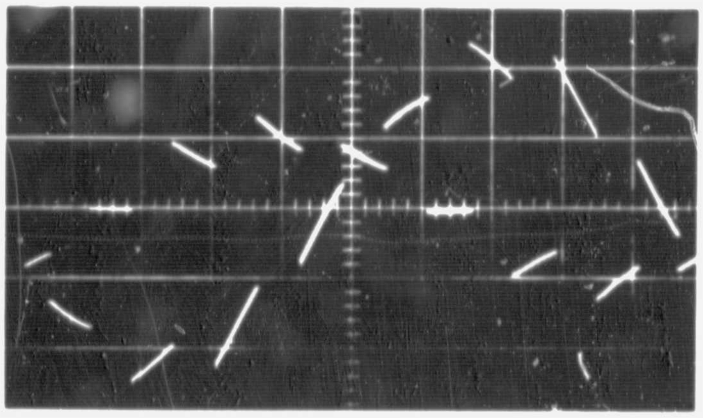


Fig. 3-3 Unbalanced Modulator Output Signal With 20K Load

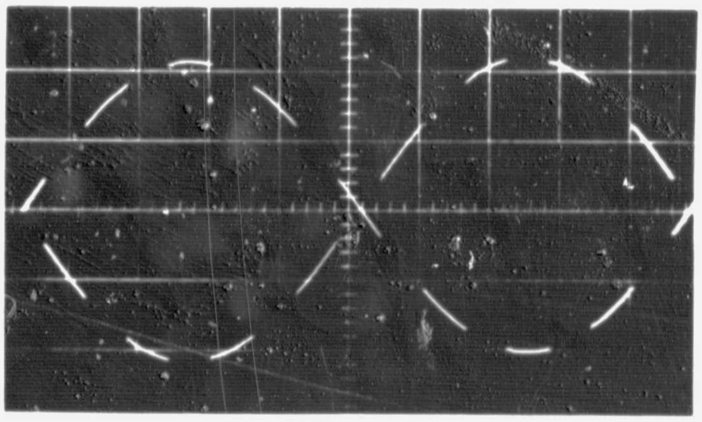


Fig. 3-4 Balanced Modulator Signal Output

The demodulators are used in the STRAP III system to obtain 0 to 5 VDC telemetry signals compatible to the typical telemetry systems flown on Aerobee missions. The existing circuit (shown in Fig. 3-5a) output impedance was so high that the input impedance of the typical telemetry system caused loading that shifted the output signal level. The output scale factor had to be calibrated after the ACS system was integrated with the telemetry system. The new demodulator shown in Fig. 3-5b is identical to the modulator discussed before. The second amplifier was included to allow the telemetry scale factor to be varied easier for special missions and to provide a consistent low output impedance interface to the T/M.

An identical circuit was incorporated into the common module for the slave roll position output. No slave roll telemetry was available on the old STRAP III systems.

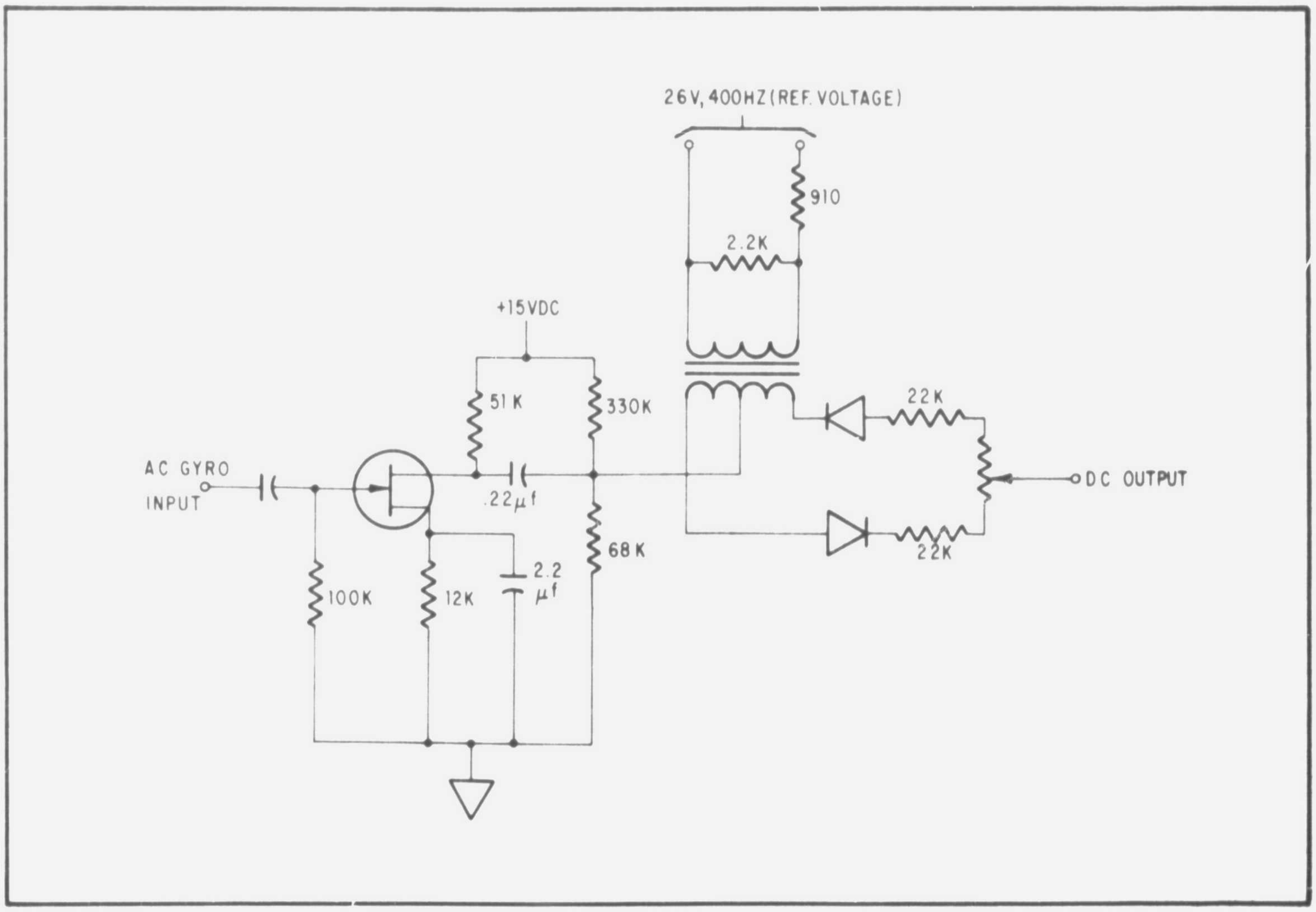


Fig. 3-5a Original STRAP Demodulator

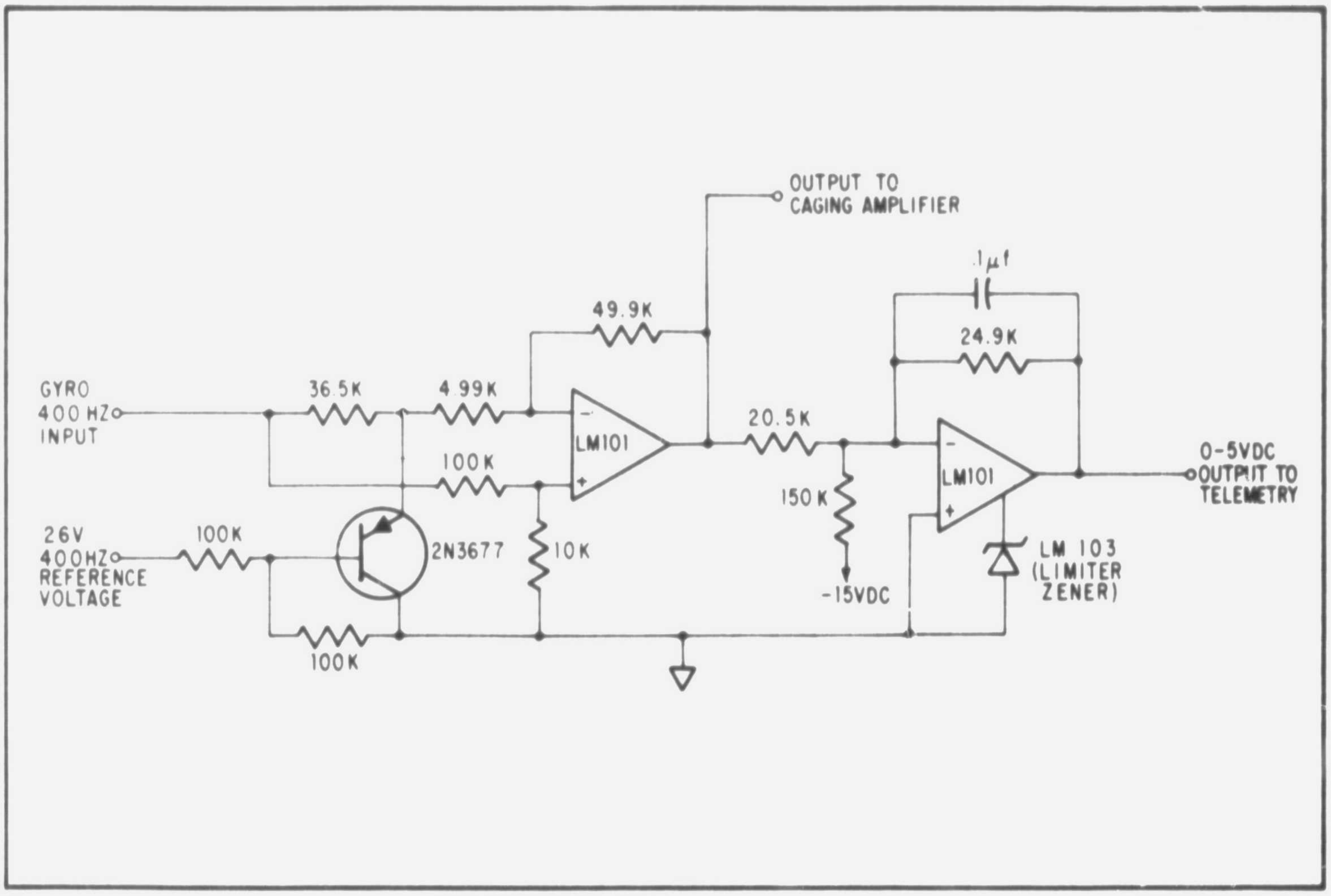
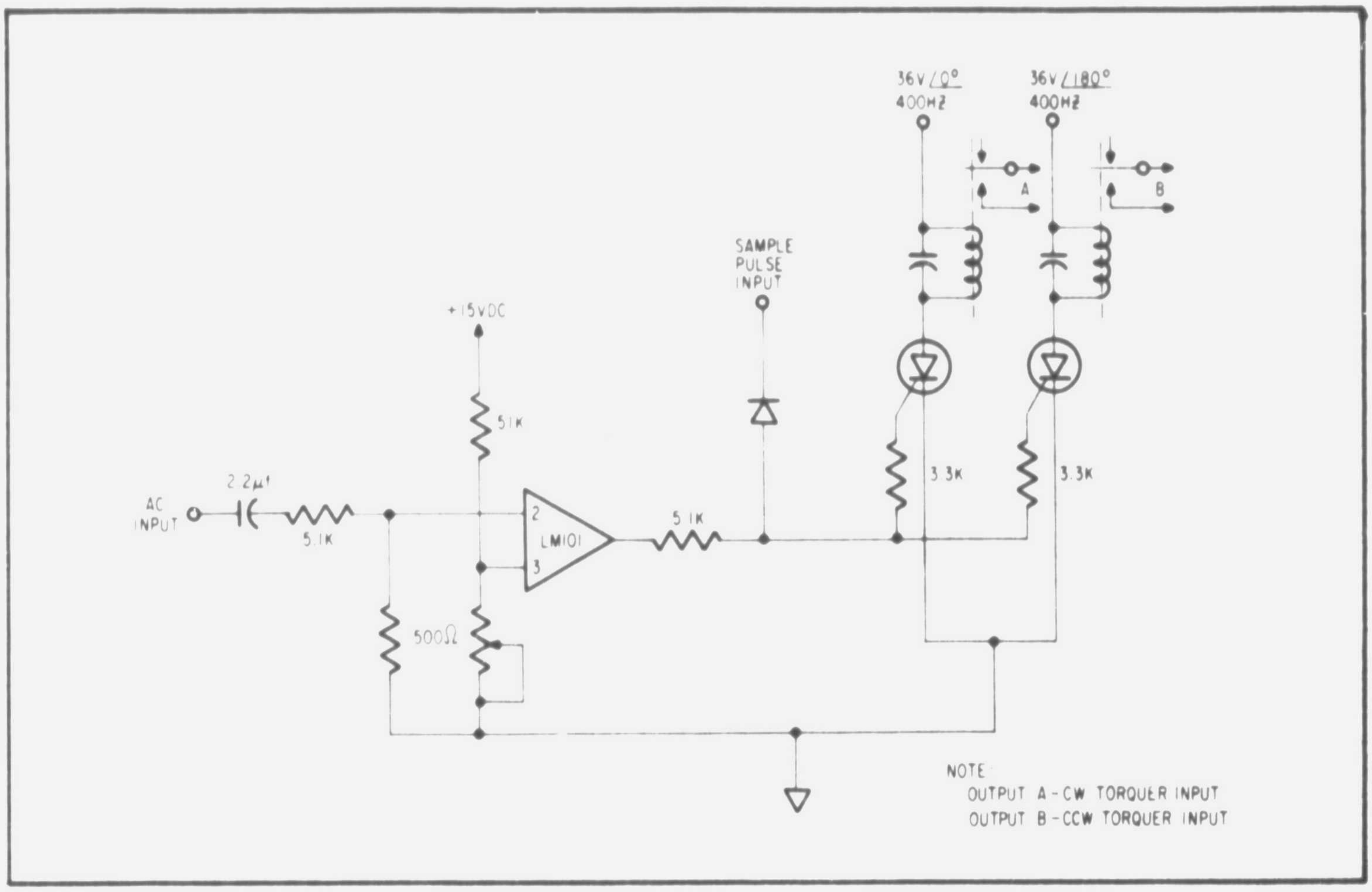


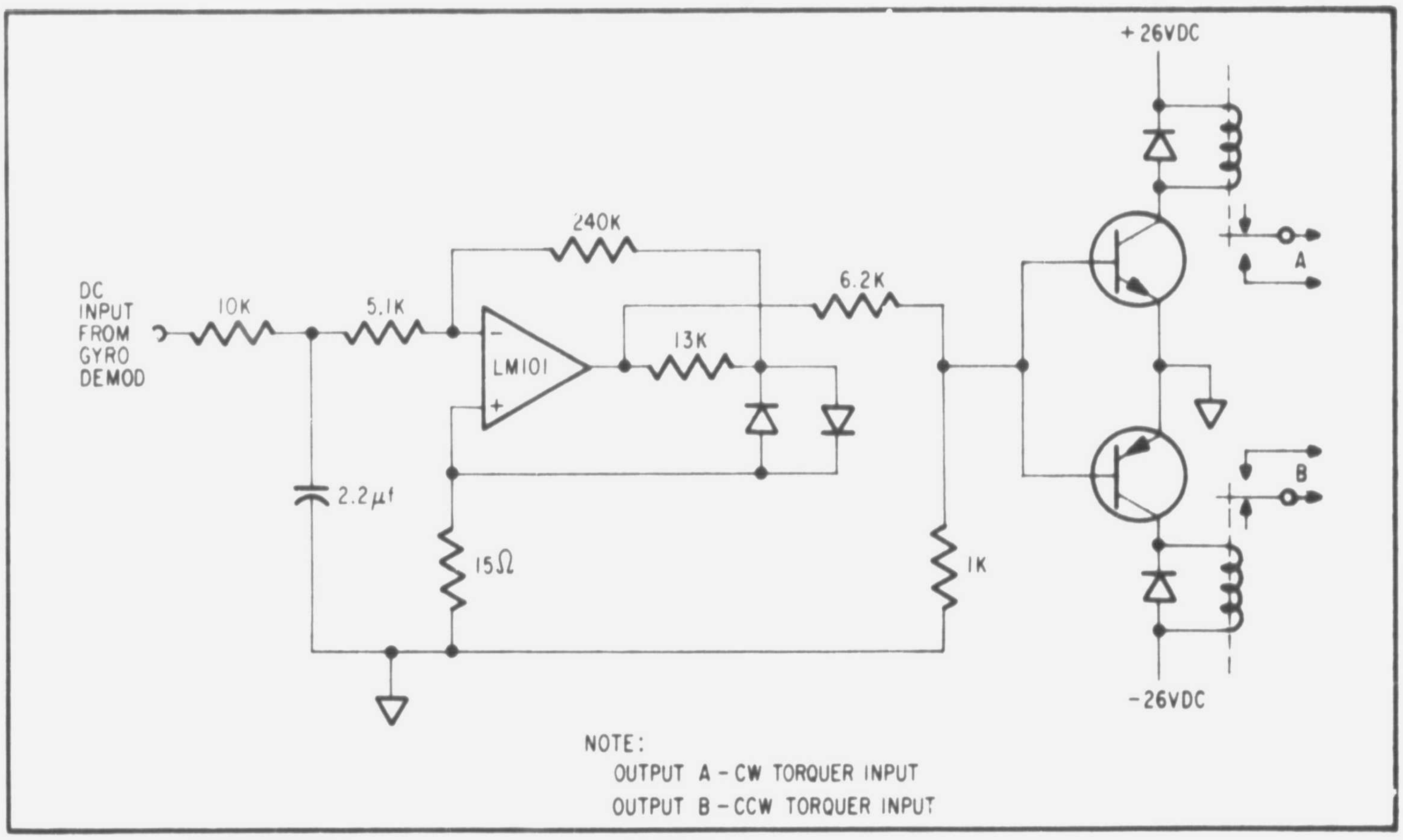
Fig. 3-5b Balanced Demodulator

<u>Caging Amplifiers</u>. The old caging amplifiers shown in Fig. 3-6 applied a 400 Hz signal into a relay coil when the input AC signal reached the threshold voltage of the silicon controlled rectifiers (SCR). The relays tended to chatter at inputs near the threshold point, a condition that was potentially damaging to the relay contacts (heavy AC currents up to 2 amps are switched on and off through the cage relay). The new caging circuit, shown in Fig. 3-7, includes some hysteresis to ensure a positive relay contact transfer when the threshold voltage is reached. The voltage across the relay coil is a DC voltage. The threshold voltage is much more consistent in the new circuit and, thus, guarantees better caging accuracy. One caging circuit is required for each of the four gyroscope gimbals.



