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IUE FINE ERROR SENSOR
OPERATIONS MANUAL
IUE-670-76-97

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1. INTRODUCTION.	1-1
1.1 International Ultraviolet Explorer Mission	1-1
1.2 IUE Accuracy	1-1
1.3 IUE Control System	1-2
1.4 IUE Basic Sensor	1-2
1.5 Basic Sensor Reference	1-2
1.6 FES Manual Objectives.	1-3
2. PURPOSE OF THE FINE ERROR SENSOR.	2-1
2.1 Purpose.	2-1
2.2 FES Modes.	2-1
2.3 FES Mode vs. IUE Requirement Matching.	2-2
2.3.1 Initial Orientation	2-2
2.3.2 Target Recognition.	2-3
2.3.3 Target Tracking	2-3
2.3.4 Automatic Acquisition	2-6
2.4 FES Location	2-6
2.5 FES Control Algorithm.	2-8
2.6 FES Calibration.	2-11
3. FES DETAILED DESCRIPTION.	3-1
3.1 General Description.	3-1
3.1.1 Mechanical Description.	3-1
3.1.2 Circuit Devices	3-1
3.1.3 Redundancy.	3-1
3.1.4 Power	3-4
3.1.5 Command	3-4

TABLES OF CONTENTS (cont)

<u>Section</u>	<u>Page</u>
3.1.6 Clock	3-7
3.1.7 Telemetry	3-7
3.2 Block Diagram and Circuit Description.	3-7
3.2.1 Sensor Head	3-7
3.2.2 Electronics Package	3-15
4. FES OPERATIONAL MODES	4-1
4.1 Introduction	4-1
4.2 Primary Mode	4-2
4.2.1 Introduction.	4-2
4.2.2 Commands for Primary Mode	4-2
4.2.3 Telemetry for Primary Mode.	4-4
4.2.4 Examples of Commanding Primary Mode	4-4
4.2.5 Operational Flow in Primary Mode.	4-11
4.3 Search and Track Mode.	4-11
4.3.1 Introduction.	4-11
4.3.2 Commands for Search and Track Mode.	4-16
4.3.3 Telemetry Output for Search and Track Mode.	4-17
4.3.4 Examples of Search and Track Mode Setup	4-17
4.3.5 Operational Flow in Search and Track Mode	4-23
4.4 Field Camera Mode.	4-23
4.4.1 Introduction.	4-23
4.4.2 Field Camera Mode-Map Only.	4-25
4.4.3 Field Camera Mode-Map and Track	4-28
4.4.4 Operational Flow in Field Camera Mode, Map Only	4-31
4.4.5 Operational Flow in Field Camera Mode, Map and Track.	4-34
4.5 Mode Switching	4-36
4.5.1 Switching to Binary Mode from the Other Modes	4-36

TABLE OF CONTENTS (cont)

<u>Section</u>	<u>Page</u>
4.5.2 Switching to Search and Track Mode from the Other Modes.	4-37
4.5.3 Switching to Field Camera Mode (Map Only) from Other Modes.	4-38
4.6 Forbidden Modes	4-39
4.7 Operation Techniques Associated with Using the FES.	4-39
4.7.1 Use of FES to Acquire a Star	4-39
4.7.2 Focusing the SI Using the FES as a Reference	4-42
4.7.3 Using the FES to Update OBC Algorithms	4-42
4.7.4 Problems Associated with Using One FES for Both TLM and OBC Updates.	4-46
4.7.5 OBC and TLM Updates Using FES No. 1 and FES No. 2.	4-46
4.7.6 Problems Associated with Dual FES Operation for OBC Update	4-47
4.7.7 FES Use by the DMU	4-47
4.7.8 Use of FES to Track Extended Sources or Bright Stars.	4-47
4.7.9 Use of FES to Track Bright Stars	4-48
4.7.10 Operation of the FES in a Degraded Mode.	4-48
4.8 Summary of Commands for Search Deflection and Track Deflection.	4-51
GLOSSARY	GL-1

ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
2-1 Track Scan Aperture Flux Interception for Different Star Magnitudes and Pattern Sizes.	2-5

TABLE OF CONTENTS (cont)

ILLUSTRATIONS (cont)

<u>Figure</u>		<u>Page</u>
2-2	Prime and Secondary FES Locations in Scientific Instrument .	2-7
2-3	FES Optical Schematic.	2-9
2-4	FES/IUE Axial Relationship	2-10
3-1	Mechanical Outline IUE-FES Sensor Head	3-2
3-2	Mechanical Outline IUE-FES Electronics Package	3-3
3-3	Serial Digital Command Interface IUE-FES	3-5
3-4	Telemetry Control Serial Digital Output IUE-FES.	3-8
3-5	Sensor Head Block Diagram.	3-11
3-6	Electronics Package Block Diagram.	3-16
3-7	Reference Voltage Generator and Digital-Analog Converter IUE-FES.	3-18
3-8	Track Scan Patterns IUE-FES.	3-20
3-9	Typical Input Isolation Circuit IUE-FES.	3-22
3-10	Search Deflection Scan	3-23
3-11	Scan Wraparound Due to Delta Command Excessively Large . . .	3-25
3-12	Scan Interrupt Caused by SDC with New Parameters Prior to End of Frame	3-26
3-13	Command Action Timing IUE-FES.	3-29
3-14	Data Output Timing IUE-FES	3-31
3-15	Error Generator IUE-FES.	3-33
3-16	FES Event Sequencing, Field Camera Mode, Search Only	3-35
3-17	FES Event Sequencing, Search & Track Mode IUE-FES.	3-37
3-18	FES Event Sequencing Track Deflection Primary Search and Track Modes.	3-40
3-19	Housekeeping Pulses.	3-41
4-1	Command Setup of X_0/x_0 , Y_0/y_0 for Primary Mode	4-6

TABLE OF CONTENTS (cont)

ILLUSTRATIONS (cont)

<u>Figure</u>		<u>Page</u>
4-2	Command Configuration for Primary Mode.	4-7
4-3	Telemetry Output for Primary Mode	4-8
4-4	Command Setup for X_0/x_0 , Y_0/y_0 Primary Mode	4-9
4-5	Command Configuration for Primary Mode.	4-10
4-6	Telemetry Output for Primary Mode	4-12
4-7	OPS Flow for FES Turn On.	4-13
4-8	OPS Flow Primary Mode	4-14
4-9	Command Setup of X_0/x_0 , Y_0/y_0 , Δ for Search and Track Mode.	4-18
4-10	Command Configuration for Search and Track Mode	4-20
4-11	Typical Search Deflection Raster.	4-21
4-12	Operational Flow for Search and Track Mode.	4-24
4-13	Command Setup of X_0/x_0 , Y_0/y_0 , Δ for FCM-Map Only	4-27
4-14	Command Configuration for FCM-Map Only.	4-29
4-15	Command Setup of X_0/x_0 , Y_0/y_0 , Δ for Field Camera Mode- Map and Track	4-32
4-16	Command Configuration for Field Camera Mode-Map & Track	4-33
4-17	Operational Flow for FCM.	4-35
4-18	Typical TLM Format.	4-43
4-19	Typical OBC Format.	4-45
4-20	Dual FES Operations	4-49
4-21	Extended Source Tracking in Field Camera Mode	4-50

TABLES

<u>Table</u>		<u>Page</u>
3-1	IUE-FES Serial Digital Command Word Bit Designation	3-6
3-2	IUE-FES Serial Digital Telemetry Word Bit Designation	3-9
3-3	Housekeeping Pulse Function	3-42

TABLE OF CONTENTS (cont)

TABLES (cont)

<u>Table</u>		<u>Page</u>
3-4	FES System Interconnect Electronic Package, Connector P1. . .	3-44
3-5	FES System Interconnect Connector S2 (FES Test)	3-45
3-6	FES System Interconnect Connector S3 (FES EP/FES SH).	3-46
4-1	UL/OL and Track Scan Rates for Primary Mode	4-3
4-2	Star Magnitude Configurations	4-15
4-3	UL/OL and Track Scan Rates.	4-17
4-4	Command Configuration for Search Deflection	4-52
4-5	Command Configuration for Track Deflection.	4-53

SECTION 1. INTRODUCTION

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1.1 INTERNATIONAL ULTRAVIOLET EXPLORER MISSION

The International Ultraviolet Explorer (IUE) is intended as a follow-on to the Orbiting Astronomical Observatory (OAO) series of ultraviolet observatories, and is based on Delta-launched spacecraft. It will be launched in late 1977, and will have a 3 to 5 year orbital life.

The IUE will be placed in an elliptical-geosynchronous orbit permitting continuous full-time coverage and operation of the spacecraft. This continuous coverage allows the use of experiments and error sensors that generate large quantities of data and/or require almost continuous ground intervention and control for effective performance. However, it does limit spacecraft weight and this limits allowable complexity and redundancy. The experiment, a 45-cm Ritchey-Chretien telescope, driving two echelle spectrographs and containing four UV convertor/SEC vidicon cameras, generates up to a 40-kb/sec video stream in the science mode. The Fine Error Sensor (FES), operating in raster fashion, requires both a considerable bit stream and a period of several minutes to build a star map. The use of this device permits a single FES to replace up to eight stellar sensors on OAO to accomplish the multiple tasks of initial stellar coordinate recognition, coarse pointing, fine pointing and fine holding.

1.2 IUE ACCURACY

The required initial pointing accuracy is 2 minutes of arc, with fine pointing of ± 1 second of arc and stability requirement of maintaining fine pointing for at least 30 minutes.

1.3 IUE CONTROL SYSTEM

The IUE control system is relatively conventional, consisting of sensors, controllers and actuators. Its implementation, however, is unconventional in as much as it utilizes a complex algorithm residing in an On-Board Computer (OBC). This processes data from the sensors by performing axis transformations to resolve sensor sensitive axes into spacecraft control axes, performs digital filtering on the resolved error data, combines the data from various sensors and bias generators, performs tests to determine whether slews are in progress, and finally generates control signals to drive three conventional inertia wheels that produce torque to achieve and maintain vehicle attitude.

1.4 IUE BASIC SENSOR

The basic sensor system is a cluster of six, single-axis, rate-integrating gyroscopes mounted on the strong ring to which the Scientific Instrument (SI) is also mounted. Each of these devices senses inputs in all three control axes, by virtue of being skewed to all axes. The OBC algorithm transforms and combines these signals to create the composite control signals.

1.5 BASIC SENSOR REFERENCE

The absolute reference for the gyros is provided by the FES. It is this device that ties the inertial coordinates of the gyro system into the celestial coordinates of the experiment and permits drift in the former to be detected, quantized, and corrected. This can be done either in open loop fashion, by observing the drift of a star field across fiducial lamps embedded in the aperture plate, or closed/open loop by allowing the FES to track a guide star and then using the resultant errors either directly in the OBC algorithm, or indirectly as ground computer-generated gyro bias compensating the drift.

1.6 FES MANUAL OBJECTIVES

In this manual, the basic mission requirements on the FES are stated and the methods whereby the FES accomplishes these requirements are described. The FES itself is explained in detail showing the inner functioning and timing. This permits the user to utilize the device most efficiently under normal modes and provides the required insight to use the FES in degraded fashion. The operations section describes the fashion in which the FES is commanded and the methods by which the data is telemetered to the ground and/or utilized in the OBC. Typical operating modes are established and typical operations, such as dual FES operation, bright star, extended source and secondary mirror focusing are discussed.

SECTION 2. PURPOSE OF THE FINE ERROR SENSOR

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2.1 PURPOSE

The purposes of the FES in the IUE are to provide information from which initial IUE orientation in the celestial sphere can be established (or re-established), to permit identification of desired target stars within a star field, to permit manual or automatic acquisition of guidance stars and to provide two axes error data from an offset star for either open or closed loop positioning of the target star in the experiment aperture.

2.2 FES MODES

To accomplish the above tasks the FES operates in various modes. All of these modes are based on counting the number of photons of sufficient energy impinging on a 12.62 arc-second square or pixel of photo-cathode surface and then electromagnetically shifting this square in discrete steps in various fashions. The total number of photon-events counted will be a function of stellar radiation within the square and the length of time that the count is continued. This digital count can be compared with commandable preset values to establish magnitude thresholds. If the stellar flux is excessive and/or the counting period is excessive, the counter will become inhibited at a count of 28,672 photon-events.

Basically, the FES utilizes this pixel in either of two deflection modes, search or track, and combines these modes with logic operations and dwell periods to function in one or another of three system modes called primary, search and track, and field camera mode. Changes between system modes can occur only by direct command, while changes in deflection mode occur as a function of precommanded logic and physical events.

Two types of commands are utilized by the FES. The first of these is a 37-bit serial digital word whose bit structure and function will be described completely in section 3. This command is used to control the operation of the FES. The second command is an impulse command called Continue Search Command (CSC) that has as its prime purpose the objective of forcing the FES to cease tracking a star by offsetting the scan pattern sufficiently to prevent reacquisition of that star.

2.3 FES MODE VS. IUE REQUIREMENT MATCHING

2.3.1 INITIAL ORIENTATION



The first IUE requirement on the FES is to help determine initial stellar orientation. By using other sensors, the IUE stabilization and control subsystem will have oriented the SI telescope to within ± 2 degrees of the North Ecliptic Pole (NEP). At this time, the FES will be operated in the field camera mode to obtain a picture of the SI telescope's view. This is accomplished by electronically stepping the internal aperture of the FES in a series of overlapping steps in a raster fashion. At each step, a count of the photons impinging on the photo-cathode at that position is made and telemetered to the ground along with the internal position coarse FES coordinates. The ground computer uses this information to recreate the telescope view. The photon counts are an indication of star magnitude and the ground system can use this information. From this display the astronomer performs comparisons between the SI view and a star map about the NEP until a pattern is recognized. The offset coordinates are entered into the ground computer which can now generate the proper slew sequences to point the SI at a target region using the normal celestial coordinates (hour angle and declination) of the target star.

To perform this image construction, the FES normally operates in the field camera mode with track disabled. It can also be operated with track enabled in which case, raster generation would cease when a suitably bright star is encountered. After the FES switches from search to track deflection, it centers the track pattern on the star.

2.3.2 TARGET RECOGNITION

The second IUE requirement, target recognition, is accomplished in the following manner. With the pointing attitude of the celestial sphere established, the astronomer designates a desired target star and enters its coordinates in the ground computer. This device determines the required slews and transmits the slew commands to the IUE. After performing the slews, the IUE settles at the new pointing direction. The FES is again operated in the field camera mode and an image is recreated on the ground. The astronomer, using an interactive device, designates one star in the pattern as the desired target star and a second, as a guide star. The ground computer generates the small slew commands required to place the target star within the spectrograph aperture and also computes the required FES X, Y offset command for capturing the guide star.

2.3.3 TARGET TRACKING

On completion of this small corrective slew, the FES is placed in the primary mode. In this mode the FES initially will perform a track deflection pattern about the commanded input coordinates. As the deflection pattern centers itself, the FES will generate a digital error signal showing the offset from star center to the commanded coordinates.

Once the coordinates of the star have been established and stabilized, the error generated can be used in conjunction with gyro rate information to control IUE position directly or it can be used to detect and correct gyro attitude drift in the pitch and yaw axes. The choice of control methodology will generally be a function of guide star brightness and in orbit experience.

