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PANORAMIC ATTITUDE SENSOR

FOR RADIO ASTRONOMY EXPLORER -B

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Final Report

Contract NAS 5-11464

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Figure 2. Technical Report Standard Title Page

Abstract

An instrument system to acquire attitude determination data for the RAE-B spacecraft was designed and built. The system consists of an electronics module and two optical scanner heads. Each scanner head has an optical scanner with a field of view of 0.7 degrees diameter which scans the sky and measures the position of the moon, earth and sun relative to the spacecraft. This scanning is accomplished in either of two modes. When the spacecraft is spinning, the scanner operates in spherical mode, with the spacecraft spin providing the rapid scan motion and the scanner step advance providing the slow sweep of lattitude to scan the entire sky. After the spacecraft is placed in lunar orbit and despun, the scanner will operate in planar mode, advancing at a rate of 5.12 seconds per revolution in a fixed plane parallel to the spacecraft Z axis. This scan will cross and measure the moon horizons with every revolution. Each scanner head also has a sun slit which is aligned parallel to the spin axis of the spacecraft and which provides a sun pulse each revolution of the spacecraft. The electronics module provides the command and control, data processing and housekeeping functions.

PREFACE

a) Objective: To provide a complete Panoramic Attitude Sensor System for the RAE-B spacecraft. This system provides to spacecraft telemetry data on the angular orientation of the spacecraft relative to the moon, earth and sun as optical targets.

b) Scope of Work: Accomplishments under this contract include design, fabrication and testing of the PAS instrument system to perform according to the specified requirements.

c) Conclusions: A PAS system has been built and delivered to GSFC which fulfills all of the requirements, and which is expected to perform satisfactorily throughout the complete mission of the RAE-B spacecraft.

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APPENDICES

Applicable Specifications and References

1. NAS 5-11464 PAS contract.
2. GSFC S-724-P7 "Panoramic Attitude Sensor" Specification Feb 27, 1970, updated June 7, 1971.
3. S-320-RAE-3 Environmental Test Specification for the Radio Astronomy Explorer (RAE-B) Subsystems.
4. Panoramic Attitude Sensor for the Radio Astronomy Explorer Spacecraft (RAE-B) proposal by EMR, with first and second revised proposals, in response to GSFC RFP 87735-121.
5. Increased Capability for the Panoramic Attitude Sensor (PAS) - technical proposal for contract modification of NAS 5-11464 - in response to GSFC modification No. 1 to NAS 5-11464 specification GSFC-S-724-P7.
6. Monthly Progress Reports - Panoramic Attitude Sensor for RAE-B July, 1971 through January, 1973.
7. Panoramic Attitude Sensor for RAE-B Life Test of Scanner Mechanism.

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

The Panoramic Attitude Sensor System is a major component of the Attitude Control System of the Radio Astronomy Explorer-B spacecraft. It provides to spacecraft telemetry digital data relating the angular positions of the moon horizon, sun and earth relative to the spacecraft orientation in real time. It consists of a pair of optical scanners mounted on the exterior of the spacecraft connected to a single electronic module. The system hardware was designed and built by EMR to provide the functions and meet the specifications set by G. S. F. C.

1.1 RAE Mission

The primary objective of the RAE-B mission is to measure galactic and solar radio noise in the absence of earth radio interference and at frequencies below the cutoff of transmission through the ionosphere. To accomplish this, the spacecraft will orbit the moon and measurements will be made when the moon shadows the spacecraft from earth. Other objectives of the RAE-B mission are: a) to search for point sources of radiation, b) to detect jovian bursts and, c) to determine lunar background. For some of these measurements the moon will provide focusing or aperture blocking for improved resolution and discrimination.

In order to perform these measurements, the spacecraft will be placed in a circular orbit about the moon at an altitude of about 1100 KM above the moon surface. The spacecraft will be spin stabilized during the transit from earth to moon. However, it will be despun during injection into the lunar orbit, and it will be gravity gradient stabilzed with the +Z axis pointed toward the center of the moon in its final orbit configuration. The Panoramic Attitude Sensor System is designed to provide attitude data throughout the entire trajectory, with spacecraft spin rates of 50 rpm, 12 rpm, 4 rpm, and zero (gravity gradient stabilization).

1.2 The PAS System

The purpose of the PAS system is to acquire data from which can be determined the orientation of the spacecraft relative to the moon, earth, and sun. Data is acquired by the two scanner heads of the PAS system, one each mounted on paddles A and C of the spacecraft. Each scanner head has two optical sensors, the sun slit and the scanner. The sun slits have a field of view which is a sector 1/2 degree wide by 180°, oriented to sweep the entire sky with every revolution of the spacecraft. The sun slit sensor has only sufficient sensitivity to respond to the sun. Thus one sun pulse is generated with each revolution of the spacecraft, as the sun slit field of view crosses the disc of the sun. The interval between sun pulses provides an accurate measure of the period of revolution of the spacecraft, while the timing of the pulse is a measure of the rotational phase relative to the plane of the sun and the spacecraft spin axis.

The other optical sensing system in the scanner head is the scanner itself. The scanner has a field of view which is circular, 0.7° in diameter, and is driven through a full 360° scan circle. As the scanner head is mounted on the spacecraft, the plane of this scan is parallel to the spacecraft spin axis. The scanner is advanced through this full circle scan in 512 discrete steps of 0.703 degrees each by a stepping motor. When the spacecraft spin rate is significant (more than 1/4 rpm) the scanner is operated in spherical mode, advancing no more than one step for each revolution of the spacecraft. In this mode of operation the spacecraft spin provides the rapid scanning motion with the stepping of the scanner providing the advance. Thus the full sphere of the sky is scanned completely with each half revolution (256 steps) of the scanner from one pole of the spacecraft to the other.

When the spacecraft spin rate is negligible (gravity gradient stabilized), the scanner is operated in planar mode. In this mode of operation the scanner is stepped through a full circle at a rate of 100 steps per second (5.12 seconds for a full revolution). Here the motor driven scan is the only motion. The plane of the scan remains fixed, and targets are measured only if they lie in that plane.

2.0 PAS SYSTEM DESIGN

The complete PAS system will be considered in three major aspects - the optical functions, mechanical functions and electronic functions. Data input is by means of the optical functions, which includes the scanner optics and the sun slit. The mechanical functions provide the motion of the scanner to relate the optical input to the geometrical orientation of the spacecraft. In addition the internal support structure and case will be considered under mechanical functions. Finally, the electronic functions take the signals from the optical sensors in the scanner, the sun slit and the shaft position encoder and translate them into a coded output. In addition, the electronics provides operational circuitry for the motor, the encoder, and the heater, and the operational command functions.

2.1 Optical Functions

Each scanner has two separate optical input systems, the sun slit and the scanner. While the output signals from these two sensors interact in the electronics, their optical input systems are totally separate.

2.1.1 Sun Slit

The sun slit is an assembly of the parts detailed on EMR drawings no.'s 3041, 3042, 2009, and 2010 together with the optical to electrical transducer - a Hewlett Packard 5082-4231 silicon PIN photodiode. The complete assembly provides an entrance slit for light which is .004 inches wide and runs 180 degrees around the perimeter of the slit assembly.

It has a radius of 0.625 inches from the center of the assembly. At the center is a diffusing aluminum cone which reflects the admitted light onto the photodiode with essentially equal efficiency for any direction of incidence. This is necessary because the unit responds only to direct sunlight which has a beam angle of only 0.5 degree and may be incident from any part of the slit. The angle of the central cone was calculated such that for specular reflection the slit would be reflected onto the sensitive area of the detector. The surface of the cone is lightly frosted with a bright anodize to provide some optical attenuation and to make alignment of the detector less critical.

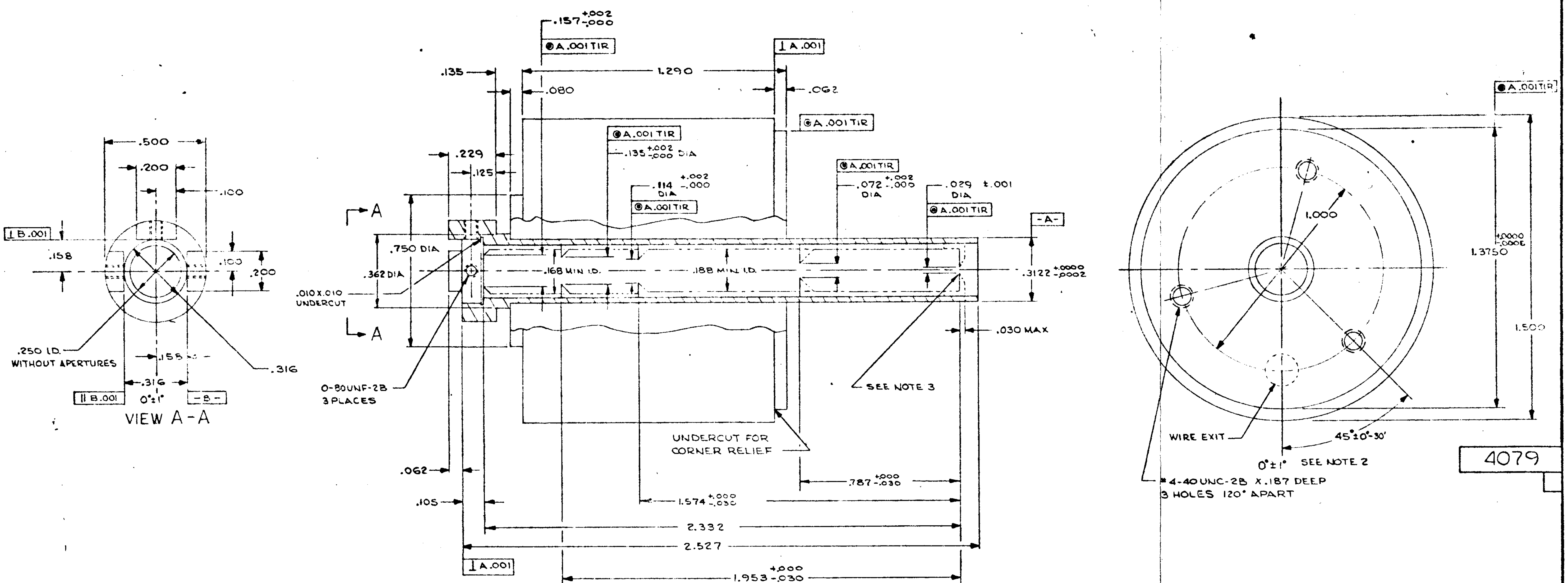
To restrict the field of view of the sun slit to a nominal 0.5 degrees, an inner slit and intermediate baffle are also provided. Both are concentric and coplanar with the outer slit and have the same slit width of 0.004 inches. Except for the reflecting cone surface, all surfaces of the slit assembly are finished with black anodize.

The slit assembly is mounted to the outside of the scanner case as shown in drawing No. 5019 with the plane of the slit parallel to the rectangular sides of the case, and perpendicular to the mounting base. As the scanner is mounted on the spacecraft, the plane of the sun slit is parallel to the axis of rotation, with the 180 degree extent running from one exis to the other.

The sensitivity threshold was set empirically using a fully assembled sun slit and thresholding amplifier. The gain of the amplifier was adjusted so that the signal reached threshold value when the sun slit assembly was exposed to a solar simulator whose exit aperture subtends 0.5 degree, and which produces about 1/3 solar constant at the scanner.

NOTES:
1. THIS PART TO MEET ALL REQUIREMENTS OF EMR SPEC. #906-
2. THE "0" POSITION AS DEFINED IN EMR SPEC #906-   SHALL BE WHEN THE SHAFT AND HOUSING ARE ORIENTED AS SHOWN.
3. APERTURE DESIGN OPTIONAL, WHERE SHOWN IN PHANTOM, AS LONG AS A KNIFE EDGE AT THE DIAMETER AND POSITION INDICATED IS ACHIEVED.
4. INTERIOR OF SHAFT TO BE OPTICAL BLACK ON ALL SURFACES.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED



4079

FOLDOUT FRAME 2

REQD	PART NO.	ITEM	DESCRIPTION	SYM

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS; DECIMALS ±.005; ANGLES ±0°-15'

MATERIAL

TREATMENT OR FINISH: SEE NOTE 4

DRAWN BY: D. MACKENZIE — DATE 8-4-72
CHECKED
ENGINEER
APPROVED
APPROVED

EMR-AEROSPACE SCIENCES DIVISION
ELECTRO-MECHANICAL RESEARCH, INC.
COLLEGE PARK, MARYLAND

ENCODER ASSEMBLY
P.A.S.

CODE IDENT NO.	SIZE	
06141	D	4079

SCALE 4/1 — SHEET

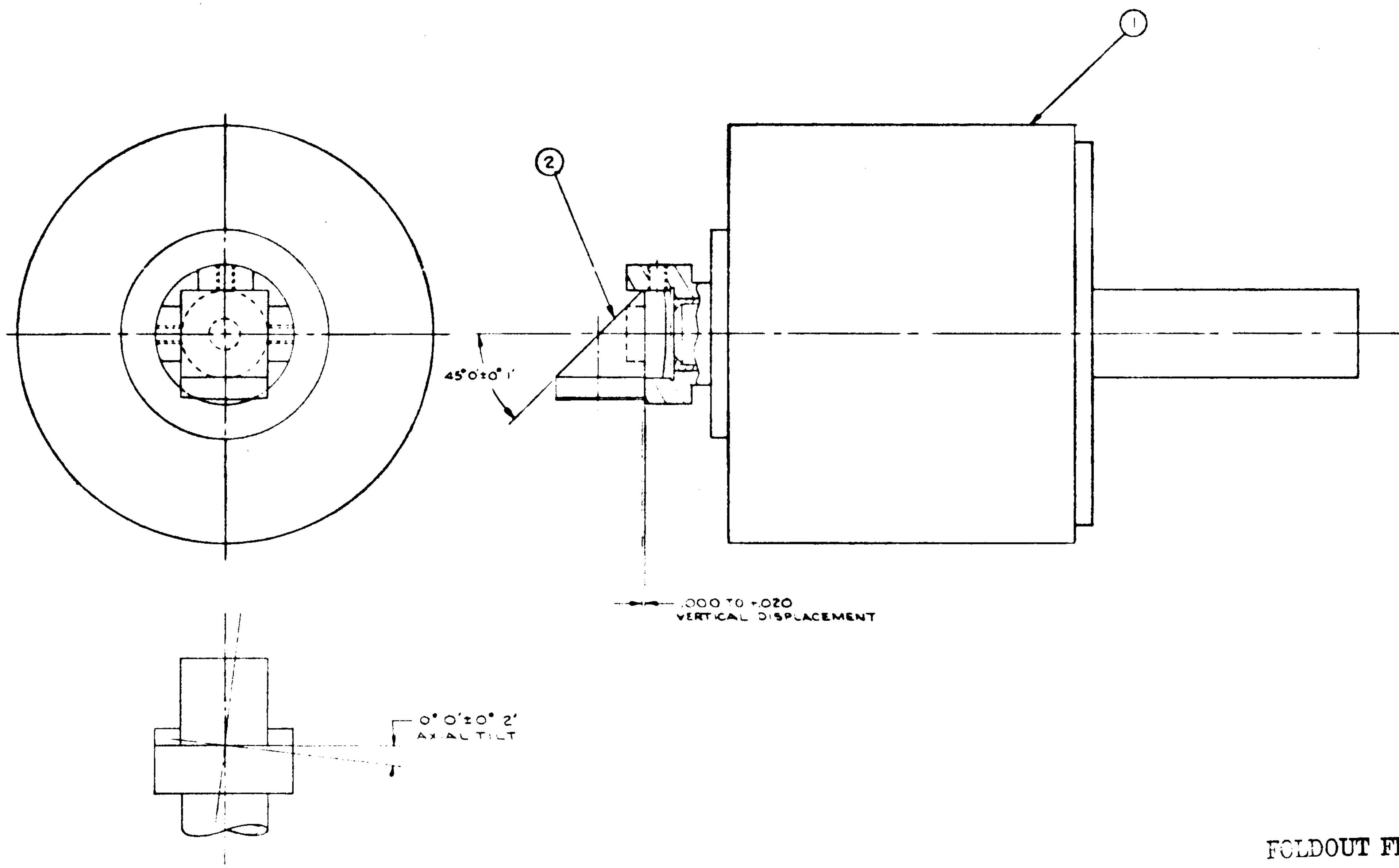
NEXT ASSY	USED ON
4045	

FOLDOUT FRAME 1

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	DELETED ITEM 3, ITEM 1 WAS 4037	8-4-72	[illegible]

NOTES: UNLESS OTHERWISE SPECIFIED:

1. COMPLETED ASSEMBLY MUST WITHSTAND ENVIRONMENTAL TEMPERATURE RANGE OF -125°C TO +150°C THEREFORE CLEARANCE OF .0007 INCH MUST BE MAINTAINED BETWEEN METAL AND GLASS WHERE GLASS IS CAPTIVE. DO NOT FILL THIS SPACE WITH CEMENT.
2. CEMENTING MATERIAL AND TECHNIQUE MUST BE SUCH THAT OPTICAL ASSEMBLY WILL REMAIN INTACT AND WITHIN TOLERANCES SPECIFIED WHEN SUBJECTED TO THE FOLLOWING ENVIRONMENTAL TESTS, SEPARATELY OR IN COMBINATION.
   a. TEMPERATURES FROM -125°C TO +150°C
   b. VIBRATION FROM 5 TO 2000 Hz @ 15g.
   c. HIGH VACUUM.
3. CEMENTING MATERIAL, WHEN CURED MUST BE FREE OF VOLATILE COMPONENTS WHICH MIGHT CONTAMINATE OPTICAL OR OTHER COMPONENTS OF THE SYSTEM.