NOTE
OUTPUT A - CW TORQUER INPUT
OUTPUT B - CCW TORQUER INPUT

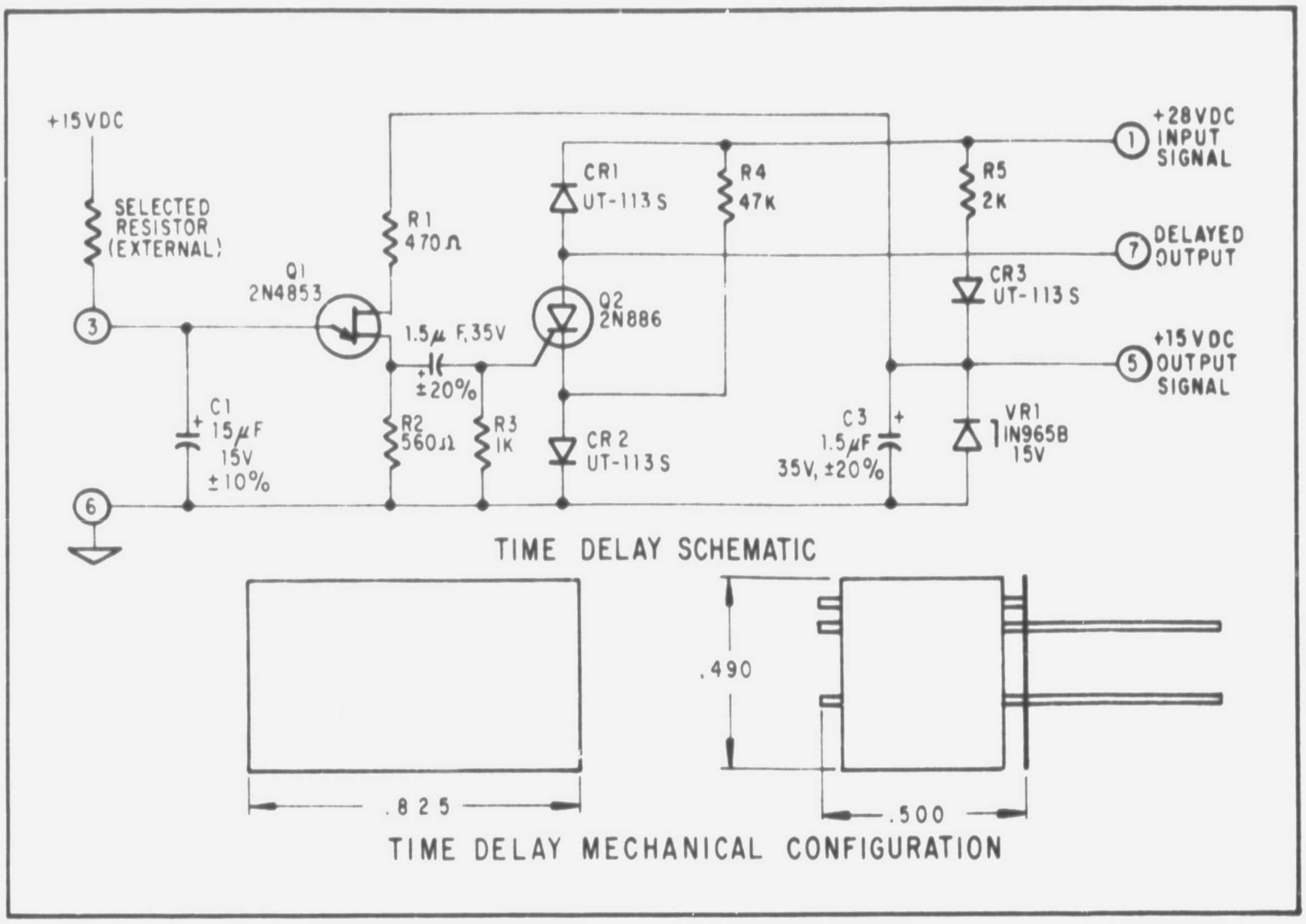
Fig. 3-6 Original STRAP III Caging Amplifier



NOTE:
OUTPUT A - CW TORQUER INPUT
OUTPUT B - CCW TORQUER INPUT

Fig. 3-7 Modified STRAP Caging Circuit

Time Delay Circuit. GSFC had some problems with a purchased time delay module and asked BBRC to package a GSFC design into a configuration that allows the new time delay module to be installed into the same printed circuit pin configuration. The resulting welded package is shown in Fig. 3-8. This package is used in the STRAP III to develop three different time relays varying from 200 ms to 60 seconds.



TIME DELAY SCHEMATIC

TIME DELAY MECHANICAL CONFIGURATION

Fig. 3-8 Time Delay Package

3.1.2 Drawing Preparation and Update

Printed Wiring Assembly (PWA) Drawing Preparation. The GSFC STRAP III systems were built using the original layout drawings, schematics, and rough part lists. To decrease the production fabrication time, a package was included in the contract to prepare production type assembly drawings. The drawing depicts the PWA in a 4-to-1 view and includes a part list which cross references the part type to its location on the PWA. The cross checks made during the PWA drawing preparation (necessary to ensure all the parts would fit) revealed problems in component mounting interference and sharp lead bends on nearly every PC board. It was also determined that the dimension control on the PC boards was insufficient to prevent interference with the module cover. The requirement for plated through holes was added to drawings which required extensive printed circuits changes.

The effort spent in eliminating interferences and adding plated through holes was beyond the original scope of the contract and contributed to the program overrun; however, the extra drawing effort actually decreased the cost of fabrication, and thus resulted in an overall savings to GSFC during the follow-on contracts.

LEA Incorporation. The contract provided a method of making minor changes to the STRAP III drawings during the fabrication without a formal change control procedure. An LEA form was completed for each change. A copy of the LEA is attached to the working drawing to ensure the changes were incorporated in the hardware. Each LEA number is added to the program configuration identification list (CIL). Updated copies of the CIL are distributed to Quality Control and the test areas. All testing or inspection was in accordance with the drawing and the latest LEA.

The LEA was used most to change material callouts, finishes, wrong drawing callouts, and other minor changes. All significant changes were coordinated with the GSFC Technical Officer and copies of all LEAs were sent to him for his review. More LEAs were written against the mechanical drawings than the electrical drawings since nearly all the electrical drawings were updated as a result of the changes described earlier.

At the end of the program, the applicable LEAs were incorporated into the drawings to reflect the "as-built" configuration. LEAs that substituted an in-house BBRC process for a GSFC process, indicated a one-time change, or indicated a rework to meet drawing requirements were not incorporated into the drawings.

This drawing control method proved to be cost effective for the STRAP III program. Configuration control was maintained by updating the drawings after each fabrication.

3.1.3 Dim Target Pointing Study

The results of this study are documented thoroughly in a separate report, "Study of STRAP III Control System Pointing a Dim Stellar Target," BBRC Report No. TR69-46, submitted to NASA/GSFC July 30, 1969. A brief summary of the results of that study is included in this section.

Peak noise amplitude on the tracker output signal while pointing at dim targets can be several times greater than the desired limit cycle amplitude. The ability to control the body axis of the system is a direct function of the signal-to-noise ratio. The purpose of this study was to determine how the performance of the existing STRAP system could be improved when pointing at the dim targets.

All of the study was performed using a DC representation (shown in Fig. 3-9) of the existing STRAP III control electronics implemented on an analog computer.

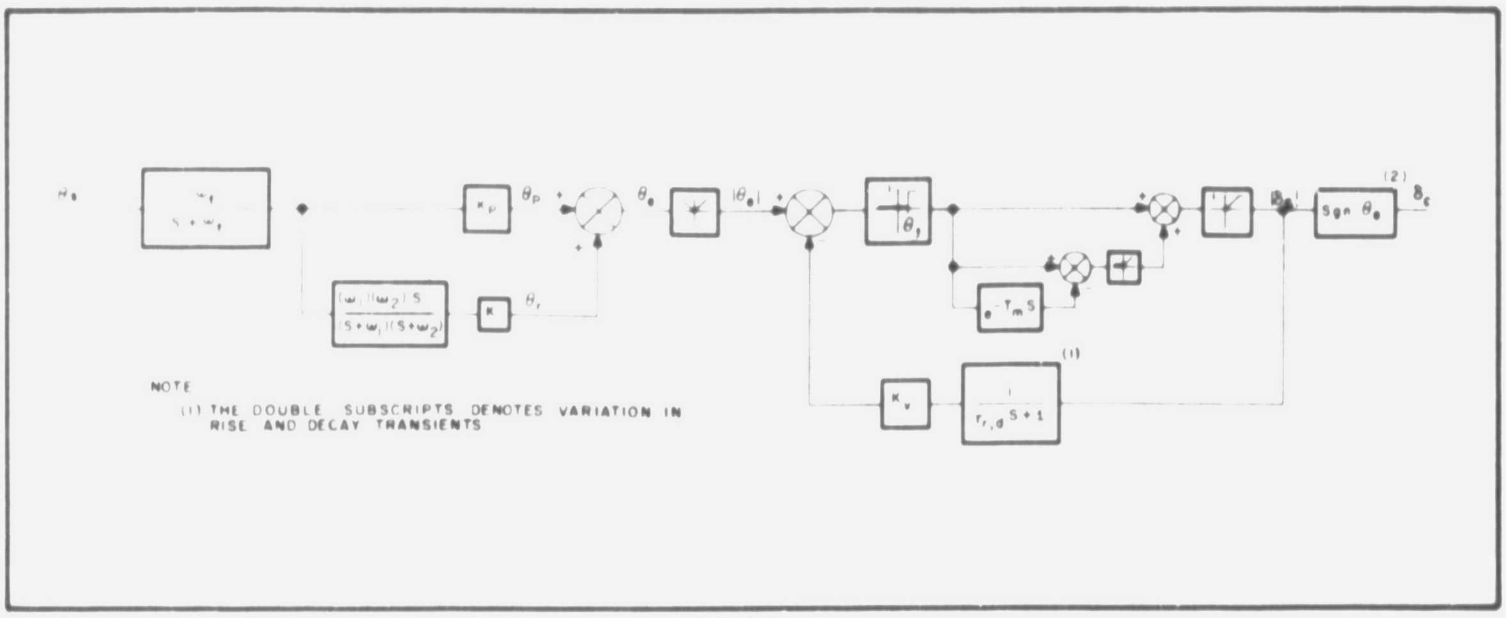


Fig. 3-9 Block Diagram Using a DC Representation for the Existing STRAP III Electronic Control Circuits

Of the approaches considered, two yielded the best results. The most rewarding was to change the method of determining vehicle rate control signal near the target. Added improvement was indicated by filtering the tracker output with a fourth-order Butterworth filter.

By changing the vehicle rate signal near null (see Fig. 3-10 Mod 1 configuration) the control system will track a +3 visual magnitude star staying within the present ±7.5 arc-second threshold for 90 percent of the time. With the same star but a preset threshold of ±5 arc-seconds, the Mod 1 stays within its threshold 65 percent of the time. If the filter (see Fig. 3-11 Mod 2 configuration) is added the system will stay inside the ±5 arc-second threshold 90 percent of the time. These results indicate a substantial improvement considering the existing system spends about half the time outside of the ±7.5 arc-second threshold tracking the +3 star.

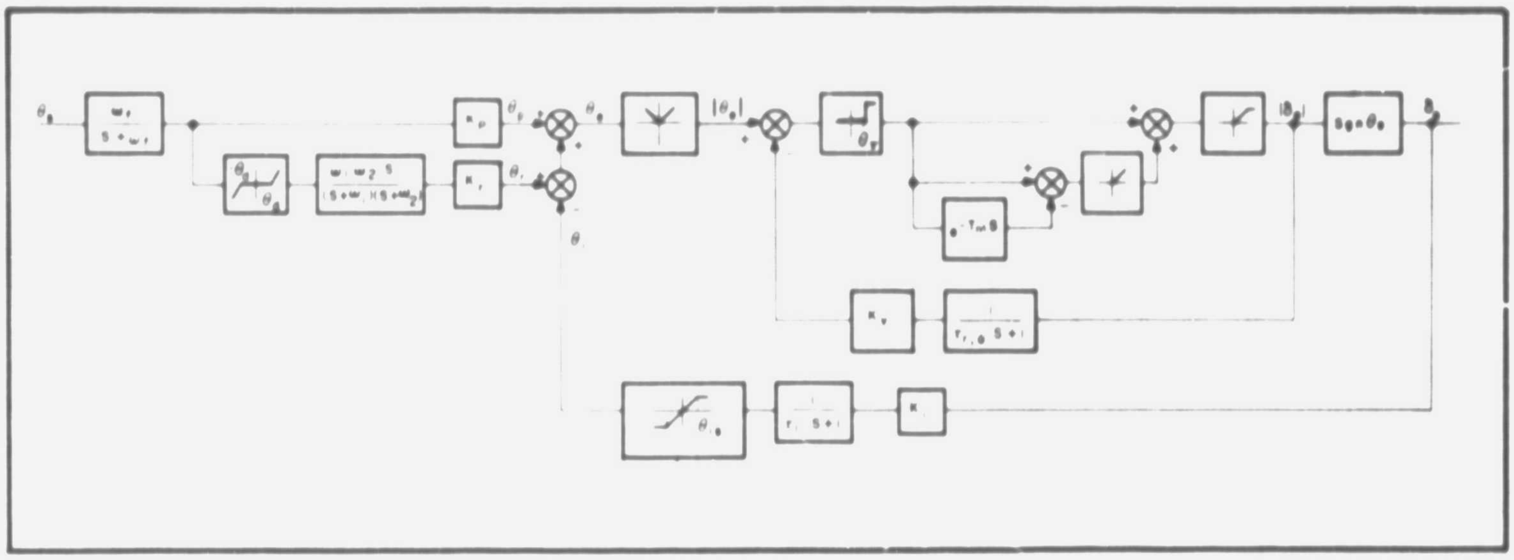


Fig. 3-10 Block Diagram DC Representation of the Mod 1 STRAP III System

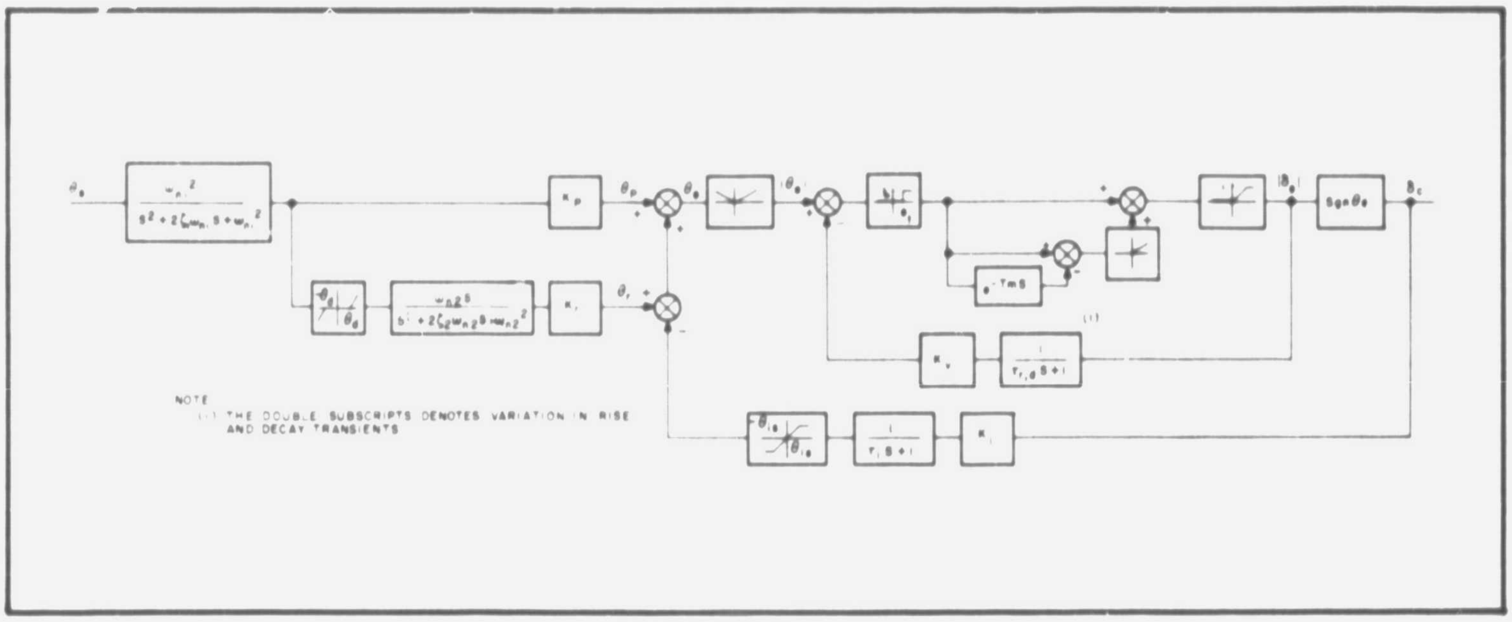


Fig. 3-11 Block Diagram DC Representation of the Mod 2 STRAP III System

The circuit modification required to incorporate the system improvements is quite extensive. When the general experimenter requirements and the improvement gained were compared, the cost to make the changes could not be justified; therefore, no further action was taken.

3.2 AEROSPACE GROUND SUPPORT EQUIPMENT DESIGN

The design of the launch and calibration panel (LCP) checker and the programmer and power switching module tester were included in the contract activities. Drawings were furnished from which the testers for the fine/universal, power supply, and the common modules could be fabricated. Some drawing update and drawing preparation was included in the contract. The following sections briefly describe the design activities conducted.

3.2.1 LCP Checker

The LCP checker is shown in Fig. 4-1. This checker applies all of the input signals to the LCP and has monitor for all the outputs to simulate the STRAP III system. By using the LCP checker, every operating function of the LCP can be verified before the unit is connected to the system.

The unit is self-contained, requiring only 115 AC, 60 Hz, and a 28 VDC power supply to operate the LCP. It is housed in a portable carrying case (identical to the module testers). In addition to the basic performance check of the LCP, the unit can be used to verify that the land lines between the blockhouse and tower are operational.

A detailed test procedure was prepared to instruct the operator on the use of the tester. Operation of the tester is straight forward and is easily used.

3.2.2 The Programmer and Power Switching (P&PS) Module Tester

The P&PS module tester is shown in Fig. 4-1. The tester is housed in a portable carrying case identical to the fine/universal and the common module testers. It contains all the power supplies required by the P&PS module including the 400 Hz square wave clock input to the timer. A count circuit verifies that all 24 of the timer pulses are present. Three electromechanical clocks are used to measure the remotely programmable time intervals, thereby verifying the programming code.

Logic and load circuits verify operation of the P&PS current regulator by simulating the two-axis free gyroscopes during the torquing maneuvers.

3.2.3 Drawing Preparation and Update for AGE

A schematic of the P&PS module and the LCP checker was prepared and some rough layout work was done for both units. Much of the existing module tester mechanical frame design was used for the two new tester designs. No complete assembly drawings of these two units were prepared.

The electrical drawings provided by GSFC for the fine/universal, common and AD-DC power supply testers had to be revised extensively to be compatible with the various STRAP III control electronics changes described in Section 3.1.1. The testers were built from red-lined drawings. No drawing update was completed on these testers.

3.3 FINE GUIDANCE ERROR SENSOR DESIGN

3.3.1 Design Approach

The FGES design was initiated using many of the concepts developed in the design of the astral tracking unit (ATU) used successfully with the BBRC developed separable payload control system (SPCS). (The SPCS is similar to the STRAP III system.)