As was mentioned earlier, the number of photon events will be a function of both stellar flux and photon counting time. For dim stars, generally dimmer than +13 m, the track deflection pattern is operated in a quarter speed mode or slow scan, dwelling four times as long at each position. This results

Slow Scan

in a data sample rate of 1.3 samples per second which is too slow for use directly in the control loop. In fast scan, 5.2 samples per second are obtained which is satisfactory for the control loop time constant. Star position is determined by counting up photons in one aperture position and then shifting the aperture a predetermined amount and subtracting the photons detected in the new location from those of the previous dwell point. If the new position has a greater or lesser flux, the counts will differ and a digital error will result. This error is used to both center the track pattern on the star and provide an indication of off-null pointing. If the star source is too bright, the up and down counters will limit and data is invalid. To overcome this effect, the distance between the two dwell points can be increased so that the stellar flux measured in each portion is sufficient for reasonably jitter-free positioning but insufficient to cause counter limiting. The shift point between the overlap pattern used for dim stars and the underlap pattern used for bright stars is approximately +7 m. Figure 2-1 attempts to portray the flux spreading and aperture interception of the two types of scan track patterns.

In the track deflection submode, the FES will track a star at rates up to 18 arc-sec/sec and for displacements up to 8 arc-min from the commanded reference position. If the rate exceeds this or the star image leaves the field-of-view or somehow becomes occulted, the loss of star presence will cause the track pattern to remain at the coordinates at which presence was lost.

If it is desired to utilize a different guide star in the FES Field-of-View (FOV), the new coordinates are entered as part of the 37-bit Serial Digital Command (SDC) and then an impulse command, Continue Search Command (CSC), is issued. This causes the FES to break track on the first star, reset the course offset registers, and permit the FES track pattern to be offset to the coordinates of the new star.

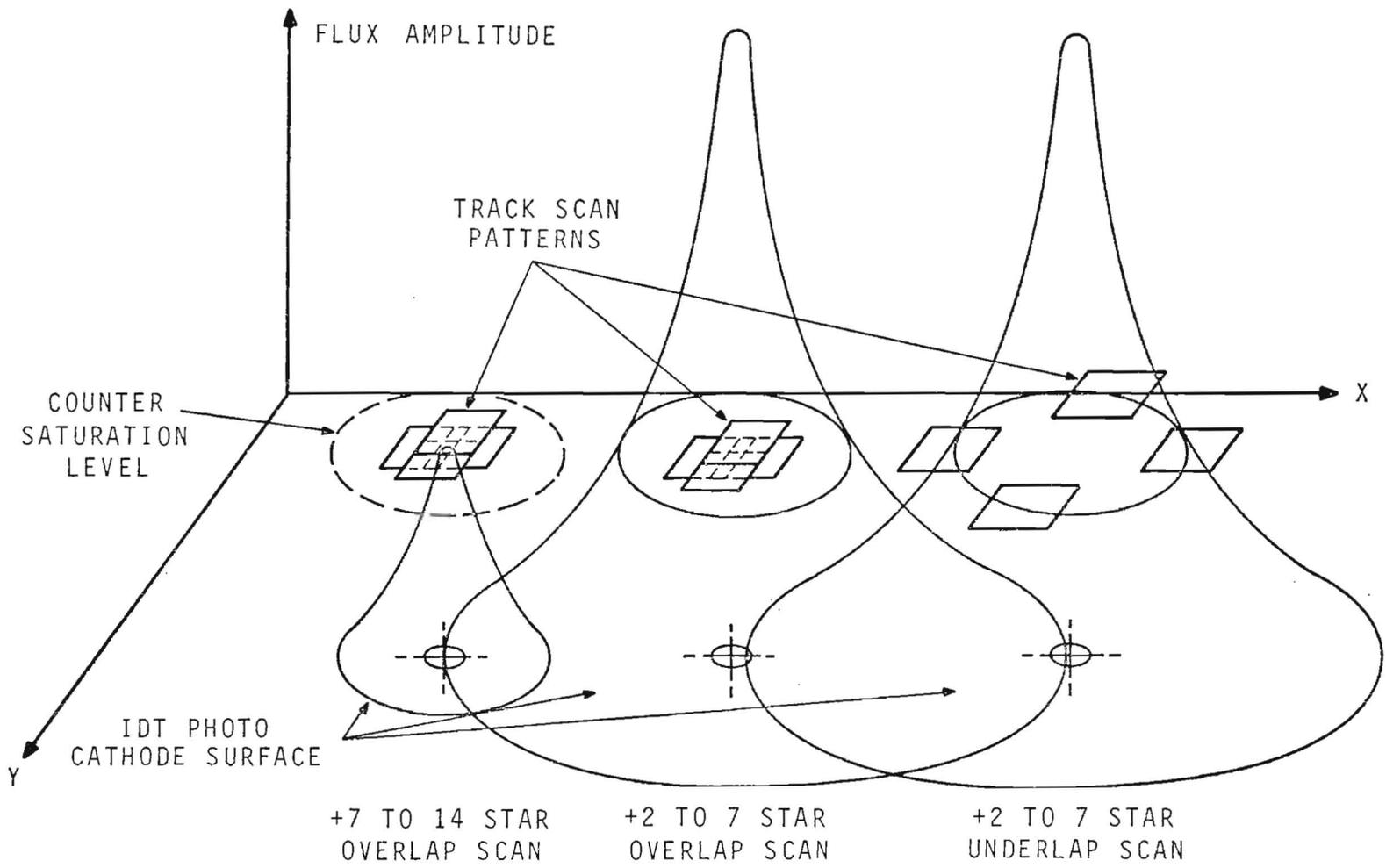


Figure 2-1. Track Scan Aperture Flux Interception for Different Star Magnitudes and Pattern Sizes

2.3.4 FES AUTOMATIC STAR CAPTURE

If the coordinates of a desired guide star of +11 m or brighter are known with good accuracy as in the case of a small slew or if the viewing area of the SI is in a low density star region, the acquisition of a desired star can be accomplished in either the field camera mode with track enabled or in search and track mode. The latter mode is faster.

In this mode the aperture image is stepped in search deflection at a 2.4 msec/step rate until a photon-count in excess of one of the four commandable thresholds is found. At this point the deflection mode would switch from search to track and develop offset errors.

2.4 FES LOCATION

Because the FES is not internally redundant and because of its importance to the mission, two FES's are installed in the IUE. Figure 2-2 illustrates the two units receiving light energy from the Scientific Instrument (SI) telescope. Near on-axis energy passes through one aperture of either two sets of aperture holes in the fold mirror at the telescope focal plane. One set of holes are 3 arc-sec in diameter and are used under experimental conditions. The other set of holes are ovals 10 arc-sec by 20 arc-sec and are used for degraded pointing experimentation. This plate also contains the fiducial lamps which are used as references to determine star images relative to the apertures. The plate also contains a low reflectivity patch near the center that attenuates star images by five orders of magnitude. The FES's receive all of the off axis energy. This energy is divided by a beam splitter in a 70/30 percent ratio. The FES that receives the 70 percent share is designated the prime unit and is the unit to which references regarding magnitude sensitivity and thresholds are made. With an effective telescope collector area of 538 sq-cms and a dwell time of 25.6 milliseconds, the prime unit can capture a +13.5 m $A_0\bar{V}$ star with at least an 85 percent probability.

2-7

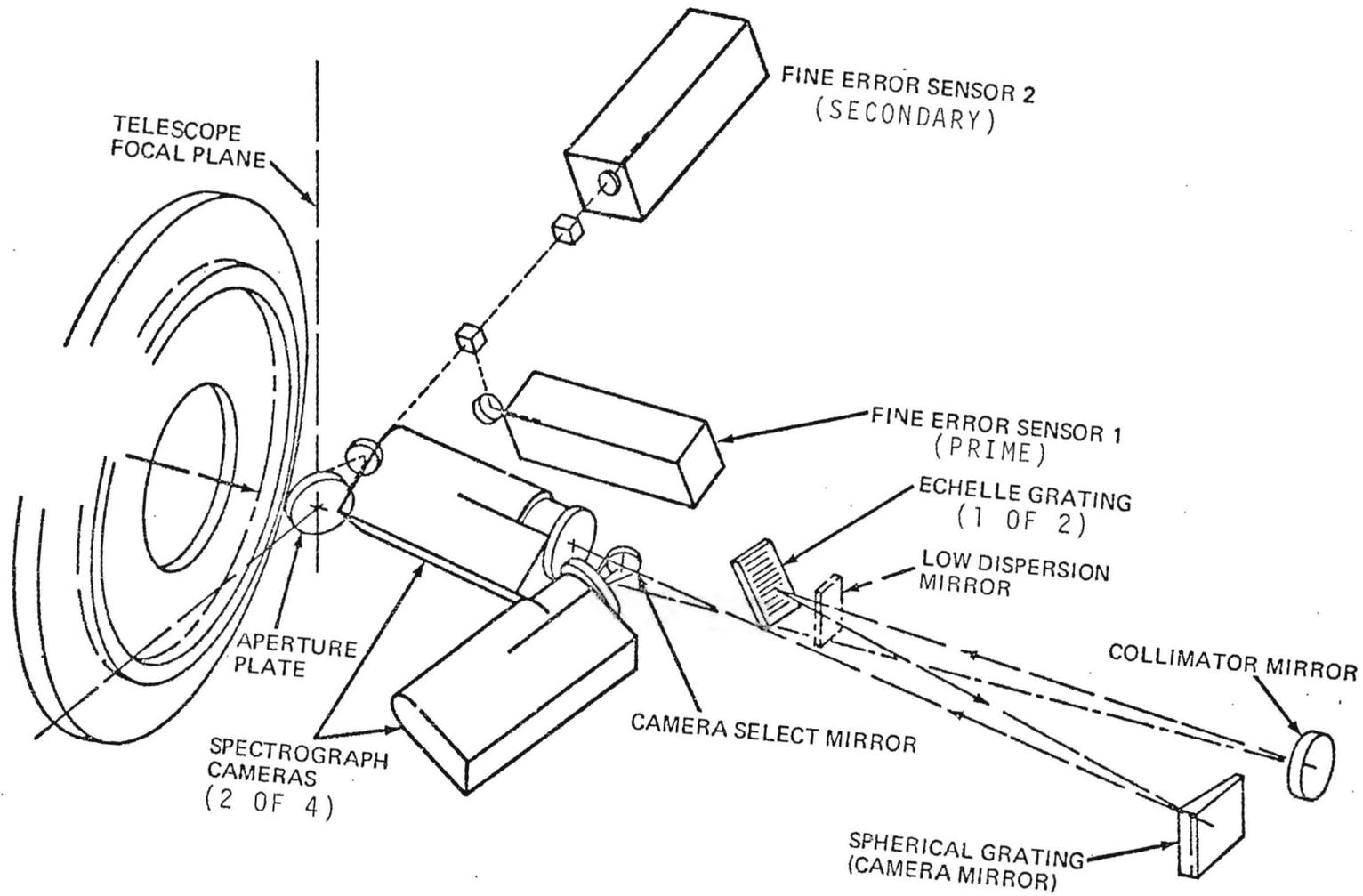


Figure 2-2. Prime and Secondary FES Locations in Scientific Instrument

The secondary unit receives only 43 percent as much energy and is about 0.93 magnitude less sensitive. All threshold settings and decisions regarding scan rates and underlap/overlap should take this into consideration. Figure 2-3 is an optical schematic showing the division of light from the telescope to the various echelle cameras and the FES's.

Incorporation of the two FES's into the SI was done in a fashion such to accommodate the optical elements most effectively with orientation of the FES internal axes relative to the IUE control axes of secondary concern. To compensate for this effect in the prime location, all the IDT's and their deflection coils are rotated 10.5 degrees relative to the mechanical axes of the sensor head. This axial relationship is shown as figure 2-4(a).

Unfortunately, the optical elements in the path to the secondary FES are such that the projection of the control axes is no longer coincident and the rotation relative to the FES mechanical axes is greater than that of the prime sensor. Figure 2-4(b) shows the angular offset of all sets of axes relative to each other at the secondary FES.

2.5 FES CONTROL ALGORITHM

Because of the axial rotation effects, the FES error data is first processed with a transformation matrix to put the data from both sensors in agreement with each other and in some relationship with the IUE control axis. These transformations are performed both on the ground for star map purposes and in the OBC for control purposes.

After axial transformation, the FES error data is processed by a six-stage Butterworth filter within the OBC. This algorithm takes the six most recent error data samples and averages them to present a relatively jitter-free data source for gyro drift trend and position referencing update.

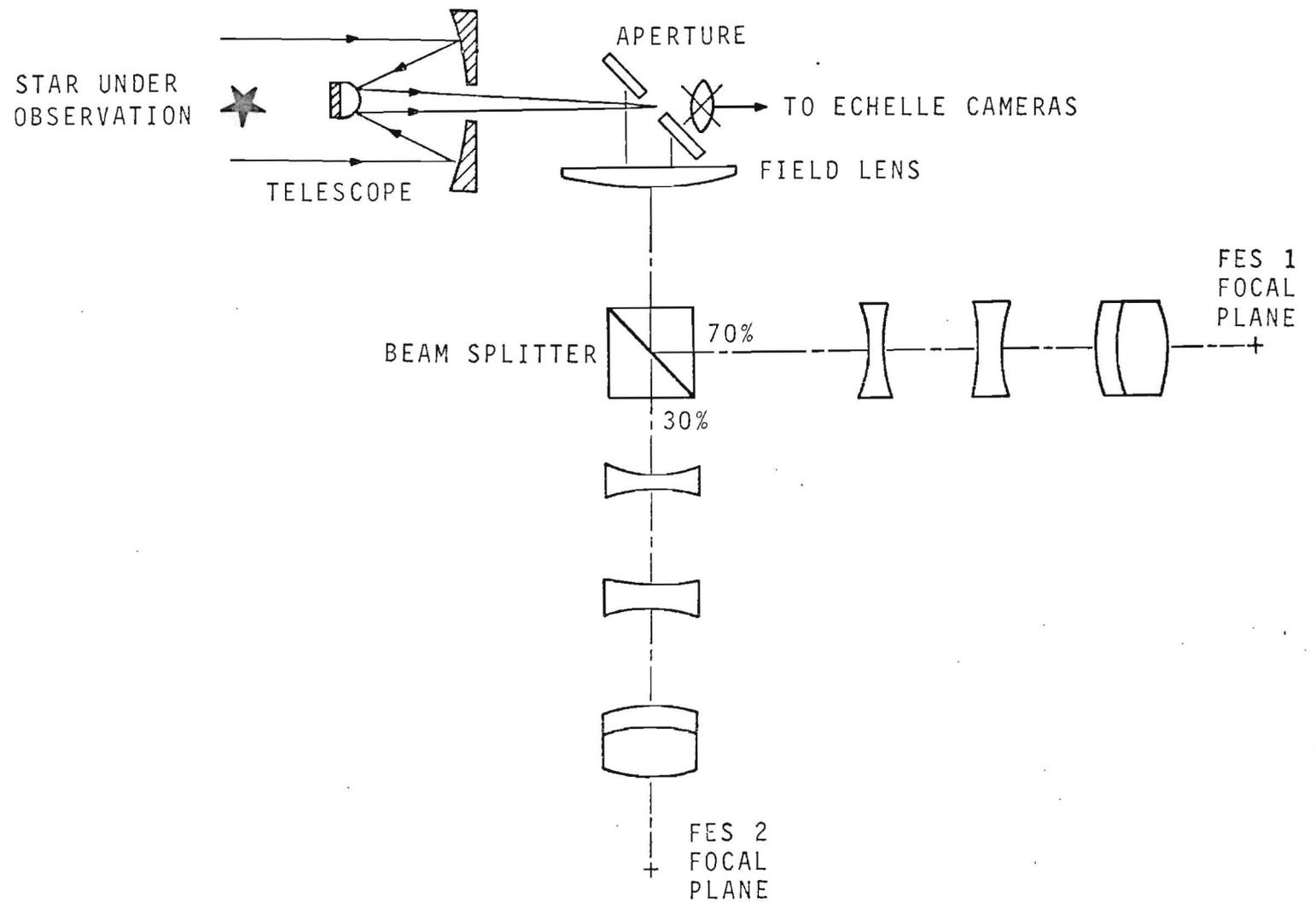
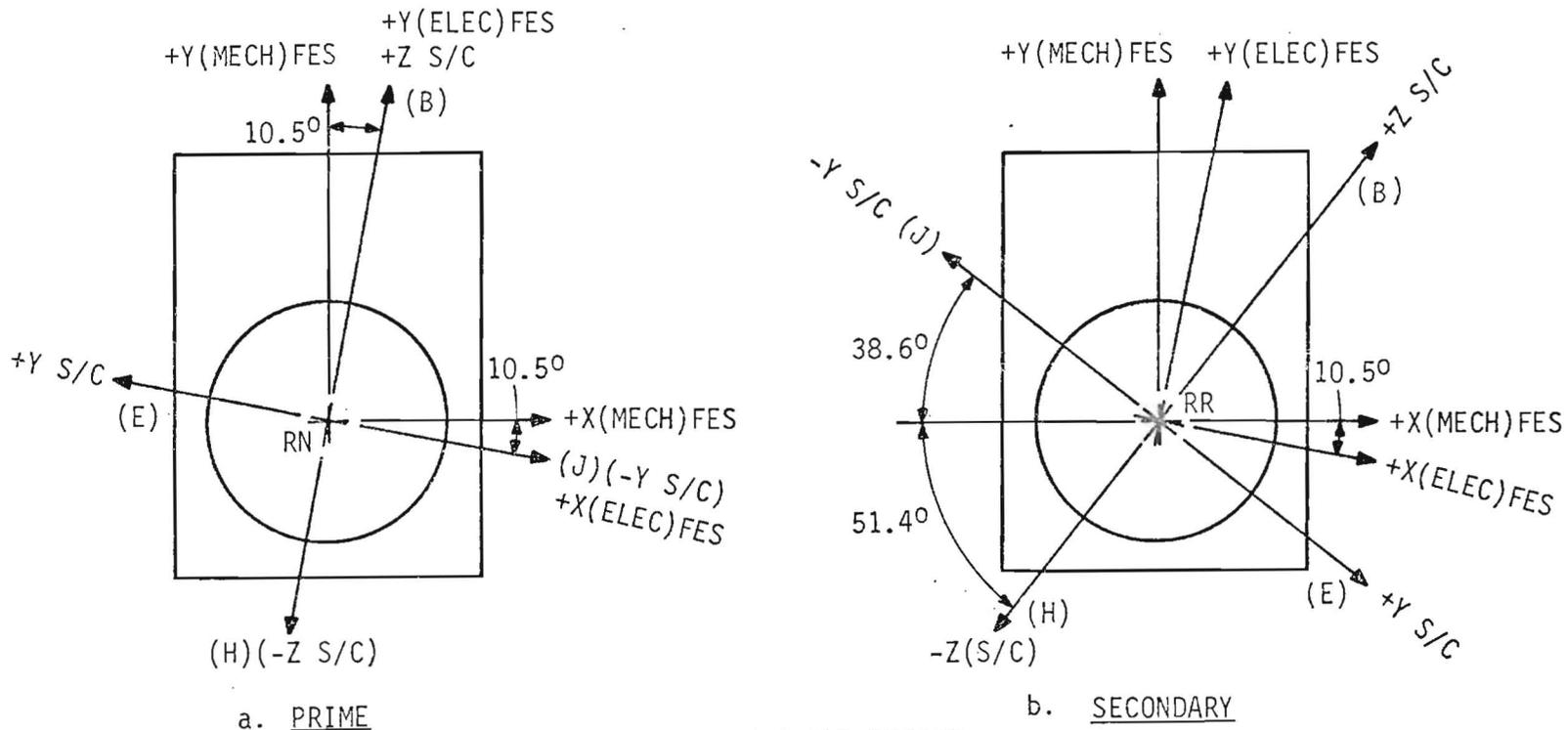