4045

A

REQ'D	PART NO	ITEM	DESCRIPTION	SYM
		5		
		4		
		3		
1	3031	2	LENS ASSEMBLY	
1	4079	1	ENCODER ASSEMBLY	A001

LIST OF MATERIALS

FOLDOUT FRAME 2

UNLESS OTHERWISE SPECIFIED
2 PL TOL 3 PL TOL ANGLES
AS NOTED

MATERIAL

FINISH

DRAWN BY MACKENZIE DATE
CHECKED
ENGINEER
APPROVED
APPROVED

DO NOT SCALE DWG.

EMR Schlumberger EMR AEROSPACE SCIENCES COLLEGE PARK, MARYLAND

ENCODER & TELESCOPE ASSY
P.A.S.

CODE IDENT NO SIZE
06141 D 4045
SCALE SHEET OF

5051
NEXT ASSY USED ON

FOLDOUT FRAME 1

2.1.2 Scanner Optics

The scanner optical system is in essence a small telescope consisting of an objective lens of 60 mm focal length, a solid state photodiode light sensor and a field stop aperture limiting the field of view to a cone of 0.7° diameter, as shown in figure 2-1. The telescope rotates through 360 degrees to scan a full circle, and a shaft angle encoder reads out in digital data the direction in which the scanner is viewing at any given instant. In designing this combination it was found that a number of virtues could be realized by integrating the telescope into a single unit with the encoder with the axis of the telescope coincident with the axis of rotation of the encoder and a 90 degree prism in front of the objective lens, as shown in figure 2-2.

The principle virtues of this configuration are:

1. It is physically very compact.
2. The angular moment of inertia is minimized.
3. The number of moving parts is minimized to one.
4. The encoder disc is integral with the rotating telescope reducing the possibility of backlash or alignment error.

However to accomplish this it was necessary to specially design the entire encoder to accomodate the large diameter hollow shaft.

The most critical optical components of the system are the optical dome (EMR drawing No.3030) which acts as a window in the pressurized case and the correction lens, prism and objective lens which are cemented together into a single unit (EMR drawing No. 3031) which cements into the top of the encoder shaft. These elements are all in the optical path, and are all exposed to direct space sunlight and so were made of optical grade Suprasil fused silica. All of these elements were ground polished to high optical standards. Cleanliness and freedom from imperfections are particularly important on the surfaces of the dome to minimize scattering of light from these surfaces into the scanner. While the purpose of the dome is to act as a window, it inevitably also acts as a negative cylindrical lens. To correct for this effect, a positive cylindrical lens is the first element of the prism lens assembly. From a ray diagram and a first order lens calculation, the required radius was calculated to be 66.4 mm.

The prism is a simple 90° prism, and the objective lens is a single element plano convex of 60.0 mm focal length. The axial chromatic aberration was calculated and found to be negligible for this application.

The entrance aperature of the scanner is a knife edged ring pressed into the top of the encoder shaft just below the objective lens. It has an inside diameter of 4.0 mm, limiting the effective light gathering area of the objective lens to 12.6 mm^2. This value was chosen as a compromise between two limitations.

1. When the scanner images the sun directly onto the detector, there must be no permanent damage.

2. When the scanner images a threshold intensity target (first quarter moon from earth) onto the detector, the signal must be sufficiently above the noise for reliable detection.

The first of these two requirements is the more simply determined. The manufacturer of the HP 5082-4231 recommends a maximum input power of 40 mw continuous. One solar constant in space is 140 mw/cm^2.

The maximum permissable entrance aperture area is therefore 29 mm^2. To provide some safety factor it was considered desirable to keep the entrance aperture area a factor of two below this limit. Two other favorable factors are 1) it was possible to provide some heat sinking of the case by epoxy mounting it to a fiberglass and epoxy holder, and 2) the detector will be exposed to the sun only for brief intervals (never to exceed 40 seconds).

Working with this as the upper limit of size for the entrance aperture, an estimate was made of the input power at the detector when a threshold level target is imaged on it. Taking the quarter moon as viewed from earth as the threshold target, we can make the following simplification: The moon seen from earth subtends less than the 0.7 degree field of view of the scanner. We can therefore simply consider the irradiance of the moon at the earth as we did with the sun rather than be concerned with the surface brightness of the moon. For a full moon, the illuminance at the earth's surface is 0.267 lm/m^2 and for a quarter moon about 1/8 of that value or 3.3×10^{-2} lm/m^2. Assuming the spectral distribution is similar to that of sunlight, and using the solar illuminance value of 1.3×10^5 $lumen/m^2$ at the earth's surface, we calculate an irradiance from the quarter moon in near earth space as

$$\frac{3.3 \times 10^{-2}}{1.3 \times 10^{5}} \times 140 \ mw/cm^2 = 3.5 \times 10^{-5} \ mw/cm^2.$$

Multiplying this by the 12.6 mm^2 area of the 4.0 mm dia entrance aperture, we have a radiant input signal at the detector of 4.4×10^{-9} watts. This compares with a noise equivalent power (NEP) of 5.7×10^{-14} watts $Hz^{-1/2}$. For the required response of 10 K Hz, the signal is roughly 3 orders of magnitude above the noise. At 7000 A wavelength, the photodiode sensitivity is 0.4 $\mu A/\mu W$ so 4.4 nanowatts input will produce about 1.7 nanoamps signal.

Because of lack of data on the true spectral distribution of moonlight, no attempt was made to calculate an integrated spectral response of the detector. As a result, the above calculations have been taken only as a first approximation which shows the probable adequacy of the signal. Rather than attempting to define the light levels, optical parameters and characteristics of the detector any more precisely, the empirical approach was adopted to prove the feasibility and to set the detection threshold.

A simple photometric instrument was built using the same optical system and detector as planned for the scanner. The photodiode output was amplified in a D. C. coupled amplifier and read out on a panel meter with a choice of a few ranges. The instrument was calibrated directly by measuring the response to the full moon and quarters moon from the earth's surface on relatively clear nights. The quarter moon signal was found to be about 1/8 that from the full moon and was taken as the working threshold level. An equivalent laboratory source was made by illuminating a small diffusely reflecting disc such as the end of a piece of chalk with a light level such that it produced the same signal from the photometer as did the quarter moon. All of these measurements were made with the source subtending less than the 0.7 degree field of view of the scanner optics. With a 0.5 degree source, it was not difficult to determine when the source was entirely within the field of view. Of course when the secondary source brightness was set using the photometer and then the secondary source was used to calibrate a scanner, it was necessary to use the same working distance from source to objective lens.

The signal levels determined in this way were adequate but not generous, and required very careful design of the following high gain D. C. coupled amplifier to avoid problems such as thermal drift.

2.2 Mechanical Functions

The principle mechanical functions required in the operation of the PAS system can be subdivided into two categories:

1) Dynamic functions - contributing to the step motion of the scanner (EMR assembly drawings 5051, 5052, and detail drawings 2014, 2029, 2030, 3034, 3035, 3036, 3043, 4079, 4038, 4039).

2) Static functions - mounting of the optical and electronic components and enclosing them in a sealed case (scanners only) (EMR drawings 5052, 7024, 5019, 4064, 3037, 3033, 3032, 2026, 2013, 2010, 2012).

2.2.1 Scanner Mechanism

The dynamic system consists of the stepper motor, gear train and encoder, together with the gear shafts and bearings. It was designed to provide a stepwise advance of the scanner in steps of 1/512 revolution in single steps or in a train of 512 steps at a rate of 100 steps per second. Since the scanner optics is mounted directly to the shaft of the shaft position encoder, it is required that the entire encoder shaft assembly be accelerated and decelerated to follow this step motion at the rate of 100 steps per second with a precision of not less than $\pm$ 6 arc minutes, and with a minimum of power dissipation in the motor. Through a combination of empirical design, calculation and testing, a drive configuration was arrived at which uses a 45° size 11 permanent magnet stepper motor to drive the encoder through a 64 to one reduction gear train. The motor size was limited by the overall volume and power dissipation limits of the system. For this size of motor, 45 degrees is the smallest step angle available. The motor used was a standard Kearfott 28 volt stepper motor, model CRO-0193-75 modified only by the substitution of dry lubricated bearings (Barden Bartemp lubricant) suitable for operation in a vacuum if necessary. The standard 28 volt windings were left unchanged. Thus, when the motor is operated at 18 volts, the current drawn and the output torque are reduced proportionately. The stall torques for the motors used were measured to be 1.0 oz-in $\pm$ 10% when energized at 18 volts, compared with a specified 1.8 oz-in at 28 volts. The power drawn by the motor driver circuit is typically (18V) (120 ma) = 2.2 watts. The power drawn is independent of load but is altered by temperature (25% higher at -20°C, 25% lower at $+ 60^{\circ}$ C due to changes in the motor winding resistance from the nominal room temperature value of 440 ohms at 20° C.

The requirement for an overall reduction ratio of 64:1 in the gear train was met by using three steps of 4:1 each. This again was a compromise between minimizing the number of steps to reduce backlash and keeping the physical size within the volume available. All of the gears in the gear train are 120 pitch precision gears mounted on exact pitch diameter centers $^{+.0002}_{-.0000}$ tolerance). The motor pinion gear is stainless steel. All others are hardened aluminum, chrome plated and reground on the wear surfaces. The high precision is necessary to minimize backlash, friction and wear. To further reduce backlash, the final drive gear is split and spring loaded. The entire gear train is lubricated with a small amount of Krytox grease applied to the gear teeth. As described in the life test report, thebacklash in this gear train was measured to be 1.8 arc minutes at the start of the test and 4.05 arc minutes at completion of the test. All gears except the last are pinned to their shafts with spiral spring pins. The final drive gear is held to the encoder shaft with a standard gear clamp.

The bearings used are dry lubricated standard precision instrument bearings with a life expectancy many times the 9000 hour projected operating life of the scanner.

2.2.2 Static Mechanical Functions

The most critical static mechanical functions are in the scanner. All of the moving components of the motor - gear train - encoder assembly must be held in very precise alignment throughout shock, vibration, or temperature variation. All of these components are mounted to a pair of precision gear plates which fit together to form a single rigid unit. The standoffs which separate the plates are integral with the upper plate which was milled from a solid block. These standoffs are pinned to the lower plate to eliminate any relative motion between the two gear plates. The entire gear plate assembly is aluminum, as are the gears, so that thermal expansion and contraction will not change the mesh clearance of the gears.

The most critical optical components - the prism, lens, and field stop aperture are all rigidly mounted to the one piece encoder shaft. The optical detector, however cannot be allowed to rotate, and so is mounted to the lower gear plate very close to the end of the encoder shaft. The alignment is critical only to within $\pm$ .005 inches and is easily maintained by the rigidity of the frame. The five small electronic boards are also mounted to the frame for convenience.

The case consists of a top and a bottom which mate at an O-ring sealed flange which is parallel to the bottom mounting surface of the scanner. The case top and bottom were both milled from solid aluminum to provide a case with the highest possible strength to weight ratio, and freedom from vacuum leaks. The gear plate assembly fits into the lower half case and is held down to three integrally milled standoffs by three screws through the lower gear plate. This rigidly supports the gear plate assembly to the case while isolating it from any possible distortion of the case.

Aside from the joint between the two case halves, the case is penetrated at 5 other places - the optical dome, the pump and fill tube, the two feedthrough terminals for the sun slit wires and the 29 pin electrical connector terminal. The optical dome is sealed to the case with an RTV silicone rubber compound selected for its flexibility at low temperatures. The dome is captive in the aluminum case and would be subject to considerable stress due to contraction of the aluminum at low temperature if the RTV lost its flexibility.

All of the other penetrations of the case are sealed with solder joints. The case halves were all gold plated around these openings to insure solderability. The fill tube is of 1/8 inch O D copper tubing soft soldered into the case, to be pinched off after pumping and filling is completed. The two terminals and the 29 pin connector are glass insulated with a metal shell which is soldered directly to the case. For the flight scanners these components were soldered to the case in an oven before any other assemblies were mounted to the case. For the prototype scanner, however, the 29 pin connector was wired before it was mounted in the case, so it was mounted with epoxy rather than solder.

The seal between the case halves was originally made using a 1/16 inch diameter O-ring of silicone rubber. However, this was found to be too permeable to the helium tracer gas used to leak test the case, so the silicone O-ring was replaced with one of Viton.

The mechanical structure of the electronics module is relatively simple. The preformed aluminum frame holds No. 1 board by means of a number of pressed dimples in the aluminum frame. No. 1 board is relatively heavy - 1/16 inch thick glass reinforced epoxy. The other five boards are stacked and held to No. 1 board by means of five screws and sets of spacers - one at each corner and one in the middle of the stack to prevent diaphragming. Soft sheet urethane foam is also placed between the boards to further damp any vibration and to prevent potting foam from entering the interboard spaces in case depotting is ever required.

The interboard wiring is brought from each board to a bundle which runs along one edge of the stack of boards to the connector, or to the other boards. This design allows separation and inspection of the individual boards after the interboard wiring is complete. When the screws and spacers are removed, the boards can be opened out like the pages of a book, using the interconnecting wire bundle as a hinge.

2.3 Encoder Design

The shaft position encoder is a major component or subassembly of the PAS scanner head which is so central to the design of the scanner that it deserves separate discussion. The basic function of a shaft position encoder is simply to translate the angular position of a shaft into an electronic read out. In the PAS scanner, however, the encoder shaft is also used as the housing of the scanner optical system, and as the final shaft of the gear train which advances the scanner. This has the advantages of making the system more compact, reducing the angular moment of inertia of the rotating assembly and eliminating the possibility of backlash or misalignment between the pointing direction of the scanner and the angle registered by the encoder. However, it also necessitated the design of an encoder specifically for this application.

The encoder used in the PAS was built by Baldwin Electronics to EMR's specifications and outline dimensions as shown in drawings 4037 and 4045. It is a 9 bit optical encoder which uses light emitting diodes and phototransistors to read out the angular position of the optical disc. The optical disc is made of thin sheet acrylic plastic and is imprinted with 9 gray code tracks. In the original design the disc was simply bonded to a flange on the shaft with epoxy. However, the discs in two encoders came loose during acceptance testing - one in vibration, one in thermal cycling during the life test. The design was modified and all encoders were subsequently reworked so that the disc is clamped between two metal flanges on the shaft and secured with three spiral pins which pass through the flanges and the disc itself.

The grating against which the disc is read is mounted to the encoder case, spaced a few thousandths of an inch above the disc. It is completely opaque except for the nine precisely positioned slits through which the nine tracks of the disc are read. The phototransistors are mounted on a circuit board immediately above the grating, and the 5 LED's are mounted on a circuit board below the disc. The driver circuit for the LED's is external to the encoder. One stage of gain is provided however on the outputs of the phototransistors. A pair of SM54L04 I. C. amplifiers mounted on an additional board provides separate amplification for each of the nine output channels to bring the signals up to TTL levels.