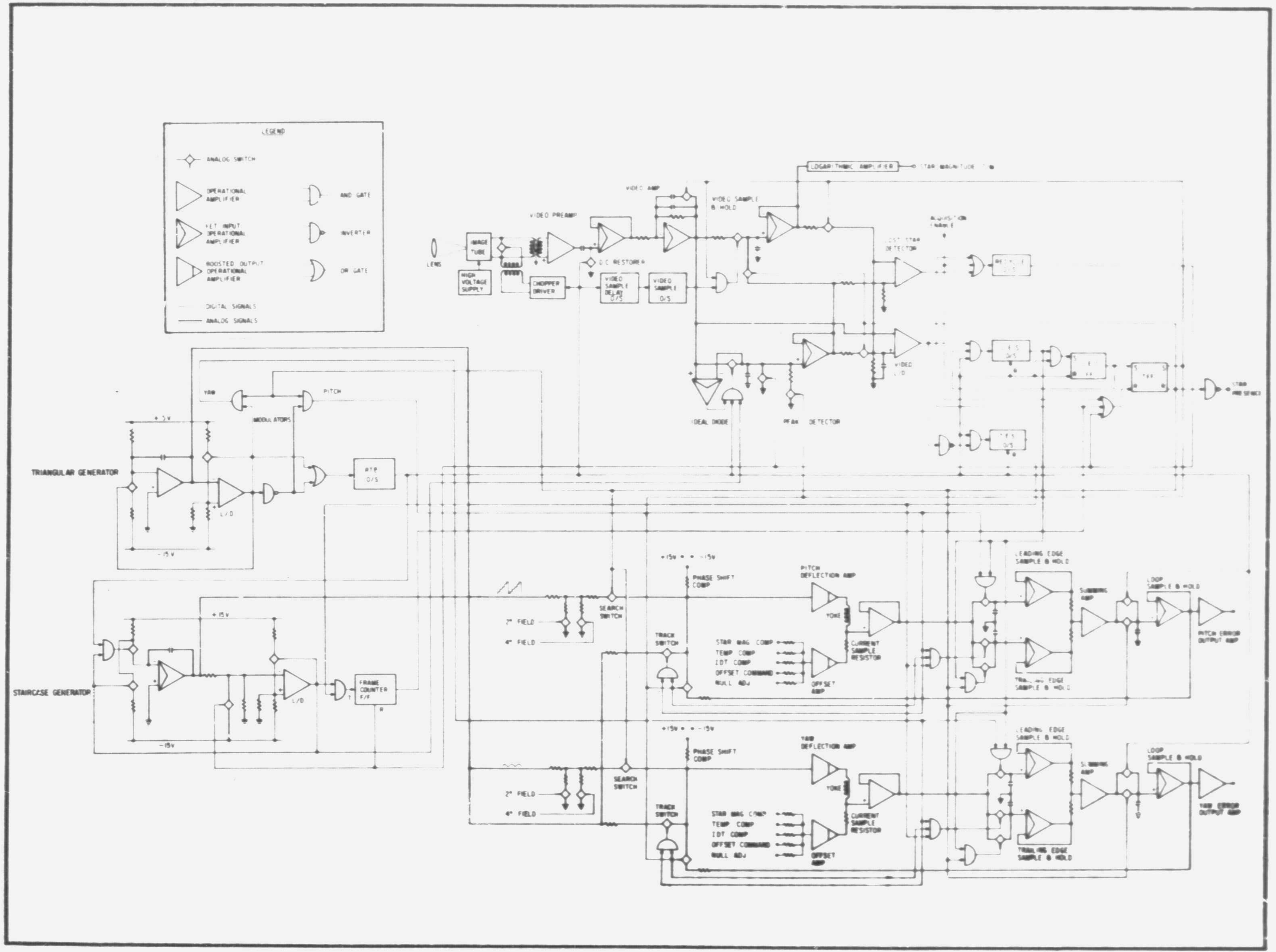


Fig. 3-12 System Block Diagram

generators. Sweep signal waveforms for acquisition and track are shown in Figs. 3-13 and 3-14. Since the instantaneous aperture is swept back and forth across the star image, the electrical signal obtained from the transducer preamplifier is in the form of a series of pulses. This signal is called the video signal in correspondence to television nomenclature; the title does not imply high-frequency capability of the associated electronics, but only that the signal is a response to visual phenomena.

In the acquisition mode, the video circuitry determines the brightest object in the tracker field of view and provides logic signals to sample the deflection current when this object is encountered. Signals to the mode logic provide the switching signals to position the track pattern over the star location and convert the tracker from the acquisition to the track mode.

The brightest object is determined by applying the video signal to a peak detector during the first acquisition frame. The peak detector holds the peak value of the largest video signal obtained on the first search frame. This peak value, multiplied by a factor of about 0.8 to account for statistical variations in pulse amplitude, becomes the level detector reference voltage on the second frame. The level detector changes state, triggering the mode logic and the sampling logic which mechanize the track mode and center and track pattern on the brightest star.

In the track mode, the video pulse is sampled over a portion of its maximum value duration to obtain a measure of video pulse height independent of the noise on the video signal. An average of these samples is divided by two and applied as the reference voltage to the video level detector. The output of the level detector provides logical signals representing the times during which the video signal exceeds and falls below the reference voltage. These leading- and trailing-edge transitions generate pulses and are properly gated in

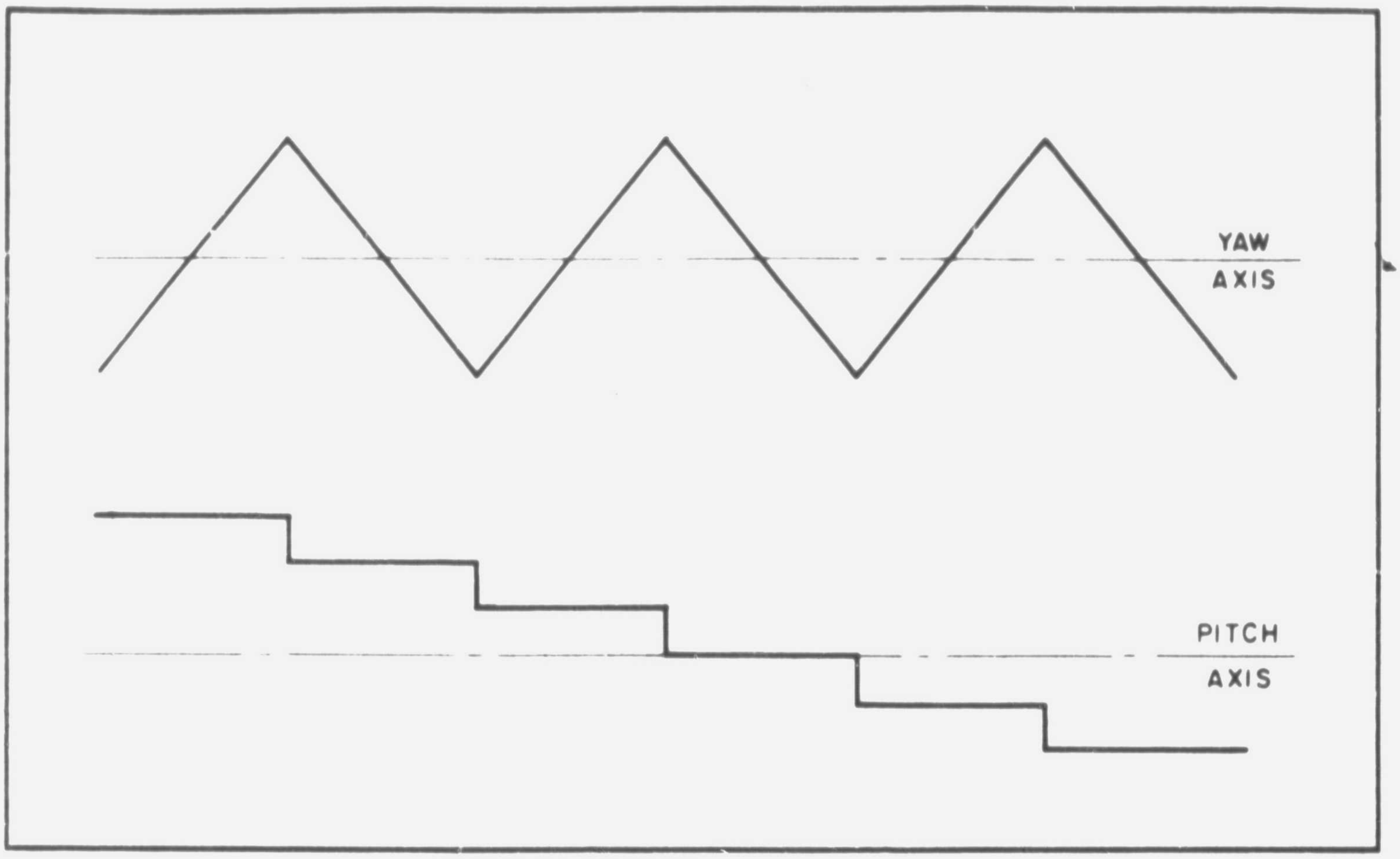


Fig. 3-13 Acquisition Mode Deflection Signals

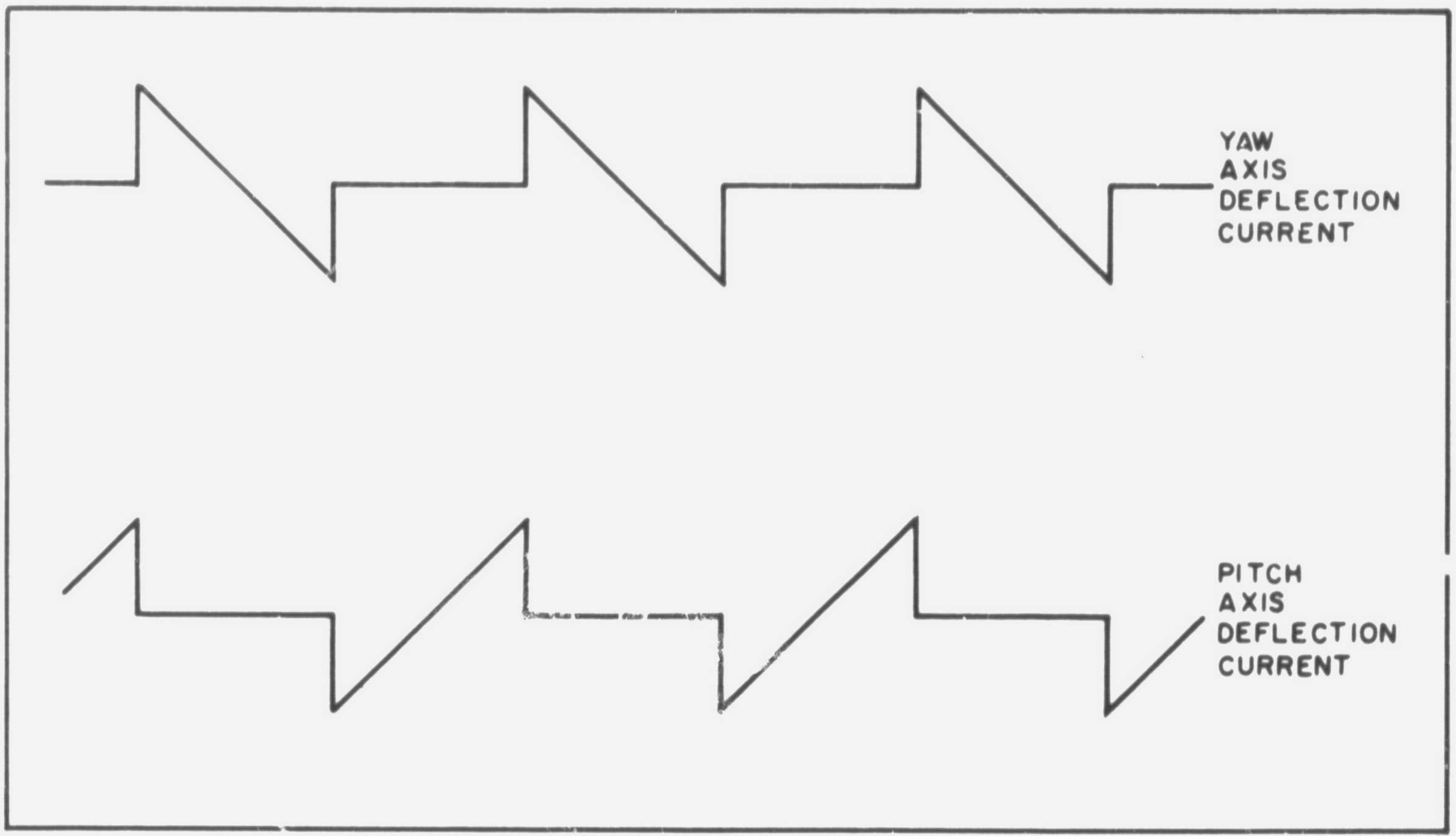


Fig. 3-14 Track Mode Deflection Signals

the sampling logic circuitry. The pulses from the sampling logic operate sample-and-hold circuits which measure deflection current when the star image is entering and leaving the instantaneous aperture (i.e., on the leading and trailing edges of the video signal). Since the scan is linear, the position of the star can be determined as the average between (1) the scan current at the time the star enters the instantaneous aperture and (2) the current when it leaves the field. The operation can best be understood by reference to Fig. 3-15, which shows the waveforms developed in the sampling logic and in the sample-and-hold amplifiers. The waveforms depict a hypothetical case where the apparent star position has shifted an amount Δ from the zero position, and the shift has been essentially instantaneous. The shift shown is greatly exaggerated for descriptive purposes (i.e., even at the maximum vehicle rate, the shift between sweeps could not be half the aperture width).

The first four waveforms are self-explanatory. The coil drive signal is the deflection signal (presumed to be the X sweep in this discussion, although the same waveforms are equally applicable to the Y sweep) controlling the position of the instantaneous aperture. This signal is the sum of a sawtooth and a bias signal. The bias is obtained from the output of the loop sample-and-hold amplifier, as explained in the following paragraphs.

At the beginning of the sweep shown in Fig. 3-15, the bias is zero (since there was no offset before the movement Δ occurred). The sample points are indicated, and waveforms (f) and (g) show the action of the two sample-and-hold circuits. Waveform (h) is the sum of (f) and (g) divided by two. After both the leading and trailing edge samples have been received and averaged, the summing amplifier output is proportional to Δ. At the end of the sweep, the loop sample-and-hold circuit is triggered sampling the averaged position sample from the summing amplifier.

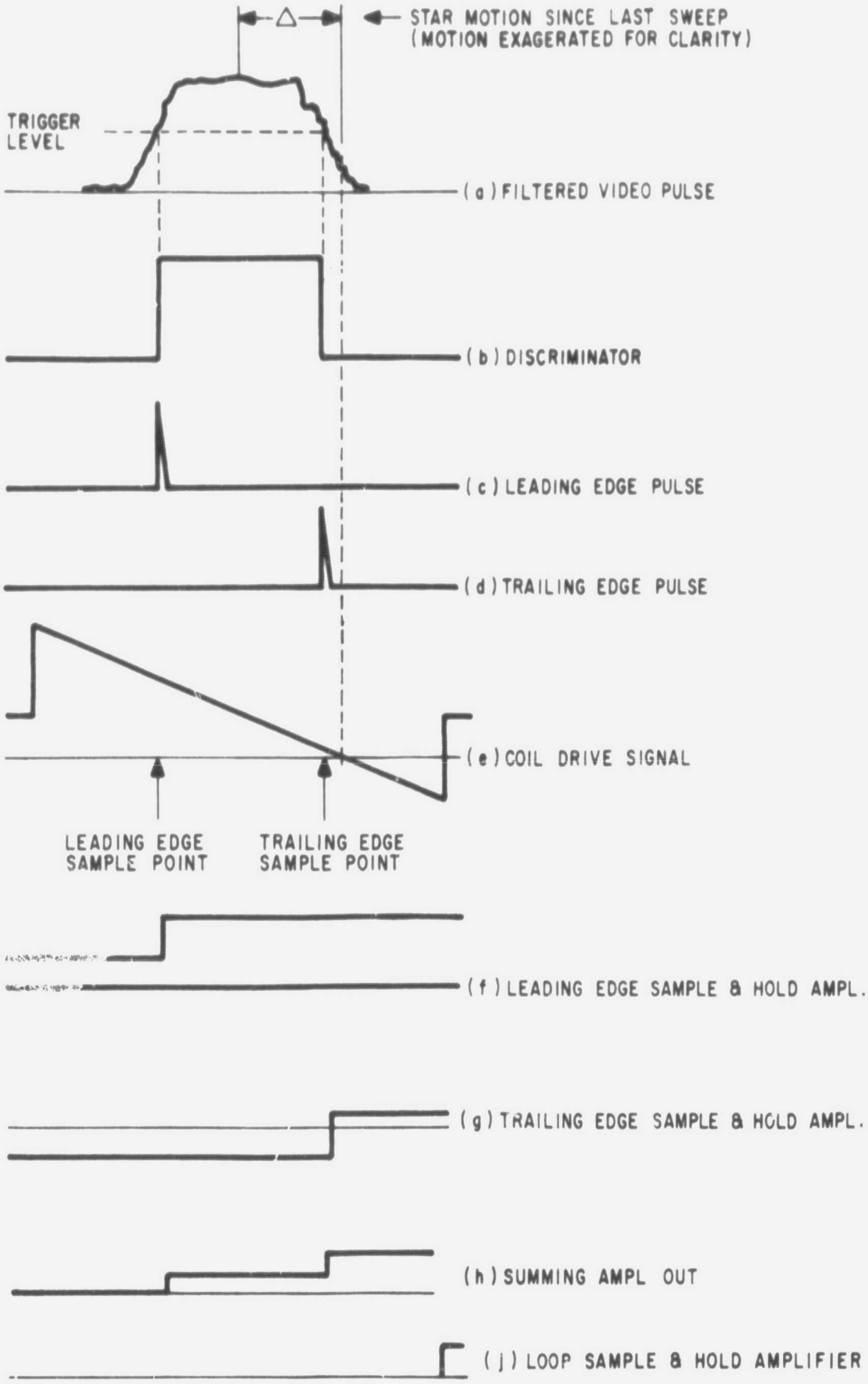


Fig. 3-15 Tracker Waveforms

Now, if the filtered signal from the loop sample-and-hold amplifier is fed to the sweep generator as a bias for the scan signal, the circuits just described can be viewed as a closed loop system which adjusts the bias voltage until the sweep is centered relative to the star. By sweeping first in X and then in Y, the star is maintained in the center of the track field as shown in Fig. 2-8. This bias voltage then becomes the analog signal proportional to displacement of the star from the center of the field of view.

The analog signal is amplified and filtered to provide the desired gain, saturation, and time-constant characteristics.

Mechanical. The tracker is shown in Fig. 2-8. The major considerations in the mechanical design of the tracker are as follows:

- Protection of the image tube from shock and vibration.
- Stability of the image tube cathode with respect to the lens optical axis in both vibration and temperature environments.
- Protection of the tube from external magnetic fields.

The central element of the tracker is the mounting flange. Mounting pads which interface the tracker with the rocket are a part of the flange and the lens threads directly onto the flange. The front magnetic shield, into which the image tube is mounted and potted, is shrink-fitted to the flange. The electronics support spool and the rear cover also attach to the mounting flange.

BBRC's method of holding the phototube is to apply a thin coating of resilient material around the front edge of the cathode. This surface is then forced into a mating surface in the main magnetic shield. Then, the tube cathode is referenced to the rear of the lens housing through a short and stable structural path. Axial lens-to-cathode distance, (i.e., focus) is defined by a precision lapped spacer between lens housing and the flange.

A three-pad, lapped reference surface is provided on the front of the lens. This surface provides for the mounting of an alignment mirror to be used during functional and environmental tests.

Attached to the rear of the flange are two power supplies which fit around the main housing and bolt to the spool. Terminals are located on one side and are recessed and covered.

The mounting flange and the main magnetic shield became the objects of an intensive design and development testing effort. An investigation was triggered by vibration tests conducted on an in-house built engineering model of the FGES. During the test, an intolerably high amplification factor of 40 at 1000 Hz was measured at the tube interface. This amplification was a factor of 10 higher than the initial analysis of the structure predicted. The solution to the problem was elusive; however, the problem was finally traced to inadequate stiffening of the flange and the method of holding the tube inside the main shielding.

Nearly forty different vibration tests were made using stiffened flanges, modified holding methods, different epoxies and methods of epoxy application before an acceptable solution was obtained. Some of the problems were subtle and difficult to trace. For instance, an "oil-canning" effect produced by the end plate of the main shield made the epoxy fill in back of the tube a detriment rather than the asset it was initially intended to be. (Note that this amplification problem was not present in the original ATU but significant modification of both the flange and the magnetic shield were made for the FGES to allow the electronics to be housed in the desired envelope.)

The amplification factor was finally reduced to an acceptable value of less than 8. All the necessary changes in the drawings and assembly procedures were incorporated into the flight model units.

3.3.3 System Configuration

Photosensor Assembly. The photosensor assembly consists of the tracker mounting flange, front magnetic shield, phototube and deflection yoke, video preamplifier, and rear magnetic shield. In the completed assembly the phototube, yoke, and preamplifier have been vacuum potted in place to prevent vibration damage and provide protection from corona and high-voltage breakdown. The sensor is the ITT F4004 electrostatically focused, magnetically deflected image dissector tube. As is usual with electrostatically focused tubes, the photocathode is formed on a convex surface which has a radius of curvature of 1.23 inches. For this application, the tube will be ordered with aperture dimensions of 0.014 by 0.014 inch. Typical performance parameters are as follows:

- Peak Radiant Sensitivity: (typical) 0.060 amp/watt (S-20 surface)
- Resolution (spot size for 80 percent of the energy) on axis: 0.004 inch
- Multiplier gain: 5×10^6

The tube has a focusing ring separated from the cathode. This allows focus adjustments, which are sometimes necessary to obtain resolution.