Figure 2-3. FES Optical Schematic



VIEW LOOKING INTO FES SENSOR

DIRECTION OF IMAGE MOTION FOR STAR WITH SOURCE
 ANGLE INCREASING IN POSITIVE S/C DIRECTIONS (+Y & +Z)

PRIME:

FOR SOURCE MOTION RN TO E
 IMAGE MOVES RN TO J WITH
 INCREASING X OF FES (ELEC OUTPUT)

FOR SOURCE MOTION RN TO B
 IMAGE MOVES RN TO H WITH
 DECREASING Y (FES ELEC OUTPUT)

SECONDARY:

(1) SOURCE MOTION RR TO E GIVES:
 IMAGE MOTION RR TO J
 INCREASING Y(ELEC) &
 DECREASING X(ELEC)

(2) SOURCE MOTION RR TO B GIVES:
 IMAGE MOTION RR TO H &
 DECREASING Y & X(ELEC)

Figure 2-4. FES/IUE Axial Relationship

In one of the control modes the raw FES data is combined with data from the six gyros in the Inertial Reference Assembly (IRA) in a complex algorithm with the process repeating every 204 milliseconds. The detailed algorithm for this program is shown in the IUE System Design Report, Volume II, Appendix C, figure C-4, issued in June 1976.

2.6 FES CALIBRATION

During the acceptance test, the FES vendor obtained data showing the shift in absolute aperture image location and IDT sensitivity as functions of sensor head internal temperature. In addition, data showing the geometric distortion of the scanning subsystem relative to the center coordinates was obtained. This information is contained in a series of equations resident in the ground computer. The geometric distortion corrections are made as a function of offset position from the center coordinate. The temperature sensitive corrections are made using a temperature sensor internal to the FES as an input to the algorithm.

SECTION 3. FES DETAILED DESCRIPTION

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3.1 GENERAL DESCRIPTION

3.1.1 MECHANICAL DESCRIPTION

The FES consists of two separate units, a sensor head and an electronic package. The sensor head containing the detector and ancillary circuits is mounted in the telescope. The electronics package contains the various control logic and processing circuitry and is mounted on the upper equipment platform. It is connected to the sensor head with a single cable. Figures 3-1 and 3-2 show the two units in outline fashion.

3.1.2 CIRCUIT DEVICES

Electronics circuits in the two units have been designed with extensive use of Operational Amplifiers (Op Amps) in the analog circuits and Complementary Metal Oxide Semi-conductor (CMOS) logic for the digital circuits. These latter devices consume power only when switching between states. However, they are susceptible to particulate bombardment damage encountered at IUE operational altitudes and have been shielded to minimize this effect.

3.1.3 REDUNDANCY

The circuitry is completely nonredundant although the design is conservative to prevent failure due to component overstress. The input and output lines incorporate isolating circuitry to prevent internal failures in the FES from propagating and causing failures in other equipments. These circuits also permit the FES to accept redundant command inputs and telemetry outputs while preserving the isolation between the independent command and telemetry systems.

3-2

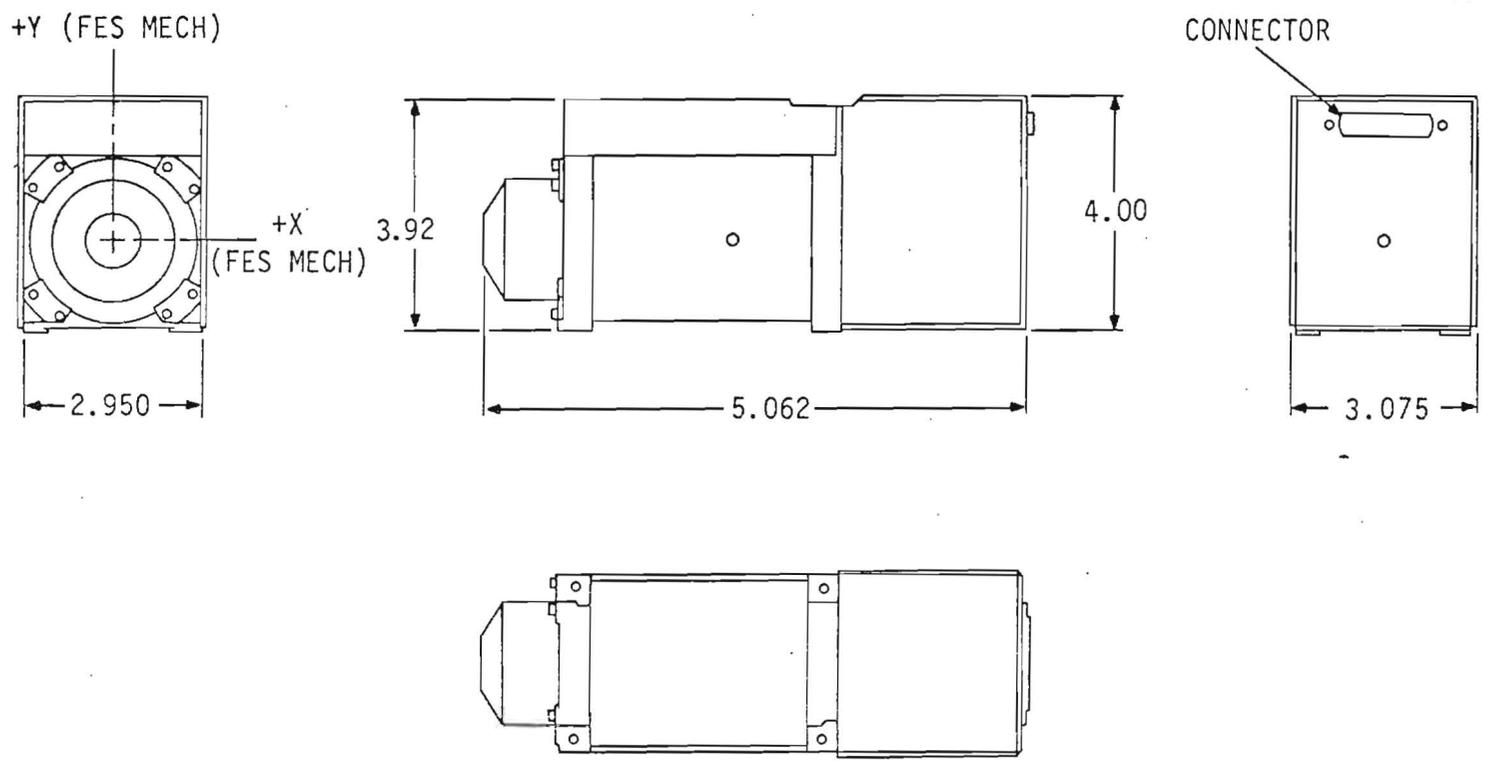


Figure 3-1 Mechanical Outline IUE-FES Sensor Head

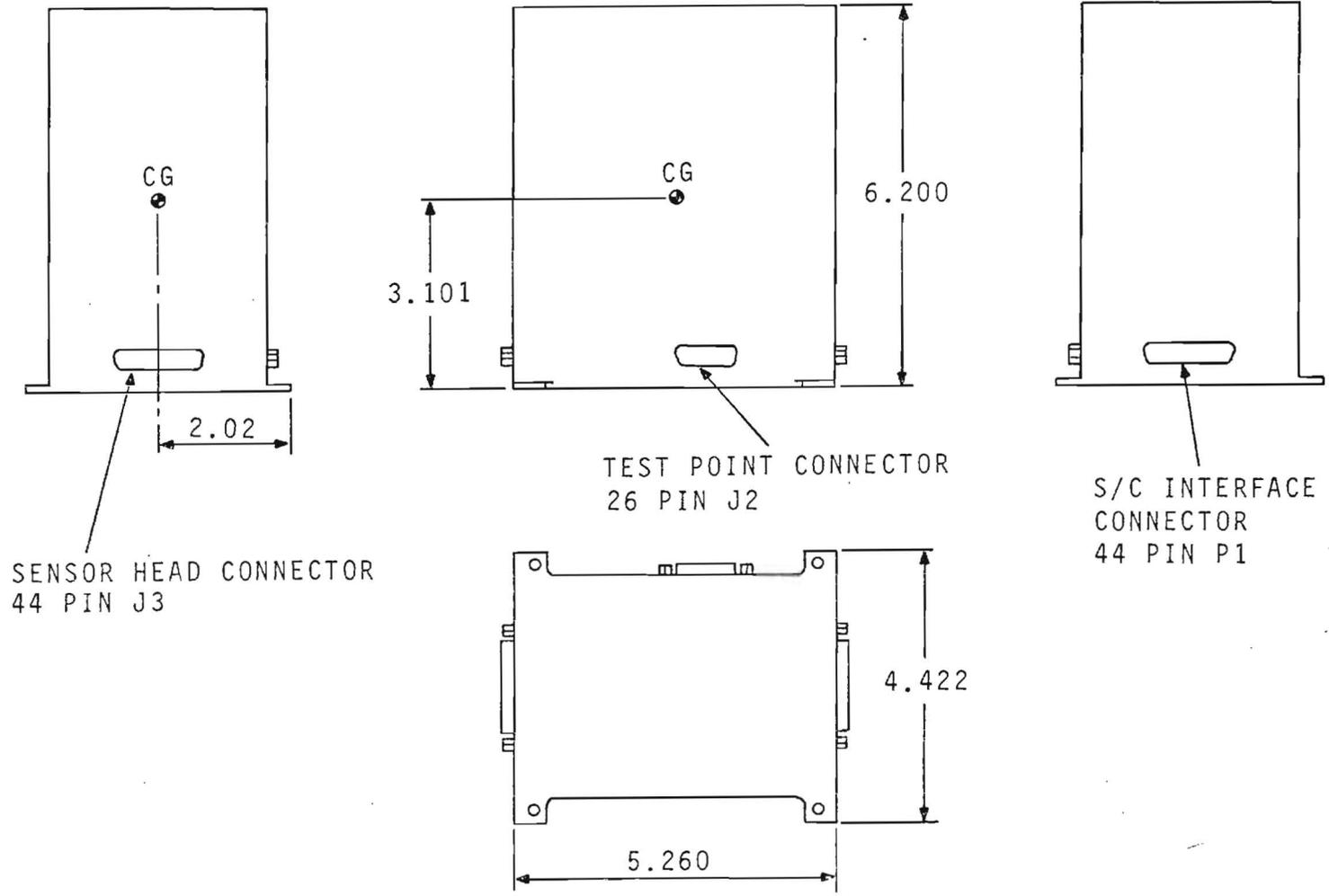


Figure 3-2. Mechanical Outline IUE-FES Electronics Package

3.1.4 POWER

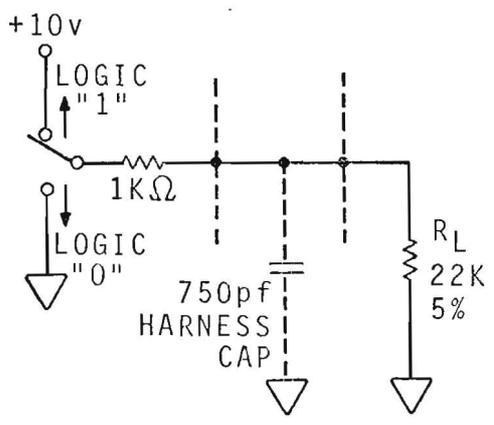
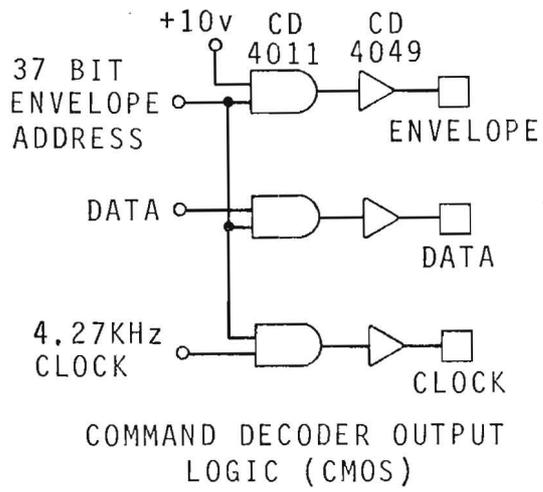
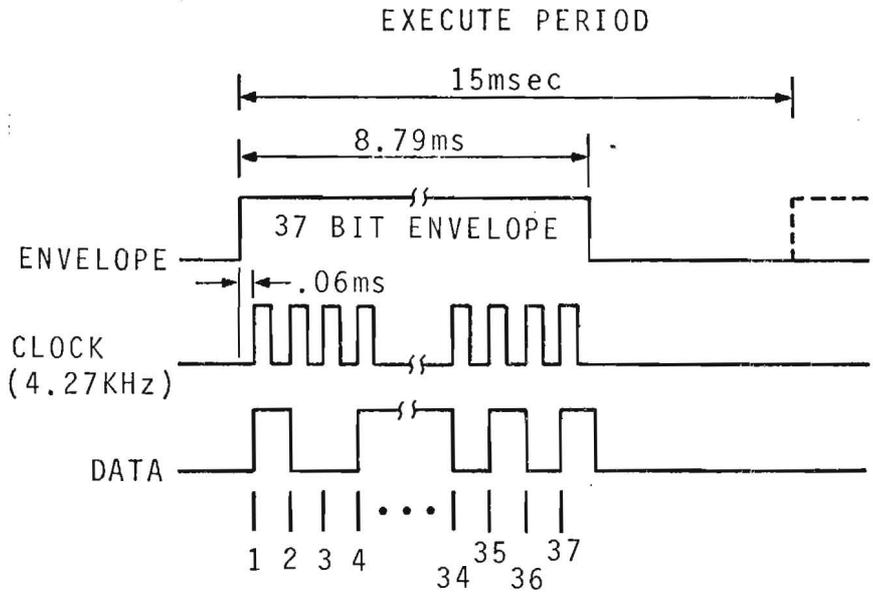
When supplied with external power sources of plus and minus 15 volts (plus or minus 1 percent) and plus 8 volts (plus or minus 1.5 percent), the FES will draw an average of less than 4.3 watts and a peak power of 4.5 watts. The unit will withstand variations of plus 3 volts or minus 20 percent on any or all input lines without damage but may operate outside of specifications at such times.