The thin walled, hollow encoder shaft turns in a spring loaded pair of dry lubricated precision bearings, one at each end of the case.

In addition to the disc mount problem, two other design weaknesses were encountered that should be improved if any additional encoders of this design are built. 1) Where the output wires attach to the first P. C. board, there was not adequate strain relief provided, and some wires broke at the solder terminals from repeated flexing when the encoder was opened several times for rework.

Once the case was fully assembled, the wires were held tight, so this appears to be a problem only when rework is required. It is then necessary to resolder the wires to be sure they are in tact.
2) The second problem was one of marginal signals on some tracks, particularly at temperature extremes. This resulted from the manufacturer's use of excessively low shunt resistors on the outputs of some phototransistors to make a fine adjustment of the switching point. From our experience, the shunt resistors should not be less than about 50K Ω, and the required accuracy should be obtained by disc and grating alignment.

2.4 Electronics Design

The basic electronic functional units of the PAS are shown in the PAS System Block Diagram, Figure 2-3. The units enclosed in the dashed boxes at the right hand side are components for the two identical scanner heads. An effort was made to minimize the portion of the electronics in the scanner heads so only those functions were included for which there was a real necessity. All other functional units were incorporated into the six boards of the electronic module.

Included in the scanner head are the scanner and sun slit photo detectors and preamplifiers, the encoder LED strobe generator, the motor driver and the heater control circuit. Each of these circuits is closely associated with a fundamental function in the scanner and must be mounted in the scanner head to minimize the possibility of crosstalk or interference. The sun slit and scanner preamps are high gain, high input impedance circuits, very susceptible to pickup of interference signals. Both require mounting as close as possible to the photo detectors, and the scanner preamp which has the higher gain was found to require extensive shielding. The motor driver and encoder LED strobe generator circuits both generate high current pulses and so were placed in the scanner head to avoid running these current pulses through the long interconnection cables from the electronics to the scanner head. Filter capacitors in both the 5 volt and 18 volt line are included in the scanner head. As a further precaution against interference, the two sensitive preamps are powered from the 12 volt line which is entirely separate and is not used to power anything else.

14-9

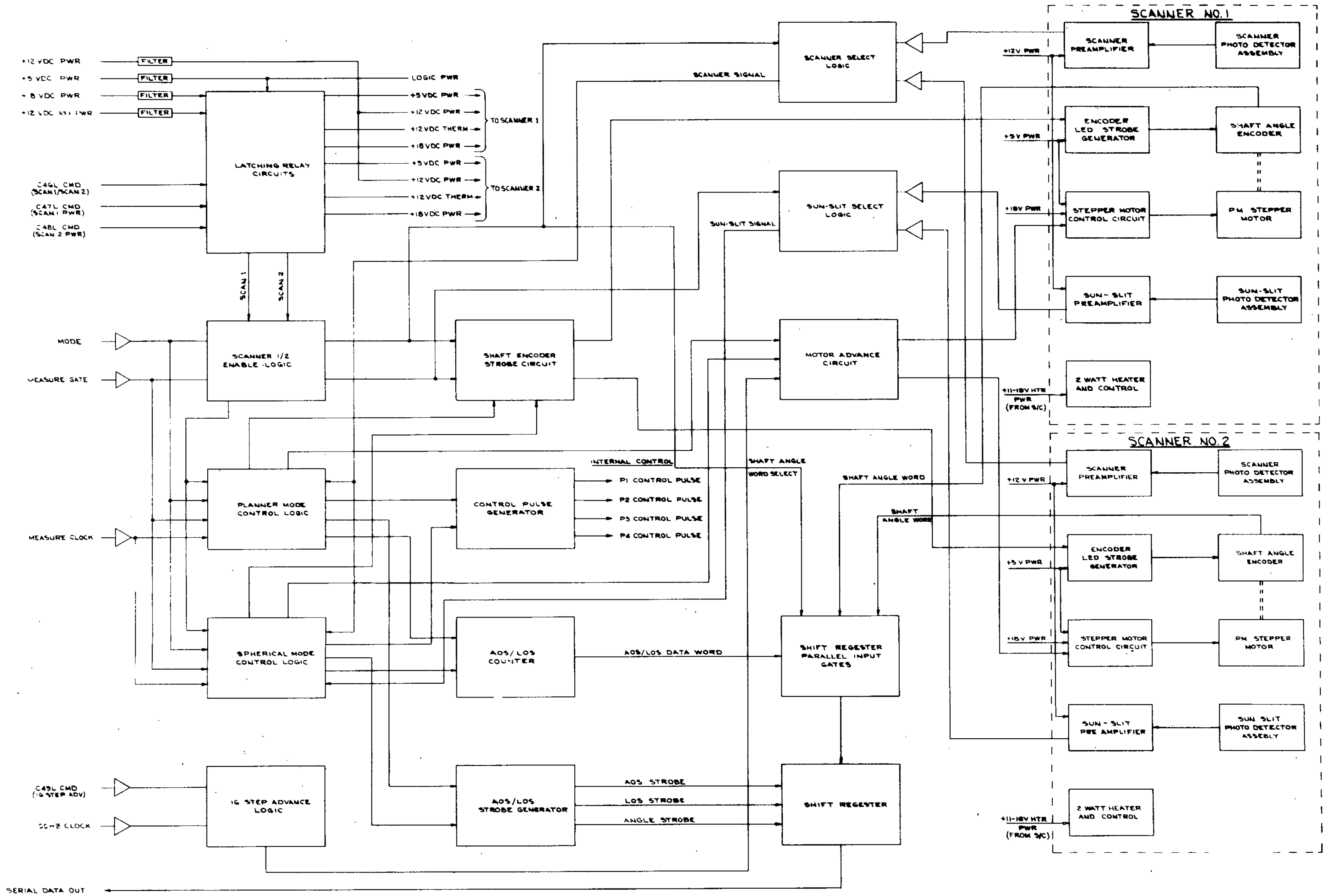


FIGURE 2-3 PAS SYSTEM BLOCK DIAGRAM

All of the remaining circuitry as shown in the functional block diagram is located in the electronics module. Board 1 carries the command relays and input conditioning circuits. Board 2 is the scanner select and pulse generator circuits. Board 3 is the mode control. Board 4 is the AOS/LOS strobe generator. Board 5 is the data register and AOS/LOS counter. Board 6 contains the encoder zero and boom blanking circuits for the two scanners. In all of these circuits the logical functions are implemented using LPTTL (low power transistor - transistor logic). For power switching and non volatile command storage latching, relays are used.

Descriptions of the operation of the scanner and electronic module circuits are included in the following sections. References are made to the scanner and electronic module logic diagrams and timing diagrams, Figures F-1 through F-14 included in appendix F.

2.4.1 Scanner Electronics

The following circuits are contained in each of the two scanner heads: Stepper Motor Control circuit, Encoder LED Strobe Generator, Scanner Photo detector -- preamplifier, Sun Slit Photo detector -- preamplifier and Scanner Heater and control circuit.

1) Stepper Motor Control - This circuit shown in Figure F-1 drives the permanent magnet stepping motor one 45° step each time a $\overline{\text{MOTOR ADV SIGNAL}}$ low-level pulse is received. A set of motor windings are energized for the duration of this 12 millisecond wide pulse

and the motor advances one step and stops. At the conclusion of the pulse a 4-bit binary counter is incremented by the signals positive trailing edge so that the following pulse drives a different set of windings and the motor advances one step further in the same direction.

The $\overline{\text{MOTOR ADV SIGNAL}}$ input, inverted by gate U2A, enables gates U1A, U1C, U1B, and U2B which decode the output of the 4-bit binary counter, U3A and U3B, enabling the 4 motor winding driver circuits two at a time. Gate U1A is enabled when the counter is binary 00 and the $\overline{\text{MOTOR ADV SIGNAL}}$ becomes a low level turning on drivers 4 and 1. When the $\overline{\text{MOTOR ADV SIGNAL}}$ returns to a high level gate U1A and drivers 1 and 4 are disabled and the counter is advanced to binary 01. When the next $\overline{\text{MOTOR ADV SIGNAL}}$ low level pulse is produced, gate U1C is enabled activating drivers 1 and 2. At the conclusion of the signal the gate and drivers are disabled and the counter is advanced to binary 10. The third $\overline{\text{MOTOR ADV SIGNAL}}$ low level pulse enables gate U1B activating drivers 2 and 3. When the signal returns to a high level the gate and drivers are disabled and the counter is advanced to 11. The fourth low level signal enables gate U2B and activates drivers 3 and 4. When the signal returns to the high level the gate and drivers are disabled and the counter is advanced to binary 00. The fifth low level $\overline{\text{MOTOR ADV SIGNAL}}$ repeats the action of the first signal. Between steps the motor driver +18 volt power is disabled to conserve power. Motor detent is achieved by the permanent magent armature in the motor.

2) Encoder LED Strobe Generator - This circuit shown in Figure F-1 is used to drive the light emitting diodes in the shaft angle encoder assembly so that the output signal levels are enabled to the electronic module. The encoder LED's are strobed to conserve power since about 1.2 amps are required to produce sufficient light output for readout. A 60 microsecond wide positive pulse, ENCODER STROBE,

is used to activate the driver whose output transistor, Q3, saturates grounding the STROBE return from the shaft encoder. A 220 microfarad capacitor in the STROBE POWER input line supplies power for the 1.2 amp, 60 microsecond pulse. Light from the LED's saturates phototransistors on the opposite side of the optical encoder disk causing inverter outputs to become high level signals. When light is blocked by the encoder disk grey code pattern a phototransistor remains open and the inverter output stays at a low level. Because of the slow response time of the phototransistors, a 50 microsecond minimum strobe signal is required to establish the 9 grey-code signal levels at the inverter outputs. When the LED strobe pulse is removed the phototransistors maintain their state for at least 10 microseconds before returning to their normal open condition. During this time the encoder data is sampled by the circuits in the Electronic Module.

3) Scanner Photodetector and Preamplifier - This circuit, shown in Figure F-2 uses a PIN photodiode and 2-stage operational amplifier to convert light from the scanner optical system to a high level analog signal for transfer to the electronics module. The amplifier is powered by a single +12 volt power input from which + 5 volt and +10 volt zener regulated power sources are derived. The operational amplifiers are powered by +10 volt and ground with a +5 volt floating common.

The first stage of the amplifier is a high input impedence (5 megohm) differential current-to-voltage amplifier with a gain of 30 millivolts/nanoamp. A 108 op amp is used here because its very low bias currents prevent excessive thermal drift with high input impedence. The output of the first stage is a +5 volt signal referenced to system ground which is reduced to a lower level as the light level on the photodiode increases. The second stage is an operational amplifier inverter with a voltage gain of 310. A 725 op amp is used here to provide a high gain over a frequency range from D. C. to 100 KHz. Its input impedence is sufficiently low (2.0 Kohms) to prevent excessive thermal drift. The output signal from the second stage, SCANNER SIGNAL is normally a +5 volt level which would increase to +8 volts as the photodiode light level increased. This output signal is offset, however, during the calibration procedure by a positive offset signal from the +10 volt source which is applied to the summing point of the last stage. This is done by exposing the photodiode to the threshold light level where switching from dark to light is desired. This increases the SCANNER SIGNAL level beyond +5 volts. The positive offset signal gain is adjusted by selecting a series resistor and resultant circuit gain whereby the SCANNER SIGNAL is reduced to +5.6 volts. This value is the switching threshold voltage for the input conditioning buffer located within the electronic module. When the threshold light level is removed from the photodiode the SCANNER SIGNAL will drop to a level of about +2 to +3 volts.

4) Sun Slit Photodetector and Preamplifier - This circuit, shown in Figure F-2 uses a PIN photodiode, differential current-to-voltage operational amplifier threshold detection circuit and inverter to convert the light level on the photodiode to a bi-level for transfer to the electronic module. The amplifier has a gain of -10.2 volts/microamp and an input impedence of 2.0K. A threshold circuit consisting of zener diode CR4 and the base emitter junction of transistor Q2 requires an amplifier output of more than +5.8 volts before transistor Q2 is turned on. With the threshold light level applied to the photodiode the operational amplifier balance resistors R16 and R17 are adjusted from their 50 kohm nominal values to cause the SUN SLIT SIGNAL output of transistor Q2 to be between the high and low levels.

5) Scanner Heater and Control Circuit - This circuit uses a thermistor bridge circuit and an operational amplifier to drive a transistor switch into saturation when the scanner temperature approaches 0 degrees Centegrade. The circuit gain is set so that there is a 5 to 10 degree lag between the time the heater starts turning on and when the full 2 watts dissipation occurs.

2.4.2 Electronic Module

This unit contains the remainder of the PAS System electronic circuits. It interfaces with the two Scanners and the spacecraft command and data systems. The spacecraft interface consists of the following signals:

PAS INPUT SIGNALS

MODE. This signal is a high level for planar mode operation and a low level for spherical mode operation.

MEASURE GATE. This signal is a high level for 10.24 or 40.96 seconds and a low level signal for 5.12 seconds. The rise time initiates the start of a measure cycle.

MEASURE CLOCK. This signal is a square wave with a spacecraft selected frequency of 400, 100, or 25 Hz in spherical mode and 100 Hz in planar mode. It is used to time AOS and LOS measurements.

100-Hz CLOCK. This signal is a square wave which is used to advance the scanner 16 steps in the spherical mode.

COMMAND C46L. This 0.5 second positive pulse toggles the Scanner Select latching relay between the Scanner 1 select and Scanner 2 select states.

COMMAND C47L. This 0.5 second positive pulse toggles the Scanner-1 Enable latching relay between the enable and disable states.

COMMAND C48L. This 0.5 second positive pulse toggles the Scanner-2 Enable latching relay between the enable and disable states.

COMMAND C49L. This 0.5 second positive pulse advances the scanner 16 steps in the spherical mode.

READOUT CLOCK. This signal consists of a group of 28 inverted square wave pulses occurring at a 200 Hz rate and starting just after the MEASURE GATE becomes a low level signal.

PAS OUTPUT SIGNALS

SERIAL DIGITAL DATA. This signal consists of a sequence of high or low level pulses occurring after each READOUT CLOCK positive transition and representing the binary status of the 27-bit PAS data word. The signal is a low level at all other times.

ANALOG FLAG STATUS. A 6-bit binary encoded analog signal containing relay status flags.

The following sections describe the operation of the electronic module circuits for spherical and planar modes of operation.

1) Input Conditioning Circuits - These inverter circuits, shown in Figure F-3 are used to match the output characteristics of the input signals from the spacecraft and the sun slit and scanner signals from the two scanners to the input characteristics of the LPTTL logic used in the electronic module. Where possible, threshold voltage points are designed to provide a maximum amount of noise immunity.

2) Latching Relay Circuits - Three latching relay circuits shown in Figure F-4 are used in PAS to provide non-volatile storage

for the C46L, C47L and C48L pulse commands from the spacecraft. Each of the three relay circuits are designed to toggle from one position to the other each time a command pulse is repeated. Power for the relay circuits is furnished by the +12 volt Relay Power input from the spacecraft.

A 6-bit R-2R ladder network is used to encode the status of the three relays into a 0.0 to +5.12 volt analog signal which is furnished to the spacecraft telemetry encoder. The code format is:

Bit No.	Command	High Function	Low Function
0 (LSB)	Spare	Always high	-
1	Scanner Select (C46L)	Scanner 2	Scanner 1
2	Scanner 2 Able/Disable (C47L)	Able	Disable
3	Scanner 2 Able/Disable (C48L)	Able	Disable
4	Spare	Always high	-
5 (MSB)	Spare	Always high	-

The latching relays control the operation of the system as described below.

1. Scanner Select (C46L) - This relay provides a high level logical signal when Scanner 2 is enabled (SCAN-2 SELECT). The signal is low when Scanner 1 is selected. The relay also furnishes +12 volt Relay Power to enable either the Scanner 2 thermistor or the Scanner 1 thermistor through 1 amp fuses.

2. Scanner No. 1 Enable/Disable - This relay furnishes +5 volt and +18 volt power to Scanner No. 1 when enabled. It also provides a logic signal (SCAN-1 +5V IN) which is high when Scanner No. 1 is enabled.

3. Scanner No. 2 Enable/Disable - This relay furnishes +5 volt and +18 volt power to Scanner No. 2 when enabled. It also provides a logic signal (SCAN-2 +5V IN) which is high when Scanner No. 2 is enabled.