The deflection yoke is of BBRC design and manufacture. The yoke is an air-core design, and the windings are symmetrical which assures an orthogonality error of less than 1.0 degree. The diode used to sense temperature for the temperature compensation circuit is imbedded and potted in the yoke.

Video Preamplifier. The video preamplifier consists of an integrated operational amplifier which is coupled to the phototube anode through an isolation transformer. This provides good isolation from the 2-kilovolt operational level of the anode and true differential sensing of the anode current. These components are packaged and potted in the base of the phototube, along with the dynode voltage-divider resistor string.

Lens. This tracker uses the Delft "Rayxar" 50 mm focal-length, f/0.75 lens. It has an on-axis spot size of about 0.003 inch. The on-axis transmission factor is approximately 0.8. To ensure proper stability of lens elements, the lens is disassembled, cleaned, and inspected. During reassembly, epoxy is placed in the retaining-ring threads before they are torqued to specification limits. During the vibration test, it was discovered that the lens was able to move inside the retainers. Holes were drilled in the side of the lens housing to permit polyurethane epoxy to be injected between the retainers and the lens. This procedure eliminated the problem on all of the remaining flight units.

Power Supplies. Two power supplies are incorporated in the tracker design; a high-voltage supply for the IDT, and a + and -15 VDC supply for electronic circuits. Both supplies use a common series preregulator and separate DC-to-DC converters. The high-voltage supply uses a voltage quadrupler on the output to obtain the required 2.4 kilovolts.

Section 4
MANUFACTURING

4.1 STRAP III SYSTEM MANUFACTURING

One of the primary goals of this program was to make the STRAP III reproducible in quantities of eight to ten at a cost compatible to the sounding rocket programs. As indicated in previous sections, considerable effort was expended to obtain production quality drawings to reduce fabrication time. In addition, a considerable amount of production engineering effort was expended in establishing suitable manufacturing processes.

A production team was organized especially for the STRAP program for both the electrical and mechanical fabrication. This team carried through the fabrication from the piece part to the final assembly stage. The production engineer worked closely with the project and design groups to ensure all the drawing requirements were met.

Tradeoff studies were made on cost advantages between in-house and outside fabrication costs, between castings and machining from raw stock, etc. Vendor searches were conducted for special operations such as dip brazing the module housings and machining of the pneumatics nozzles. Special tooling and jigs were prepared as capital equipment by BBRC to reduce the fabrication costs.

All soldering was completed per NHB 5300.4(3A) except where the original design prevented compliance. No lead clinching was performed on the printed circuit assemblies because the design did not allow for "clinch pads."

Some problems were encountered in soldering to the module PC board terminals. Some of the terminals were connected to printed wire paths on both the top and bottom of the boards. When the wires were soldered to the terminals, the solder connection between the terminal and the bottom printed circuit ribbon in many instances was damaged and, in some instances, open connections resulted. This problem was remedied by a change in soldering procedure to prevent excessive heating of the terminal.

4.2 FGES MANUFACTURING

The manufacturing of the FGES was handled by a special group trained in the processing and manufacture of precision optical gear. Extremely close tolerances are required in some critical parts of the tracker to hold the arc-second stability requirements. Special tooling was prepared to assist in many of the operations, especially those involving the lens and the phototube.

Since most of the electronics are made up of welded modules, a special test fixture was built which permitted each welded module to be tested before and after final potting. Problems detected before potting can be reworked easily.

Most of the final assembly work for the star tracker was done by the star tracker test group. Several critical potting and assembly functions must be accomplished during the test phase, and can be handled only by highly skilled individuals.

4.3 AGE MANUFACTURING

All of the module testers and the LCP checks were built by the STRAP system test group with limited support for the engineering machine shop. The units were handled as engineering development models because of inadequacy of drawing definition and because only one unit of each was to be built. Much of the electronic circuitry is built on terminal boards with solid and/or stranded wire interconnections between components.

The first LCP was purchased from Lockheed Electronics, a company which previously has built units for GSFC. The last two units were built in-house by BBRC after comparing the final costs of the first purchased units with the in-house estimates for the job.

One each of all the AGE built on this program is shown in Fig. 4-1.

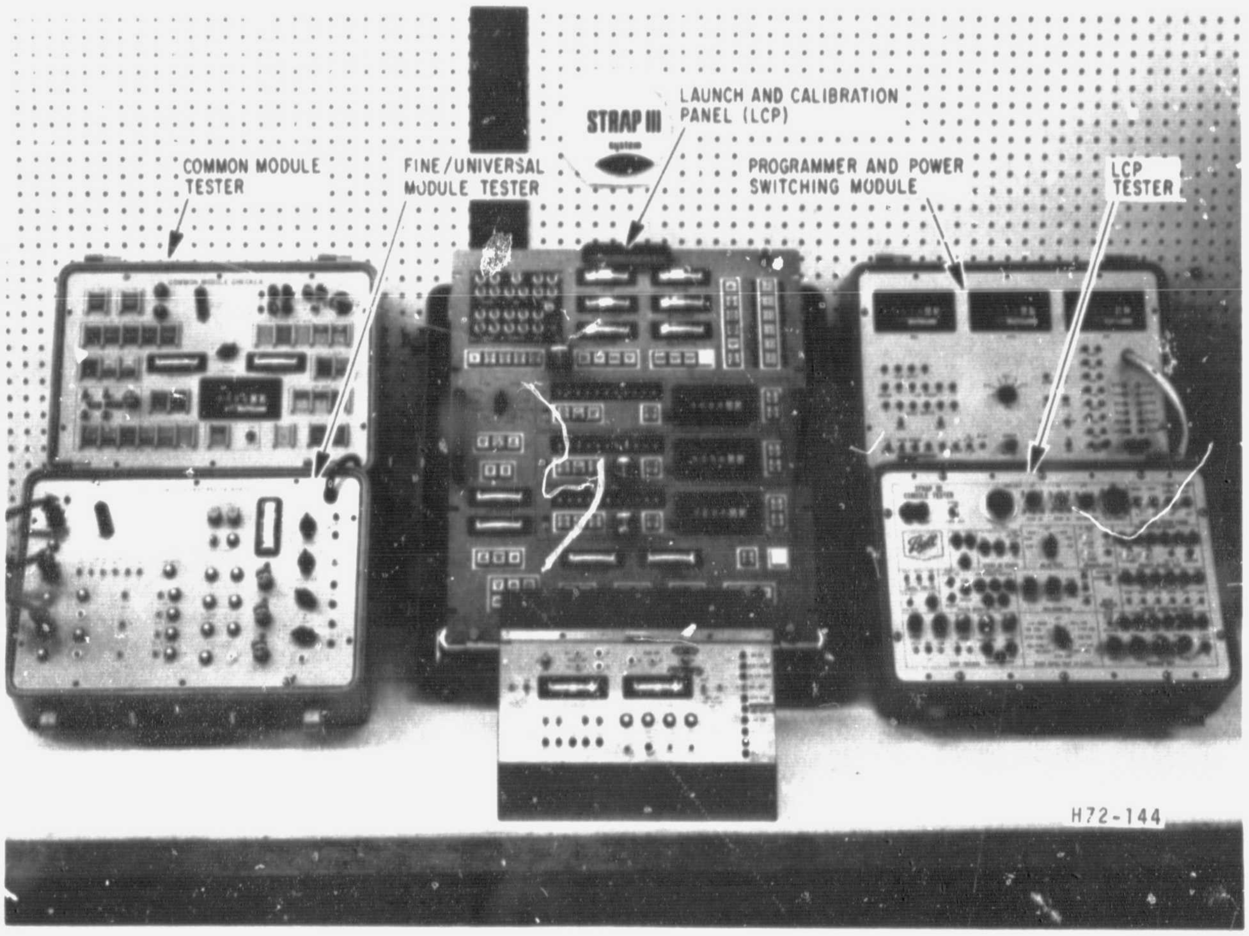


Fig. 4-1 STRAP III AGE

C-2

Section 5
TEST PROGRAM

5.1 STRAP III ACS TEST PROGRAM

5.1.1 Test Methods and Test Procedure Development

The entire test program for the STRAP III ACS system presented a unique challenge. No test specifications, test procedures or written test methods were available for the module, RSP, or system functional tests.

Since the flight hardware and much of the AGE were built from existing drawings, it was relatively easy to identify the required measurements in a test procedure. The measurement limits, however, were more difficult to define. It was the desire of both BBRC and GSFC to develop realistic operating limits to ensure adequate system performance. Both also wished to avoid the pitfalls of making the requirements unnecessarily severe. To obtain realistic limits, it was mutually decided to obtain data from the first three systems using test procedures which identified the necessary measurements. Using a combination of calculated values backed up by the data from the first three units, the final measurement limits were established for the last five systems.

The overall system air bearing and environment test conditions were outlined in the GSFC test procedure, "Final Acceptance Test, STRAP III Attitude Control System," 721.1-016. This document served as a guideline for the preparation of formal step-by-step environmental and air bearing test procedures.

The existing GSFC procurement specifications for the major purchased hardware (including the position gyroscopes, rate gyroscope packages, timers and the pneumatic solenoid valves) served as excellent criteria for the development of the necessary incoming test procedures.

Fifteen test procedures for the STRAP III ACS were written during the course of the program. All were used on this program and have been established as the official test criteria for the follow-on programs. All of the test procedures except the air bearing preparation and operating procedure were prepared on NASA/GSFC drawing formats and were reviewed by the program technical officer.

The general philosophy was that the test procedures reflect details about only the GSFC-furnished AGE. The air bearing preparation and operating procedure, therefore, was prepared using the BBRC drawing format since BBRC owns the two STRAP III ACS air bearings. The configuration and operation of these units is considerably different than the existing GSFC equipment, therefore, the procedure for the BBRC tables is not useful to GSFC.

5.1.2 Test Equipment

The AGE designed and fabricated as part of this contract is listed in Table 5-1. In addition, BBRC designed, built and purchased a considerable amount of equipment for the support of this program. That equipment is listed in Table 5-2.

Table 5-1
AGE FABRICATED ON CONTRACT NAS 5-11664

Launch and Calibration Console (LCC) (3 ea)
Common Module Tester (1 ea)
Fine/Universal Module Tester (1 ea)
Programmer and Power Switching Module Tester (1 ea)
Power Supply Tester (1 ea)
LCC Tester (1 ea)

Table 5-2

BBRC STRAP III ACS TEST EQUIPMENT

1 ea	Free Gyro Test Fixture, BBRC
1 ea	Rate Gyro Test Fixture, BBRC
2 ea	2-Axis Divider Head, Imperial/Opto-Metrics Tools, Inc.
2 ea	Rate Table, Genisco, Type 50181, Model C-181
1 ea	Gyro Scorsby Table, Ideal-Aerosmith, Inc., Model 1412
1 ea	RSP Test Fixture, BBRC
1 ea	2 Channel Oscillograph Recorder, Brush # Mark 220
*2 ea	Oscilloscope, Tektronix Model 564B with 3A6 Plug-In
*1 ea	Oscilloscope, Tektronix Model 541 with Type D Plug-In
3 ea	Power Supply, 40 VDC, 12 Amp Current Limited, Electronic Measurements Model BE-40-10ML
2 ea	Power Supply, 40 VDC, 25 Amp Current Limited, Technipower Model LA40-25M
*2 ea	Power Supply, 50 VDC, 500 ma. Current Limited, Power Designs Model TW5005
*1 ea	Electronic Counter, Hewlett Packard Model 522B
3 ea	True RMS Voltmeter, Hewlett Packard Model 3400A
*3 ea	Digital Voltmeter, Hewlett Packard Model 3440A
*3 ea	VOM, Simpson Model 260
*1 ea	Decade Resistor Box, Shallcross Model 833
*1 ea	Helipot Precision Potentiometer, 5 watt, 1%, 10K ohm
2 ea	Dummy Valve Loads and Telemetry Signal Junction Box (BBRC)
1 ea	Pneumatics Valve Test Fixture
2 ea	Air Bearing Test Tables (BBRC)
2 ea	Air Bearing Alignment Fixture (BBRC)
*1 ea	VHF Receiver, Neuns-Clarke, Model 1674
1 ea	8-Channel Telemetry Discriminator, EMR, Model 4150
*1 ea	Strip Chart Recorder, Honeywell, Model 1912
1 ea	Pneumatic Fill Facility (BBRC)

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*Standard laboratory gear available for general use, and not purchased specifically for the STRAP program.

5.1.3 Subassembly Functional Testing

Test Methods and Approach. Functional tests are performed on the major components (three-axis rate gyroscopes, two-axis free gyroscopes, and pneumatics solenoid valves), the RSP, and each of the electronics modules to determine its ability to meet individual test procedure requirements. Each individual component or subassembly (except the solenoid valves) is integrated into a complete system for acceptance testing. No individual environmental tests are performed at the subassembly level. The initial component selection to establish circuit operating biases and gains is accomplished as part of the functional testing.

Since the final system performance is directly dependent on the individual component parameters, extensive incoming inspection tests are performed on the two-axis free gyroscopes and the three-axis rate gyroscope package. These tests include, but are not limited to, individual drift measurements (both random and scorsby) scale factor and threshold on the free gyroscopes; scale factor, offset, hysteresis, and linearity tests on the rate gyroscopes.

After the free gyroscopes are installed into the RSP, a complete functional test is performed including gyroscope alignment and RSP performance. Much of the alignment of the RSP is inherent because of machining and assembly tolerances; however, the gyroscope roll axis null must be adjusted to coincide with the primary RSP reference surface (the accurately machined battery box cleats mounted on the bottom of the RSP). The two inner gimbals of the gyroscopes (which become the RSP pitch and yaw axes) are then adjusted to obtain orthogonality. A precisely aligned fixture mounted to a two-axis rotary table (accuracy of the table is <±1 arc min) is used to determine the RSP roll position zero.

Subassembly Test Problems and Final Results. Several isolated failures occurred during the various module tests; however, two problems plagued the entire test program. The first problem encountered was abnormally high failure rates in both the half crystal 2PDT and 4PDT momentary relays, particularly the latter type. (This problem continued through the system environmental air bearing tests.) The problem with the 4PDT relays became so acute that the NASA/GSFC initiated a retrofit activity to replace them with a specially built welded module containing two Teledyne relays (miniature relays contained in a TO-5 transistor case). The drawings for later versions of the STRAP have been revised to allow the two relays to be installed directly on the PC boards.

Failures of the 2PDT relays were fewer in number but sufficient to cause considerable concern about their reliability. All relays purchased during follow-on procurements were from a new source with a better overall reliability history and all relays were screened to tighter specifications.

The second problem encountered was the difficulty in balancing the caging nulls and valve firing nulls with respect to the input nulls. This problem was caused by the accumulation of offset voltages in the LM101 integrated circuit operational amplifiers used in the modulators, demodulators, and caging amplifiers in the fine and universal modules. This was not a component problem, but rather a design deficiency, since the maximum offset voltages were not considered adequately. The problem was minimized by selecting low offset voltage devices in the critical circuits. The setup, test, component selection, and rework required more effort per system than should have been necessary. This problem has since been eliminated in the later versions of the STRAP III system by using a LM101A with lower offset voltages and the addition of a special bias circuit.

5.1.4 System Environmental Acceptance Tests

Environmental Acceptance Test Approach. Environmental test levels for the STRAP III acceptance tests are listed in Table 5-3. The test sequence for the tests is usually (but is not restricted to) vibration, high temperature, and low temperature. Initially, the sequence was picked arbitrarily; however, in practice, it has been effective. More problems have been detected during or after vibration than in temperature; thus the repeat cycle time is minimized.

A pre- and post-functional test is performed for each environmental exposure. The test sequencing is arranged so the post-functional check for one environment can serve as the pre-functional check for the next test.

All vibration tests are performed on the Ling L-200 Shaker system in the BBRC environmental test facility. A Team Corporation 1830 hydrostatic bearing table is used in the two lateral axes to guarantee linear vibration. At least one control accelerometer and one test accelerometer are monitored during the test to verify vibration input levels.

The system power is applied during the vibration tests. The umbilical is left so that the system can be monitored more thoroughly during the test.

Temperature tests are all conducted in the BBRC Tenny programmable temperature chamber. The systems are soaked at the chamber ambient temperature for a minimum of four hours. A complete functional test is performed before, after and at each temperature extreme.

Table 5-3
ENVIRONMENTAL TEST LEVELS PERFORMED BY BBRC ON STRAP III ACS

VIBRATION	DESIGN QUALIFICATION		FLIGHT ACCEPTANCE
1. SINUSOIDAL			
Sweep rate	2 octaves per min.		4 octaves per min.
Thrust (z-z axis) levels	2.3 g	10-60 Hz	1.5 g
	4.5 g	60-160	3.0 g
	7.5 g	160-2000	5.0 g
Lateral (x-x and y-y) levels	5.4 in/sec constant velocity	10-60 Hz	3.6 in/sec constant velocity
	5.3 g	60-250	3.5 g
	7.5 g	250-2000	5.0 g
2. RANDOM			
Duration	20 sec per axis		10 sec per axis
Thrust (z-z axis) levels	0.056 g^2/Hz	20-2000 Hz	0.025 g^2/Hz
Lateral (x-x and y-y) levels	0.113 g^2/Hz	20-2000 Hz	0.050 g^2/Hz
SHOCK			
3 mutually perpendicular axes			
Level	30 ±5 g		None
Shape	Sine		
Duration	11 ms ±2 ms		
TEMPERATURE			
Range	-10°C to +60°C		0°C to 50°C

The acceleration test initially included in the test program was waived by GSFC. It was mutually agreed that a meaningful acceleration test could not be performed satisfactorily on the centrifuge because of the gyroscope gimbal restrictions.

Environmental Test Problems and Results. The relay problem outlined in the subassembly test continued into the environmental tests of the system. There were several other isolated component failures and a few workmanship problems that were revealed during the course of the tests but no specific trends other than the relay failures were noted during the tests.

After the initial units were checked and the limits established, the remainder of the units passed all of the environmental test requirements without difficulty.

5.1.5 System Qualification Tests

Test Approach. The qualification test program was identical to the acceptance test program except a shock test was included and the vibration and temperature tests were conducted at the qualification levels listed in Table 5-3.

The shock test (first in the test series) was performed on the BBRC-owned Avco SM-030 shock machine. The standard Aerobee vibration fixtures were adapted for use in the shock test. Power was applied to the system during the test.

S/N 101 STRAP system was designated as the qualification model for this program. In retrospect, it may have been more appropriate to qualify a later serial number unit. Since S/N 101 was used to familiarize personnel with the system, it was the most extensively tested of the first eight systems; however, because the test procedures were in the infancy stage during those tests, S/N 101 has the least formally recorded data. Final buy-off of the system was actually based on witnessing the test and examination of the raw data by the GSFC technical representatives.

Qualification Test Problems and Results. The qualification environmental tests on S/N 101 revealed several problems common to all of the systems. All of the systems were consequently reworked to eliminate the problems, thus avoiding similar difficulties during the acceptance tests.

A total of nine ACS malfunctions was detected during the environmental qualification tests; seven occurred during vibration testing, two during temperature testing. Of the seven failures during vibration testing, three were relay failures. The remaining single-occurrence problems were as follows: a component failure (LM101), a terminal soldering problem, a broken wire in the distribution module, and a component failure caused by a poorly mounted transistor in the power supply. The malfunctions that occurred during temperature testing were a transistor failure in the power supply and a nutation of one of the gyroscopes at low temperatures. The latter condition was bought off by GSFC without modification.

The terminal soldering problem identified in one of the modules of S/N 101 during the qualification vibration test led to an investigation of all the modules in the first eight systems. It was discovered that all the modules had signs of the same problem. The terminals are swaged into the PC board through a hole in the conductor ribbon pad. In some instances the terminals make contact with both a front and back side conductor ribbon. The terminal is then soldered to the pads. When wires were later added to the terminals, the solder between the terminals and the circuit pad was disturbed resulting in cracks in the solder. Contamination in the form of trapped flux and oxidation then accumulated to cause a high resistance path.