3.1.5 COMMAND

The FES receives and accepts two types of commands. The first of these is a 37-bit Serial Digital Command (SDC), that is required to establish modes, set up different parameters within the modes and transfer to new modes. The second type of command is an impulse, Continue Search Command (CSC), and is used primarily to interrupt operation of one mode (track deflection) and resume the alternative mode (search deflection). Refer to the flow diagrams for the total function of CSC in each FES mode.

The SDC consists of a command envelope, a series of 37-clock bits within that envelope and 37-NRZ bits of command. The characteristics of the command generator including waveforms are shown in figure 3-3. The isolating input circuits of the FES appear as a 22 K resistive load to ground. There are ten bit groupings in the SDC that set the various FES modes and the operating conditions within the modes. Table 3-1 shows the 37-bit word and identifies the command function of each bit. These will be explained in detail later in this section.

The other command, the CSC, is a positive going pulse of 15 msec duration. Source impedance is similar to that for the SDC and the FES load.



OUTPUT EQUIV. CIRCUIT OF TYP. ENVELOPE DATA OR CLOCK LINES

Figure 3-3. Serial Digital Command Interface IUE-FES

Table 3-1. IUE-FES Serial Digital Command Word Bit Designation and Continue Search Command Functions

Command Word	Bit Number	Bit Function	Mnemonic
X ₀ Coarse offset deflection coordinate or starting coordinate for raster scan	1	Sign Bit, 0 = plus	FESX = (-63 to +63)
	2	1 = 276.48 arc sec	
	3	1 = 138.24 arc sec	
	4	1 = 69.12 arc sec	
	5	1 = 34.56 arc sec	
	6	1 = 17.28 arc sec	
	7	1 = 8.64 arc sec	
Y ₀ Coarse offset deflection coordinate or starting coordinate for raster scan	8	Sign Bit, 1 = minus	{2's complement}
	9	1 = 276.48 arc sec	FESY = (-63 to +63)
	10	1 = 138.24 arc sec	
	11	1 = 69.12 arc sec	
	12	1 = 34.56 arc sec	
	13	1 = 17.28 arc sec	
	14	1 = 8.64 arc sec	
Δ or Delta Number of steps in raster line and number of lines in raster frame (square raster size) = 2Δ + 1	15	1 = 276.48 arc sec	
	16	1 = 138.24 arc sec	
	17	1 = 69.12 arc sec	
	18	1 = 34.56 arc sec	
	19	1 = 17.28 arc sec	
20	1 = 8.64 arc sec		
Under/Over Lap Track Scan	21	0 = Over, 1 = Under	FLAP = 1,0
X ₀ Fine offset deflection coordinate or starting coordinate for raster scan	22	1 = 4.32 arc sec	FESXF = (0 to 31)
	23	1 = 2.16 arc sec	
	24	1 = 1.08 arc sec	
	25	1 = 0.54 arc sec	
	26	1 = 0.27 arc sec	
Y ₀ Fine offset deflection coordinate or starting coordinate for raster scan	27	1 = 4.32 arc sec	FESYF = (0 to 31)
	28	1 = 2.16 arc sec	
	29	1 = 1.08 arc sec	
	30	1 = 0.54 arc sec	
	31	1 = 0.27 arc sec	
TE Track Enable*	32	0 = Map only, 1 = Map then Track	FES TE = 1,0
TSR Track Scan Rate	33	0 = Fast Track Scan, 1 = Slow Track Scan	FESSR = 1,0
THD Threshold Set [†]	34	00 = +11 m, 01 = +10 m 10 = +9 m, 11 = +8 m	FESTHD =
	35		
SM System Mode	36	00 = Primary, 01 = Search & Track, 10 & 11 = Field Camera	FESSM = (0 to 3)
	37		
* Ignored if Bit 36 = 0 † Ignored if Bit 32 = 0			
Continue Search Cmd	CSC	Primary Mode = Reset Error Registers (Ex & Ey = 0) & Center Track Deflection at SDC value of X ₀ , X ₀ & Y ₀ , Y ₀ Search & Track or Field Camera Mode, Track Enable = Cease track, return to coordinate of Star Acquisition, Decrement Y by two 8.64 arc sec steps	IMP, (62, 63) 62 for No. 1 53 for No. 2

3.1.6 CLOCK

To perform its internal logic operations, the FES requires accurate timing. This is supplied by two clock signals generated in the Data Multiplexing Unit (DMU). These clocks are positive going pulses of about 7 volts amplitude and occur at rates of 10-kHz and 160-kHz. The FES interface appears as a resistance to ground and loads the 10-KHz clock with 10 k ohms and the 160-kHz clock with 2.7 k ohms. Clock pulse widths are 50 μ sec for the 10-kHz clock and 3.125 μ sec for the 160-kHz clock.

3.1.7 TELEMETRY

The FES presents three telemetry interfaces to the IUE. All are available from redundant output circuits decoupled to prevent line or component failures from affecting the other line. Two of these signals, an analog measurement of Image Dissector Tube (IDT) photo-cathode temperature and a bi-level indication of star presence are continuously available. The third output is a 56-bit serial digital word and becomes available when the DMU issues a Digital Word Gate (DWG) to the FES along with 56 data out-shift pulses occurring in seven groups of eight pulses each. The timing relationship of these signals is shown on figure 3-4.

The bit structure and definitions are shown in table 3-2. The significance of the telemetry will be explained later in this section and the following section. The various offset registers (X & Y coordinate and the seven Most Significant Bits [MSB] of Ex & Ey) express negative values in two's complement.

3.2 BLOCK DIAGRAM AND CIRCUIT DESCRIPTION

3.2.1 SENSOR HEAD

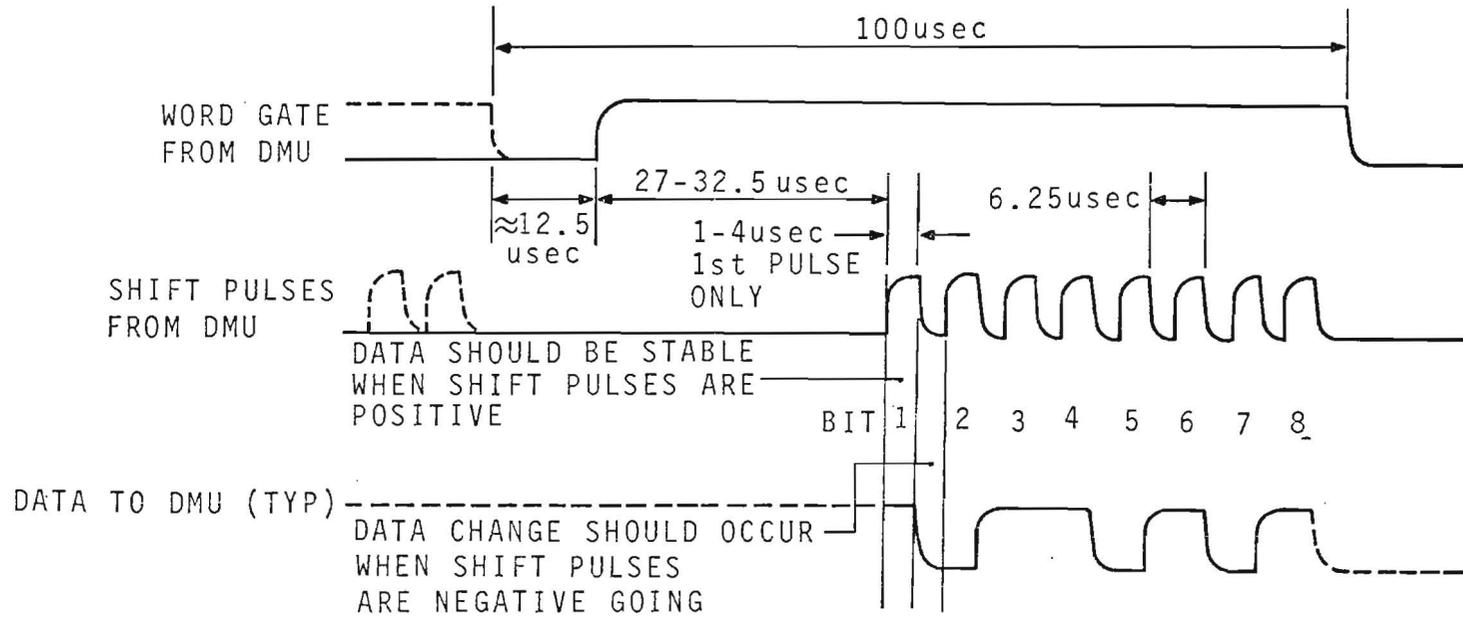


Figure 3-4. Telemetry Control Serial Digital Output IUE-FES

Table 3-2. IUE-FES Serial Digital Telemetry Word Bit Designation

Telemetry Word	Bit Number	Bit Function	
SM (System Mode)	1	Reflects Bits 36 & 37 of SDC	
	2		
X Coordinate Search Defl - X position of Pixel Track Defl - X coordinate of initial star acquisition	3	Sign 0 = plus	
	4	1 = 276.48 arc sec	
	5	1 = 138.24 arc sec	
	6	1 = 69.12 arc sec	
	7	1 = 34.56 arc sec	
	8	1 = 17.28 arc sec	
	9	1 = 8.64 arc sec	
	Y Coordinate Search Defl - Y position of Pixel Track Defl - Y coordinate of initial star acquisition	10	Sign 1 = minus
		11	1 = 276.48 arc sec
12		1 = 138.24 arc sec	
13		1 = 69.12 arc sec	
14		1 = 34.56 arc sec	
15		1 = 17.28 arc sec	
16		1 = 8.64 arc sec	
C _T Star Magnitude Count Binary number of photon- events during count period		17	1 = 2 ¹⁴ counts
	18	1 = 2 ¹³ counts	
	19	1 = 2 ¹² counts	
	20	1 = 2 ¹¹ counts	
	21	1 = 2 ¹⁰ counts	
	22	1 = 2 ⁹ counts	
	23	1 = 2 ⁸ counts	
	24	1 = 2 ⁷ counts	
	25	1 = 2 ⁶ counts	
	26	1 = 2 ⁵ counts	
	27	1 = 2 ⁴ counts	
	28	1 = 2 ³ counts	
	29	1 = 2 ² counts	
	30	1 = 2 ¹ counts	
31	1 = 2 ⁰ counts		
SP (Star Presence)	32	1 = Tracking Star	
Ex Error in X X offset of star tracked relative to point of acquisi- tion Ex invalid in Search Defl (Field Camera Mode)	33	Sign 0 = plus	
	34	1 = 276.48 arc sec	
	35	1 = 138.24 arc sec	
	36	1 = 69.12 arc sec	
	37	1 = 34.56 arc sec	
	38	1 = 17.28 arc sec	
	39	1 = 8.64 arc sec	
	40	1 = 4.32 arc sec	
	41	1 = 2.16 arc sec	
	42	1 = 1.08 arc sec	
	43	1 = 0.54 arc sec	
	44	1 = 0.27 arc sec	
	Ey Error in Y Y offset of star tracked relative to point of acquisition. Ey invalid in Search Defl (Field Camera Mode)	45	Sign 1 = minus
46		1 = 276.48 arc sec	
47		1 = 138.24 arc sec	
48		1 = 69.12 arc sec	
49		1 = 34.56 arc sec	
50		1 = 17.28 arc sec	
51		1 = 8.64 arc sec	
52		1 = 4.32 arc sec	
53		1 = 2.16 arc sec	
54		1 = 1.08 arc sec	
55		1 = 0.54 arc sec	
56		1 = 0.27 arc sec	

3.2.1.1 Detector and High Voltage. Figure 3-5 is a block diagram of the sensor head. Most of the analog circuitry is in this unit as is the high voltage circuitry and the detector tube. The detector tube is an Image Dissector Tube (IDT) with a square aperture between photo-cathode and the first dynode and twelve stages of electron multiplication before the final anode. The overall high voltage is set in the range of 1.5 kV to 2.0 kV and is supplied by a low power oscillator driving a ten-stage voltage multiplier from a secondary winding on the oscillator transformer. An external capacitor is used to set the oscillator frequency. The emitter-base junction of the transistor is used in a oscillator circuit with the amplitude of oscillation and, thus, the amplitude of the high voltage, controlled by varying the dc voltage to the collector of the oscillator transistor.