3) Scanner Select Logic - This circuit consists of the Scanner 1/ Scanner 2 Enable Logic, Scanner Select Logic and Sun Slit Select Logic shown in the PAS System Block Diagram, Figure 2-3. The logic circuit is shown in Figure F-5 and consists of a group of Nand-Nor gates which select the input/output signals for one of the two scanners as determined by the status of the SPHERICAL MODE, SCAN-2 SELECT, $\overline{\text{SCAN-1}}$, and $\overline{\text{SCAN-2}}$ input signals. Figure 2-4 shows the program for this circuit.

4) Power-Up Reset - This circuit, shown in Figure F-5 is used to reset specific storage elements when the power is being turned-on so that the system will be ready for normal operation. It consists of an inverter whose input is held at a low level and output at a high level by a slowly charging capacitor as the system power voltages rise to their operating levels. Several milliseconds after power is up the capacitor voltage reaches the inverter's threshold level and the output switches to a low level disabling the circuit. The diode provides a fast discharge path for the capacitor during power turn-off.

5) Control Pulse Generator - This circuit, shown in Figure F-5 consists of single-shot multivibrator U102, flip-flop U204B and 18 delay inverters, U215D through U215F. A signal timing diagram is given in Figure 2-5. The circuit is activated in the spherical mode by the $\overline{\text{SM-PULSE GEN ENABLE}}$ signal and in the planar mode by the $\overline{\text{PM PULSE GEN ENABLE}}$ signal. Each time a negative transistion occurs on either of these signals the single-shot multivibrator generates a positive pulse, P1, whose pulse width is nominally 60 microseconds.

Figure 2-4 SCANNER SELECT CIRCUIT PROGRAM

PAS MODE	INPUT FUNCTION		OUTPUT FUNCTIONS	
Description	Signal	Status	Signal	Status
1. Spherical Mode with Scanner No. 1 operating.	SPHERICAL MODE SCAN-2 SELECT (C46L) SCAN-1 (C47L) SCAN-2 (48L)	High Level Low Level Low Level Low or High Level	SCAN SIGNAL PAS SUN PULSE SCAN-1 ENC PWR STROBE SCAN-2 ENC PWR STROBE SCAN-1 MOTOR ADV SCAN-2 MOTOR ADV	SCAN-1 SIGNAL SCAN-1 SUN PULSE Enabled Disabled Enabled Disabled
2. Spherical Mode with Scanner No. 2 operating.	SPHERICAL MODE SCAN-2 SELECT (C46L) SCAN-1 (C47L) SCAN-2 (C48L)	High Level High Level Low or High Level Low Level	SCAN SIGNAL PAS SUN PULSE SCAN-1 ENC PWR STROBE SCAN-2 ENC PWR STROBE SCAN-1 MOTOR ADV SCAN-2 MOTOR ADV	SCAN-2 SIGNAL SCAN-2 SUN PULSE Disabled Enabled Disabled Enabled
3. Planar Mode with Scanner No. 1 operating.	SPHERICAL MODE SCAN-2 SELECT (C46L) SCAN-1 (C47L) SCAN-2 (C48L)	Low Level Low or High Level Low Level High Level	SCAN SIGNAL PAS SUN PULSE SCAN-1 ENC PWR STROBE SCAN-2 ENC PWR STROBE SCAN-1 MOTOR ADV SCAN-2 MOTOR ADV	SCAN-2 SIGNAL SCAN-2 SUN PULSE Disabled Enabled Disabled Enabled
4. Planar Mode with Scanner No. 2 operating.	SPHERICAL MODE SCAN-2 SELECT (C46L) SCAN-1 (C47L) SCAN-2 (C48L)	Low Level Low or High Level High Level Low Level	SCAN SIGNAL PAS SUN PULSE SCAN-1 ENC PWR STROBE SCAN-2 ENC PWR STROBE SCAN-1 MOTOR ADV SCAN-2 MOTOR ADV	SCAN-2 SIGNAL SCAN-2 SUN PULSE Disabled Enabled Disabled Enabled
5. Planar Mode with Scanners No. 1 and No. 2 operating alternately.	SPHERICAL MODE SCAN-2 SELECT (C46L) SCAN-1 (C47L) SCAN-2 (C48L)	Low Level Low or High Level Low Level Low Level	SCAN SIGNAL PAS SUN PULSE SCAN-1 ENC PWR STROBE SCAN-2 ENC PWR STROBE SCAN-1 MOTOR ADV SCAN-2 MOTOR ADV	Alternate Mode 3 - Mode

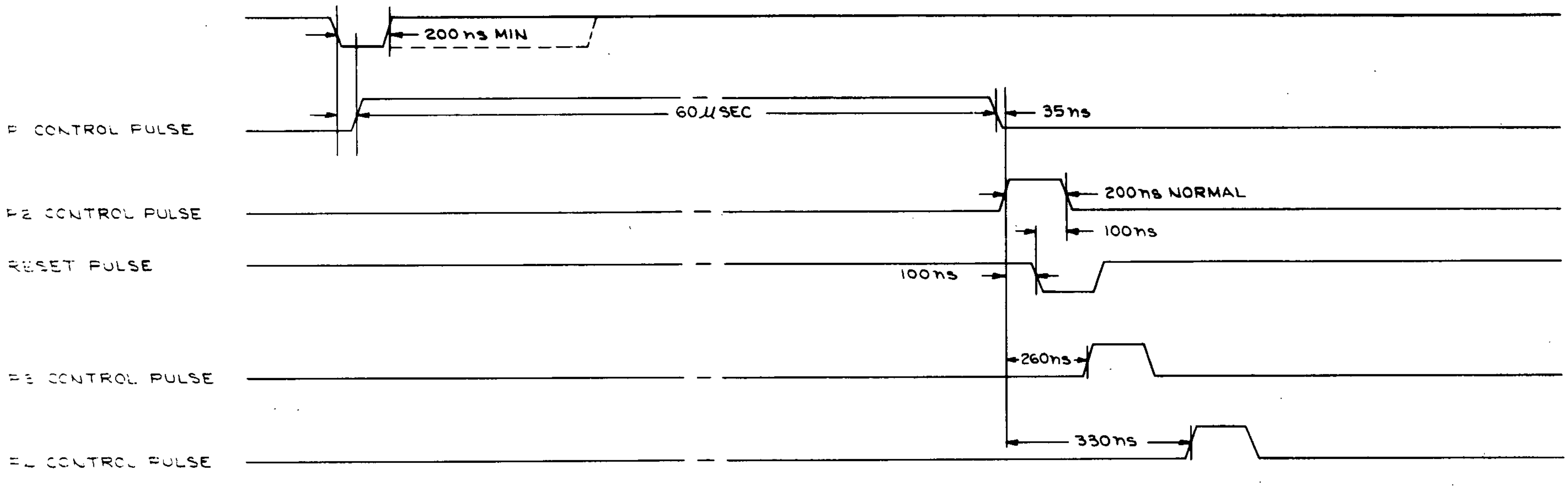


FIGURE 2-5 CONTROL PULSE GENERATOR TIMING DIAGRAM

This pulse is used to activate the shaft encoder LED strobe generators in the scanners. The P1 signal trailing edge triggers a single-shot generator consisting of flip-flop U204B and delay inverters U215D, U215E and U215C, producing a positive pulse, P2, whose pulse width, as determined by the propagation delays of the three inverters and the Q-reset delay of the flip-flop, is 200 ms. The P3 signal is similar to the P2 signal except that it is delayed 260 ms by 8 inverters. The P4 pulse is delayed 330 ms from P3 by 10 inverters. The P2 pulse is used to strobe the shaft-encoder angle (9 level grey code) into the Shift Register and Boom Blank and Encoder Zero Circuits. The P3 signal is used to disable the Planar Mode Control Logic at the conclusion of a measure cycle. The P4 signal is used to increment the AOS/LOS Counter and Stepper Motor Advance Circuit.

6) Stepper Motor Advance Circuit - This circuit, shown in Figure F-5 consists of single-shot multivibrator U101 and Nor gate U211B. The circuit is triggered by the negative transition of any one of the four input signals $\overline{\text{SM MOTOR ADVANCE A}}$, $\overline{\text{SM MOTOR ADVANCE B}}$, $\overline{\text{SM MOTOR ADVANCE C}}$, and $\overline{\text{PM MOTOR ADVANCE}}$. The 12 millisecond wide output signal is transferred through either Scanner 1 select gate U213B to become $\overline{\text{SCAN-1 MOTOR ADVANCE}}$ or Scanner 2 select gate U213D to become $\overline{\text{SCAN-2 MOTOR ADVANCE}}$.

7) AOS/LOS Counter - This circuit, shown in Figure F-6 is a 10-bit binary ripple counter which is made up of flip-flop U520B, U520A, and 4-bit counters U507, and U508. The counter is incremented by either the $\overline{\text{SM INCR CTR (P4)}}$ or the $\overline{\text{PM INCR CTR (P4)}}$ signals through Nor gate U517B. The counter is cleared before the start of each measure cycle by the MEASURE GATE through Nor gate U512C. In the spherical mode the counter is cleared immediately after the AOS and LOS STROBE signals are generated by $\overline{\text{SMCLEAR CTR (P3)}}$.

The clear pulse is followed immediately thereafter by the SM INCR CTR (P4) signal which sets the counter to a binary -1. The timing of these three pulses is critical and delay inverters are provided for the $\overline{\text{SM CLEAR CTR (P3)}}$ signal so that it doesn't interfere with the data transfer. The $\overline{\text{SM INCR CTR (P4)}}$ signal is also delayed to prevent interference with the clear signal. In the planar mode the count is not cleared after the AOS and LOS STROBE signals are generated.

8) Data Selection Gates - This circuit, shown in Figure F-7 consists of 9 sets of Nand-Nor gates whose function is to select data from one of three sources; Scanner 1 shaft angle encoder during spherical mode, Scanner 2 shaft angle encoder during spherical mode or selected data during planar mode for transfer to the Shift Register. The gates are enabled by signals from the Scanner 1/2 Enable Logic.

9) Shift Register - This circuit, shown in Figures F-6 and F-7 consists of a 28 element, parallel-input, serial-output, register which is used to store the sphierical or planar mode data as it is acquired and then transfer the data to the spacecraft data system at the conclusion of each measure cycle. The data formats for the spherical and planar modes are found in Figure 2-6. The shift register has three modes of operation: the serial-shift mode which transfers stored data to the spacecraft, the spherical data storage mode, and the planar data storage mode.

The serial-shift mode begins when the MEASURE GATE changes to a low level signal with the shift register loaded with data. Parallel data-transfer gates to the register are disabled and serial data transfer gates between the outputs and J-K inputs of the register elements are

REGISTER ELEMENT NO.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
ZERO	ANOMOLY FLAG ZERO TARGET=1	AOS COUNT (BINARY)									LOS COUNT (BINARY)							SCANNER ANGLE (GREY)									AOS COUNT
		2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^9

SPHERICAL MODE FORMAT

REGISTER ELEMENT NO.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
ZERO	ANOMOLY FLAG ZERO TARGET=1	AOS COUNT (BINARY)									LOS COUNT (BINARY)									ZERO	ZERO	SCANNER ID SCAN 2=1	SCANNER OFF-ZERO = 1	ZERO	ZERO	ZERO	ZERO
		2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^8	2^7								

PLANAR MODE FORMAT

FIGURE 2-6 SHIFT REGISTER DATA FORMATS

enabled. Parallel data-transfer clock input gates to the register are disabled and serial-shift clock input gates are enabled connecting the $\overline{\text{R/O CLOCK}}$ signal to the clock input of each register element. This spacecraft furnished signal consists of a group of 28 low level pulses occurring at a 200 Hz rate just after the MEASURE GATE becomes a low level signal. Each time the $\overline{\text{R/O CLOCK}}$ returns to the high level the contents of the register are shifted from each element to the next lower element. The DR-0 output which is the SERIAL DIGITAL DATA signal successively transfers the status of each element from 1 to 27 to the spacecraft data system. The J-K input of element DR-27 is always a zero in the shift mode because the AOS/LOS Counter output, CTR-2^9, is reset by the MEASURE GATE low level signal resulting in the serial data being replaced by all zeros at the conclusion of the serial readout.

The spherical data storage mode begins when the SPHERICAL MODE signal is a high level and the MEASURE GATE changes from a low to high level. This disables the serial data-transfer gates and enables the parallel data-transfer gates which transfer spherical mode data from the AOS/LOS Counter and MODE SELECTION GATES to the J-K inputs of the register elements. The serial-shift clock input gates are also disabled and the parallel data-transfer clock gates are enabled connecting the $\overline{\text{AOS STROBE}}$, $\overline{\text{LOS STROBE}}$ and $\overline{\text{ANGLE STROBE}}$ signals to the clock-inputs of specific sections of the Shift Register. When the AOS STROBE signal is generated sometime during the measure cycle the 10 parallel outputs of the AOS/LOS Counter are clocked into elements DR-2, DR-3 to 6, DR-7 to 10 and DR-27 of the register. When the LOS STROBE signal is generated either before or after the $\overline{\text{AOS STROBE}}$, the 7 least significant parallel outputs of the AOS/LOS Counter are clocked into elements DR-11 to 13 and DR-14 to 17. The AOS/LOS Counter is cleared and incremented just after the AOS and LOS strobe pulses are generated to assure that each new count has time to ripple through the counter before a second strobe can be generated. At the conclusion of the measure cycle the $\overline{\text{ANGLE STROBE}}$ and resultant DR STROBE signals are generated and the 9 level parallel output of one of the two scanner shaft-angle encoders is transferred from the Mode Selection Gates to register elements DR-18 to 21, DR-22 to 25, and DR-26. The shaft encoder is previously activated by the LED Strobe Generator in the scanner and has valid output data. In addition to the $\overline{\text{ANGLE STROBE}}$ signal, a FLAG STROBE signal is generated transferring the FLAG output signal from the anomoly flag latch to element DR-1. Element DR-0 is held reset during the spherical data storage mode by the MEASURE GATE through the RESET DR-0 low level signal. This assures that SERIAL DIGITAL DATA will be a low level signal except during the serial shift mode.

The planar data storage mode begins when the SPHERICAL MODE signal is a low level and the MEASURE GATE changes from a low to a high level. This disables the serial data transfer gates and enables the parallel data-transfer gates which transfer planar mode data from the AOS/LOS Counter and the Mode Selection Gates to the J-K inputs of the register elements. The serial-shift clock input gates are also disabled and the parallel data-transfer clock gates are enabled connecting the $\overline{\text{AOS STROBE}}$, $\overline{\text{LOS STROBE}}$, and $\overline{\text{DR STROBE}}$ to the clock inputs of specific sections of the Shift Register. When the $\overline{\text{AOS STROBE}}$ signal is generated sometime during the measure cycle the 9 least significant parallel outputs of the AOS/LOS Counter are clocked into elements DR-2, DR-3 to 6 and DR-7 to 10. When the $\overline{\text{LOS STROBE}}$ signal is generated, either before or after the $\overline{\text{AOS STROBE}}$ the 9 least significant parallel outputs of the AOS/LOS Counter are clocked into elements DR-11 to 13, DR-14 to 17, and DR-18 to 19. (Elements DR-20 to 21 receive a low level signal). The AOS/LOS Counter is not cleared after the AOS and LOS strobe signals are generated as in the spherical mode. It is incremented immediately after the strobe, however, so that there is sufficient settling time before another strobe can be generated. At the conclusion of the measure cycle, the DR STROBE signal is generated clocking the SCANNER 2 identification and the OFF ZERO FLAG into elements DR-22 to 23 (elements DR-24 to 25 receive a low level signal). Elements 26 and 27 are disabled and thus remain low. The FLAG STROBE also occurs at the conclusion of the measure cycle and clocks the FLAG signal output of the anomoly flag latch into element DR-1. Element DR-0 is held reset as in the spherical mode by MEASURE GATE through $\overline{\text{RESET DR-0}}$.