A procedure was developed for reworking the modules to eliminate the problem. A different terminal type was incorporated in the follow-on program which also improved this situation.

All of the distribution modules were reworked when a broken wire was discovered in S/N 101 after the initial vibration run. The failure was traced to excessive wire tension caused by inadequate service loops. Careful investigation of this unit and the remaining seven units revealed other wires with the same problem. A revised wiring procedure was incorporated during the follow-on procurements to avoid recurrence of the problem.

The lack of silicon grease under the AC-DC power supply power transistors contributed to the failure during the qualification temperature tests. All of the power supplies were reworked to ensure this problem would not recur. The GSFC drawing was also updated to include a callout with instructions on how to apply the silicon grease and the proper heat sink preparation.

5.1.6 System Acceptance Air Bearing Tests

Test Approach. All of the system air bearing tests are conducted on the three-axis air bearing table shown in Fig. 5-1. This unit was designed and fabricated by BBRC especially for the STRAP III test program. The air bearing table has a self-contained pneumatics system which simulates the flight pneumatics. The acceleration levels in all three axes can be varied over a range of 1.5 to 3.0 deg/sec^2 in roll and 1.8 to 8.0 deg/sec^2 in pitch and yaw for the coarse mode. The fine control acceleration can be varied over a range of 0.04 to 1.8 deg/sec^2. The air bearing also contains an FM-FM telemetry system to broadcast performance data from the test stand to the ground station. The ground station contains a receiver, a bank of FM-FM discriminators and a strip chart recorder.

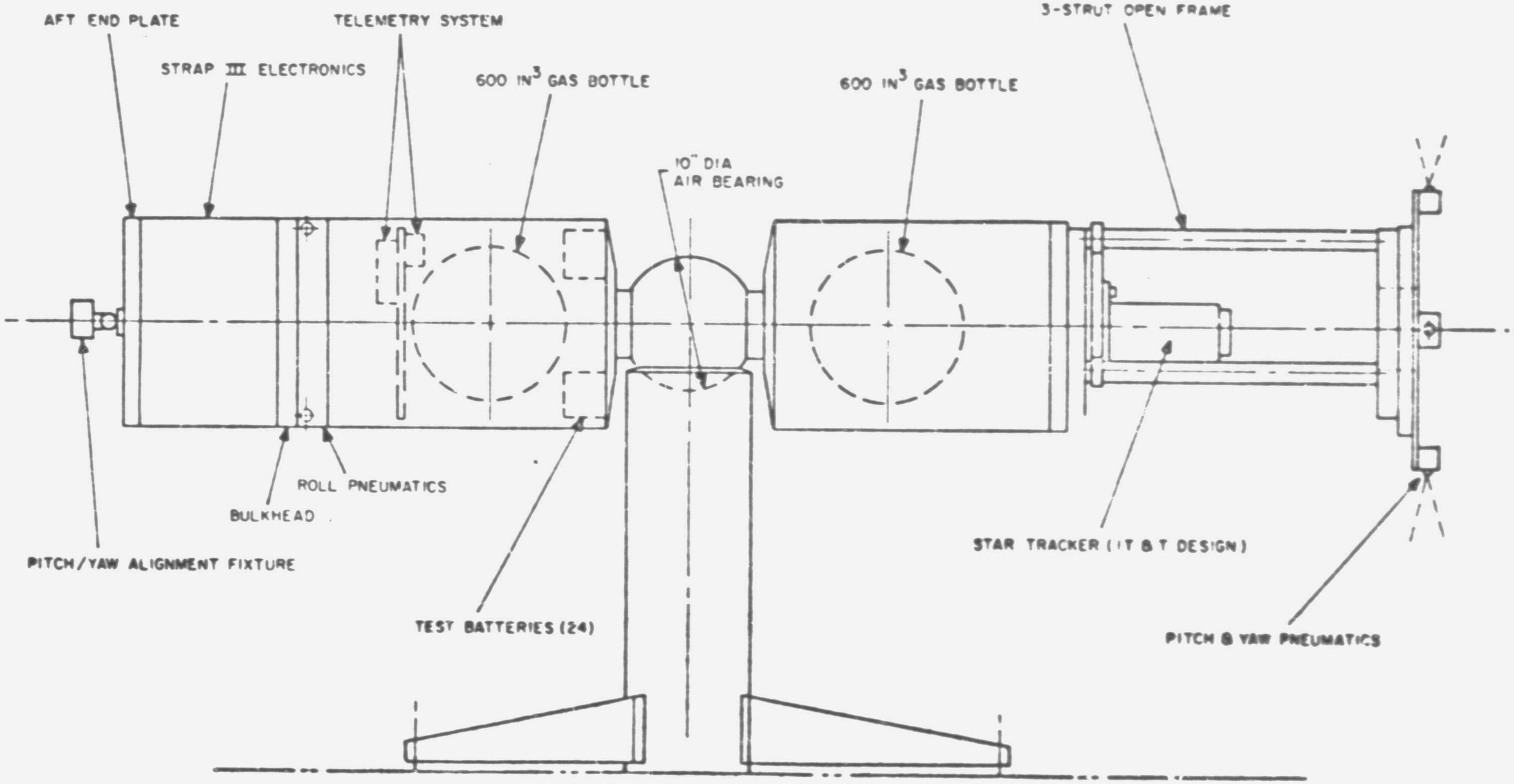


Fig. 5-1 STRAP III Air Bearing Simulator

A star source identical to the one described in the FGES test section (see Fig. 5-5) is used during the tests to verify the fine mode operation.

The STRAP III system is programmed to torque all three axes in both the clockwise and the counterclockwise directions to verify proper coarse mode torquing and acquisition characteristics. The program also includes a maneuver in both pitch and yaw to bring the star outside the FGES linear range to verify the system acquisition and operation in the intermediate and fine modes. The accelerations are adjusted to the minimum levels for all acceptance tests. All pointing tests have been performed using a GSFC-furnished star tracker observing a +1 magnitude star.

Air Bearing Acceptance Test Results. The air bearing tests verified the STRAP III performance characteristics well. Some of the operating specification limits outlined in GSFC test procedure 721.1-016 were increased at the lower acceleration levels with GSFC concurrence. The changes were in acquisition time and overshoot angle, both of which are a direct function of the acceleration characteristics.

5.2 FINE GUIDANCE ERROR SENSOR TEST PROGRAM

5.2.1 Test Methods and Test Procedure Development

The test program for the FGES was planned around the rquirements of the FGES specification A6000-4, dated 10 July 1969. The "Test Specification - Celestial Attitude Error Sensor Assembly," BBRC Drawing Number 36165 was written during the design phase. It identifies special test methods and the limits for all system parameters. Using this document as a definition, two detailed test procedures (P-110383 for qualification and P110369 for acceptance) were written. These procedures outline the test setup, the test to be conducted and the measurement limits.

5.2.2 Test Equipment for FGES

A considerable amount of special equipment is required for the test of the FGES. A partial list of this equipment is shown in Table 5-4. A sketch of the special Star Simulator/Autocollimator designed and built by BBRC for star tracker testing is shown in Fig. 5-2.

Table 5-4
SPECIAL TEST EQUIPMENT FOR STAR SENSOR PROJECTS

Item	Manufacturer, Model, Characteristics
1. Pritchard photometer	Photo Research Corp., Model 1970 PR
2. Irradiance standard	Goddard Space Flight Center
3. Star source/autocollimator	BBRC
4. Rotary table	Optometric, 2-axis: azimuth accuracy, 5 arc-sec; elevation accuracy, 1 arc-min
5. Theodolite	Wild T-3A
6. Corner cube	Davidson
7. Autocollimator	Davidson D-656
8. Special alignment equipment	Ten inch diameter transfer mirror, pentaprism, alignment prisms
9. Clean hood	Torit Mfg. Co.
10. Granite slabs	Do-all, 2 x 10 x 1 ft and 2-1/2 x 8 x 1 ft
11. Electronic equipment	Oscilloscopes, power supplies, recorders, etc.

Other facilities available for specialized testing include collimators and an image scanner for optics evaluation, spectrophotometers and monochromators for spectral response measurements, and environmental test facilities including vibration, shock, thermal-vacuum, and other test equipment. A special high-quality optical window is installed in the thermal-vacuum chambers to test thermal-vacuum null stability of the star tracker.

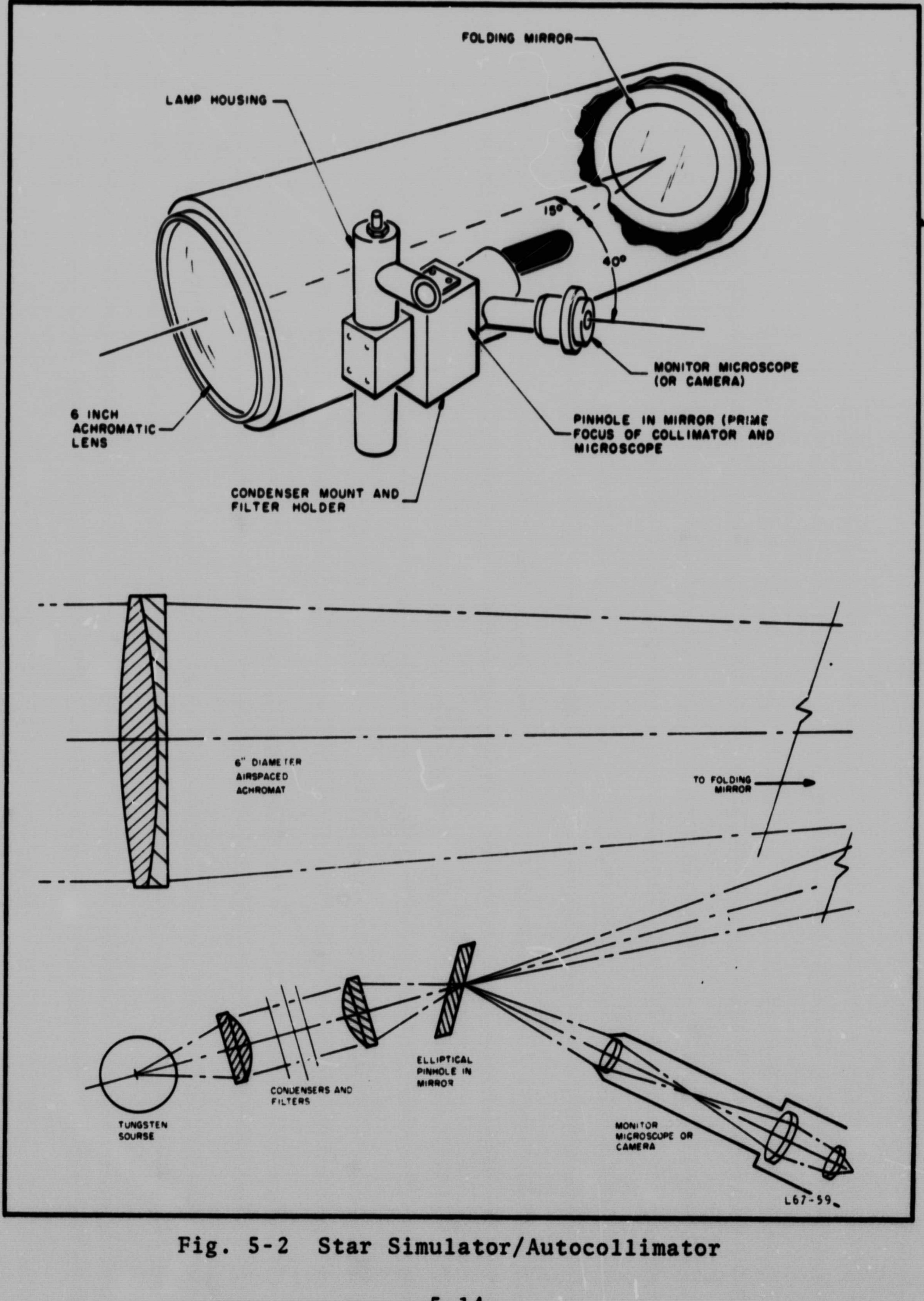


Fig. 5-2 Star Simulator/Autocollimator

5.2.3 FGES Qualification Testing

The FGES Qualification Test program was identical to the Acceptance Test program except for the following:

- Environment Tests were performed at the qualification levels listed in Table 5-3, Section 5.1.4.
- Qualification included shock and humidity tests.
- More detailed data were taken on the qualification unit.
- Tests were conducted per BBRC Test Procedure P-110383.

A summary of the post-environmental test data taken during the qualification tests of S/N 002 FGES is shown in Table 5-5. Two significant deviations appear in the data, the null shift during vibration and the inability to operate over the entire star magnitude range of -1 to +4. The null shift problem was traced to movement of the lens elements in the lens housing. This condition has been corrected on all subsequent star trackers by injecting polyurethane between the lens elements and the lens housing. The null shift due to vibration in the last seven units was reduced to less than 15 arc-seconds.

All of the qualification tests were conducted over a star magnitude range of -0.5 to +4. The dynamic range problem of the tracker is discussed in Section 3.3.1.

Table 5-5

RESULTS OF FGES QUALIFICATION AND ACCEPTANCE TESTS

TEST RESULTS

NOTE: Checks (✓) indicate unit meets or exceeds specification requirements. Whenever a blank (_) occurs, there is no spec requirement.

Item No.	Customer Spec Paragraph (A6000-4)	Test Parameter	Requirement	S/N 002	S/N 27007	003	004	005	006	007	008	Remarks
1	3.2.1	Weight	<11.5 pounds	8.4 pounds	✓	✓	✓	✓	✓	✓	✓	
2	3.2.2	Size	Diameter ≤5.0" Length ≤11.5"	Diameter=5.00" Length=11.43"	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	
3	3.3.1	Power Consumption	Nominal ≤10.0 watts Maximum ≤12.5 watts	Nominal=6.42 watts Maximum=8.00 watts	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	
4	3.3.1	Increase of output error noise with 2 v - 2KHz square wave on input power line.	≤10 $\widehat{\text{sec}}$	<1 $\widehat{\text{sec}}$	✓	✓	✓	✓	✓	✓	✓	
5	3.6.1 & 3.6.2	Acquisition performance:	% of acquisition complete 1st sequence									
		Command Field of View / Location of Target Star / Mag of Target Star / Mag of Competing Star	Qual / Accept									
		8° / +4° Pitch / -0.5 / +1.0	≥80% / ≥80%	100%	✓	✓	✓	✓	✓	✓	✓	
		8° / +4° Pitch / +3.0 / +4.5	≥80% / ≥80%	95%	60%	✓	✓	✓	✓	✓	✓	
		8° / +4° Pitch / +4.0 / +6.0	≥80% / ≥80%	65%	0%	45%	60%	✓	✓	✓	✓	
		*8° / +2° Pitch / -0.5 / +0.5	≥80% / ___	95%	*	*	*	*	*	*	*	Star Magnitude should be -1 everywhere -0.5 is shown per A6000-4
		8° / +2° Pitch / +3.0 / +4.0	≥80% / ≥80%	80%	✓	✓	✓	✓	✓	✓	✓	
		8° / +2° Pitch / +4.0 / +5.5	≥80% / ≥80%	70%	✓	✓	✓	✓	✓	✓	✓	
		*4° / +2° Pitch / -0.5 / +0.5	≥80% / ___	100%	*	*	*	*	*	*	*	
		*4° / +2° Pitch / +3.0 / +4.0	≥80% / ___	100%	*	*	*	*	*	*	*	
		*4° / +2° Pitch / +4.0 / +5.5	≥80 / ___	90%	*	*	*	*	*	*	*	
		*2° / +1° Pitch / -0.5 / +0.5	≥80% / ___	100%	*	*	*	*	*	*	*	
		2° / +1° Pitch / +3.0 / +4.0	≥80% / ≥80%	100%	0%	60%	✓	✓	✓	✓	✓	
		*2° / +1° Pitch / +4.0 / +5.5	≥80%	95%	*	*	*	*	*	*	*	
		*Eliminated for Acceptance Tests			(See Remarks)							S/N27007 was not adjusted to operate at +4
6	3.6.2	Reduced Search Field Sizes	4° ± .25° dia & 2° ± .25° dia	4.25° square & 2.25° square	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	
7	3.6.3	Star Presence Signal										
		(a) Output errors when star presence signal changes state.	<5.0 $\widehat{\text{min}}$	<3.9 $\widehat{\text{min}}$	>10 $\widehat{\text{min}}$	9 $\widehat{\text{min}}$	7.7 $\widehat{\text{min}}$	7.2 $\widehat{\text{min}}$	8.7 min	✓	6.5 min	
		(b) Time for output errors to reach final value	<100 ms	<40 ms	✓	✓	✓	✓	✓	✓	✓	
		(c) Star presence signal level	+7.5 v	+7.5 v	✓	✓	✓	✓	✓	✓	✓	
		(d) Noise feedback applied to star presence signal output.	No effect on tracker operation	No effect on tracker operation	✓	✓	✓	✓	✓	✓	✓	
8	3.7.2	Size of linear range	>±16 $\widehat{\text{min}}$ but <±20 $\widehat{\text{min}}$	>±16.8 $\widehat{\text{min}}$ but <±17.6 $\widehat{\text{min}}$	✓	✓	✓	✓	✓	✓	✓	
9	3.7.3	Slope of error signal in linear range	5 ± 0.25 mv/$\widehat{\text{sec}}$	$5 {+0.10 \atop -0.05}$ mv/$\widehat{\text{sec}}$	✓	✓	✓	✓	Pitch5.35 mv/$\widehat{\text{sec}}$ Yaw 5.37 mv/$\widehat{\text{sec}}$	✓	✓	006 bought off by GSFC as acceptable

Table 5-5 (Cont.)

Item No.	Customer Spec Paragraph (A6000-4)	Test Parameter	Requirement	S/N 002	S/N 27007	TEST RESULTS						Remarks
						003	004	005	006	007	008	
10	3.7.4	Saturated region. Characteristics:										
		(a) Size	From edge of linear range to greater than ±4°	From edge of linear range to greater than ±4°	✓	✓	✓	✓	✓	✓	✓	
		(b) Output levels in saturated region	Constant within ±5%	Constant within ±2%	✓	✓	✓	✓	✓	✓	✓	
		(c) Difference between positive & negative values in saturated region.	<5%	<4%	✓	✓	✓	✓	✓	✓	✓	
11	3.7.5	(a) Crosstalk in linear region.	<5%	<2%	✓	✓	✓	✓	✓	✓	✓	
		(b) Crosstalk throughout entire field	<10%	<4%	✓	✓	✓	✓	✓	✓	✓	
12	3.7.6	Output noise in non-null offset mode										
		(a) For targets -0.5 to +3 magnitude	<10 $\widehat{\text{sec}}$	<9 $\widehat{\text{sec}}$	10.6 $\widehat{\text{sec}}$	10.2 $\widehat{\text{sec}}$	12.8 $\widehat{\text{sec}}$	11.7 $\widehat{\text{sec}}$	15.9 $\widehat{\text{sec}}$	14.6 $\widehat{\text{sec}}$	14.7 $\widehat{\text{sec}}$	S/N 27007 was not adjusted to operate at +4
		(b) For targets -0.5 to +4 magnitude	<20 $\widehat{\text{sec}}$	<15 $\widehat{\text{sec}}$	See Remarks	✓	✓	✓	25.1 $\widehat{\text{sec}}$	✓	23.5 $\widehat{\text{sec}}$	
13	3.7.6	Sustained oscillations on output	<1 mv rms	<1 mv rms	✓	✓	✓	✓	✓	✓	✓	
14	3.7.6	Output noise in null offset mode										
		(a) For targets -0.5 to +3 magnitude	<15 $\widehat{\text{sec}}$	<12 $\widehat{\text{sec}}$	✓	✓	✓	16 $\widehat{\text{sec}}$	33 $\widehat{\text{sec}}$	✓	✓	
		(b) For targets -0.5 to +4 magnitude	<25 $\widehat{\text{sec}}$	<18 $\widehat{\text{sec}}$	See Remarks	✓	✓	✓	39 $\widehat{\text{sec}}$	✓	✓	S/N 27007 was not adjusted to operate at +4
15	3.7.7	Output amplitude at 5 cps	Down <3 db	Down <0.25 db	✓	✓	✓	✓	✓	✓	✓	
16	3.7.7	Output phase lag at 5 cps	<45°	<45°	58°	✓	✓	✓	✓	49°	50°	
17	3.7.8	Environmental effects on null errors										
		(a) Max shift due to vibration		65 $\widehat{\text{sec}}$								
		(b) Max shift due to pressure	No specific requirement for individual environmental effects	7 $\widehat{\text{sec}}$								
		(c) Max shift due to temperature		31 $\widehat{\text{sec}}$								
		(d) Max shift due to humidity		23 $\widehat{\text{sec}}$								
		(e) Max shift due to shock		15 $\widehat{\text{sec}}$								
		RSS (root sum square) total	The RSS total shall be <45 $\widehat{\text{sec}}$	77 $\widehat{\text{sec}}$	✓	✓	✓	✓	✓	✓	✓	

Table 5-5 (Cont.)