High voltage regulation is maintained via a feedback circuit that uses a portion of the potential between the lowest dynode and ground as an input to an Op Amp. A diode across the input protects the Op Amp against high voltage spikes or arc-over. The output of the non-inverting Op Amp is connected to a second Op Amp used as a comparator. The inverting input of this device receives an external reference voltage developed in the electronics unit. This voltage source is carefully controlled and compensated against both temperature and input voltage effects. An external resistor allows adjusting this reference voltage to set the high voltage at the proper level. The comparator output is amplified and inverted with a third Op Amp and the output is applied to the gate of an FET. This modulates the source-drain resistance and thus varies the base voltage on an emitter follower. The oscillator transistor collector is the emitter load. A diode on the FET gate is made available at the test connector. Connecting this point to a negative voltage will turn off the FET and disable the high voltage. There is no inherent protection built into the FES and the combination of high ambient light and high voltage can lead to degradation of sensitivity

3-11

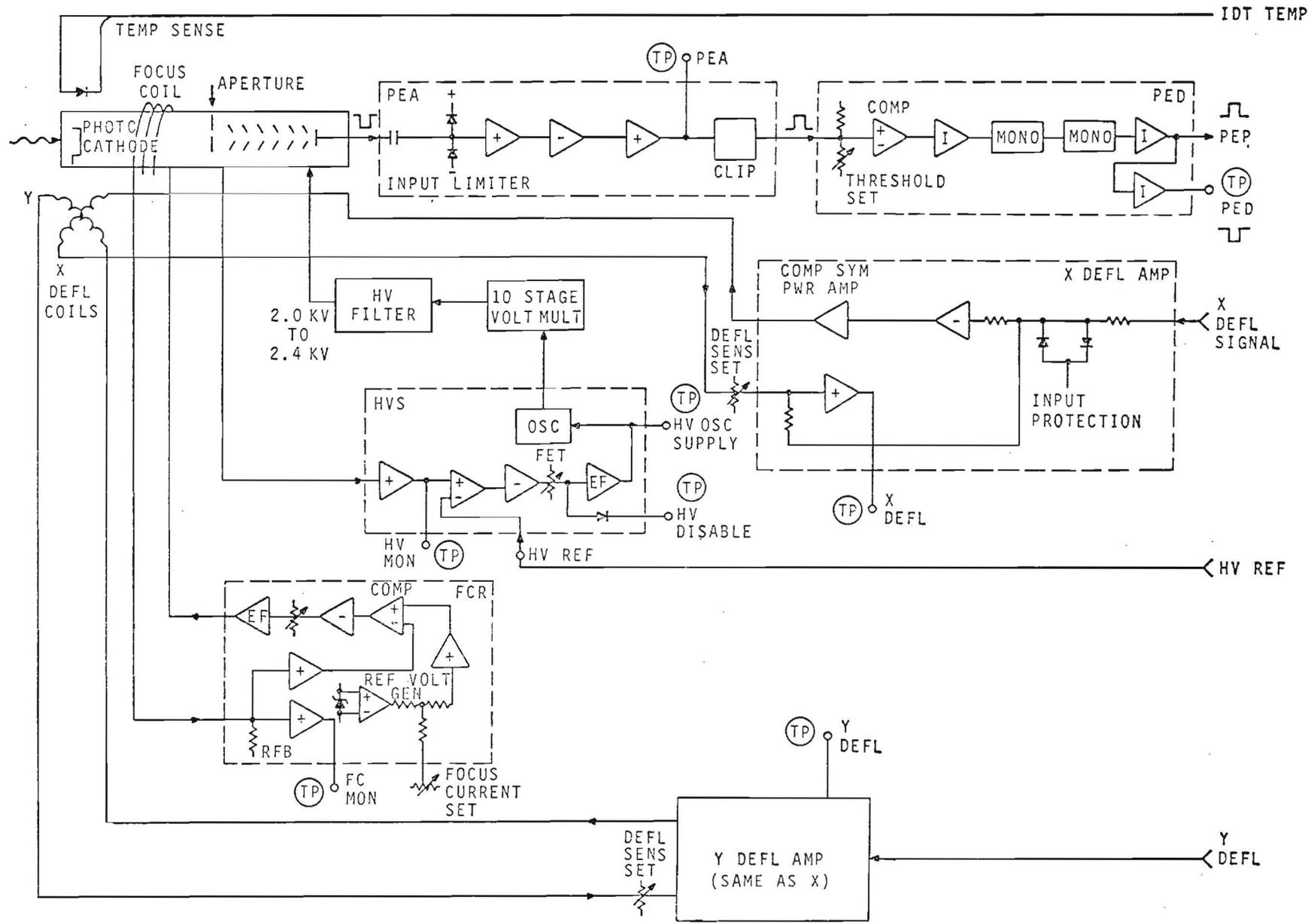


Figure 3-5. Functional Block Diagram IUE-FES Sensor Head

or outright failure. A passive IDT (i.e. one with no high voltage present), can withstand high light levels with no damage.

In operation, as the high voltage rises, the increasing voltage tapped off the dynode string is compared to a reference and the difference is inverted and integrated. The negative going voltage at the FET gate pinches off the junction increasing the source-drain resistance and thus decreasing the base voltage of the emitter follower and the oscillator collector supply.

Since the high voltage is supplied by the plus and minus 15 volt supplies, it will be present when they are switched into the FES. Several seconds will be required for the high voltage to rise and stabilize. The feedback voltage and the high voltage reference are available at test points. These are not presently telemetered.

A diode is potted in close proximity to the photo-cathode of the IDT. The V-I characteristics of this device are very sensitive to ambient temperature. This variation is telemetered to the ground and is used in a compensation algorithm to correct both offset and sensitivity variations that are caused by thermal changes in the IDT. The calibration equation is generated by the FES vendor during acceptance test. This equation also provides for geometric distortion correction.

3.2.1.2 Photon-Event Circuits. As photons impinge on the IDT photo-cathode, they cause an electron flow that ultimately results in a negative going pulse at the IDT anode. This signal is coupled through a high voltage capacitor into the Photon-Event Analog (PEA) module. Here it is amplified and shaped by three Op Amp stages. Two of these are non-inverting while the third inverts to produce a positive going output pulse. This is clipped at +6.2 volts and supplied to the Photon-Event Digital (PED) module.

In the PED the video pulse is compared in an Op Amp comparator with a preset dc threshold. Pulses which exceed this level are deemed to be true photon

events and are processed with a TTL inverter and two monostable multivibrators to generate a uniform, positive pulse of approximately 0.5 μ sec width at the TTL up-level of plus 5.0 volts. A pulse will be generated for each photon-event at the IDT cathode. The inverse of this Photon-Event Pulse (PEP) is available at the test connector.

3.2.1.3 Focus Circuit. The electrons emitted from the photo-cathode by a photon impingement must be kept from scattering such that only a few pass through the aperture. To accomplish this a uniform, stable magnetic field is established axially to the tube. This field causes the electrons to travel in a tight spiral until they impinge on the first dynode.

To generate this field, an external electromagnet termed the focus coil is used. The magnetic field generated by this device has a strength which is a function of the number of coil turns (unvarying) and the coil current. This latter can vary as a function of supply voltage and coil resistance. Compensation of these effects is performed with an active feedback circuit.

Current for the focus coil is supplied by a drive transistor connected as an emitter follower with the focus coil as its load. The low side of the coil returns to ground through a selected, precision resistor. The voltage detected across this resistor will be a function of coil current and, thus, axial magnetic field around the IDT.

This current feedback voltage is made available as a test point through an isolating Op Amp.

An Op Amp with a precision, zener diode input is used to generate a stable reference voltage that is independent of supply voltage and ambient temperature effects. The absolute value of this voltage is set with an external precision resistor. This reference voltage passes through a non-inverting, isolating Op Amp and is one input of a voltage comparator. The other input is the feedback voltage derived from focus coil current.

The output of the comparator now contains the compensated focus voltage. It is inverted and integrated with an Op Amp and used to modulate the gate of an FET. The source-drain resistance of the FET varies the base voltage to the drive emitter follower and, thus, varies the focus coil current.

As focus coil resistance rises with temperature, the feedback voltage falls. This is inverted and reflected as an increase in FET gate voltage, resulting in lower source-drain resistance and a higher drive voltage on the focus coil. The higher voltage compensates for the increased coil resistance to maintain a constant coil current and constant magnetic field.

3.2.1.4 X, Y Deflection Circuits. The electron stream created by a photon impingement will travel in a line parallel to the axis of the IDT from the point of impingement to the aperture plate. Only those electrons travelling through the aperture plate will be electron-multiplied and eventually become a photon event. In order to make off-axis electron streams bend to pass through the aperture, it is necessary to apply an additional, external magnetic field.

Unlike the non-varying focusing field, the deflection field must be variable to allow bending of the electron stream from any point on the photo-cathode such that it will pass through the aperture.

This field is generated by two components, X and Y, in quadrature. Both of these components may consist of a relatively static offset; a small, slowly varying correction; and a dynamic scanning function.

The X and Y fields are generated by a pair of deflection coils mounted axially to the IDT. These coils are aligned with the IDT such that motion of the electron image will be parallel to the sides of the aperture. The entire coil/IDT assembly is mounted in the sensor head skewed at an angle of 10.5 degrees as shown in figure 2-4 to compensate for optical rotation. These coils are driven by a pair of identical amplifiers, which

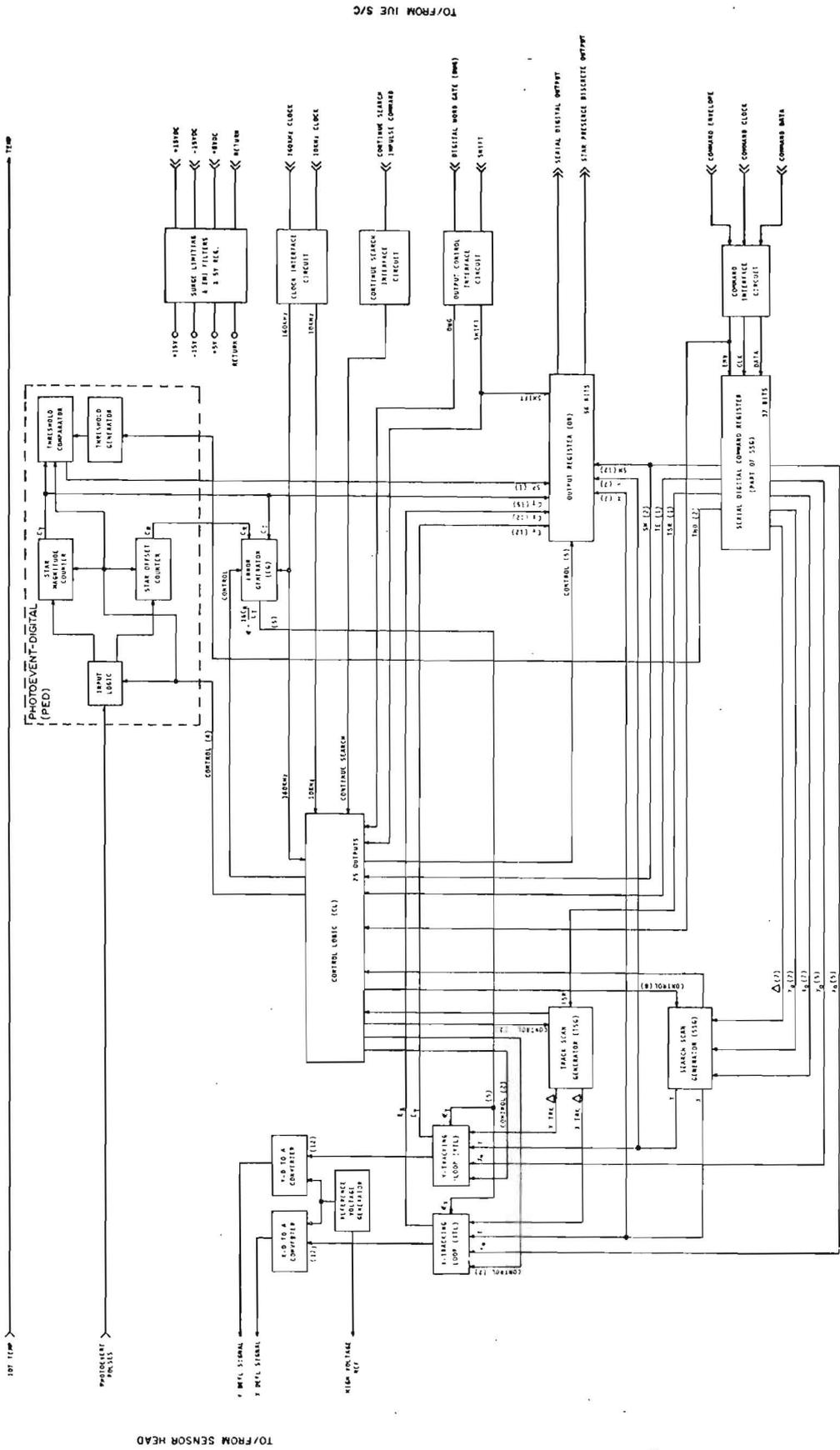
convert deflection voltage to deflection current. The input signal (from the electronics unit) is inverted with an Op Amp. The output of the Op Amp drives a pair of NPN-PNP transistors connected as a complementary-symmetry amplifier configuration with the deflection coil as a load for the collectors. The coil return goes to ground through an external resistor that is selected for overall gain (deflection sensitivity). The voltage developed across this resistor is a function of coil current and is used to provide negative feedback to the Op Amp. This ensures linear coil current, hence deflection, and compensates for coil resistance changes due to temperature that would result in position changes in deflection. The coil current is supplied as a test point via an isolating, non-inverting, unity gain Op Amp.

3.2.1.5 Physical Considerations. The IDT with the temperature sensing diode and dynode resistors is solid potted under vacuum conditions. The other circuits, including the high voltage multiplier, are conformal coated and baked under vacuum conditions while the coating sets. This minimizes overall weight and outgassing.

3.2.2 ELECTRONICS PACKAGE

The various major elements of the EP are shown in figure 3-6, which is a functional block diagram of the EP. Most of the circuitry in this unit is standard CMOS for low power consumption, although there are some TTL logic circuits and a few analog devices. The EP is interconnected to the sensor head to which it supplies filtered power, X and Y deflection signals, and a reference voltage for the HVPS and from which it receives several circuit monitoring test points, IDT photo-cathode temperature telemetry and the digitized photon-event signal. The EP interfaces the FES with the IUE through power, command unit, and data management unit interfaces.

3.2.2.1 Surge Limiting, 5 Volt Regulator & EMI Filter. The prime functions of this module are to limit in-rush current to the FES from the external source of plus and minus 15 volts and to reduce the external plus 8 volts



TO/FROM IUE S/C

TO/FROM SENSOR HEAD

Figure 3-6 Functional Block Diagram Electronics Package IUE - FES

regulated supply to a plus 5 volts regulated supply for use in the FES TTL logic circuits. The plus and minus surge limiters use series pass transistors to provide dynamic variable input impedance at the cost of a collector-emitter voltage drop, while the plus 5-volts regulator uses a conventional series pass transistor driven by an emitter follower. This is referenced to a selected zener diode in series with two diodes to provide junction voltage temperature compensation.

3.2.2.2 Voltage Reference and X & Y Digital-Analog Converter. The X and Y D-A converters are identical circuits. Each utilizes a hybrid thick-film chip to convert a 12-bit digital input to an analog voltage. The resulting output is buffered and inverted by an Op Amp with the D-A converter as part of the negative feedback loop. This signal is then presented to the sensor head as the input to the X (or Y) deflection coil driver.

The accuracy of the incremental steps of the D-A chip is accomplished by using a temperature compensated voltage reference source. This employs a compensated zener diode followed by a non-inverting Op Amp to supply an accurate positive reference voltage for the D-A chips. This output is attenuated by selected precision resistors, buffered with a unity gain Op Amp and made available to the sensor head as the high voltage reference input. A second attenuator is used to develop a "plus reference" signal. The zener diode is also used as a reference for an inverting Op Amp, whose output is attenuated to provide a "negative reference" signal. These signals are used in the sensor head X and Y deflection drive amplifiers to compensate temperature induced offsets in the output stage. The reference voltage for the DAC is available as a test point. Figure 3-7 shows these functions in more detail.