10) Encoder Zero and Boom Blanking Circuits - These 6 circuits, shown in Figure F-8 are used in the planar mode to locate the encoder "zero" position and boom blanking start and stop positions for each of the two scanners. Each circuit is pre-programmed to decode a selected shaft encoder position from step-0 through step-511 as specified in the following table:

Scanner	Decoder	Step
1	Encoder Zero	256
1	Boom Blank Start	(disabled)
1	Boom Blank Stop	(disabled)
2	Encoder Zero	0
2	Boom Blank Start	
2	Boom Blank Stop	

The Encoder Zero decoders are interrogated by the PM ENC-1 STROBE(P2) and the PM ENC-2 STROBE (P2) pulses. The outputs are combined in Nor gate U614A to produce the ENC ZERO(P2) signal which indexes each scanner to its "zero" starting position.

The Boom Blank Start decoder output for Scanner 2 sets the boom blank latch U613A/U613B and the Boom Blank Stop decoder output resets the boom blank latch. The reset-output of the latch, $\overline{\text{BOOM BLANK}}$, is used to disable the scanner output signal during the pre-programmed boom-blank interval for Scanner 2. The Boom Blank circuit for Scanner 1 is not required and is therefore disabled.

11) Spherical Mode Control Logic - This circuit, shown in Figure F-8 controls the operation of the PAS System during spherical mode operation. It is required to perform the following functions:

- Perform measure cycles between the first and second sun pulses after each measure gate leading edge.
- Increment the AOS/LOS Counter during the measure cycle.
- Process scanner signals and record AOS and LOS counts during the measure cycle.
- Advance the scanner one stop at the conclusion of each measure cycle.
- Advance the scanner one step each sun pulse (except the sun pulse that starts the measure cycle) when no scanner targets are detected.

- Record the sun pulse to sun pulse AOS count when no targets are present during the measure cycle.

The circuits within the Spherical Mode Control Logic which implement the above functions are described below. Timing diagrams for spherical mode functions are found in Figures F-11 and F-12.

a) Measure Clock Frequency Multiplier: This circuit doubles the frequency of the MEASURE CLOCK signal supplied by the spacecraft from 25, 100, or 400 Hz to 50, 200, or 800 Hz to increase the resolution of spherical mode measurements. The circuit consists of inverters U309A, U309E, and U309F; flip-flops U305A and U305B, N$_{O}$r gate U310A and delay inverters U307A, U307F, U307E, U307B, and U307C. The flip-flops are normally reset with the Q outputs low. This forces the output of the last delay inverter (U307C) high enabling the flip-flops. When the SPHERICAL MODE signal is also high the clock inputs are enabled. During each negative transition of $\overline{\text{MEASURE CLOCK}}$ flip-flop U305A is set and the Q-output changes from a low to high level. This transition propagates through the delay inverters and results in the output of the last inverter going low some finite time later. This causes U305 to reset and the Q-output changes from a high to low level. This second transition propagates through the delay inverters and results in the output of U307C going high. The pulsewidth of the Q-output signal is determined by the propagation delays of inverter U309A, Nor gate U310A, the 5 delay inverters, and the reset-Q delay of the flip-flop. For this circuit the nominal pulse width is 260 ms. Flip-flop U305B functions similarly when positive clock transitions occur at the input to inverter U309E. The combined signal at the output of Nor gate U310A is a chain of 250 ms positive pulses at a rate double that of the measure clock.

b) Sun Pulse Conditioning Single-Shot: The purpose of this circuit is to produce one 225 ns pulse for each positive transition of the sun pulse. The sun pulse originates in one of the two scanner sun slit detectors or the SAS system in the spacecraft and is applied to the clock input of flip-flop U306A. The flip-flop along with inverters U308E, U308D, U308F, U308B, and U308C constitute a single-shot pulse generator. Each positive sun pulse transition sets the flip-flop which remains set until the positive Q-output transition propagates through the delay inverter chain and resets the flip-flop. The negative Q-output transition propagates through the delay inverters and releases the reset input so that the flip-flop is ready for the next positive sun pulse transition. The output pulse has a nominal pulsewidth of 225 ns.

c) Measure Cycle Control Circuit: This circuit consists of flip-flops U303A, U303B, U304A and U304B. Its purpose is to initiate a measure cycle on the first positive sun pulse transition to occur after the measure gate goes high, and to conclude the measure cycle on the second positive sun pulse transition.

The 4 flip-flops are held reset in planar mode by the low level SPHERICAL MODE and MEASURE GATE signals. When spherical mode is selected the reset-inputs become high levels releasing the flip-flop for clock operation. Flip-flop U303A is set by the positive transition of the measure gate once the SPHERICAL MODE high level enables the D-input. The Q-output high level enables Nand gates U310D and U311A and the D-input of flip-flop U304A resulting in the following operations.

Nand gate U310D transfers clock pulses from the output of the measure clock frequency multiplier to the input of the Control Pulse Generator which produces one chain of P1, P2, P3, and P4 pulses for each clock pulse generated during the measure cycle.

Nand gate U311A transfers the P4 pulse output from the Control Pulse Generator to become $\overline{\text{SM INCR COUNTER(P4)}}$. This signal increments the AOS/LOS Counter which counts at the system measure clock rate (2 times the spacecraft measure clock rate) during the measure cycle.

Flip-Flop U304A remains reset during the measure cycle. The second sun pulse positive transition following the measure gate sets this flip-flop whose Q-output then enables the D-input of flip-flop U304B. The next P1 pulse generated after the second sun pulse sets flip-flop U304B through the clock-input. When this flip-flop is set Nand gates U311B, U311C, and U311D are enabled resulting in the following operations.

Nand gate U311C transfers the same P1 pulse that set flip-flop U304B through to the Encoder LED Strobe Generator ($\overline{\text{SM ENCODER ENABLE P1}}$)) in the selected Scanner, resulting in a readout of the shaft angle 9-level output.

Nand gate U311B transfers the P2 pulse immediately following the P1 pulse through to the Shift Register Parallel Input Gates ($\overline{\text{ANGLE STROBE(P2)}}$) where it is used to strobe the shaft angle word into the data register.

Nand gate U311D transfers the P4 pulse through to the Motor Advance Circuit ($\overline{\text{SM MOTOR ENABLE-B(P4)}}$) where it advances the selected scanner stepper motor one step. The P4 pulse is also transferred through Nor gate U314A and inverter U309C to the reset-inputs of flip-flops U303A, U303B, and U304A terminating the measure cycle. Flip-flop U304B is reset at the conclusion of the measure gate; however, no additional control pulse chains are generated since the Control Pulse Generator has been disabled.

d) Scanner Signal Control Circuit: This circuit consisting of Nand gates U312D, U315A and U315B, Nor gates U313B and U314C and inverter U309B, processes the SCAN SIGNAL from the selected scanner photodetector and produces output signals for the AOS/LOS Pulse Generator.

The circuit operates only during a measure cycle and is otherwise disabled by the low level Q-output of U303B applied to the input of Nand gates U312D, U315A, U315B, and the reset-input of target latch U313B/U314C. During the measure cycle all gates are enabled. So long as no targets are detected by the scanner, target latch U313B/U314C remains reset enabling gate U315B which transfers successive P2 pulses to the $\overline{\text{SM NO-TARGET(P2)}}$ input of the AOS/LOS Pulse Generator. Should a target be detected during the measure cycle, target latch U313B/U314U will be set disabling gate U315B and enabling gate U315A which transfers successive P2 pulses to the $\overline{\text{SM TARGET (P-2)}}$ input of the AOS/LOS Pulse Generator. Following each P2 pulse the P4 pulse from gate U311A ($\overline{\text{SM INCR COUNTER(P4)}}$) attempts to reset the flip-flop. If the SCANNER signal remains high, however, the target latch remains set and the P2 pulses continue. When a target is lost, the target latch remains set until the next control pulse chain is completed; then it is reset by P4, and operation reverts back to the original no-target mode described previously. The purpose of the target latch is to prevent very narrow targets (less than one measure count wide) from being lost.

e) Search Mode Control Circuit: This circuit, composed of Nand gates U312A and U316A and search mode inhibit latch U312C/U312B, causes the scanner to advance one step for each sun pulse (except the sun pulse which initiates the measure cycle) when no targets are being detected. Search mode inhibit latch U312C/U312B is normally reset when no targets are present enabling Nand gate U316A which transfers conditioned sun pulses to the Motor Advance Circuit advancing the scanner one step per sun pulse. At the beginning of the measure gate U316A is disabled by the $\overline{Q}$-output of flip-flop U303A inhibiting the motor advance for the sun pulse which initiates the measure cycle. At the conclusion of the measure cycle a motor advance is always initiated by gate U311D which resets flip-flop U303A so that subsequent sun pulses are transferred through gate U316A. When a target is initially detected, the search mode inhibit latch U312C/U312B is set inhibiting further sun pulse advances of the motor until the following measure cycle is completed, whereupon, the P4 pulse from gate U311D is transferred through Nor gate U314A and inverter U309C to the reset-input of the search mode inhibit latch, re-establishing the search mode.

12) AOS/LOS Strobe Generator (Spherical Mode): This circuit processes the $\overline{\text{SM NO-TARGET(P2)}}$ and $\overline{\text{SM TARGET(P2)}}$ pulse chains from the Spherical Mode Control Logic to produce an $\overline{\text{AOS STROBE(P2)}}$ signal and an $\overline{\text{LOS STROBE(P2)}}$ signal. These pulses are used to transfer the AOS and LOS data from the AOS/LOS Counter to their respective sections of the Shift Register. Since the circuit is designed to function for both Spherical and Planar Modes several planar mode elements which are not operational during spherical mode operation will not be discussed here.

The circuit is enabled for spherical mode operation by the high level SPHERICAL MODE signal and all flip-flops and latches are reset between measure cycle measurements by the $\overline{\text{MEASURE GATE}}$ high level signal.

a) Normal Target Mode: This mode occurs when a target is acquired and lost within the measure cycle. At the beginning of the measure cycle when there is no target the $\overline{\text{SM NO TARGET(P2)}}$ signal will consist of a series of inverted P2 pulses while the $\overline{\text{SM TARGET(P2)}}$ signal will be a high level. The first inverted P2 pulse of the $\overline{\text{SM NO TARGET(P2)}}$ signal transfers through Nor gate U407B and Nand gate U412A setting the step zero no target latch U412C/U409A. The P4 pulse immediately following the P2 pulse enters the system as the $\overline{\text{SM INCR COUNTER(P4)}}$ signal. This pulse sets the step zero disable latch U409C/U412D which then inhibits U412A so that subsequent P2 pulses are inhibited. The step zero no-target latch U412C/U409A is used to establish that the initial status of the scanner signal is low. When a target is acquired the $\overline{\text{SM NO TARGET(P2)}}$ signal becomes a high level and the $\overline{\text{SM TARGET(P2)}}$ signal becomes a group of inverted P2 pulses commencing on the first interval after target detection. The first P2 pulse of this group transfers through Nor gate U407A, Nand gate U408C, inverter U411C and Nand gate U413C to become the $\overline{\text{AOS STROBE(P2)}}$ pulse which is used to transfer the AOS/LOS Counter data to the AOS section of the Shift Register. The same P2 signal is transferred through a delay circuit consisting of Nor gate U414C, Nand gate U414B, and 6 inverters, U416C through U416F and becomes the $\overline{\text{CLEAR COUNTER(P3)}}$ signal. This signal is used to clear the AOS/LOS Counter just after the AOS data transfer and just before the P4 signal increments the counter. The trailing edge of the P2 signal sets the AOS inhibit flip-flop U410B which disables Nand gate U413C so that subsequent P2 pulses in the group are inhibited. The flip-flop also resets latch U412C/U409A which then enables U408B. When the target is lost the $\overline{\text{SM TARGET(P2)}}$ signal becomes a high level and the $\overline{\text{SM NO TARGET(P2)}}$ signal becomes a group of inverted P2 pulses. The first P2 pulse of this group is transferred through Nor gate U407B, Nand gate U408B, inverter U411B, and Nand gate U413D and becomes $\overline{\text{LOS STROBE(P2)}}$. This signal is used to transfer the LOS count from the AOS/LOS Counter to the LOS section of the Shift Register. The P2 pulse trailing edge sets the LOS inhibit flip-flop U410A which then disables Nand gate U413D so that subsequent P2 pulses are inhibited. With both the AOS inhibit and LOS inhibit flip-flops set no further AOS or LOS strobe pulses can be generated even if further targets are detected during the measure cycle.

b) Inverted Target Mode: This mode occurs when a target is present at the beginning of the measure cycle and is lost and re-acquired within the cycle. The circuit functions in much the same manner as before. Initially the $\overline{\text{SM TARGET(P2)}}$ signal consists of a group of inverted P2 pulses as dictated by the presence of a target and the $\overline{\text{SM NO TARGET(P2)}}$ signal is a high level. The first P2 pulse of the group is transferred through Nor gate U407A and Nand gate U406 causing the step zero target latch U406C/U408A to become set. The $\overline{\text{SM INCR COUNTER(P4)}}$ signal which consists of a group of inverted P4 pulses sets the step zero disable latch U409C/U412D with the P4 pulse immediately after the first P2 pulse disabling Nand gates U406D and U406A and enabling Nand gate U408B. The conditions are now set for the circuit to produce an $\overline{\text{LOS STROBE(P2)}}$ pulse when the target is lost and the $\overline{\text{SM NO TARGET(P2)}}$ signal becomes a group of inverted P2 pulses. The first pulse of the group also generates the $\overline{\text{CLEAR COUNTER(P3)}}$ signal just after the $\overline{\text{LOS STROBE(P2)}}$ signal. In addition the P2 pulse transfers through inverter U411A and Nand gate

U414A to set the anomoly flag latch U414D/U415A. This latch set-output becomes the ANOMOLY FLAG signal which is a high level when a target is present at the beginning of the measurement. LOS inhibit latch U410A is set by the trailing edge of P2 so that subsequent P2 pulses are inhibited. The LOS inhibit latch also resets the step zero target latch U406C/U408A which then enables Nand gate U408C. When the tartet is re-acquired the first P2 pulse of the $\overline{\text{SM TARGET(P2)}}$ signal transfers through to become the $\overline{\text{AOS STROBE(P2)}}$ signal. The falling edge of the P2 pulse sets the AOS inhibit flip-flop U410B which together with the LOS inhibit flip-flop U410A prevents the generation of subsequent AOS or LOS strobe pulses during the measure cycle even if further targets should occur. This means that the first LOS and the first AOS are recorded even if the first AOS is from a different target.

The $\overline{\text{SM MOTOR ENABLE-B}}$ signal which occurs at the end of the measure cycle transfers through Nor gate U412B and becomes the ANOMOLY FLAG STROBE signal that transfers the ANOMOLY FLAG signal to the Shift Register.

c) Spacecraft Spin Count Mode: This mode occurs when there are no targets present during a measure cycle. For this condition the $\overline{\text{SM NO TARGET(P2)}}$ signal consists of a series of inverted P2 pulses lasting the duration of the measure cycle while the $\overline{\text{SM TARGET (P2)}}$ signal remains at a high level: The first $\overline{\text{SM NO TARGET(P2)}}$ pulse of the measure cycle is transferred through Nor gate U407B, and Nand gate U412A and sets the step zero no target latch U412C/U409A. The $\overline{\text{SM INCREMENT COUNTER(P4)}}$ signal consisting of a series of inverted P4 pulses sets the step zero disable latch U409C/U412D immediately after the U412C/U409A latch is set resulting in gate U412A being disabled and gate U408C being enabled. Subsequent $\overline{\text{SM NO TARGET(P2)}}$ pulses are inhibited. At the conclusion of the measure cycle the $\overline{\text{ANGLE STROBE(P2)}}$ inverted pulse is transferred through gates U407A, U408C, U411C, and U413C and becomes $\overline{\text{AOS STROBE(P2)}}$. This pulse is used to transfer the contents of the AOS/LOS counter to the AOS section of the Shift Register. The AOS count is equal to the sun pulse to sun pulse count for the measure cycle from which the spacecraft spin rate is derived. The LOS count is zero since no $\overline{\text{LOS STROBE(P2)}}$ signal is generated.

13) 16-Step Advance - This circuit is used in the spherical mode to advance the scanner 16-steps each time a C49L command is received from the spacecraft. The 0.5 second C49L signal enables the clock input of the 100 to 50 Hz divider flip-flip. The 100 Hz CLOCK signal is divided producing a 50 Hz square wave output which becomes the $\overline{\text{SM MOTOR ENABLE-C}}$ signal. The selected stepper motor is advanced one step for each negative transition of this signal as is 16-step counter U301. When the counter reaches step 16 the D_o output changes from a high to low level setting the 16-step disable flip-flop. The $\overline{Q}$-output of the flip-flop resets the 100 to 50 Hz divider flip-flop inhibiting further stepper motor advances. When the $\overline{\text{C49L}}$ signal returns to a high level the 16-step disable flip-flop is reset and the circuit is ready for another C49L command.