Item No.	Customer Spec Paragraph (A6000-4)	Test Parameter	Requirement	S/N 002	TEST RESULTS							Remarks
					S/N 27007	003	004	005	006	007	008	
18	3.7.8.3	Non-environmental effects on null errors										
		(a) Max excursion due to power supply variations	10 $\overset{\frown}{\text{sec}}$ maximum	2 $\overset{\frown}{\text{sec}}$	✓	✓	✓	✓	✓	✓	12 $\overset{\frown}{\text{sec}}$	Due to dropout of high voltage regulator at 24.0 v. At 24.2 v unit is in spec.
		(b) Max excursion due to target magnitude variation										
		(1) -0.5 to +3.0 magnitude	6 $\overset{\frown}{\text{sec}}$ maximum	5 $\overset{\frown}{\text{sec}}$	13 $\overset{\frown}{\text{sec}}$	18 $\overset{\frown}{\text{sec}}$	12 $\overset{\frown}{\text{sec}}$	8 $\overset{\frown}{\text{sec}}$	✓	9 $\overset{\frown}{\text{sec}}$		S/N 27007 was not adjusted to operate at +4
		(2) -0.5 to +4.0 magnitude	12 $\overset{\frown}{\text{sec}}$ maximum	9 $\overset{\frown}{\text{sec}}$	See Remarks	22 $\overset{\frown}{\text{sec}}$	17 $\overset{\frown}{\text{sec}}$	✓	✓	13 $\overset{\frown}{\text{sec}}$		
		(c) Max excursion due to earth's magnetic	10 $\overset{\frown}{\text{sec}}$ maximum	6 $\overset{\frown}{\text{sec}}$	✓	✓	✓	✓	✓	✓	✓	
		(d) Max excursion due to acquisition position	10 $\overset{\frown}{\text{sec}}$ maximum	4 $\overset{\frown}{\text{sec}}$	✓	✓	✓	✓	✓	✓	✓	
19	3.7.8.4	Null error crosscoupling	<±4.0 $\overset{\frown}{\text{min}}$	<±3.0 $\overset{\frown}{\text{min}}$	✓	✓	✓	✓	✓	✓	✓	
20	3.7.8.5	External electrical null adjustment range	>±2.0 $\overset{\frown}{\text{min}}$	>±4.6 $\overset{\frown}{\text{min}}$	✓	✓	✓	✓	✓	✓	✓	
21	3.7.8.6	Offset point mode										
		(a) Range	±4°	±4°	✓	✓	✓	✓	✓	✓	✓	
		(b) Nominal gain	Not specified	0.40°/volt	–	–	–	–	–	–	–	
22	3.8.1	Star magnitude telemetry										
		(a) Output range	0.0 <voltage<+5.0	0.2<voltage<4.2	✓	✓	✓	✓	✓	✓	✓	
		(b) Nominal gain	Not specified	1 volt/magnitude	–	–	–	–	–	–	–	
		(c) Noise feedback applied to star magnitude telemetry output	No effect on tracker operation	No effect on tracker operation	✓	✓	✓	✓	✓	✓	✓	
23	3.8.1	Noise feedback applied to high voltage telemetry output	No effect on tracker operation	No effect on tracker operation	✓	✓	✓	✓	✓	✓	✓	

A total of seven other nonconforming items was detected during the qualification testing. Of the seven, two were component failures or repairable defects. The other items were slight deviations from the specification requirements. The post-environmental test deviations are indicated in Table 5-5. During temperature test the percent of time the tracker would capture a +3 and +4 magnitude star on the first scan was less than 80 percent during the high and low temperature tests. The star tracker never failed to acquire the star during one of the subsequent scans in any test. The null shift at 60°C also fell 5 arc-seconds outside of the 30 arc-second maximum. The lens problem discussed before allowed more shift due to temperature for this unit than for any of the subsequent units.

The qualification tests verified the FGES star tracker basically met the specification requirements. The few deviations to the specification were not considered to be detrimental for the intended use of the FGES. The most serious problem revealed by the tests was the lens shift with vibration which has been eliminated from subsequent units.

5.2.4 FGES Acceptance Testing

The FGES Acceptance Tests were conducted per BBRC Test Procedure P110369. The environmental tests were limited to vibration, temperature and vacuum tests. The vibration and temperature levels are listed in Table 5-3. The pressure test requires a change from local ambient to the equivalent pressure at 350,000 feet in approximately 90 seconds.

The seven trackers subjected to the acceptance tests passed the test requirements except for minor discrepancies in output noise, null shift with target magnitude and the signal level with respect to the true value when the star presence signal occurs. (The above statement is supported by the data shown in Table 5-5.)

The latter deviation (Item 7, Table 5.5) is not an operational problem for the STRAP system since the true signal value is reached before 2 seconds after the star presence signal output occurs. (The STRAP system has a built-in 2-second delay before control is turned over to the tracker.) In all the star trackers, the true value appears at the output less than 100 ms after star presence occurs.

The noise deviations (Items 12 and 14, Table 5-5) are a direct function of the phototube characteristics and could have been improved if select tubes were used. The noise characteristics obtained were considered a reasonable tradeoff between performance and cost.

The target magnitude null variation (Item 18[b], Table 5-5) was not considered objectionable enough in each case to justify the additional cost of readjustment of the compensation circuit.

All of the other deviations are peculiar to the individual tracker and again the cost of rework to eliminate the slight over specification condition could not be justified.

5.2.5 Problems Encountered During FGES Tests

Several significant problems were encountered during the test program that required a considerable amount of effort to track down and solve. The problem of lens shift with vibration has been discussed in the qualification test section. After the problem was identified, it was apparent that this effect had been the cause of other large, unexplainable shifts that occurred during preliminary tests of the first two trackers.

Another problem was tracked to the residual magnetism in the two-axis rotary table used in the dark room. Unusually large shifts occurred when the earth's magnetic field effect measurements were attempted. Differences in null were also experienced when the tracker was taken from the dark room to the vacuum and temperature chambers for tests. When the earth's field measurements were made at the BBRC magnetics building, results were as expected. Reproducible data were obtained in the dark room by removing the star tracker from the rotary table for the magnetic field tests. All tests in the temperature and vacuum chambers used the initial ambient null indication in the chamber as a baseline. The null is observed before the unit is removed from the rotary table. The reading is then compared with that taken after the unit is returned from the temperature of vacuum chamber to ensure no large shift occurred.

All of the other problems were minor in nature such as compatibility of test gear with the system, ground loop problems in test setup, etc. The final test methods and procedures developed from these experiences produced consistent and repeatable data.

Section 6
CONCLUSIONS AND RECOMMENDATIONS

The primary program objective of the program was accomplished; eight sets of flight hardware were fabricated and tested within the original program estimates. The cost of the support efforts (such as design, drawing update, AGE fabrication and test, etc.) and the redesign to eliminate design deficiencies caused a total program overrun of approximately 15 percent. The number of hours required to produce the ACS and the pneumatics was reduced on each of the next two procurements of eleven and eight systems. Increased costs resulted from price increases of piece parts, subcontracts and rise in labor rates to negate a total system cost reduction.

All of the flight hardware performed adequately to meet the GSFC experimenter support requirements. Both the ACS and the FGES performed as well or better than previous units built in-house at GSFC or that had been purchased from other sources. The flight history on all the BBRC-furnished equipment has been excellent. No flight failures have been attributable to workmanship or design inputs for which BBRC was responsible.

During the BBRC fabrication and test of the first eight systems, a number of problems were noted that could have been eliminated by modifying the system. In addition, GSFC encountered other problems during the test and flight of these units. As a result, considerable changes were incorporated into the systems by rework on the first group of eight and by redesign before fabrication of the follow-on units was begun. Additional changes were incorporated to improve the capability, reliability and performance of the system. Some of these changes and improvements are listed below:

- Replace all of the 4PDT and 2PDT relays originally called for on the drawings with units having higher reliability ratings.

- Develop a piece part screening program to improve the reliability and increase the confidence level in the electronics piece parts.

- Redesign the experimenter service module to simplify the fabrication of this package for each mission.

- Modify the power supply to improve the oscillator circuit and the output power driver capability.

- Redesign the RSP electronics card to make it a PC board rather than the original terminal board configuration.

- Develop an alternative source for the RSP slip rings.

- Change the LM101 to an LM101A and add biasing capabilities to the fine and universal modules to eliminate the LM101A offset accumulation which caused an unbalanced switch limit condition.

- Add components to obtain a hysteresis in the discriminator circuit to reduce relay chatter at the threshold levels.

- Change the alignment specification for the three-axis rate gyroscope package to avoid duplication of gyroscope alignment effort at the gyroscope manufacturer and BBRC.

- Update the procurement specification for the rate gyroscopes, free gyroscopes, and the programmer to reflect the latest requirements.
- Update the RSP to allow it to operate at spin rates as high as 7 RPS (original capability was 3.5 RPS).
- Initiate a redesign of the pneumatics valve to eliminate a design problem which periodically occurred to jam the valve shut.
- Revise the drawing for the pneumatics cables to improve the appearance and reliability.
- Requalify the ACS system to the high vibration levels of the Aerobee 170.

Because all these changes have already been incorporated, BBRC has no further recommendations for the ACS at this time. Our strongest recommendation was made as an option to the proposal for the second contract to build eleven ACS systems. This recommendation was to eliminate all the relays in the system, replace the AC coupled circuits with DC coupled circuits and incorporate the dim target pointing improvement. GSFC chose not to make the changes because they could not tolerate the resulting delivery schedule delay and because the cost of the modification was greater than the budget would allow.

Considerable work is being done at both GSFC and BBRC on new advanced systems to replace the present STRAP III system. These advanced systems will provide better acquisition accuracy and more flexibility. This effort, therefore, takes precedence over any major refinement of the present ACS.

If additional FGES star trackers are to be built in the future, a complete study should be conducted to outline the required prime operating characteristics. Reasonable tradeoffs can then be made to determine what improvements, if any, should be incorporated. As a minimum, we recommend the following changes be considered:

- Tighten the specifications of the image dissector tube to improve the signal-to-noise characteristics of the tracker.
- Perform the minor redesign to extend the electronics dynamic range which will allow the tracker to operate over the entire -1 to +4 magnitude range.
- Modify the star magnitude compensation circuit to reduce the null shift due to magnitude change.

The drawings for all of the AGE for the STRAP III ACS exist only as red-lined drawings and rough engineering sketches. Before any new equipment is built, we recommend that as a minimum all the tester schematics and parts lists should be updated.

Section 7

NEW TECHNOLOGY REPORT

Since this program was basically a build-to-print program, no new technology (inventions, discoveries, improvements, innovations, etc.) resulted from the work performed under this contract. The review activities were conducted in accordance with BBRC's corporate procedures which comply to NASA's published guidelines.

Appendix A

FINE GUIDANCE ERROR SENSOR SPECIFICATION

FINE GUIDANCE ERROR SENSOR

SPECIFICATION

A6000-4

10 July 1969

DESIGN AND PERFORMANCE SPECIFICATION
FOR A
FINE GUIDANCE ERROR SENSOR

1.0 SCOPE

This specification defines the requirements of a Fine Guidance Error Sensor (herein after referred to as a "tracker). The tracker will be used to provide two axis analog error signals to a control system that in turn orients a scientific payload toward stellar and planetary targets during a suborbital rocket flight.

2.0 APPLICABLE DOCUMENTS

Tracker Outline and Mounting Drawing

Payload Interface Drawing

3.0 REQUIREMENTS

3.1 GENERAL BACKGROUND INFORMATION AND OPERATIONAL DESCRIPTION

The tracker will be used to provide two axis analog error signals for use in a rocket pointing control. A typical mission sequence is as follows:

a. Payload on launch platform - power applied to tracker, no acquisition enable signal.

b. Payload launched - acquisition enable signal given to tracker at altitude greater than 350,000 feet at a time as short as 90 seconds after initial power application.

c. Tracker searches its 8-degree diameter field of view, acquires the brightest target in the field of view, and provides analog error signals and a star presence signal to the control system. After the tracker provides the star presence signal, the tracker error signals are used as the primary guiding signals for the control system in pitch and yaw.

d. Tracker continues to provide error signals on the initially acquired target or is successively pointed to new areas of the celestial sphere and acquires new targets as required throughout the rest of the attitude controlled part of the mission (typically four to five minutes).

e. Payload re-enters atmosphere and is recovered by means of a parachute system. Power is applied to the tracker throughout the mission, including the descent phase.

3.2 PHYSICAL REQUIREMENTS

3.2.1 Weight

The tracker shall weigh less than 11.5 pounds.

3.2.2 Size

The tracker, including all electronics shall not be more than 5.0 inches in diameter and 11.5 inches in length. A length of not more than 10.0 inches is preferred. The tracker connector and the mating connector shall be within this envelope.

3.2.3 Connector

A hard mounted connector shall be provided for signal and power interface. The preferred connector is a Cannon "D" series, 25 pin unit.

3.2.4 Mounting

The preferred method of mounting the tracker is by means of a flange or three bosses located approximately in the c.g. plane of the tracker. It is desirable that the tracker be designed so that it can be installed from the front of the payload (see Fig. 1).

3.2.5 Provisions for Attaching Filter or Aperture

Threads or other suitable means shall be provided on the lens barrel to facilitate attachment of a filter or aperture.

3.2.6 Alignment

The plane defined by three pads on the mounting flange (or the three mounting bosses if that approach is taken) shall be defined as the reference mounting surface. An axis perpendicular to the reference mounting surface to within one arc minute shall be defined as the tracker roll reference axis. It is desired that the reference mounting surface be sufficiently well defined (e.g., lapped pads) that it can be used to define the tracker roll reference axis for null accuracy checks (see Section 3.7.8). The tracker pitch or yaw axis must be appropriately defined to an accuracy of better than one degree.

3.2.7 Leak Rate

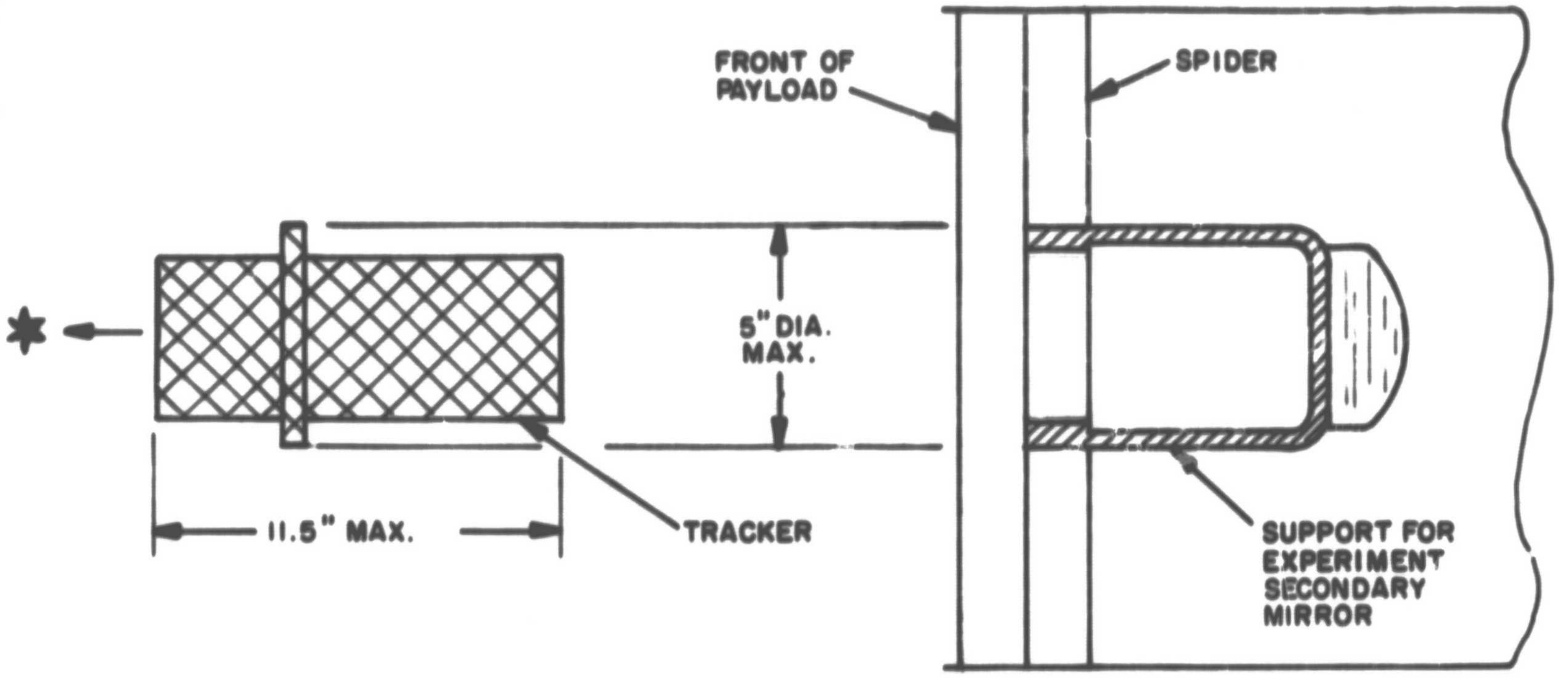
If the tracker is pressurized, the leak rate in an atmosphere of 1×10^{-6} mm of mercury shall be less than 1×10^{-4} cc/sec when corrected to standard temperature and pressure.

If the tracker is not pressurized, it shall have suitable vent holes to allow rapid out-gassing during ascent. After being above 350,000 feet for 10 seconds, the outgassing shall not exceed the leak rate given above for the pressurized tracker.

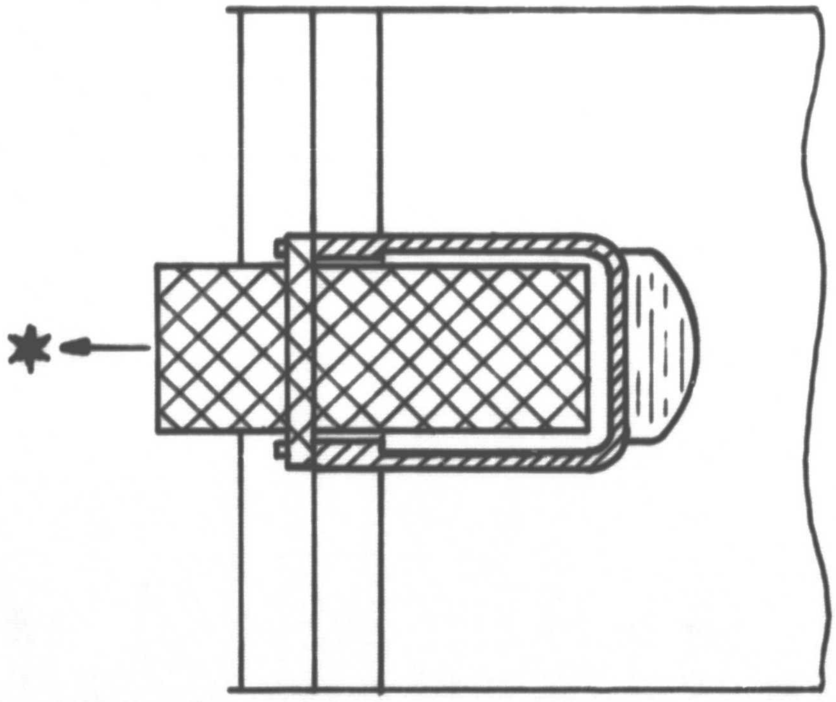
3.3 ELECTRICAL REQUIREMENTS

3.3.1 Power

Power available for use by the tracker is +28 ± 4v DC and -28 ± 4v DC. Absolute voltage differential between positive and negative supplies will not exceed 4 volts. Power supply voltage line



VIEW SHOWING TRACKER BEFORE INSTALLATION



VIEW SHOWING TRACKER AFTER INSTALLATION

Figure 1. Typical Tracker Payload Interface Schematic

drops will be simulated by a 2,000 cps square wave of 2 volts amplitude with the instantaneous line voltage never exceeding 32 volts or dropping below 24 volts. This simulation of voltage line drops shall not cause faulty tracker operation or increase the error signal noise by more than 10 arc seconds rms.