3.2.2.3 Track Scan Generator. The Track Scan Generator (TSG) is used to generate a scanning pattern used when the FES is in the track deflection mode. This pattern can be either of two sizes as selected by the underlap/overlap bit 21 of the SDC and can be accomplished at either of two scan rates, as selected by the fast/slow scan bit 33 of the SDC. The aperture of the

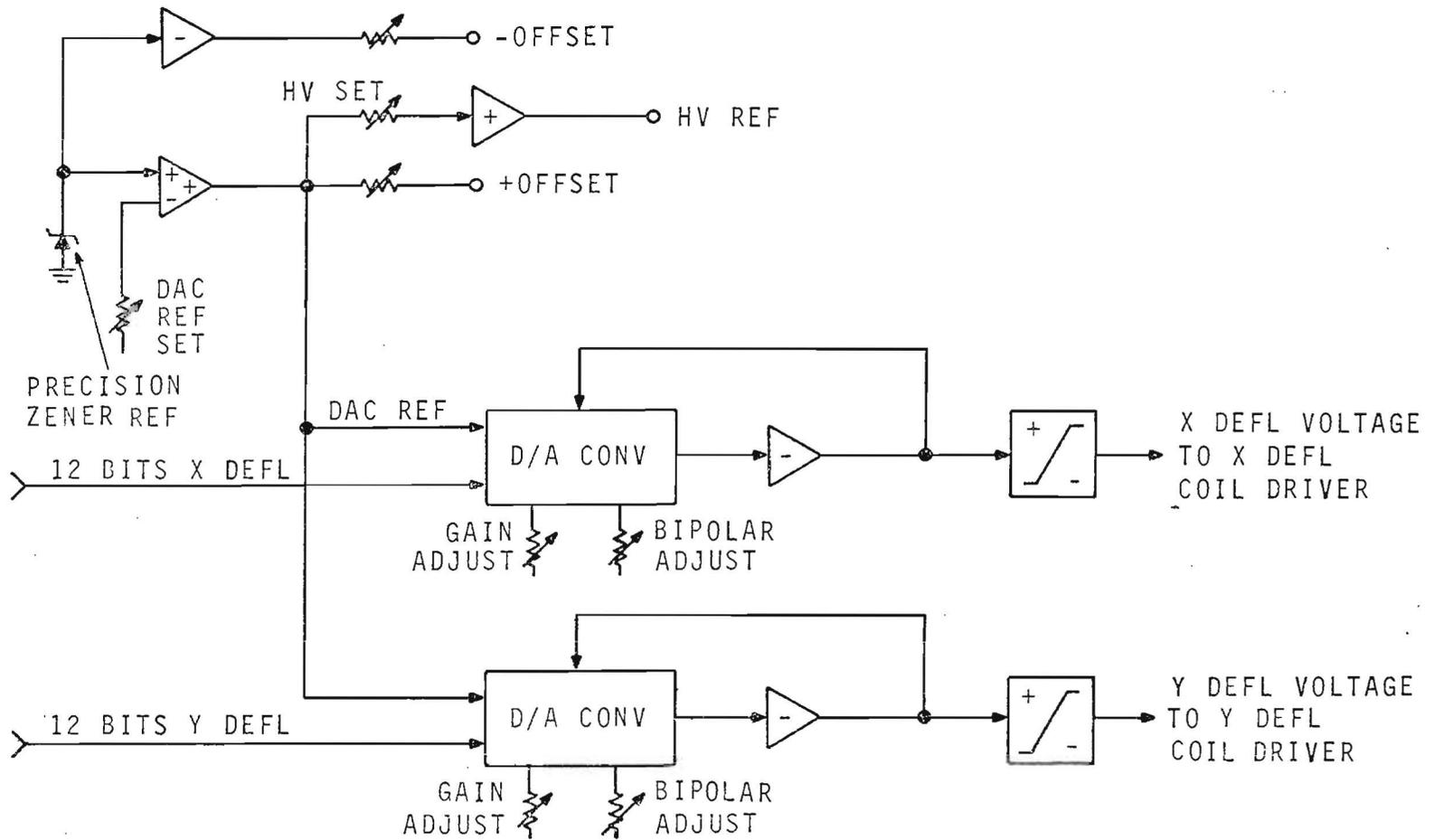


Figure 3-7. Reference Voltage Generator and Digital-Analog Converter IUE-FES

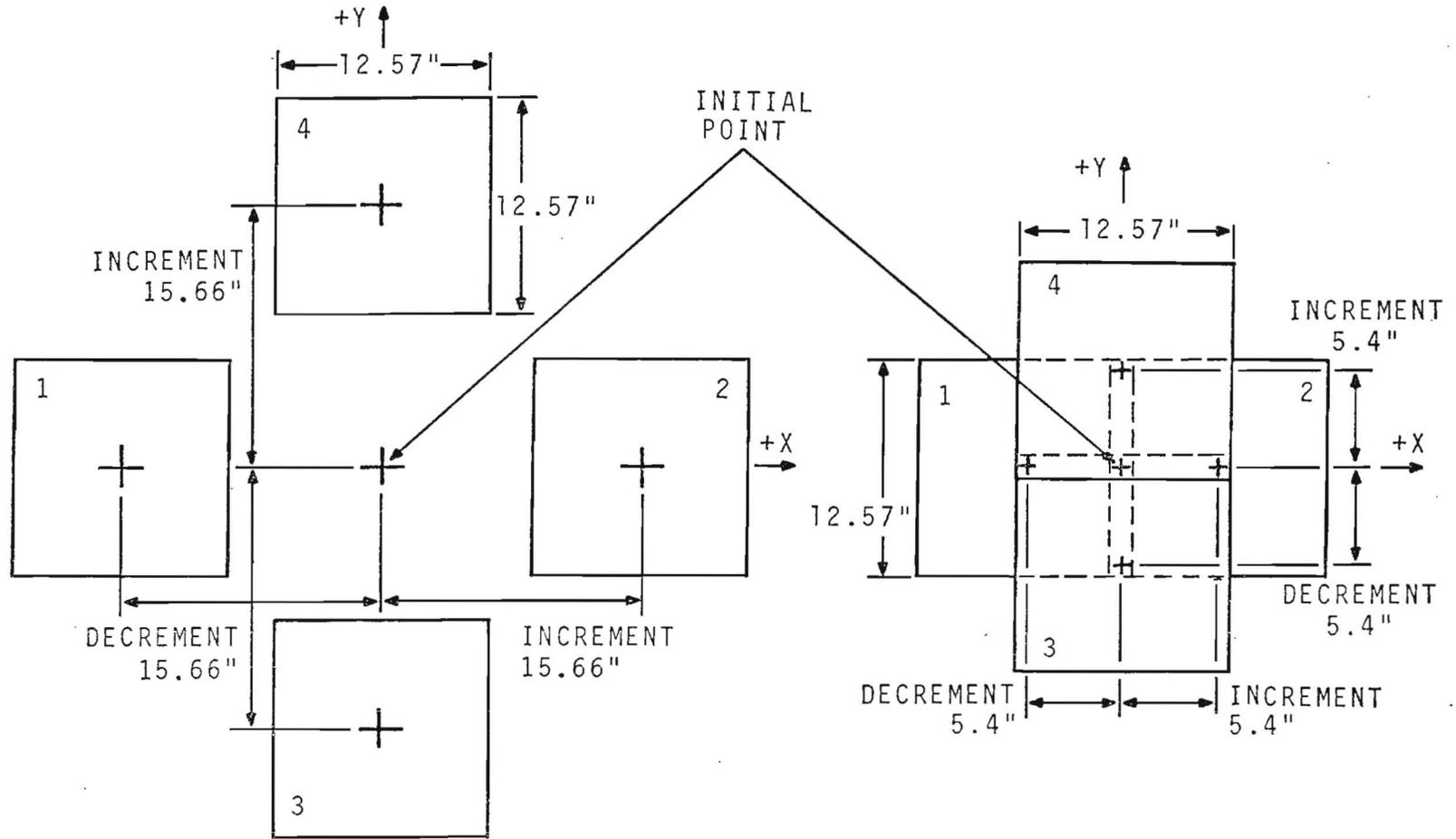
IDT is a square which, with the optics of the IUE telescope, subtends an angle of 12.57 arc-sec by 12.57 arc-sec. This aperture is effectively positioned at some point in the overall FOV of the FES by inputs to the deflection system. The TSG alternately decrements and then increments this initial position by subtracting then adding counts to the digital offset count. This is done first in one axis of deflection and then in the other. In the overlap mode, the TSG decrements and increments approximately 20 counts* of 0.27 arc-sec each for a variation of plus and minus 5.4 arc-sec about the center point. In the underlap mode, the TSG decrements and increments 58 counts of 0.27 arc-sec, each for a variation of plus and minus 15.66 arc-sec about the center point. These two scan patterns showing the resulting under/overlap of the aperture are shown in figure 3-8.

In the fast track mode, the aperture is allowed to dwell for 48 msec at each of the four points in the pattern. This yields a total time of 192 msec per pattern or 5.2 complete samples per second. Since the FES is a photon-event counting device, longer dwells allow counting more photons and thus allowing recognition and tracking of dimmer stars.

To achieve this, the TSG has a slow track mode, where the dwell time is increased by a factor of 4 to 192 msec per point, 768 msec per pattern, or 1.3 samples per second.

Besides generating small offsets, the TSG also generates two control signals to the control logic for use elsewhere in the FES. The first of these is "measure X". This signal goes high when the TSG is incrementing/decrementing the X offset. During this interval there is no TSG offset to the Y deflection. When the "measure X" signal goes low, the X offset is removed and the TSG increments/decrements the Y offset. The second pulse occurs at twice the rate and indicates when X (or Y) is being incremented and when X (or Y) is being decremented. This pulse also controls the up/

*The exact number is vendor selected during fabrication and test.



UNDERLAP TRACK SCAN
SHOWING POSITION OF
APERTURE FOR FOUR
POINTS OF SCAN

OVERLAP TRACK SCAN
SHOWING POSITION OF
APERTURE FOR FOUR
POINTS OF SCAN

Figure 3-8. Track Scan Patterns IUE-FES

down converter (refer to paragraph 3.2.2.10). Both of these signals are available as test points.

3.2.2.4 Input Isolation Circuits. Input Isolation Circuits (IIC) are used to prevent line faults or faults from the external redundant command unit or digital multiplex unit from affecting the non-faulted line or source. Basically, the IIC's consist of resistively decoupled invertors driving OR/NOR gates to develop combined, isolated signals. They are used on the command envelope, command data, command clock, 160-KHz clock, 10-KHz clock, DWG, and DMU shift pulse inputs. A typical circuit is shown in figure 3-9.

3.2.2.5 Output Isolation Circuits. The OIC's function in similar fashion as the IIC's to provide redundant, decoupled output lines for the 56-bit serial digital telemetry word, and the star presence discrete bi-level.

3.2.2.6 Search Scan Generator. The Search Scan Generator (SSG) is used when the FES is in the search deflection mode. It accepts the 7 bit X and Y coarse command from the SDC register along with the Δ (or delta) command. Using these commands, it generates a 7-bit offset in both X and Y to serve as the initial start point of a search raster. This start point locates the upper left corner of the raster, which can be anywhere in the FOV. A typical raster is shown in figure 3-10. Depending on system mode, the SSG increments the X offset while maintaining the Y offset in one coarse (8.64 arc-sec) bit steps once every 2.4 msec (search & track mode), until a total X offset of twice delta plus one has been accomplished. When the X offset has been completed, the SSG generates an End-Of-Line (EOL) signal and the next step blanks output data, returns X to the initial point and decrements the Y offset by one coarse count. If there have been any changes in the SDC regarding initial point or delta, those changes pertaining to the X axis will be accepted at this time. The Y axis initial parameters will not be changed. The SSG continues to generate steps and lines in this fashion until the Y offset has been decremented to the full two delta plus one number of steps. At this time, the SSG generates

3-22

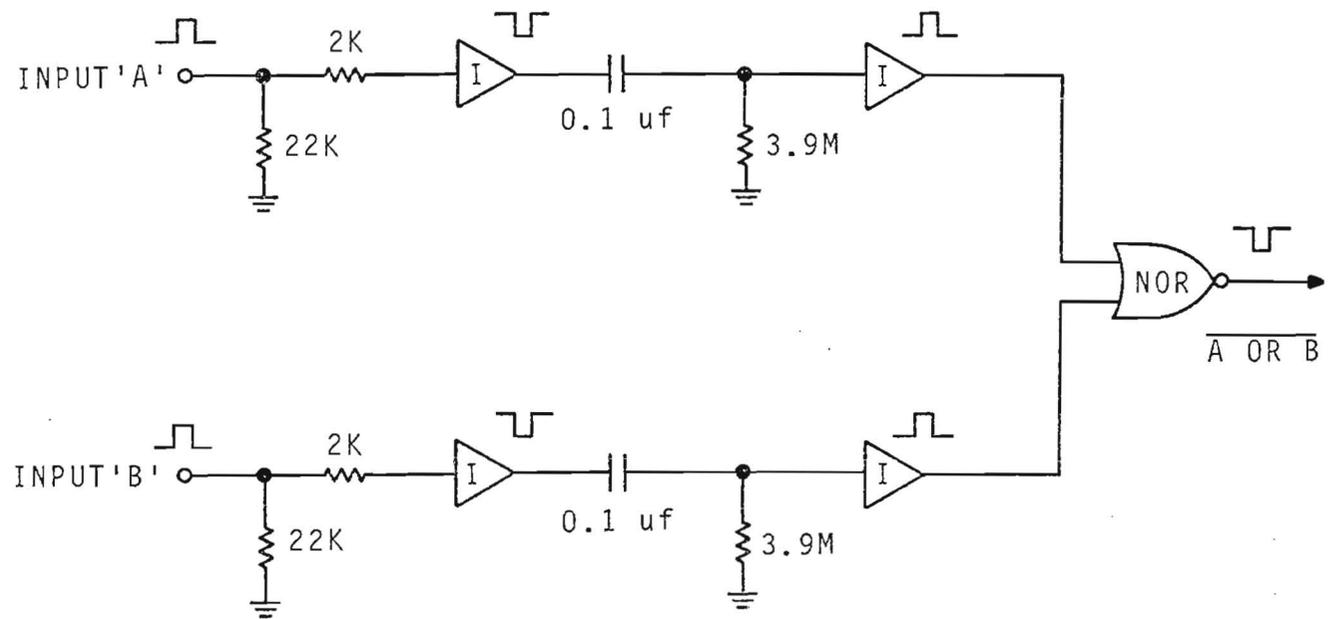


Figure 3-9. Typical Input Isolation Circuit IUE-FES

an End-Of-Frame (EOF) signal, both X and Y offsets are reset to the initial point, and the raster will be repeated. It is also at this time that any changes in Y initial offset and Y delta will be incorporated and the new frame will be a square with the new X, Y offsets and delta.

Since the aperture is 12.57 arc-sec and the steps are 8.64 arc-sec, there is about 50 percent overlap from step to step and from line to line. This yields two samples per pixel and increases the probability of detecting a star in that pixel.

If a delta command is too large for the initial start point, the raster will wrap around and continue in the same direction. The resultant raster will appear as shown in figure 3-11, while figure 3-12 shows the raster resulting from a change in X_0 , Y_0 and delta part way through a frame. The fastest method of recovery is to command a system mode change to primary mode and then return to field camera mode or search and track mode with the proper parameters in the SDC.