14) Planar Mode Control Logic - This circuit shown in Figure F-9 controls the operation of the PAS system during planar mode operation and implements the following planar mode requirements.

*Indexes the scanner mechanism to the shaft encoder step-zero position.

*Initiates a measure cycle at the beginning of each measure gate.

*Advances the stepper motor at a 100 steps per second rate for a total of 512 steps (one scanner revolution) during the measure cycle.

*Verifies that each subsequent measure cycle commences with the scanner at step zero.

*Delays processing of scanner signal 4 steps for signal qualification.

*Compares each scanner signal with the scanner signal for the three following steps.

*Accepts an AOS transition from "0" to "1" only if the following 3 steps are "1's" also.

*Accepts an LOS transition from "1" to "0" only if the following 3 steps are "0" also.

*Rejects all scanner information during pre-programmed Boom-Blanking intervals to avoid false targets.

*Accepts the first AOS and last LOS transitions that occur during a measure cycle.

The above requirements are implemented by the circuits discussed below. These circuits are enabled by the high level PLANAR MODE signal are reset by the low level MEASURE GATE each cycle.

a) Measure Cycle Control Circuit: This circuit consists of gates U315C, U313A, and U320A and the measure cycle enable flip-flop U306B. The flip-flop is set each time the MEASURE GATE goes high starting the measure cycle. The Q-output enables

Nand gate U320A transferring the MEASURE CLOCK through to become $\overline{\text{PM PULSE GEN ENABLE}}$, a 100 Hz square wave which enables the Control Pulse Generator once each negative transition producing one set of P1, P2, P3, and P4 pulses. The control pulse sets continue at the 100 Hz rate for the duration of the measure cycle.

b) Encoder Zero Detector: This circuit consisting of gates U318C, U313D and U313D and latches U317D/U317A, U317C/U317B and U319A/U320D, operates as follows: The P1 pulses generated during the measure cycle transfer through Nand gate U318C to become the $\overline{\text{PM ENCODER ENABLE(P1)}}$ signal which activates the shaft encoder strobe generator within the selected scanner causing a readout of the shaft angle. The readout is decoded by the Encoder Zero circuit which produces a P2 pulse at the ENC ZERO(P2) input only if the encoder is at the zero position during the strobe time. If it is at some other position no P2 pulse is generated. The initial zero check is made on the first P1-P2 pulse combination to occur during the measure cycle. If the encoder is on zero an ENC ZERO(P2) pulse is generated and the step-0 zero latch U317C/U317B is set. If the encoder is off zero no pulse is generated and the latch remains reset. The P4 pulse following the P2 pulse transfers through Nand gate U318B and becomes the $\overline{\text{PM MOTOR ENABLE(P4)}}$ signal which advances the scanner 1 step. This signal also sets the step-0 disable latch U317D/U317A which then inhibits the set-input of the step-0 zero latch. The status of the step-0 zero latch indicates the status of the scanner mechanism at the beginning of the measure cycle; set for on Zero and reset for off zero. The reset-output becomes the OFF ZERO FLAG signal. Step-0 disable latch U317D/U317A enables Nand gate U313C. When a second ENC ZERO(P2) pulse occurs, normally at the end of a measure cycle, the step-512 zero latch U319A/U320D is set. The reset-output of the latch becomes a low level disabling Nand gate U318B which controls the stepper motor and U318C which controls the shaft angle encoder strobe circuit. This completes the scanner cycle which consists of 512 scanner steps if the scanner was on zero at the beginning of the cycle. When the scanner is off zero initially the scanner cycle will be less than 512 steps, the exact number depending on the initial position. At the conclusion of the measure gate all three latches are reset in preparation for the next measure gate.

c) Four-Step Delay Circuit: This circuit is required for the operation of the 4-step qualification circuit. It consists of 4-step delay counter U401 and several associated gates. At the beginning of the measure cycle Nand gate U319B is enabled by the set-output of measure cycle enable flip-flop U306B and the inverted C_o output of the 4-step delay counter (the counter is initially reset to "all zeros" at the beginning of the measure cycle). P4 pulses transfer through Nand gate U319B and Nor gate U319C and increment the 4-bit counter once each scanner step. When the counter has reached step 4 (binary 0100) the C-output becomes a high level disabling Nand gate U319B to inhibit further counting and start the scanner qualification analysis. Nand gate U320B is enabled transferring P4 pulses to the AOS/LOS counter incrementing it once each scanner step starting with step 4. At the conclusion of the 512-step scanner cycle the step-512 zero latch is set enabling Nand gate U318A and transferring P4 pulses through to increment the 4-step counter again. Four more steps are counted advancing the counter to 8 (binary 1000). The D-output becomes a high level enabling Nand gate U406A which transfers P3, one step later, to become the $\overline{\text{PLANAR MODE RESET(P3)}}$ signal. Measure cycle enable flip-flop U306B is reset and the measure cycle is concluded. The result of this 4-step delay is that the scanner signal analysis for each step is delayed so that the scanner signal for the following three steps can be compared with it in the qualification circuit.

d) 4-Step Qualification Circuit: This circuit consists of the 4-bit qualification shift register U402, 4 inverters, and Nand gates U404 and U405. We shall assume the boom blanking circuit to be inoperative and $\overline{\text{BOOM INHIBIT}}$ becomes a high level signal enabling Nand gate U320C. Throughout the measure cycle the P4 pulse clocks the present status of SCANNER SIGNAL into the shift register just before the scanner is advanced to the next step. When the stepper motor has advanced 4-steps the scanner status for steps 0, 1, 2, and 3 are contained in the shift register. At this time the 4-bit binary counter has reached step 4 and the C-output is high enabling Nand gates U404 and U405. The AOS/LOS counter is delayed 4-steps so that comparisons of the 4-steps in the shift register are referenced to the first of those steps.

The U405 gate will transfer a $\overline{\text{PM TARGET(P2)}}$ signal pulse for each step that there are 4 high level outputs (targets) present on the qualification shift register. The U404 gate will transfer a $\overline{\text{PM NO-TARGET (P2)}}$ signal pulse for each step that there are 4 low level outputs(no-targets) present on the qualification shift register. No P2 pulses are generated on either the $\overline{\text{PM TARGET(P2)}}$ or the $\overline{\text{PM NO-TARGET(P2)}}$ signals for steps where are both high and low levels present on the qualification shift register. This will happen each time there is a transition from no-target to target (AOS) or from target to no-target (LOS). This transitional period will be 4 steps long for a sharp well defined horizon but it could be longer for a terminator. The AOS/LOS strobe generator circuit described below analyzes the $\overline{\text{PM TARGET(P2)}}$

and $\overline{\text{PM NO-TARGET(P2)}}$ signals and decides when the AOS and LOS strobe signals are to be generated.

15) AOS/LOS Strobe Generator - Planar Mode - This circuit shown in Figure F-10 is used for both spherical and planar mode operation. In planar mode it is enabled by a low level SPHERICAL MODE signal. All flip-flops and latches are reset at the conclusion of each measure gate. The circuit operates in several modes, depending on the nature of the target, to produce AOS and LOS strobe pulses which transfer the count from the AOS/LOS Counter to the AOS and LOS sections of the shift register.

a) Normal Target Mode: In this mode a target is first acquired and then lost within the 512-step scanner cycle. The scanner signal analysis begins with steps 0, 1, 2, and 3 scanner status in the qualification shift register and an AOS/LOS Counter output of zero. The $\overline{\text{PM NO-TARGET(P2)}}$ signal produces a P2 pulse which transfers through gates U407B and U412A to set the step zero no-target latch U412C/U409A enabling the AOS channel. The initial status of the scanner at step zero is thus determined. The $\overline{\text{PM INCR COUNTER(P4)}}$ signal increments the AOS/LOS Counter and sets the step zero disable latch immediately after the step zero no target latch is set inhibiting subsequent $\overline{\text{PM NO-TARGET(P2)}}$ pulses which are generated for each step after step zero so long as no target is detected. When a target is detected the qualification shift register will contain both low and high level signals for at least 4-steps. During this interval no pulses are generated by either the $\overline{\text{PM NO-TARGET(P2)}}$ or $\overline{\text{PMTARGET(P2)}}$ signals. Should the target be 4 or more steps long the qualification shift register will eventually contain all high level signals and the $\overline{\text{PM TARGET(P2)}}$ signal will generate a P2 pulse. This pulse transfers through gates U407A, U408C, U411C, and U413C to become the $\overline{\text{AOS STROBE(P2)}}$ signal which transfers the AOS/LOS Counter status to the AOS section of the Shift Register. The P2 pulse trailing edge sets the AOS INHIBIT flip-flop which disables the AOS circuit so that additional P2 pulses are inhibited. $\overline{\text{PM TARGET (P2)}}$ pulses will continue for each step so long as all four qualification output levels are high. The AOS inhibit flip-flop also resets the step zero no-target latch enabling the LOS channel. When the target is lost there are at least 4 steps with no output pulses from either the $\overline{\text{PM TARGET(P2)}}$ or the $\overline{\text{PM NO-TARGET(P2)}}$ signals followed by a P2 pulse from the $\overline{\text{PM NO-TARGET(P2)}}$ signal when all four qualification shift register outputs return to low levels. This P2 pulse transfers through gates U407B, U408B, U411B, and U413D to become the $\overline{\text{LOS STROBE(P2)}}$ signal. The P2 pulse trailing edge sets the LOS inhibit flip-flop which disables the LOS channel so that subsequent P2 pulses are inhibited. Should another target appear during the scanner cycle, however, the first $\overline{\text{PM TARGET(P2)}}$ pulse for this target will transfer through gates U407A, U408C, U411C, U413B, U413A, and U411D and reset the LOS inhibit flip-flop enabling the LOS channel again. When the second target is lost a second $\overline{\text{LOS STROBE(P2)}}$ is generated and a new LOS count is transferred from the AOS/LOS Counter to the LOS section of the Shift Register. This updating of the LOS count continues each time a target is detected during the scanner cycle. The AOS signal is not updated for additional targets.

b) Inverted Target Mode: In this mode the target is detected at the beginning of the scanner cycle and is lost and re-acquired during the measure cycle. The initial comparison of steps 0, 1, 2, and 3 generates an $\overline{\text{PM TARGET(P2)}}$ signal which sets the step zero target latch U406C/U408A. This is followed by the $\overline{\text{PM INCR COUNTER(P4)}}$

pulse which sets the step zero disable latch enabling the LOS channel. When the target is lost the first $\overline{\text{PM NO-TARGET(P2)}}$ signal pulse becomes the $\overline{\text{LOS STROBE(P2)}}$. When a $\overline{\text{LOS STROBE(P2)}}$ signal precedes the $\overline{\text{AOS STROBE(P2)}}$ signal anomoly flag latch U414D/U415A is set and the ANOMOLY FLAG signal becomes a high level. When the target is re-acquired the first $\overline{\text{PM TARGET(P2)}}$ pulse becomes the $\overline{\text{AOS STROBE(P2)}}$ signal. As in the normal target mode subsequent losses of target generate additional $\overline{\text{PM NO-TARGET(P2)}}$ signals updating the LOS count.

c) Step Zero Transition: For this mode a transition is in progress when steps 0, 1, 2, and 3 are compared and no $\overline{\text{PM TARGET(P4)}}$ or $\overline{\text{PM NO-TARGET(P4)}}$ signal pulses are generated. Neither the step zero target nor the step zero no-target latches are set. When the step zero disable latch is set by the $\overline{\text{PM INCR COUNTER (P4)}}$ signal both the AOS and LOS channels are opened. When the first set of 4 high level or 4 low level outputs are present on the qualification shift register either an $\overline{\text{AOS STROBE(P2)}}$ or an $\overline{\text{LOS STROBE(P2)}}$ pulse will be generated. The circuit will operate as described above thereafter.

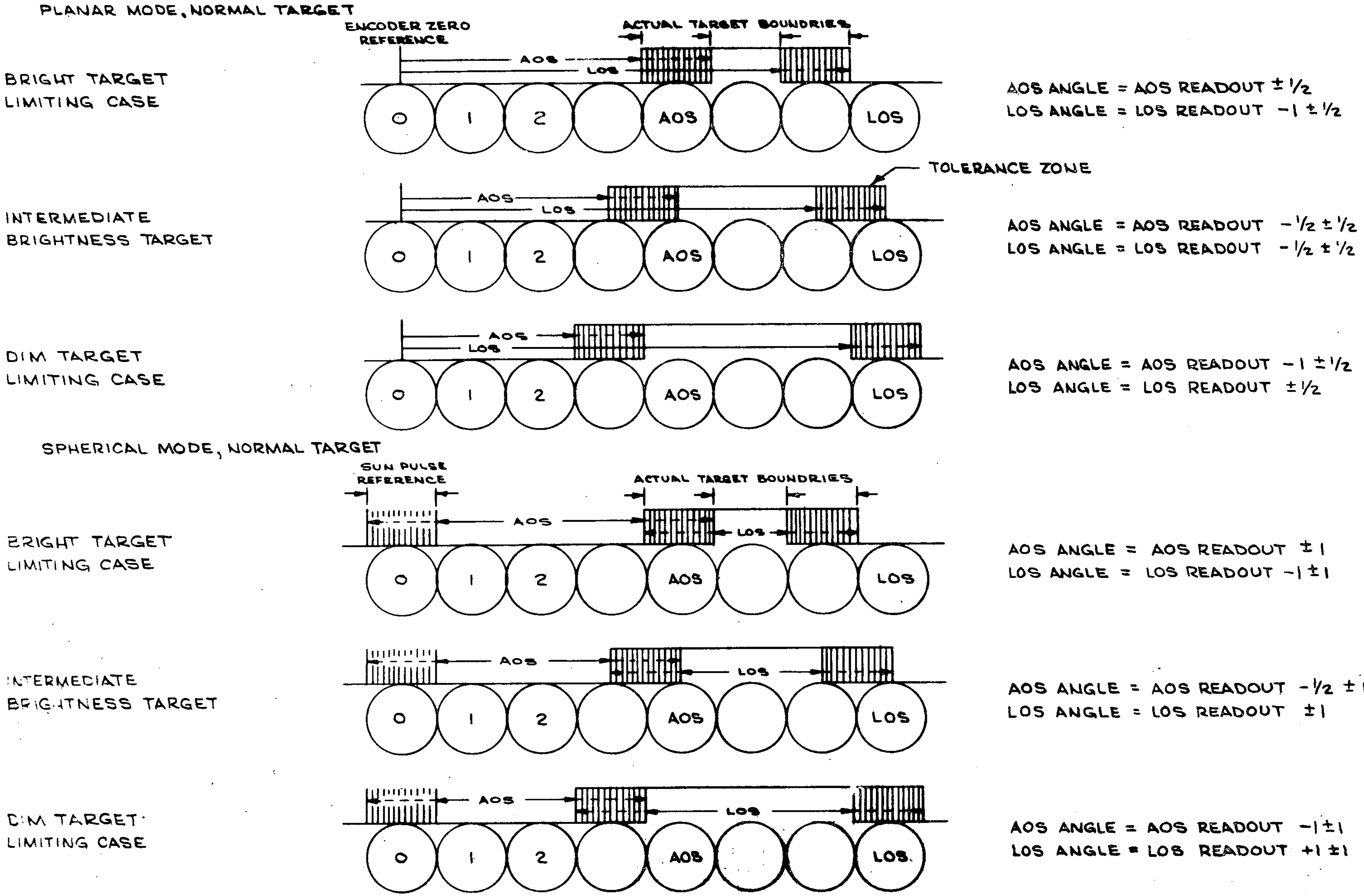
d) Boom Blanking Mode: When the $\overline{\text{BOOM INHIBIT}}$ signal is a low level for several successive steps the P4 pulses which advance the shift register are inhibited and the 4 output levels remain static until the $\overline{\text{BOOM INHIBIT}}$ signal returns to a high level. This prevents the qualification circuit from examining false scanner signals resulting from reflections from spacecraft booms.