The nominal power consumed by the tracker shall be no more than 10.0 watts. The maximum power consumed by the tracker shall be 12.5 watts.

3.3.2 Signals

Input - The following input signals shall be provided to the tracker (see Fig. 2).

a. Power (+28v DC and/or -28v DC, see Section 3.3.1).

b. Reduced acquisition field of view signals, 4° and 2° (+28 ± 4v DC, see Section 3.6.2).

c. Offset point signal (summed current or voltage, see Section 3.7.8.6).

d. Acquisition enable signal (ungrounding of a pin, see Section 3.6.1).

Output - The following output signals shall be provided by the tracker (see Fig. 2).

a. Pitch analog error signal (see Section 3.7).

b. Yaw analog error signal (see Section 3.7).

c. Star presence signal (see Section 3.6.3).

d. Star magnitude telemetry signal (see Section 3.8).

e. High voltage telemetry signal (see Section 3.8).

3.4 TARGET CHARACTERISTICS

The targets shall be stars or planets of minus one to plus four visual magnitude. For the purposes of the specification, the target brightness shall be defined by a point source standard of irradiance supplied by GSFC. The spectral characteristics of this standard are essentially that of a AOV star. Tests may be run either using this standard as a source or a suitable collimated source whose brightness is appropriately related to the standard.

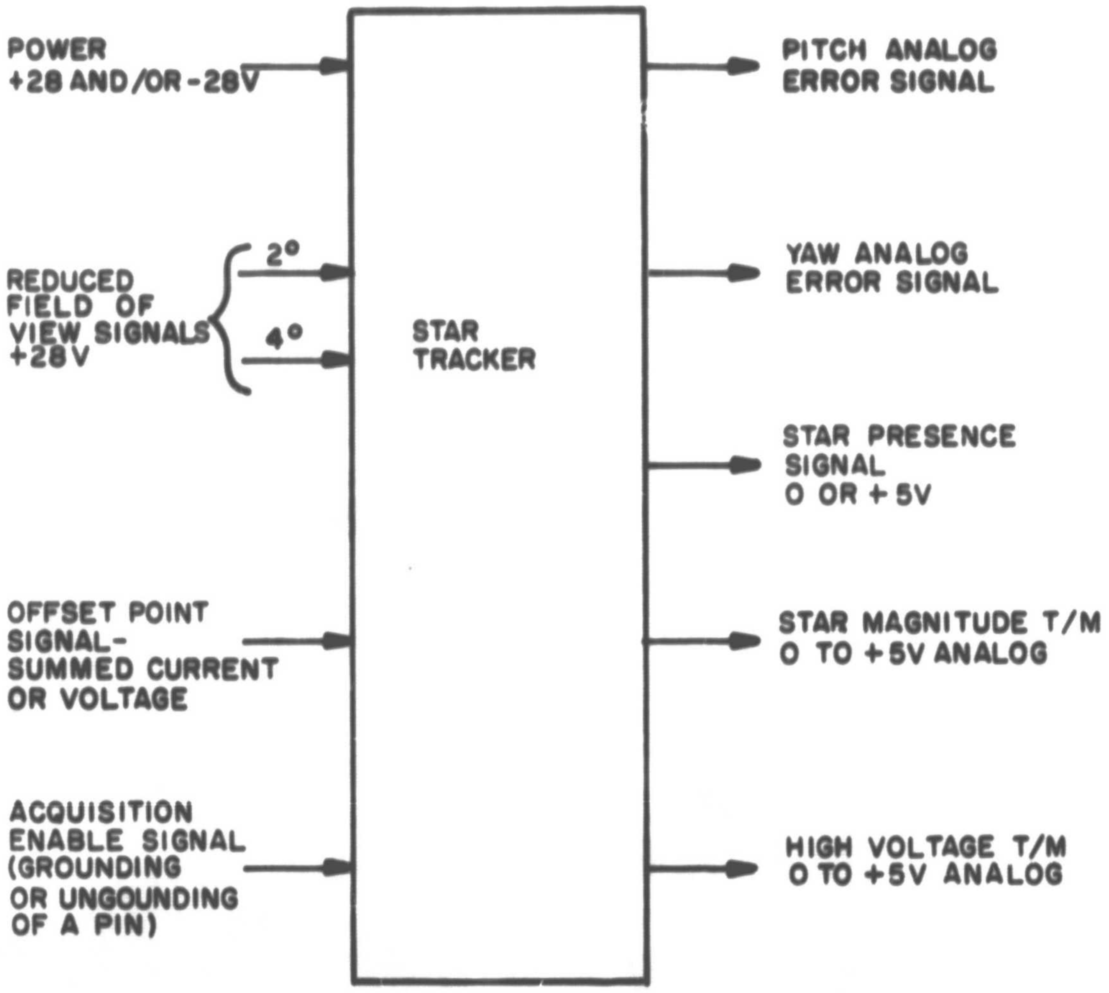


Figure 2. Input/Output Signal Diagram

The standard of irradiance shall be considered to be an accurate simulation of a m_x magnitude star under the following conditions:

1. The standard point source is used at that distance from the instrument X, where S_x is the absolute spectral irradiance produced by the source at the objective lens of the instrument and,

2. The magnitude equation gives $m = m_x$, when it is solved using the relative spectral response of the instrument, R_λ (R_λ must be measured by the contractor and furnished with each tracker to permit this equation to be solved).

   The magnitude equation is:

$$m = 2.512 \log \frac{\int S_x R_\lambda d\lambda}{\int S_{AOV} R_\lambda d\lambda}$$

The relative spectral energy distribution of the standard star, S_{AOV}, is given in Table I. This relative function is sized absolutely by noting that a zero visual magnitude star shall produce 2.65 x 10^{-10} photons above the atmosphere as listed in "Astrophysical Quantities" by C. W. Allen, 2nd Edition, 1963.

3.5 GENERAL OPERATING RESTRICTIONS

3.5.1 Altitude

The altitude will be greater than 350,000 feet.

3.5.2 Sun Position

The sun will be a minimum of five degrees below the Earth's horizon throughout the required operating altitude range of the tracker. The maximum target declination angle (i.e., the angle from Zenith to the target) shall be 80 degrees.

3.5.3 Competing Stellar or Planetary Targets

The angle between the brightest target and any other significantly bright target will be at least 40 minutes of arc.

3.6 ACQUISITION PERFORMANCE REQUIREMENTS

3.6.1 Full Field of View Mode

With target characteristics as defined in paragraph 3.4, and under the conditions of paragraph 3.5, the tracker shall acquire the brightest target in an eight degree circular field of view centered on the roll reference axis in the following cases:

Table I: RELATIVE SPECTRAL ENERGY DISTRIBUTION OF THE STANDARD STAR

Wave Length (AU)	Relative Sensitivity	Wave Length (AU)	Relative Sensitivity	Wave Length (AU)	Relative Sensitivity
2920	4.80	4000	11.26	5080	6.69
2940	4.79	4020	11.80	5100	6.62
2960	4.77	4040	11.89	5120	6.56
2980	4.74	4060	11.62	5140	6.49
3000	4.73	4080	10.86	5160	6.41
3020	4.71	4100	9.02	5180	6.36
3040	4.70	4120	9.63	5200	6.30
3060	4.69	4140	10.52	5220	6.22
3080	4.66	4160	11.16	5240	6.17
3100	4.64	4180	11.02	5260	6.10
3120	4.63	4200	10.91	5280	6.04
3140	4.62	4220	10.79	5300	5.99
3160	4.61	4240	10.66	5320	5.92
3180	4.58	4260	10.53	5340	5.88
3200	4.56	4280	10.41	5360	5.81
3220	4.54	4300	10.09	5380	5.76
3240	4.53	4320	8.67	5400	5.70
3260	4.51	4340	7.99	5420	5.62
3280	4.49	4360	8.22	5440	5.58
3300	4.47	4380	9.37	5460	5.52
3320	4.46	4400	9.76	5480	5.48
3340	4.45	4420	9.64	5500	5.41
3360	4.44	4440	9.53	5520	5.37
3380	4.42	4460	9.44	5540	5.30
3400	4.39	4480	9.33	5560	5.24
3420	4.37	4500	9.23	5580	5.19
3440	4.37	4520	9.12	5600	5.12
3460	4.35	4540	9.02	5620	5.08
3480	4.33	4560	8.92	5640	5.02
3500	4.30	4580	8.80	5660	4.97
3520	4.29	4600	8.70	5680	4.90
3540	4.27	4620	8.60	5700	4.86
3560	4.25	4640	8.50	5720	4.80
3580	4.21	4660	8.40	5740	4.74
3600	4.19	4680	8.30	5760	4.69
3620	4.19	4700	8.20	5780	4.63
3640	4.19	4720	8.10	5800	4.59
3660	4.19	4740	8.01	5820	4.52
3680	4.19	4760	7.92	5840	4.48
3700	4.20	4780	7.84	5860	4.42
3720	5.03	4800	7.77	5880	4.38
3740	5.48	4820	7.32	5900	4.48
3760	5.99	4840	6.18	5920	4.41
3780	6.96	4860	6.00	5940	4.38
3800	7.92	4880	6.13	5960	4.33
3820	8.43	4900	7.12	5980	4.30
3840	9.97	4920	7.28	6000	4.27
3860	11.26	4940	7.20	6020	4.22
3880	11.01	4960	7.11	6040	4.19
3900	10.70	4980	7.04	6060	4.13
3920	11.95	5000	6.97	6080	4.10
3940	10.88	5020	6.90	6100	4.08
3960	10.25	5040	6.82	6120	4.02
3980	10.07	5060	6.77	6140	4.00

Table I (Continued)

Wave Length (AU)	Relative Sensitivity
6160	3.97
6180	3.92
6200	3.89
6220	3.85
6240	3.81
6260	3.78
6280	3.74
6300	3.70
6320	3.68
6340	3.62
6360	3.60
6380	3.57
6400	3.52
6420	3.49
6440	3.47
6460	3.41
6480	3.39
6500	3.36
6520	3.19
6540	2.47
6560	1.94
6580	2.29
6600	2.94
6620	3.14
6640	3.11
6660	3.09
6680	3.07
6700	3.03
6720	3.01
6740	2.99
6760	2.98
6780	2.93
6800	2.91
6820	2.89
6840	2.88
6860	2.85
6880	2.82
6900	2.80
6920	2.79
6940	2.77
6960	2.73
6980	2.71
7000	2.70
7020	2.68
7040	2.67
7060	2.63
7080	2.61
7100	2.60
7120	2.58
7140	2.57
7160	2.53
7180	2.51
7200	2.50
7220	2.49
7240	2.48
7260	2.45
7280	2.43
7300	2.41
7320	2.40
7340	2.38
7360	2.34
7380	2.32
7400	2.29
7420	2.26
7440	2.23
7460	2.22
7480	2.20
7500	2.20
7520	2.19
7540	2.18
7560	2.16
7580	2.13
7600	2.11
7620	2.11
7640	2.10
7660	2.09
7680	2.08
7700	2.06
7720	2.03
7740	2.02
7760	2.01
7780	2.00
7800	1.99
7820	1.98
7840	1.97
7860	1.93
7880	1.92
7900	1.90
7920	1.90
7940	1.89
7960	1.88
7980	1.87
8000	1.84
8020	1.82
8040	1.81
8060	1.80
8080	1.80
8100	1.79
8120	1.78
8140	1.78
8160	1.77
8180	1.76
8200	1.74
8220	2.03
8240	2.02
8260	2.00
8280	1.99
8300	1.98
8320	1.95
8340	1.92
8360	1.91
8380	1.89
8400	1.88
8420	1.87
8440	1.85
8460	1.82
8480	1.81
8300	1.80

a. The brightest target is located anywhere in the field of view, its magnitude is in the -1 to +3 range and the next brightest target in the field of view is at least 1.5 magnitudes dimmer.

b. The brightest target is located anywhere in the field of view, its magnitude is in the -1 to +4 range and the next brightest target in the field of view is at least 2.0 magnitudes dimmer.

c. The brightest target is located in the central 4° x 4° portion of the field of view, its magnitude is in the -1 to +3 range and the next brightest target in the field of view is at least 1.0 magnitudes dimmer.

d. The brightest target is located in the central 4° x 4° portion of the field of view, its magnitude is in the -1 to +4 range, and the next brightest target in the field of view is at least 1.5 magnitudes dimmer.

In all of the above cases, the selection of the brightest target must be accomplished with a 99.5 percent probability. In 80 percent of the trials, acquisition of the brightest target will be completed, error signals generated, and the star presence signal provided within 1.0 second after the acquisition enable lead is ungrounded. The target may be moving at a rate relative to the tracker as high as 0.5 degree per second.

3.6.2 Reduced Field of View Modes

The tracker shall be capable of being commanded to have reduced acquisition fields of view of either 4° ± 1/4° diameter or 2° ± 1/4° diameter, centered on the tracker roll axis. The reduced field of view modes shall be commanded by the application of +28 ± 4v DC to the appropriate input pin. When the reduced field of view mode command is removed, the acquisition field of view shall return to its full 8 degree diameter in less than 0.01 second. While operating in the reduced acquisition field of view modes, the other tracker characteristics, i.e., null accuracy and tracking signal characteristics, shall not be affected. While operating in the reduced field of view modes, with target characteristics as defined in paragraph 3.4 and under the conditions of paragraph 3.4, the tracker shall acquire the brightest target in its reduced field of view in the following cases:

a. The target's magnitude is in the -1 to +3 range and the next brightest target in the reduced field of view is at least 1.0 magnitudes dimmer.

b. The target's magnitude is in the -1 to +4 range and the next brightest target in the reduced field of view is at least 1.5 magnitudes dimmer.

The probabilities, acquisition time limits and target rates which applied in the full field of view mode also apply in the reduced field of view modes.

3.6.3 Star Presence Signal

A binary signal output shall be provided to indicate that star selection has been accomplished and that valid error signals are available. Valid error signals shall be defined as signals which indicate true target position to better than 5 arc minutes. These error signals shall settle to their true values (i.e., be within the requirements of paragraph 3.7) in less than 100 milliseconds after star presence is indicated.

Star presence shall be indicated by a voltage level of 4.5 ± 0.5v with a minimum external load impedance of 10,000 ohms. The "0-State" shall be within 0.0 to +0.5 volt with no current feedback into the tracker by the load. The tracker shall be immune to control system noise feedback applied to the star presence signal output when the noise is simulated by a 500 millivolt rms source varying from 100 cps to 10,000 cps with an internal resistance of 10,000 ohms.

3.7 TRACKING PERFORMANCE REQUIREMENTS

3.7.1 General

The tracker shall provide pitch and yaw error signals proportional to the angular errors in orthogonal pitch and yaw planes. The pitch or yaw angular error is defined as the component in the pitch or yaw plane of the angle between the null line of sight (line of sight with both axes at electrical zero) and the line of sight to the target. The amplitude response characteristics of each channel shall be as shown in Fig. 3 independent of the error in the other channel over the full field of view of 8 degrees or larger when loaded by an impedance of 30 Kohms or greater.

3.7.2 Size of Linear Range

The linear region in each channel shall be greater than ±16 minutes of arc but less than ±20 minutes of arc, measured from null. The error signals must be smoothly continuous through null in each channel for all error values in the other channel. Switching discontinuities and transients shall not exceed 10 percent of the instantaneous value and shall not occur within the central area defined by the linear region in both axes.

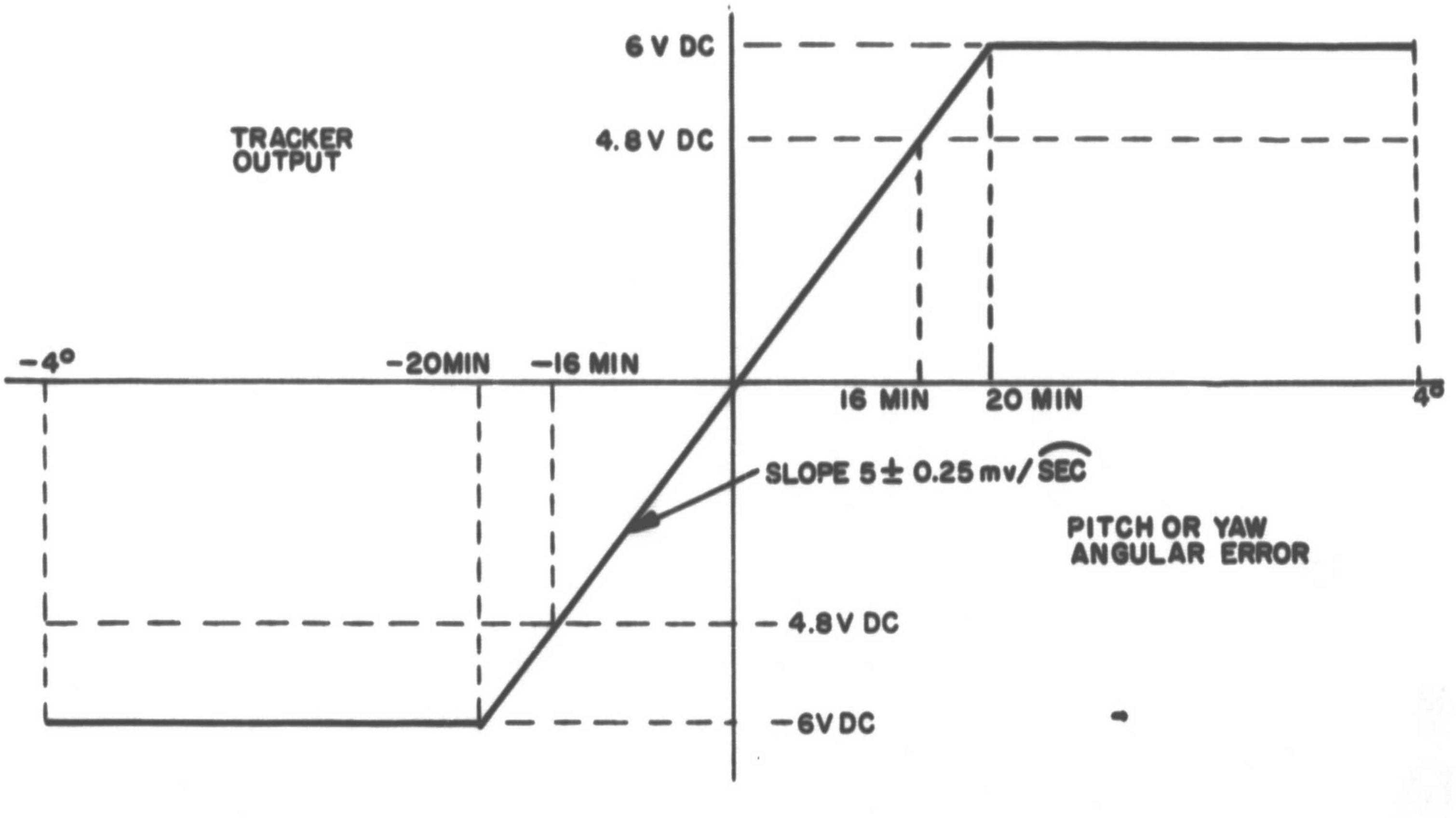


Figure 3. Error Signal Characteristics

3.7.3 Slope of Error Signal in Linear Range

The slope of the linear region shall be 5 mv/second of arc ± 0.25 mv/second of arc for all targets. The slope must be smoothly continuous over the linear region.