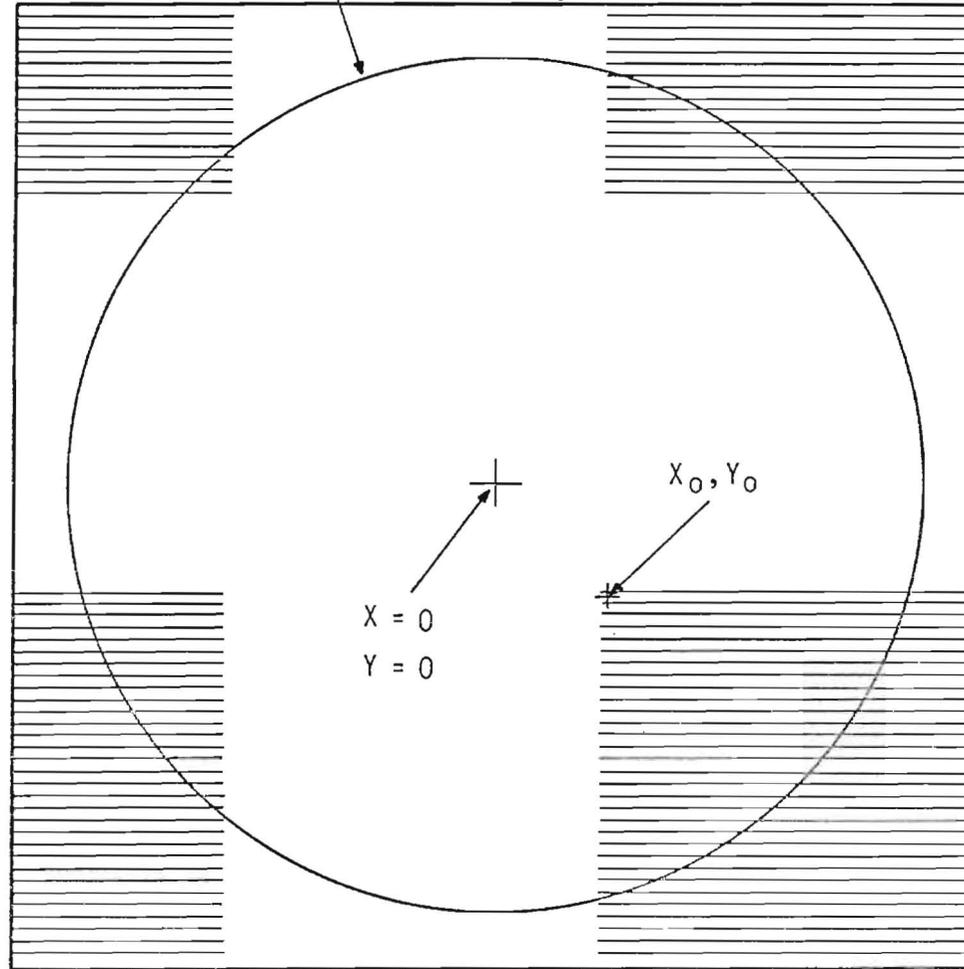
3.2.2.7 X and Y Tracking Loop. The function of these identical modules is to receive X or Y offsets from various sources depending on system mode and combine them into a single, 12-bit word that is then used by the DAC to generate the X and Y deflection voltages.

In the search deflection mode, the X, Y TL receives a 7-bit word of coarse position from the SSG and combines this with a 5-bit word of fine position (x_0 , y_0) from the SDC register. These are combined in the X, Y TL's to produce a 12-bit word to the X, Y DAC that varies in one coarse bit steps as the SSG increments or decrements.

In track deflection, primary mode, the initial track coordinate is established by the X, Y TL utilizing the 7 X_0/Y_0 coarse bit word from the SDC register and the 5 x_0/y_0 fine bit word also from the SDC register. These are combined

$8\widehat{\text{min}}$ 1/2 CONE ANGLE
TELESCOPE F.O.V.

$18\widehat{\text{min}}$ X $18\widehat{\text{min}}$ FES F.O.V.



$X_0 \approx +4\widehat{\text{min}}$
 $Y_0 \approx -6\widehat{\text{min}}$
 $\Delta \approx 5\widehat{\text{min}}$
($2\Delta + 1 \approx 10\widehat{\text{min}}$)

3-25

Figure 3-11. Scan Wraparound Due to Delta Command Excessively Large

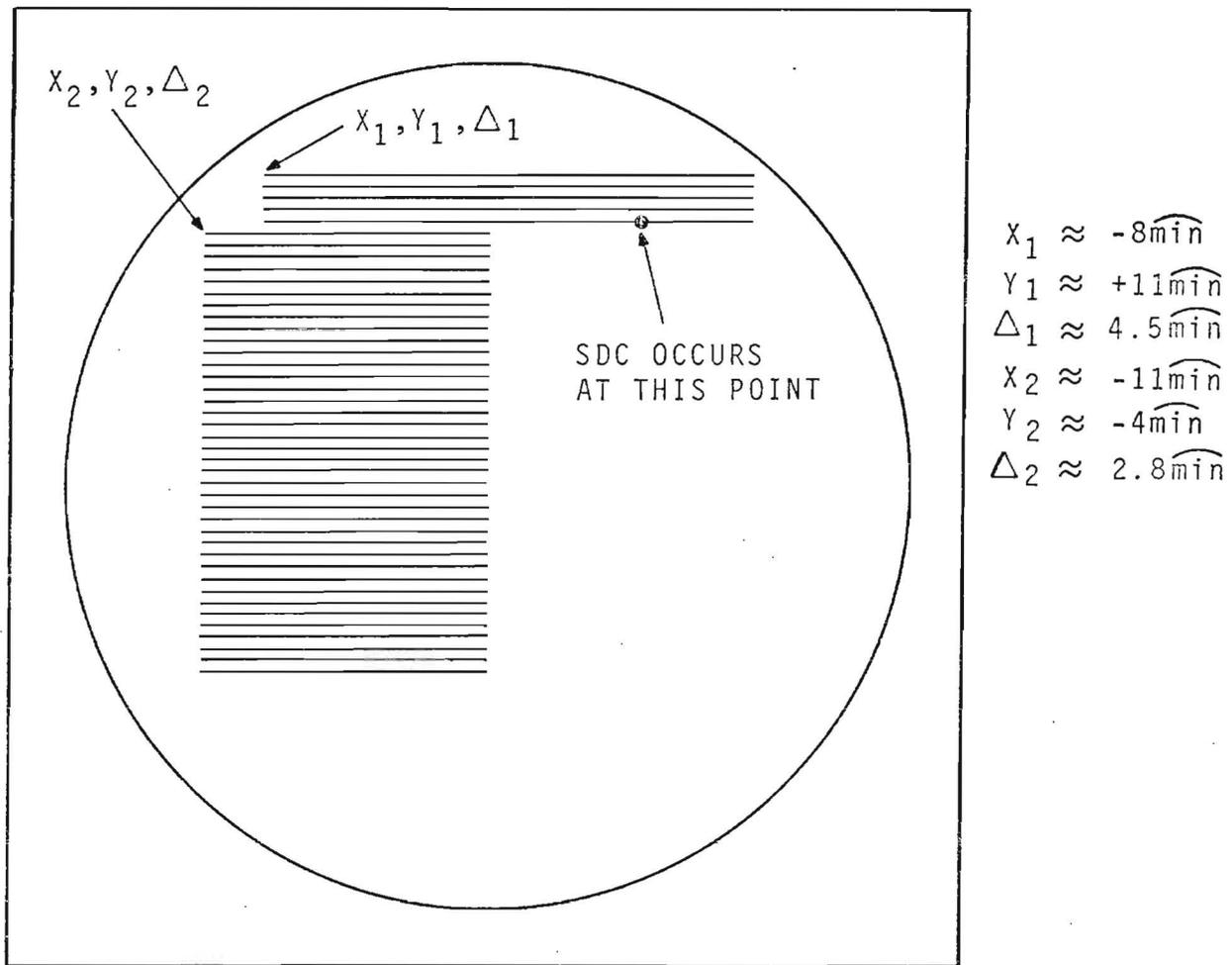


Figure 3-12. Scan Interrupt Caused by SDC With New Parameters Prior to End-Of-Frame

and are then incremented or decremented by either ~ 20 (overlap) or 58 (underlap) fine bits from the TSG. The total X_0, x_0 plus X trk Δ and Y_0, y_0 plus Y trk Δ , are combined to generate the 12-bit deflection word.

Whenever a star presence is indicated, an error generator will develop a digital corrective signal. This digital correction increments or decrements the X_0, x_0 and Y_0, y_0 signal and is combined with the TSG scan signal to generate the 12-bit DAC deflection signal which centers the track scan pattern over the peak stellar energy. The digital difference between the commanded X_0, x_0 and Y_0, y_0 and that required to center the pattern on the star is presented as E_x or E_y , two 12-bit words for use in the control system via the telemetry loop and OBC.

3.2.2.8 Serial Digital Command Register. When a 37-bit SDC is issued to the FES it must be stored until such time in the FES internal operations that it can be examined and implemented.

To accomplish this, the three components of a command signal, the command envelope, the command clock, and the command data are first isolated by the IIC's and then the 37 bits of command data are clocked into a holding register, the Serial Digital Command Register (SDCR). The command data will remain undisturbed until receipt of a new SDC at which time the old command will be completely overwritten.

The various components of the command word are available continuously and in parallel fashion to those portions of the FES with which they are concerned. New commands are acted upon only under control of the FES control logic and then as a function of other logic conditions. The control logic has a definite time at which it will command other segments of the FES to accept new command inputs. This time is termed the Housekeeping Envelope (HKE). The command envelope is used to signal the control logic that a new SDC has been received and that all 37 bits are in storage. Depending on the deflection mode, the new command will be

implemented at the next HKE after the fall of the command envelope or the second HKE following. The former case is always true for search deflection wherein a new command is processed at the end of dwell time, which is the HKE. This may also be true in track deflection if the command envelope falls before the midpoint of a photon count measurement. If it occurs after the midpoint, the FES will continue the computation to complete the track cycle and the command will be implemented on the second HKE following. Figure 3-13 shows examples of all three command situations.

A command changing system mode is always acted upon immediately within the preceding limitations. Maximum delays are 576 msec slow track, 144 msec fast track, and 3.6 msec search. Commands changing parameters in sub-modes such as threshold changes, underlap/overlap changes, fast/slow track changes, and x_0 , y_0 are also implemented promptly. Other changes within a mode must await completion of some internal event. Thus, if in field camera mode or the search portion of search and track mode a change is made in X_0 , Y_0 or delta, the X_0 and delta will not become effective in X until the End-Of-Line (EOL) signal occurs and the Y_0 and delta will not become effective in Y until the End-Of-Frame (EOF) signal occurs.

3.2.2.9 Output Register. The FES operates synchronously with the DMU in the field camera mode and asynchronously in the primary and search and track modes. To accommodate this asynchronous operation, the digital output information is stored in a 56-bit output register. Information is available in essentially parallel form from various sources within the FES. Upon receipt of a Digital Word Gate (DWG), the FES generates a load pulse to transfer data from these various sources into the output register. If this pulse occurs during an HKE, several of the data sources may be changed and the output word would be incomplete. In

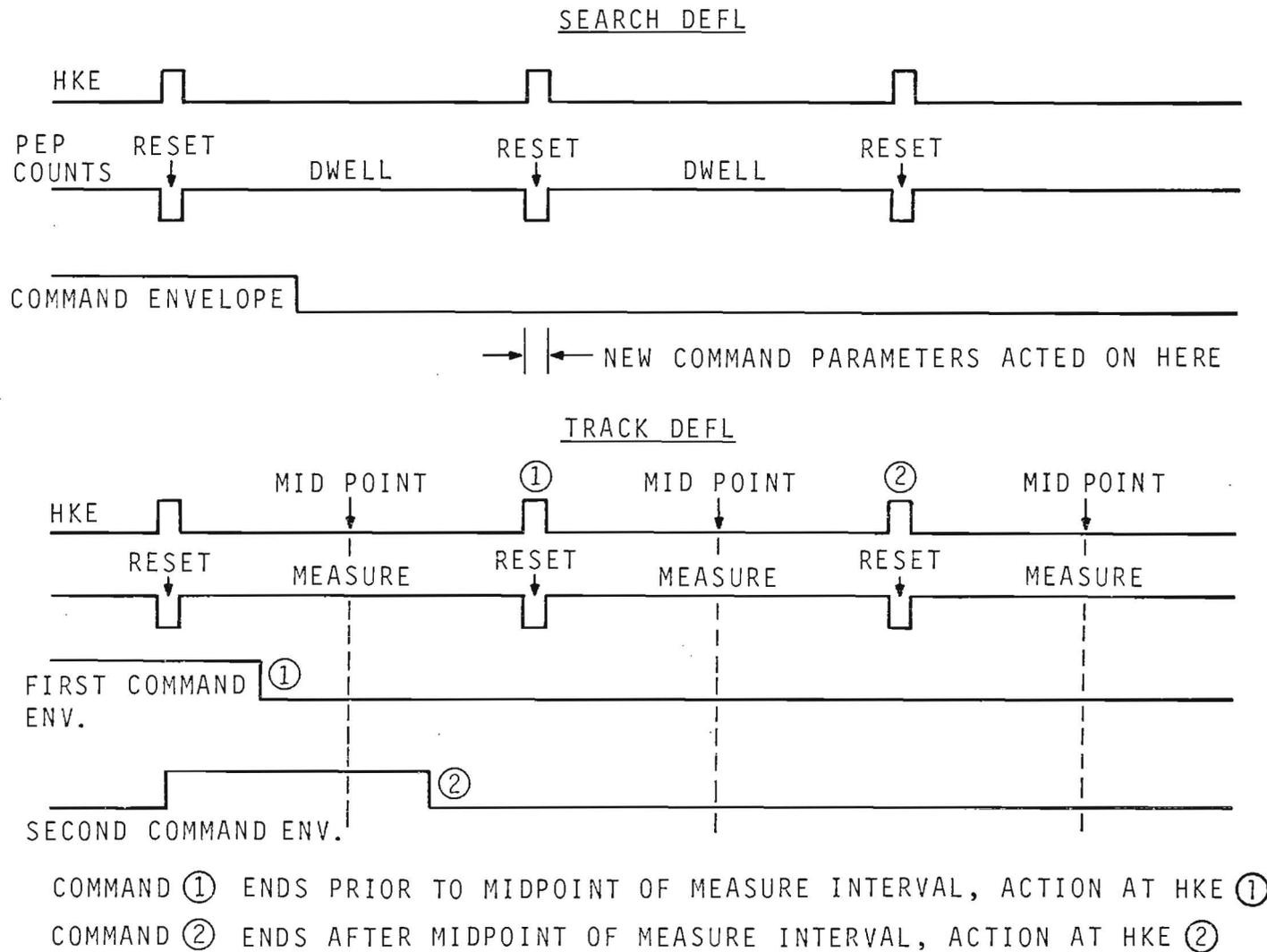


Figure 3-13. Command Action Timing IUE-FES

this case, internal logic senses the coincidental presence of the load pulse and HKE and generates a second load pulse. Shortly thereafter the DMU issues 56 shift pulses and the loaded data is shifted out of the DWG in serial fashion. The timing of the various events is shown as figure 3-14. Telemetry data comes from four areas in the FES. The SM comes directly from the SDCR and is a reflection of the commanded mode state. The X and Y words come from the SSG, the C_T and SP words come from hold register 2 and the Ex and Ey words originate in the X, Y, TL.

3.2.2.10 Photon Event Digital Circuits. The Photon Event Digital (PED) circuits have five distinct areas. The first of these is an input logic gate that is under the control of the control logic. This gate allows Photon Event Pulses (PEP) from the sensor head to be entered into two counters. The first is the star magnitude counter (C_T), that produces a count of up to 2^{15} PEP's. The counter will hold a count after the input logic stops the PEP stream until reset by the control logic. The count in the fifteen stages is available to the output register as the 15-bit C_T word. The second counter, the star offset counter, is run in parallel with the C_T counter in track deflection mode. Under control logic direction it can both count up and then count down against the up count. It can hold its count for error processing and be reset.

The fourth area of the PED is the threshold generator. This device receives the two THD bits from the SDCR and sets one of four count magnitudes as acceptable. These are inserted in the threshold comparator and are compared with the C_T output of PEP's. When C_T exceeds the commanded threshold count, a star presence flip-flop is set. At the next HKE, this event is used to change the internal FES operation. It is then made available to the output register as the SP word and as a discrete bi-level TLM point.