2.5 PAS Output Data Interpretation

The purpose of the PAS system is to measure the spin rate and orientation of the spacecraft relative to the sun, moon and earth. This data is read out as shown in the data format chart, Figure 2-6. In spherical mode, the data consists of the anomoly flag, the AOS count, the LOS count, and the encoder shaft angle. In planar mode, the output data consists of the anomoly flag, AOS count, LOS count, scanner identity and scanner off zero flag. In both cases, the anomoly flag indicates whether or not a target is in the field of view of the scanner at the start of the scan (Anomoly flag = 0 for normal target - target not present at start of scan. Anomoly flag = 1 for inverted target - target present at start of scan.) However, the start of scan is not defined the same in planar mode as it is in spherical mode. In spherical mode the start of scan is the pointing direction of the scanner at the time the PAS sun pulse occurs, which will always be in a plane through the spin axis perpendicular to the plane of the sun and the spin axis. In planar mode there is no sun pulse and so no sun reference. The zero reference is simply the encoder starting point (encoder zero for scanner 2 encoder 180° for scanner 1) both of which lie in the spacecraft X-Y plane as the scanners are mounted on the spacecraft.

The data readouts can best be described by reference to the timing diagrams, Figures 2-7, 2-8, 2-9, and 2-10. Consider first the planar mode. In planar mode the full circle scan is always divided into 512 parts, so each step corresponds to 0.703 degrees. The measure clock used to drive the stepper has a frequency of 100 hz, but this rate does not have any real significance to the measurement. It is more

RELATIONSHIP OF AOS AND LOS READOUTS TO ACTUAL TARGET ANGLES



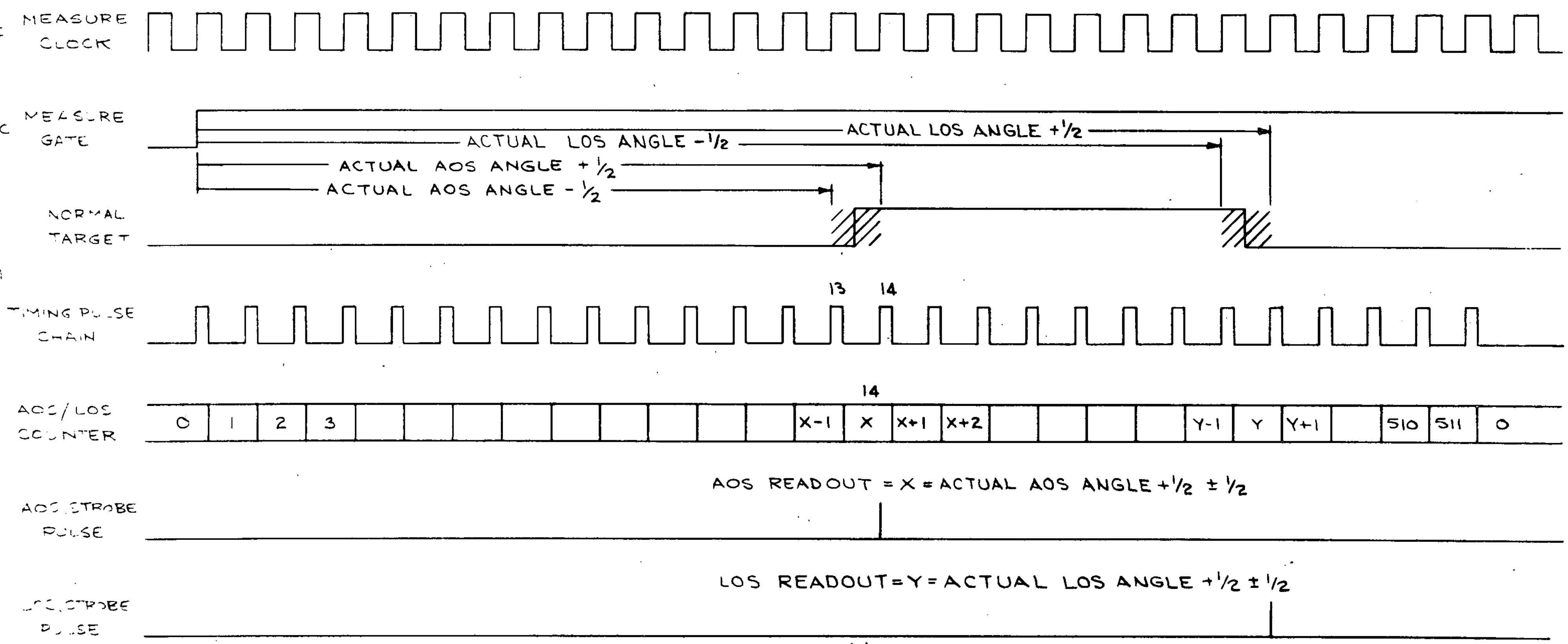
45-a

FIGURE 2-7

PLANAR MODE TIMING DIAGRAM

(NORMAL TARGET)

45.B



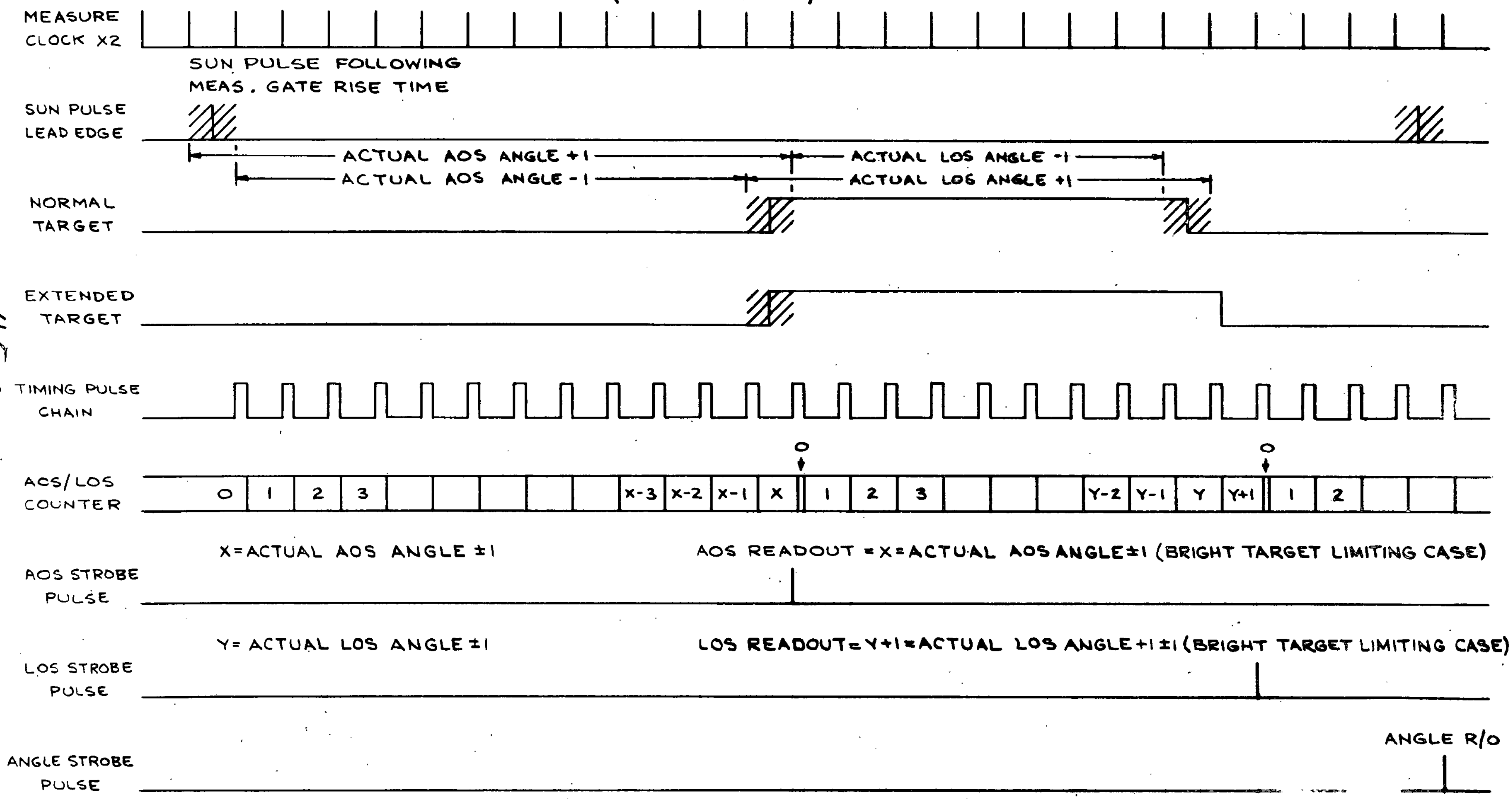
AOS READOUT (MEASURE GATE TO AOS) = ACTUAL ANGLE $^{+1}_{-0}$ INCREMENT

LOS READOUT (MEASURE GATE TO LOS) = ACTUAL ANGLE $^{+1}_{-0}$ INCREMENT

FIGURE 2-8

SPHERICAL MODE TIMING DIAGRAM

(NORMAL TARGET)



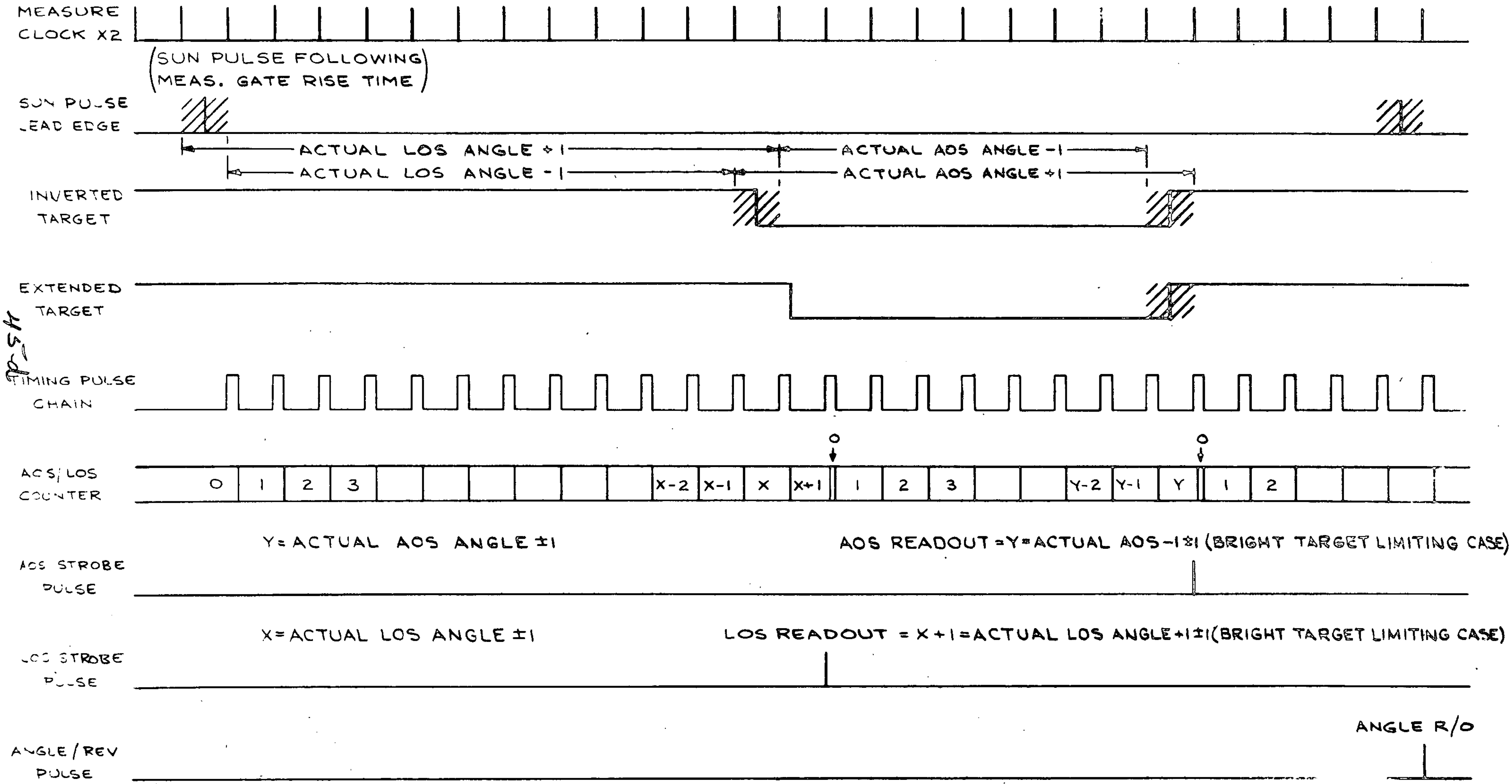
AOS READOUT (SUN PULSE TO AOS) = TRUE ANGLE ± 1 INCREMENT

LOS READOUT (AOS TO LOS) = TRUE ANGLE +1 ± 1 INCREMENT

AOS READOUT + LOS READOUT (SUN PULSE TO LOS) = TRUE ANGLE +1 ± 1 INCREMENT

FIGURE 2-9

SPHERICAL MODE TIMING DIAGRAM
(INVERTED TARGET)



45-d

LOS READOUT (SUN PULSE TO LOS) = TRUE ANGLE +1±1 INCREMENT

AOS READOUT (LOS TO AOS) = TRUE ANGLE -1± 1 INCREMENT

LOS READOUT + AOS READOUT (SUN PULSE TO AOS) = TRUE ANGLE ±1 INCREMENT

FIGURE 2-10

helpful to think of the clock pulses as corresponding to angular steps of $.703^{\circ}$. Nominally, the scanner comes to rest between steps and while it is at rest (or nearly at rest) the measurements are made. Thus the AOS and LOS counts are always an integral number of steps. The real physical angles which they represent, however, will in general not be an integral number of steps. A scan begins with the rise of the measure gate. As the scanner steps, at some position a target will first be registered. The count to this step will be the AOS readout. However, the actual edge of the target may have been encountered as much as a half step angle earlier or a half step angle later. For a target brightness well above the sensitivity threshold, a target will be registered if it shows in any part of the field of view. Thus for a very bright target, the actual AOS angle is equal to the AOS readout $\pm$ 1/2 step. For a dim target (threshold brightness), however, the entire field of view must be filled, and we then have the actual AOS angle equal to the AOS readout $-1 \pm 1/2$.

For a typical intermediate target, threshold signal is reached when for example half of the field of view of the scanner is filled. We then have.

$$\text{AOS actual angle} = \text{AOS readout } -\tfrac{1}{2} \pm \tfrac{1}{2}$$

In planar mode, the LOS readout measures the count from start of scan to loss of target, so the LOS actual angles will be related to the LOS readouts as follows:

Limiting case, bright target: LOS angle = LOS readout $-1 \pm \frac{1}{2}$

Limiting case dim target: LOS angle = LOS readout $\pm$ 1/2

Intermediate case LOS angle = LOS readout $-\frac{1}{2} \pm \frac{1}{2}$

In spherical mode the situation is further complicated by the fact that the rotation of the spacecraft is not synchronous with the clock, and the angle increment corresponding to each clock interval depends upon the spacecraft spin rate at the particular time. The spin period is measured as the AOS count sun pulse to sun pulse, when no target is crossed by the scanner. The pointing direction latitude of the scanner is read out from the encoder. Interpretation of the AOS and LOS target readouts is similar to the situation described for the planar mode with the added uncertainty introduced by the lack of synchronism in the staring point. The LOS readout also has a different starting point in spherical mode. Because of the necessity to read out the encoder angle, there were not enough bits available in the shift register to read out the LOS from start of scan. The logic was therefore modified to make the LOS count begin at the target acquisition, and so only count the target width.

The resulting AOS and LOS readout interpretations are therefore as follows: (see Figure 2-7)

Bright target

AOS angle = AOS readout ± 1

LOS angle - LOS readout -1 ±1

Dim target

AOS angle - AOS readout -1 ±1

LOS angle = LOS readout +1 ±1

Intermediate target

AOS angle = AOS readout $-\frac{1}{2}$ ±1

LOS angle = LOS readout ± 1

3.0 FABRICATION OF THE PROTOTYPE AND FLIGHT PAS SYSTEM

Fabrication of the flight PAS system will be considered in three stages: 1) parts procurement, 2) fabrication of subassemblies, and 3) final assembly or integration of these subassemblies into the complete system.