3.7.4 Saturated Region Characteristics

The saturated region shall extend from the linear region to the edge of the 8 degree circular field of view in each axis. Positive and negative saturated levels shall be constant within ±5 percent over the saturated region. The average value of the positive and negative saturated signals shall not differ in magnitude by more than 5 percent.

3.7.5 Crosstalk Effects on the Value of the Output Signals In the Linear Regions

The output of the pitch or yaw error channel measured at a constant angular deviation from electrical zero in the pitch or yaw error channel linear region shall not vary more than 5 percent of its instantaneous value or 25 millivolts, whichever is larger, as the target is moved throughout the linear region of the cross axis; and it shall not vary more than 10 percent of its instantaneous value or 25 millivolts, whichever is larger as the target is moved throughout the entire field of view in the cross axis.

3.7.6 Noise

Non-Null Offset Mode - In the pitch and yaw linear regions, the rms variations in the pitch and yaw error signals, while the target is stable both in amplitude and angular attitude with respect to the tracker shall be no greater than the value of the DC output error signal corresponding to 10 arc seconds angular error. This shall be true for targets over the range of -1 to +3 magnitude (as defined in paragraph 3.4). In the pitch and yaw linear regions, the rms noise shall be less than 20 arc seconds for targets as dim as +4 magnitude.

There shall be no sustained oscillations on the error signal outputs greater than 1 millivolt rms.

Null Offset Mode - For null offsets greater than 18 arc minutes, the rms noise in the pitch and yaw linear regions shall be less than 15 arc seconds for targets over the range of -1 to +3 magnitude and less than 25 arc seconds for targets as dim as +4 magnitude. There shall be no sustained oscillations on the error signal outputs greater than 1 millivolt rms.

3.7.7 Time Constant

The first break point of the amplitude-frequency response shall not be less than 5 cps. At 5 cps, the amplitude shall not be down more than 3 db and the phase lag shall be less than 45 degrees.

3.7.8 Null Accuracy

3.7.8.1 General

The maximum angular error between the tracker reference roll axis and the tracker electrical null axis (both pitch and yaw output signals nulled) as a result of all environmental and operational effects shall be one arc minute. The tracker roll reference axis shall have a known and stable relationship to the tracker reference mounting surface. The following paragraphs establish limits for errors due to environmental and non-environmental effects. Any additional sources of null error not specifically called out in the following paragraphs must be small enough so that the overall null accuracy requirement of one arc minute can be met. Null errors shall be within specification requirements a maximum of one second after the target is brought to the null position.

3.7.8.2 Environmental Effects on Null Errors

The RSS (Root Sum Square) total of the null shifts caused by tracker operation over the temperature and pressure range specified in paragraph 3.10.3 and exposure to the environments specified in paragraphs 3.10.1 and 3.10.2 shall be a maximum of 45 arc seconds.

3.7.8.3 Non-Environmental Effects on Null Error

a. Power Supply Variations - The maximum angular excursion of the tracker electrical null axis due to power supply variations over the range listed in paragraph 3.3.1 shall be 10 arc seconds in each axis.

b. Target Magnitude Variation - The maximum angular excursion of the tracker electrical null axis due to variation in target magnitude from -1 to +3 shall be six arc seconds in each axis. The maximum angular excursion due to variation in target magnitude from -1 to +4 shall be 12 arc seconds.

c. Effect of Earth's Magnetic Field - The maximum angular excursion of the tracker electrical null axis due to the effects of the Earth's magnetic field shall be 10 arc seconds.

d. Effect of Target Position in the Acquisition Field of View - The maximum angle between the electrical null axis when a target is acquired in the center of the field of view and the electrical null axis when a target is acquired anywhere else in the field of view is 10 arc seconds.

3.7.8.4 Null Error Crosscoupling

The electrical zero in each channel as a function of error in the other channel must fall within a zone ±4 arc minutes wide at ±4 degrees error in the other channel, and reducing in width linearly to zero at the null line of sight (both channels nulled) as shown in Fig. 4.

3.7.8.5 External Electrical Null Adjustment

The tracker must provide an external means for electrically adjusting the alignment of the null axis of the tracker over a range of at least ±2 minutes of arc to a resolution better than ±5 arc seconds. This adjustment must be accessible from the front of the tracker when it is mounted on the payload (see Fig. 1).

3.7.8.6 Offset Point Mode

The tracker shall have a capability for offset pointing up to ±4 degrees in each axis. Offset pointing shall be externally commanded when the tracker has acquired a star by a single pin for each axis to which an externally adjusted voltage or current is applied to obtain the required offset angle. All of the null accuracy requirements listed in paragraphs 3.7.8.1 through 3.7.8.4 apply to the offset point mode except that the null errors are now referred to the offset null axis rather than the tracker roll reference axis.

3.8 STAR MAGNITUDE AND HIGH VOLTAGE TELEMETRY SIGNALS

3.8.1 General

The tracker shall have suitable electrical outputs for telemetering the star magnitude (accurate to within 0.5 stellar magnitude) and high voltage. The tracker shall meet requirements with loads of 50,000 ohms or higher on the telemetry outputs. The tracker shall be immune to control system noise feedback

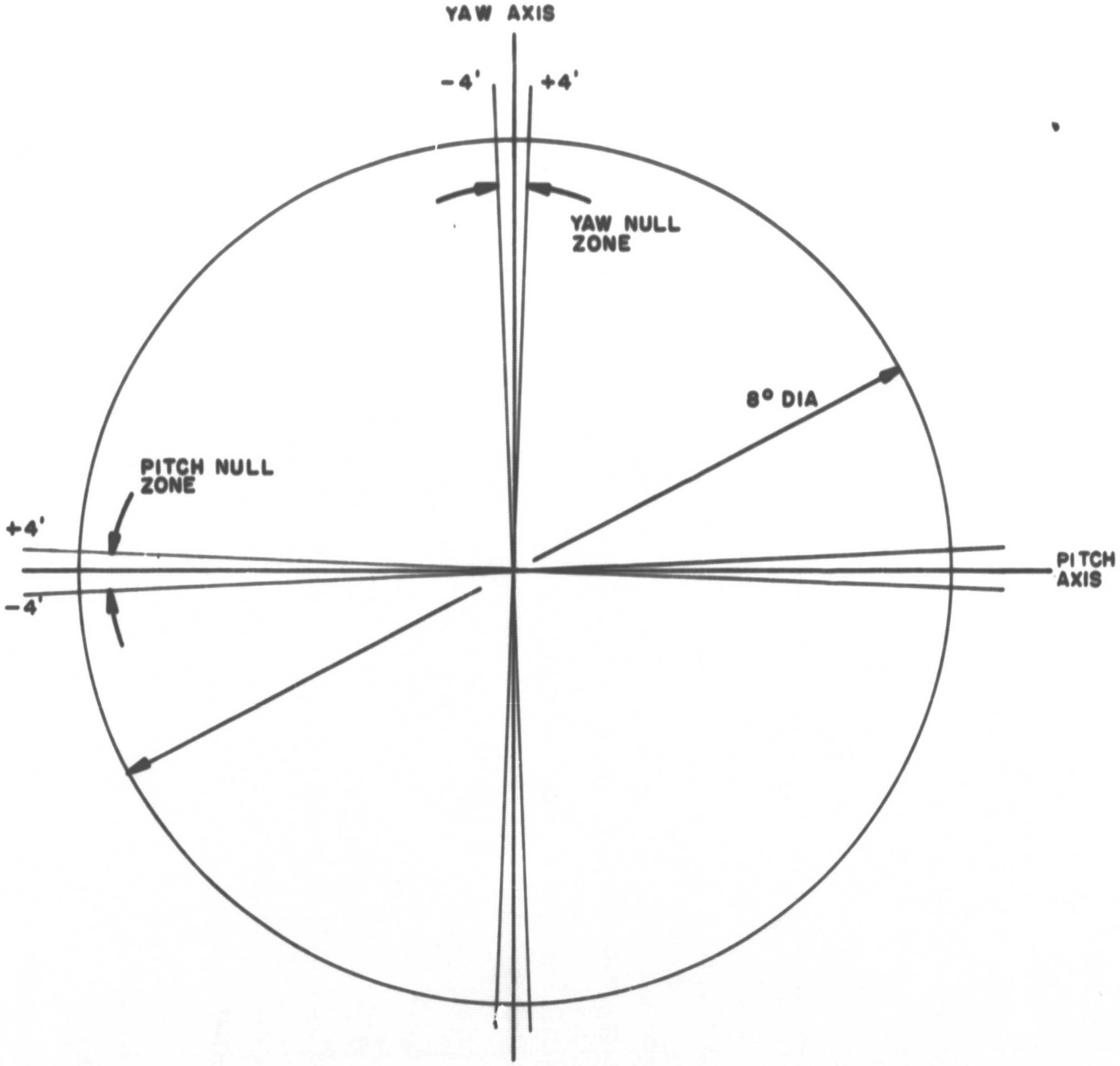


Figure 4. Null Error Crosscoupling Diagram

applied to the star magnitude, and the high voltage telemetry outputs when the noise is simulated by 500 millivolt rms source varying from 100 cps to 10,000 cps with an internal resistance of 10,000 ohms. In no event shall any T/M output be less than 0.0 volts or more than +5.0 volts.

3.8.2 Calibration of the Star Magnitude Telemetry Output

The star magnitude telemetry signal shall be calibrated. The following method is presented as an acceptable way of performing the calibration. By using the standard source, it is possible to effect a calibration by viewing the standard source at any distance between fifteen and thirty feet. The star tracker anode current shall be measured when the standard source is being used to irradiate the objective lens of the instrument telescope. Calibration is then performed as follows:

a. The specific distance between the instrument and the source shall be measured and noted.

b. The tracker shall be aligned with the point source and positioned for a zero error signal.

c. Measure the anode current with the scan disabled and measure the star magnitude telemetry voltage with the scan operating.

d. The magnitude at the test distance can be scaled from the third magnitude distance and a calibration curve of log anode current versus magnitude can be drawn through the determined magnitude, current point.

e. A plot of anode current versus star magnitude TM over the operating range of the tracker should then be furnished.

3.9 RELIABILITY AND LIFE

The tracker shall have a design operating life of not less than 1000 hours with a reliability of 98 percent.

3.10 ENVIRONMENT

3.10.1 Shipping

The tracker shall operate properly after being exposed to the following environment during shipment: temperatures over the range of -20°C to +70°C.

3.10.2 Launch Standby, Launch and Ascent

The tracker shall operate properly after being exposed to the following environments with the power on.

3.10.2.1 Humidity

Relative humidity of 95 percent at 30°C, followed by cooling to 15°C.

3.10.2.2 Vibration

Acceptance Levels-

Sinusoidal Vibration (4 oct/min)

Roll Axis:

10-60 Hz, 1.5 g, 0 to peak
60-160 Hz, 3.0 g, 0 to peak
160-2000 Hz, 5.0 g, 0 to peak

Lateral Axes:

10-60 Hz, 3.6 in/sec constant velocity
60-250 Hz, 3.5 g, 0 to peak
250-2000 Hz, 5.0 g, 0 to peak

Random Vibration (10 sec/axis)

Roll Axis:	.025 g^2/Hz over a 20-2000 Hz range
Lateral Axes:	.05 g^2/Hz over a 20-2000 Hz range

Qualification Levels-

Sinusoidal Vibration (2 oct/min)

Roll Axis:

10-60 Hz, 2.3 g, 0 to peak
60-160 Hz, 4.5 g, 0 to peak
160-2000 Hz, 7.5 g, 0 to peak

Lateral Axes:

10-60 Hz, 5.4 in/sec constant velocity
60-250 Hz, 5.3 g, 0 to peak
250-2000 Hz, 7.5 g, 0 to peak

Random Vibration (20 sec/axis)

Roll Axis: 0.056 g^2/Hz over 20-2000 Hz range
Lateral Axes: 0.113 g^2/Hz over 20-2000 Hz range

3.10.2.3 Shock - Acceptance and Qualification Levels

30 g half sine, 11 ms duration applied in each of the three mutually perpendicular axes individually.

3.10.2.4 Pressure - Acceptance and Qualification Levels

From pressure at sea level to pressure at 350,000 feet in approximately 90 seconds.

3.10.3 Operating Environment

The tracker shall operate properly under any combination of the following environments.

3.10.3.1 Temperature - Acceptance and Qualification Levels

Acceptance Level: 0°C to +50°C
Qualification Level: -10°C to +60°C

3.10.3.2 Pressure - Acceptance and Qualification Levels

Sea level pressure to pressure at an altitude of 600,000 feet.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 STANDARD CONDITIONS

Tests performed at standard conditions shall be performed within the following environmental ranges.

● Temperature:	+15°C to +30°C
● Pressure:	525 to 810 mm Hg
● Relative Humidity:	0 to 55 percent

4.2 MEASUREMENT TOLERANCES

All measurements shall be made with instruments which are appropriate for the quantity to be measured and the environmental condition under which measured. The maximum allowable tolerances for test conditions shall be as follows.

● Acceleration:	±10 percent
● Vibration Amplitude: (g's or inches)	±10 percent
● Vibration Frequency:	±2 percent or 1 Hz whichever is greater
● Temperature:	±2°C

4.3 QUALIFICATION TESTING

The tracker design shall be qualified. Qualification is defined as testing which demonstrates that the proposed design is capable of meeting the specified requirements at qualification environmental levels. The tests need not be run in the order listed.

4.3.1 Initial, Interim, and Final Performance Tests

Before and at the conclusion of qualification testing, a complete performance test shall be conducted to verify tracker compliance with all the performance requirements of paragraphs 3.6 through 3.8. Appropriate interim tests should be conducted between environmental exposures to allow the determination of the effect of that particular exposure.

4.3.2 Tests to be Conducted

4.3.2.1 Vibration

The tracker shall meet the requirements of Section 3.0 after being exposed to the qualification vibration levels listed in paragraph 3.10.2.2. Power shall be applied to the tracker during vibration. Null offset checks shall be made after each axis of vibration.

4.3.2.2 Shock

The tracker shall meet the requirements of Section 3.0 after being exposed to the qualification shock level listed in paragraph 3.10.2.3. Power shall be applied to the tracker during shock testing.

4.3.2.3 Pressure

The tracker shall meet the requirements of Section 3.0 after and during exposure to the pressure environment described in paragraph 3.10.2.4. The tracker shall be placed in a chamber at ambient pressure and turned on. After proper tracker operation is verified, the chamber shall be evaluated to 10^{-4} mm Hg in not more than three minutes of time. The tracker shall exhibit no corona or other undesirable high voltage effects while it is operating in the chamber both during pumpdown and at 10^{-4} mm Hg pressure. Null accuracy shall be checked while the tracker is at reduced pressure.

4.3.2.4 Temperature

The tracker shall meet the requirements of Section 3.0 after and during exposure to the temperature levels listed in paragraph 3.10.3.1. The tracker shall be exposed to temperatures over the range of -10°C to 60°C. Tracker operation shall be demonstrated for at least one hour at -10°C, 30°C and 60°C. Tests made at each of these temperatures shall include acquisition, linearity, throughout the linear range and null accuracy.

4.3.2.5 Humidity

The tracker shall meet the requirements of Section 3.0 after being exposed to the humidity level listed in paragraph 3.10.2.1. The tracker shall be subjected to a relative humidity of 95 percent while being held at a stabilized temperature of 30°C. The duration of the exposure shall be 24 hours. At the end of the 24-hour period, the tracker shall be energized while in the chamber and shall and shall exhibit no internal arcs, current surges or other operating anomalies. Upon completion of the humidity test the tracker shall be immediately placed in a 15°C temperature chamber for two hours, with the power applied to the unit. The tracker shall be placed in a vacuum chamber and the pressure reduced to 10^{-4} mm Hg in three minutes. Proper tracker operation will then be demonstrated. Power is to be applied during the evacuation.

4.4 ACCEPTANCE TESTING

4.4.1 Environmental Exposures

4.4.1.1 Vibration

The tracker shall be exposed to the acceptance random vibration levels in paragraph 3.10.2.2. The maximum null shift due to this exposure shall be 30 arc seconds.

4.4.1.2 Temperature

The tracker shall be exposed to temperatures over the range specified in paragraph 3.10.3.1. On-axis testing only is required. The maximum null shift over the range shall be 30 arc seconds.

4.4.1.3 Pressure

The tracker shall be placed in a chamber, turned on and then the chamber pressure shall be evacuated to 10^{-4} mm Hg in not more than three minutes. The tracker shall exhibit no corona or other undesirable high voltage effects while it is operating in the chamber both during pumpdown and at 10^{-4} mm Hg pressure.

4.4.1.4 Performance Testing

Compliance of the tracker to the requirements of Section 3.0 shall be demonstrated.

4.5 GENERAL NOTES ON TESTING

The following is included to indicate the scope of testing deemed necessary to demonstrate compliance of the tracker to the specification requirements in particular areas. Where a suggested test method is given, it is intended only as an indication of one acceptable way it could be done, not a requirement that it be done in that manner.

a. Testing to Verify Acquisition Performance - The field of view of the tracker should be mapped by moving a star through the tracker field of view. Acquisition must then be demonstrated by placing the brightest target at the lowest response point (excepting very small localized spots) in the appropriate acquisition field of view and the appropriate dimmer target at the highest response point in the appropriate acquisition field of view. Successful acquisition shall be conducted with enough target pairs to demonstrate full compliance with paragraph 3.6.

b. Noise Tests - Compliance with the noise requirements shall be demonstrated at several locations in the linear range including null and at two or more locations in the rest of the field of view. Tests shall be run with both dim and bright targets to demonstrate full compliance with paragraph 3.7.6. A suggested method of noise testing is to take N samples of output error voltage V_i at equal time intervals, τ of at least one second. N should probably be on the order of at least 100. The system rms angular noise in arc seconds is then given by:

$$\sigma_h = \sqrt{\sum \left(V_i - \frac{\Sigma V_i}{N} \right)} \times G$$

where G is the measured tracker angular sensitivity in arc seconds/volt.

c. Time Constant Tests - Compliance with the time constant requirement shall be demonstrated by tracking a target moving at an appropriate rate and measuring the ability of the tracker to follow it. A suggested method is to place an oscilloscope a sufficient distance from the tracker, appropriately sweep the spot, and track the spot.

d. Tests to Determine the Effect of Earth's Magnetic Field - Compliance with the magnetic shielding requirement shall be demonstrated. A suggested method is by monitoring the null offset caused by orienting the tracker in enough positions with respect to the Earth's field that worst case effects due to the full plus/minus variations in the Earth's field are measured.

e. Null Accuracy Tests - The roll reference axis of the tracker must be optically defined to an accuracy of at least as good as 5 arc seconds to permit meaningfull null accuracy tests to be conducted. This may be accomplished by means of a permanent alighment mirror located on the tracker, a removable mirror which mates with reference pads on the tracker, etc. This alignment reference must be demonstratably stable with respect to the mounting surface of the tracker. All null accuracy tests which are conducted must be referenced to this optically defined roll reference axis.

f. Effect of Targets Close to the Target Being Tracked - Compliance with the requirements of paragraph 3.5.3 shall be demonstrated by placing a target 1 magnitude dimmer than the target being tracked at an angle of 40 arc minutes from the tracked target and monitoring the null error.

g. Typical Operating Sequence - The ability of the tracker to comply with the null accuracy requirements for a typical mission shall be demonstrated. A suggested test sequence is:

   1. Place a target approximately one degree off the tracker null axis.

   2. Turn on tracker.

   3. 90 seconds after the tracker is turned on provide the tracker with the acquisition enable signal.

   4. After the "star presence" signal is given by the tracker, bring the target to the tracker null axis in 5 to 10 seconds of time.

   5. Monitor the tracker error signals and verify that the tracker meets the null accuracy requirements within the time limits given in paragraph 3.7.8.1.