3.1 Parts Procurement

Parts procurement began with compilation of the parts list during the design phase of the program. Breadboard versions of each major subassembly - electronic, optical and mechanical were built using commercial grade parts and were tested to prove the design concepts or in some cases to determine exact component values or configuration. Electronic components were chosen wherever possible from the Goddard Preferred Parts List, and availability and delivery times for these components, flight qualified were checked before they were designed into the system. Similarly for mechanical and optical components, availability or feasibility of fabrication were major considerations in the choice or design of a part. In general, the electronic components are completely specified by a part number and are simply listed on the PAS parts list. The majority of optical and mechanical parts were specified by procurement or fabrication drawings.

3.1.1 Electronic Parts

All of the electronic components used in the PAS system are listed by part number and description in the PAS parts list, which is included as an appendix to this report. The majority of these components are listed in the Goddard PPL and were purchased prescreened by the manufacturer to the appropriate GSFC specification which is listed in the column headed "Specification Number". When electronic components were required for which no equivalent was listed in the PPL, the parts were purchased unscreened and tested by EMR. These components are all listed on the first page of the PAS parts list as "Qualified by EMR screening". Selection of these components was based upon their performance and reputation for reliability. Screening procedures were written specifically for each of these components and were approved by Goddard. These procedures are listed by their EMR number in the specification column of the parts list.

The most critical of these items are the photodiodes, phototransistors, and the light emitting diodes. The screening procedure for each consisted of an initial measurement of electrical/optical performance characteristics, temperature cycling, leak test, 168 hour burn in at 55° C or a bake at 100° C, and a final test of electrical/optical performance. All three kinds of devices were subjected to 100% testing, and individual components were rejected for performance out of specification, leakage, or excessive change in operating characteristics between the initial and final check.

The General Electric light emitting diodes LED SSL 35 had a rejection rate of 12 out of 27 tested. This rate was considered excessive, so the SSL 35's were not used. Thirty SSL-55C's were purchased and subjected to the same test. All thirty were found acceptable, and so the SSL-55C's were used in the encoders. The LS-600 phototransistors also used in the encoders had a rejection rate of four out of fifty tested. Of these four, all were defective at the start of the test. None degraded appreciably during the course of the test. For the Hewlett Packard 5082-4231 silicon PIN photodiodes used as the prime sensors in the scanner and sun slit there were no rejections out of ten samples tested.

3.1.2 Optical Components

The optical components of the PAS scanner consist of the objective lens and prism assembly, the transparent dome, the apertures and baffles within the encoder shaft, the prism cap, the sun shade over the dome and the sun slit assembly. Of these components, the most critical are the prism lens assembly and the transparent dome, both made of optical grade Suprasil fused silica. The prism - lens assembly was fabricated to EMR's specifications by Special Optics, Inc. of Cedar Grove, New Jersey. The interface joints between the three components were cemented with Epo Tek 301 epoxy. The transparent dome was fabricated by P. G. C. Corporation of Bethesda, Maryland.

The remainder of the scanner optical system consists of the apertures and baffles in the hollow encoder shaft. They were fabricated and assembled in the encoder shaft by Baldwin in accordance with EMR drawing No. 4037. The sun slit is an assembly of three pieces which were all machined by EMR in accordance with EMR drawings No. 3041, 3042, and 2010. Other accessory optical parts such as the scanner lens hood and sun shade were also fabricated in the EMR shops.

3.1.3 Mechanical Components

The gears, shafts and bearings were all stock or slightly modified stock items, and were purchased from a stock supplier of precision mechanical components. The scanner mechanism frames were produced to EMR specifications by a local specialty precision machine shop. The remaining hardware, scanner cases, sun slit pieces, mounting hardware and spacers were made in the EMR shops. P.C. board layout and taping was performed by EMR, but etching and tinning of the circuit boards was performed by Vitro Laboratories of Silver Spring, Maryland.

3.2 Fabrication of Subassemblies

The principle subassemblies of the PAS system are the six electronic boards of the electronics module, the scanner mechanical assembly and the five small electronic boards which go in each scanner head. Assembly of the electronics boards was performed by EMR's electronics fabrication group in accordance with the appropriate GSFC specifications for the assembly of flight electronics hardware. On each board, all components are mounted on one side of the board only, and the majority of the track is on the opposite side of the board. Thus the component is held very securely to the board and cannot come loose by lifting the pads. This is particularly important for the relays mounted on board 1 which are the largest components used. The solder joints were subject to 100% inspection by EMR quality control. The boards were also inspected for correct components and correct placement of the components, and absence of damaged or lifted pads.

The prism- - lens assembly was mounted in the seat provided in the top of the encoder shaft by the optical fabricators - Special Optics, Inc. The assembly was mounted with epoxy, and the alignment adjusted and checked by means of an auto collimator to within 2 arc minutes as the epoxy was in process of hardening.

The complete encoder was then assembled to the scanner head frame together with the shafts, gears, bearings, and motor which form the scanner mechanism. At this stage, the encoder was aligned with the motor in its servo mount while running at 100 steps per second by monitoring each of the nine output channels of the encoder. Since the encoder disc is divided into 512 sectors each defined by transitions in the 9 gray coded tracks, the objective of the alignment procedure is to make the disc step positions correspond to the points halfway between the defining transitions. Because the 9 tracks are not perfectly aligned with one another, it is necessary to check the outputs of all nine. With the motor running at 100 steps per second, the outputs are displayed one at a time on an oscilloscope and the motor is rotated first clockwise, then counterclockwise until the transition points of the encoder are found where one or more of the outputs becomes indeterminate. These points are marked on the motor mounting and the motor is set in the middle of this range and clamped.

The angular rotation of the encoder disc is $\frac{360}{512} = 0.703$ degrees or 42.2 arc minutes. The inaccuracies in the encoders ranged from about 17 arc minutes to 29 arc minutes, leaving a setting width of about 13 arc minutes for the worst case. With a 64 to 1 gear train ratio, this corresponds to an adjustment range of about 14 degrees of rotation at the motor.

Other subassembly steps include mounting the sunslit and the optical dome to the top half of the scanner case and mounting the connector to the case bottom. The sun slit simply attaches to the outside of the case with two screws. The slit spacing is checked with a brass gauge to be 0.004 inches after the screws are tightened and the unit is then sealed to maintain this spacing with a small bead of epoxy at each end.

3.3 Final Assembly

Final assembly of the electronics module consisted primarily of interwiring the six separate boards. The boards were interwired as shown in EMR drawing No. 5049. with No. 26 teflon covered wire for flexibility. The interconnect wires in all cases pass through a strain relief hole before soldering to the pads provided on the board. The interconnect wires, whether going between boards, or from a given board to the connector, leave each board only from the left hand edge, and enter a bundle which acts as a hinge allowing the boards to be spread like pages of a book for inspection. After inspection a conformal coating of Solithane urethane was applied to both surfaces of all boards. The boards were then stacked with the aluminum spacers and soft urethane foam separators and bolted together into a single unit which slips into the aluminum frame package.

Final assembly of the scanners begins with the mechanical subassembly on the scanner frame. The scanner detector is mounted to the frame opposite to the exit aperture at the end of the encoder shaft. With the scanner field of view filled with a diffuse light source, the detector is positioned for maximum signal and secured in place. The various boards with interconnecting wires attached are mounted in their appropriate locations on the scanner frame. In the confined space available inside of the scanner case, routing the wires between boards and to the main connector requires considerable care. All wires must be kept clear of any moving parts - particularly the gears. The high sensitivity scanner detector and preamp must be well shielded and isolated from the power circuits such as the encoder strobe and motor driver. And the main bundle of wires to the case connector must be long enough to allow the scanner frame to be removed from the case, but compact enough to fit when the frame assembly is seated in the case.

To accomplish this, the five small boards on the scanner were first interwired to one another on a dummy frame. The wires were all routed such that the five boards as a unit could be removed from that frame and placed on an actual flight frame without removal of any connections. No interconnect wires pass through the frame. Wires destined to go to the case connector wire left overlength. The scanner detector leads were insulated, twisted and shielded from the detector case to the preamp board. A complete shield around the scanner preamplifier board was also found to be necessary. This was formed of about 2 mil shim brass and mounted under the screws which hold the preamp boards to the frame. A shield was also found to be necessary between the sun slit amplifier and the scanner amplifier. A piece of shim material, insulated on both sides with teflon tape and grounded, was slipped between the two boards without modification of the original mounting.

The main wire bundle to the connector includes most of the encoder wires, power to all of the boards and the heater, and the signal output wires. These wires are dressed across the frame into a bundle which passed down the back of the frame and under the motor driver board, and is cut off with sufficient length to solder to the connector inside the case while the scanner frame is still out of the case.

4.0 TESTING

Formal testing, under the supervision of the EMR Quality Control staff and the cognizance of the government DCAS representative was performed in four different stages of the program. These stages of testing are as follows:

1) Component qualification. Qualification testing of nonstandard components or components not available already certified for space flight use.

2) Life test. A prototype mechanical assembly was operated for a number of cycles equivalent to one year in space and evaluated.

3) System qualification. The complete system was subjected to an operational test at high and low temperature extremes and after being subjected to sinusoidal and random vibration.

4) System calibration. The optical and electronic accuracy of the system was checked on a test range simulating the signal inputs in space.

4.1 Component Qualification

A number of compenents required for the fabrication of the PAS system were not available prescreened by the manufacturer to GSFC specifications. These components were the following:

Stepper motor	CRO-0193-75
PIN photodiode	HP 5082-4231
Light emitting diode	LED SSL55C
Phototransistor	LS-600
Hermetic connector	HSM29-20 PS
Hermetic terminal	AA40W-HP

Screening procedures were established and tests performed on all of the above components (100% testing) to be used in the flight systems. These tests were performed at the testing facilities of the quality control department of EMR Photoelectric. The detailed test procedures and the results of the tests are described in the several test procedures and reports generated for these tests. They will only be summarized here.

Stepper Motor Test. EMR procedure No. 023420-6 motor dimensions, electrical resistance and torque checked for conformance to specifications. Torque checked at - 25^{o} C and + 75^{o}C. Stepping operation checked at 12 V input.

Pin Diode Test (EMR procedure 023420-2A),
Photo Transistor Test (EMR No. 023420-4A),
Light Emitting Diode Test (EMR No. 023420-5A),

Each of these electronic components was subjected to essentially the same test. Initial determination of operating parameters followed by 5 temperature cycles - 55^{o} C to + 85^{o} C, gross and fine leak test to 10^{8} CC/sec, 168 hour burn in at + 55^{o} C (48 hour bake for the LED's) and a final measurement of operating parameters. Components were rejected for operating parameters out of spec or for excessive change in parameters from initial to final measurements. For these opto-electronic components, the operating parameters measured included light sensitivity or output as appropriate.

Hermetic connector test. (EMR No. 023420-8A and 8B). Specified parameters - visual and mechanical specifications, resistance pin to pin greater than 10^8 ohms and resistance pin to case greater than 10^9 ohms, and contact resistance per MIL-C-28748 verified before and after high temperature bake at 100° C for 48 hours, temperature cycling; 5 cycles - 55° C to + 150° C and vibration at 30 g for 10 minutes. Leak rate was also verified to be less than 10^{-8} CC/sec.

Hermetic terminal test (EMR No. 023420-10). Visual and leak check before and after 5 temperature cycles - 55° C to + 150° C.

4.2 Life Test

In order to confirm the ability of the PAS system to continue to operate for one year in space without failure or loss of accuracy due to wear of the moving mechanical parts, a life test was performed on a mechanical prototype assembly. This assembly was built with a motor, gears, bearings and shafts identical to those to be used in the flight units, and an encoder which was mechanically identical to the flight encoders. As described in the life test final report, "Panoramic Attitude Sensor for RAE-B, Life Test of Scanner Mechanism", the assembly was operated for one million revolutions of the encoder shaft, which is equivalent to one year of operation at the normal duty cycle in planar mode.

At the end of the test, the unit showed some wear, but was still operating reliably and with a precision within the specified limits.

After completion of the required 1.0×10^6 encoder revolutions, the measurements of motor holding torque, gear train friction and backlash were repeated. Comparison of the results of these measurements with the initial measurements shows a definitely measurable reduction in friction and increase in backlash, but the backlash remained within the limiting tolerance of 0.10 degree, and the entire mechanism continued to function properly. Below is tabulated a comparison of the results of the initial and final measurements.

	Initial	Final
1) Motor holding torque @ 18.0 V	0.99 oz in	0.93 oz in
2) Gear train friction	1.4 to 2.7 oz in	0.3 to 0.8 oz in
3) Gear train backlash	1.8 arc minutes	4.05 arc minutes
4) Indexing repeatability	0.6 arc minutes	1.0 arc minutes

4.3 Qualification Test

Each prototype and flight PAS electronics module and scanner was subjected to the qualification tests defined in EMR test procedure 6341-2045-1 "Envoronmental Qualification Test Procedure, Panoramic Attitude Sensor for RAE-B", which is included as an appendix to this report. The tests consisted of vibration of the scanner heads, leak test of the scanner heads followed by an operational test of the entire system at room temperature and again at - 20° C and at +60° C.

The operational tests do not test every possible function of the scanner, but do exercise and spot check the primary modes of operation. Using the PAS test set to command the system and read out the operation, the operating tests check the following:

1) Operating current drawn from each the 5V, 12V, 18 volt.

2) Planar mode operation - 512 step advance of the scanner with stop on zero, reset to zero if interrupted.

3) Spherical mode operation and encoder readout correlation with step advance for first 32 steps.

4) Planar mode normal target readout for a given simulated target input.

5) Planar mode inverted target readout.

6) Spherical mode normal target readout.

7) Spherical mode inverted target readout.

Simple as these tests are they are sufficient to detect the majority of possible failures. The failure of the encoder disc bond during vibration was immediately evident in the planar mode operating test.

4.4 Calibration Test

The actual calibration of the PAS system is built into the hardware in the alignment of the optics to the encoder in the precision of the step angle and in the correct functioning of the electronic logic. The calibration test simply provides several simulated optical targets and checks the measurements of these targets as made by the PAS system against their actual geometrical dimensions. The calibration tests are described in EMR procedure No. 6341-2045-2 "Calibration Procedure, Panoramic Attitude Sensor for RAE-B", a copy of which is included in the appendix of this report.

Briefly, the procedure consists of the following:

1) Spherical Mode Spin Period Measurement.
2) Spherical Mode Agimuth Angles (X-Y) plane AOS, LOS and AOS to LOS Measurement Accuracy Test.
3) Spherical Mode Elevation Angles (Z axis reference AOS, LOS and AOS to LOS Measurement Accuracy Test.
4) Planar Mode (Z axis reference) AOS, LOS and AOS to LOS measurement accuracy test.

These tests are performed on the completed PAS system, testing one scanner at a time with the PAS electronics module. Both units are connected to the test set which provides the power, clock, commands and reads out the data. In these test, the PAS interfaces with the test set in much the same way as it will with the spacecraft.

For the spherical mode tests the scanner head is mounted on a spin table in the same orientation as it will mount on the spacecraft, with the plane of the sun slit and the plane of the scanner rotation both parallel to the spin axis. The spin table has slip rings to transmit all of the scanner inputs andoutputs. The exact spin rate of the spin table is determined by measuring precisely the interval between sun pulses using a separate external electronic timer.

The spin period measurement by the PAS system is made by counting in the AOS register the number of spacecraft clock cycles from sun pulse when no target is present for the scanner. This AOS count divided by the exact clock frequency is the spin period as measured by the PAS system. When an optical target is present in the scan path of the scanner an AOS and an LOS count are measured. Assuming the spin table angular speed is constant, the AOS count divided by the full revolution count is the actual geometrical angle from the scanner pointing direction at the time of the sun pulse to the beginning of the target. The LOS count is the number of clock pulses from the time the scanner registers the target until it registers no target. The LOS count divided by the clock frequency gives the target angular width (in units of a full revolution).

Spherical mode elevation angles are determined by operating the scanner in the search and measure modes with a target present and the spin table rotating. The encoder read out is registered by the test set for the advance step after which the target is first detected. Planar mode elevation angles are read in the same way except the scanner mounting is not rotating.

Measurements of the sun response width of the sun slit were made by placing the scanner head on an indexed rotary table in the beam of the solar simulator at a distance of about 57 inches from the projection lens.