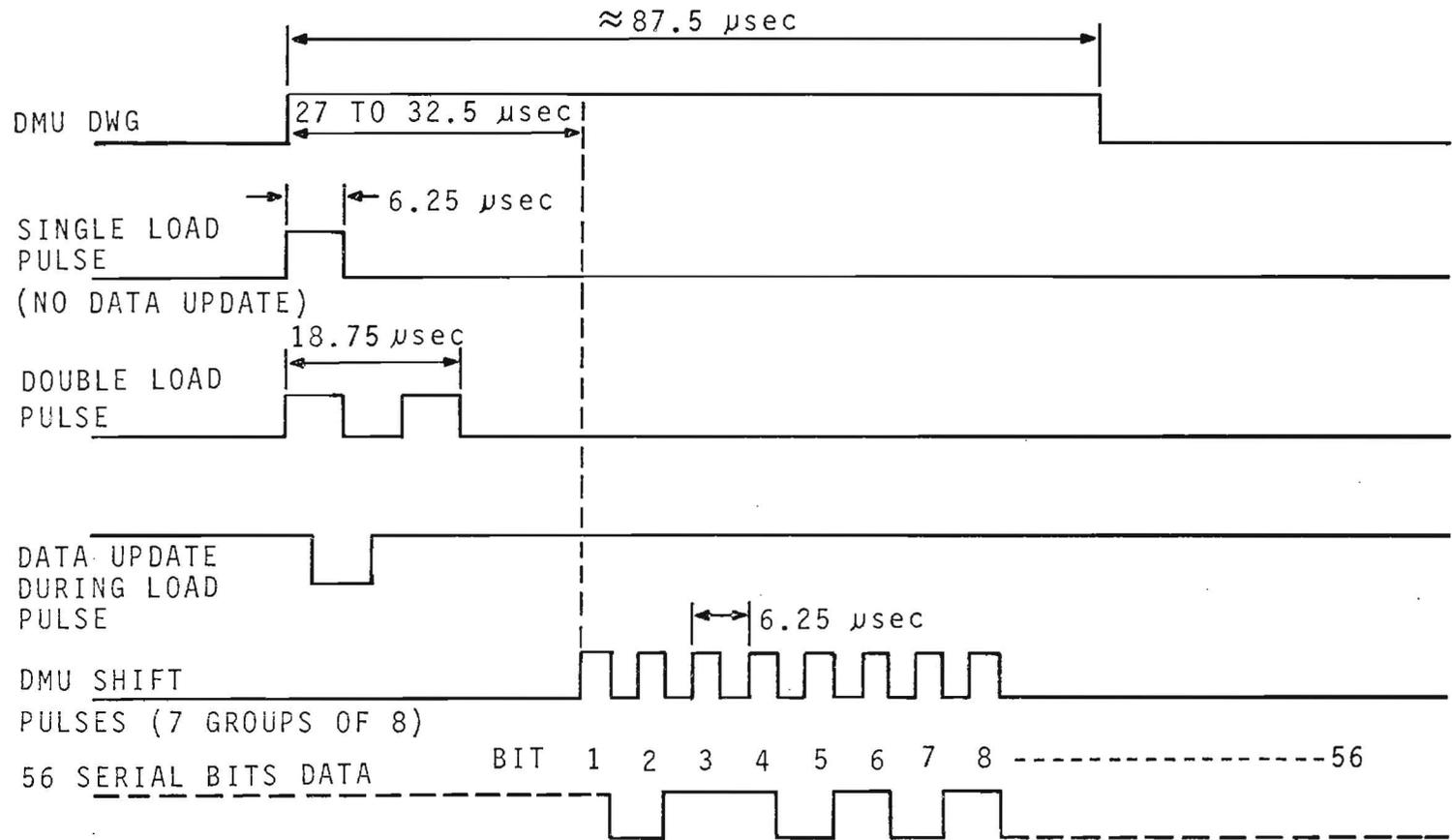


Figure 3-14. Data Output Timing IUE-FES

3.2.2.11 Error Generator. When the FES is in track deflection mode and a star of suitable brightness is within the TSG pattern, the error generator is used to determine the offset between the center of brightness and the center of the TSG pattern. Since the TSG pattern operates first in X and then in Y, only a single error generator synchronized with the TSG is necessary.

In operation, the error generator receives a total PEP count, C_T , from the PED and a residual count, C_R , which is the difference between the star offset counter's up count and down count. The error generator develops a digital error, ϵ , via the equation:

$$\epsilon = K * \frac{C_R}{C_T} \quad \text{where } K = 16$$

ϵ has a maximum value of $(-K+1)$ to $(K-1)$ or -15 to $+15$ bits with a weight of 0.27 arc-sec/bit. These bits are added (or subtracted) from the 2^{12} bits of X or Y coordinate data to move the TSG pattern in such a direction as to center the star. Succeeding updates result in new ϵ 's and a continuing correction until the TSG pattern is centered over the star. The total of these corrections is the 2^{12} bit error word E_x or E_y , where $\sum \epsilon_{ix} = E_x$ and $\sum \epsilon_{iy} = E_y$. The iterative operation of the error generator is shown in figure 3-15.

As a worst case example, a bright star in the FOV of the FES with the TSG set at slow track and the TH set at +11m can produce an SP at least 8 arc-minutes away from the TSG pattern coordinates. It would take considerable time for E_x and E_y to stabilize since the TSG pattern can only be shifted 4.05 arc-sec per cycle. At this rate, the 8 arc-minute offset would require 119 cycles or 91 seconds at slow track to pull in the star. From an operational standpoint, this would mean that up to 91 seconds must elapse between receipt of SP from the FES until the errors are stable enough to enter the control loop.

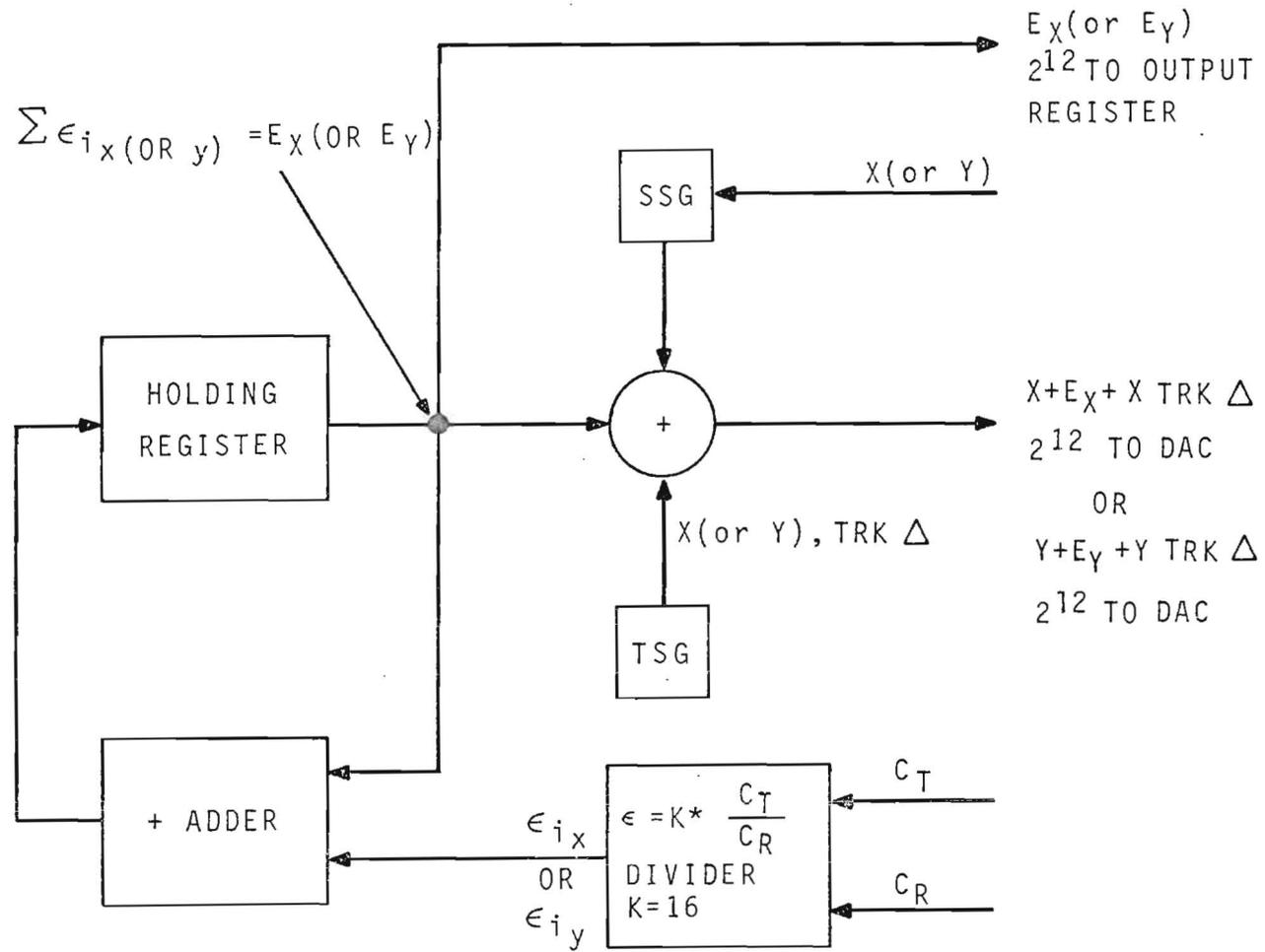


Figure 3-15. Error Generator IUE-FES

3.2.2.12 Control Logic. Internal operations of the FES are governed by the control logic. This unit divides FES functioning into two basic periods. The first period is operation wherein the FES operates on photon-events in the manner dictated by system mode and deflection mode. The second period is housekeeping, wherein the results of the previous operational period are made available to the output register, internal computation circuits are switched between axes, automatic mode transfers are performed on the basis of the gain or loss of SP, and new parameters from the SDCR are implemented, if appropriate.

The interval between Housekeeping Events (HKE) or operational time is a function of system and deflection modes as is the duration of the HKE. These periods are synchronized externally with the DMU in the field camera mode and run asynchronously in the search and track and primary modes. However, the basic internal timing is provided by the 10-kHz and 160-kHz clocks from the DMU so there is some synchronization between the FES and IUE in these modes.

Figure 3-16 shows the FES operation in the simplest mode, the Field Camera Mode (FCM), under static conditions, i.e. no new SDC's to be acted upon, and Track Enable (TE) set to '0' (search only). A DWG from the DMU triggers an HKE. This causes transfer of C_T accumulated during the previous operational time to the output register, clears the C_T register, and increments the X offset by one major count (8.64 arc-sec). At the end of the HKE, the reset C_T is reenabled and PEP's are counted until the DMU generates another DWG. The number of counts during this time is a function of star brightness and dwell time between DWG's. Typically, this will be 25.6 msec and, thus, the favored FES (the one receiving 70 percent of the illumination) should detect a +13.5 magnitude star.

If, at the next HKE, the control logic detects that the X coordinate has been incremented completely, it generates an End-Of-Line (EOL) signal. During

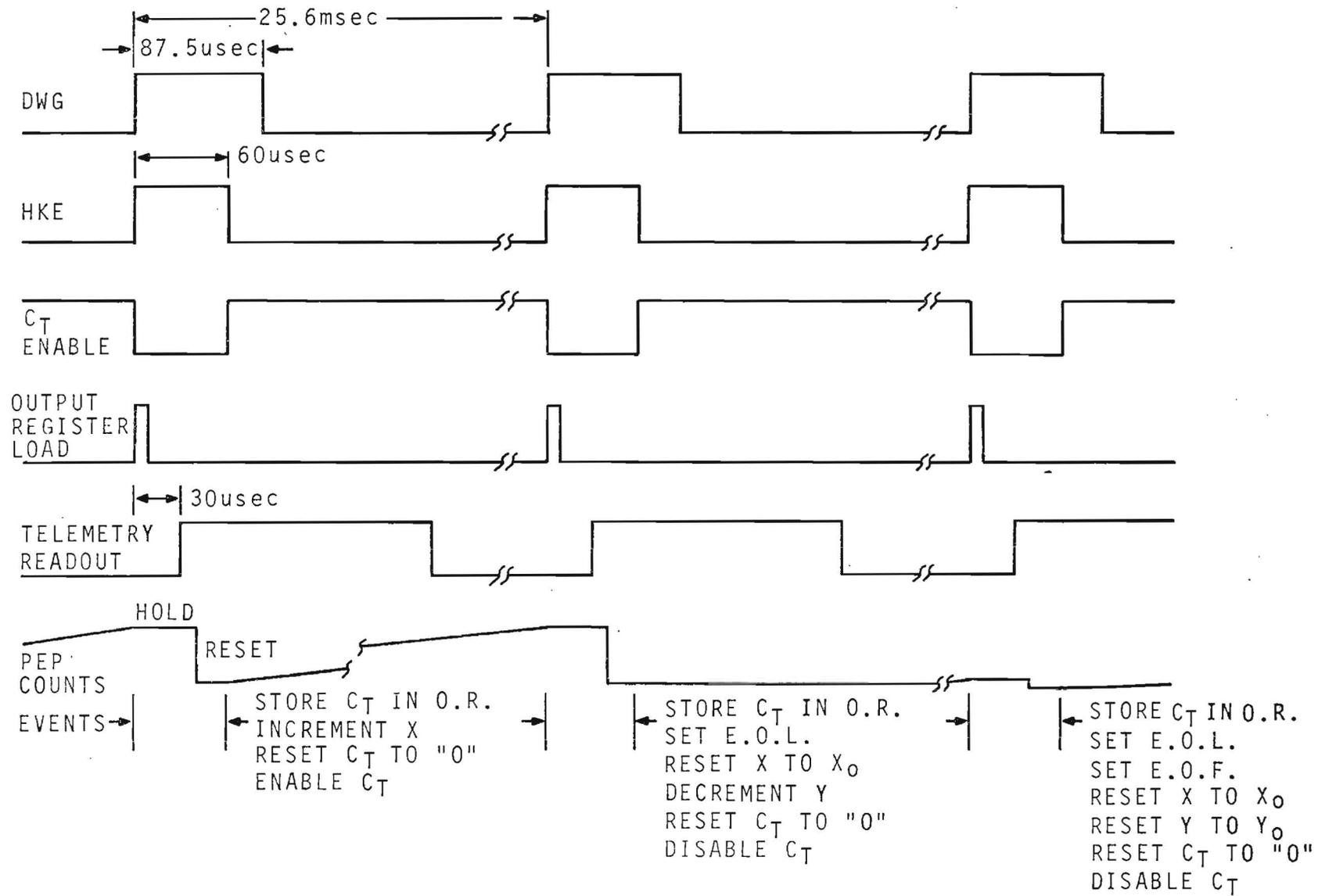


Figure 3-16. FES Event Sequencing Field Camera Mode, Search Only

the HKE, the X coordinate will be reset to X_0 , the Y coordinate will be decremented by one count and the C_T register will be suppressed and cleared. Note that in the event a new SDC had occurred, any changes in X_0 and Δx would be incorporated at EOL.

If the raster is completed during this dwell period, at the HKE an EOF signal would occur. Both X and Y would reset to X_0 , Y_0 , and the C_T register would be suppressed and cleared. Note that at this time, changes in Y_0 and ΔY from a new SDC would be incorporated.

FES operation becomes more complex if the field camera mode is commanded with the Track Enable (TE) bit set to '1'. In this condition, the FES logic checks at each HKE for the state of the SP flip-flop. If this has been set during the previous dwell period as a result of the C_T count exceeding the commanded threshold, the control logic will perform several functions during the HKE. It will load the PEP count and SP into Holding Register 2 (HR2). The deflection mode will be switched from search to track with the selection of underlap/overlap and fast/slow track pattern having been set by the most recent SDC. The C_T , C_R counters and SP will be cleared (reset) and the FES will transfer to internal timing established by the TSG and control logic for future event sequencing. The TSG will be started at the end of the HKE.

When the FES is operated in the search and track mode, internal event sequencing is quite similar to that of FCM with the chief exception that the dwell time between raster steps is internally set at 2.4 msec by the SSG and the system runs asynchronously with the DMU. It is possible but probably pointless to increase the DMU update frequency to follow the raster since there will be no video output until a suitable star is found at which point the raster will halt. Timing of events in the STM are shown on figure 3-17. As in FCM, an HKE is triggered periodically. During

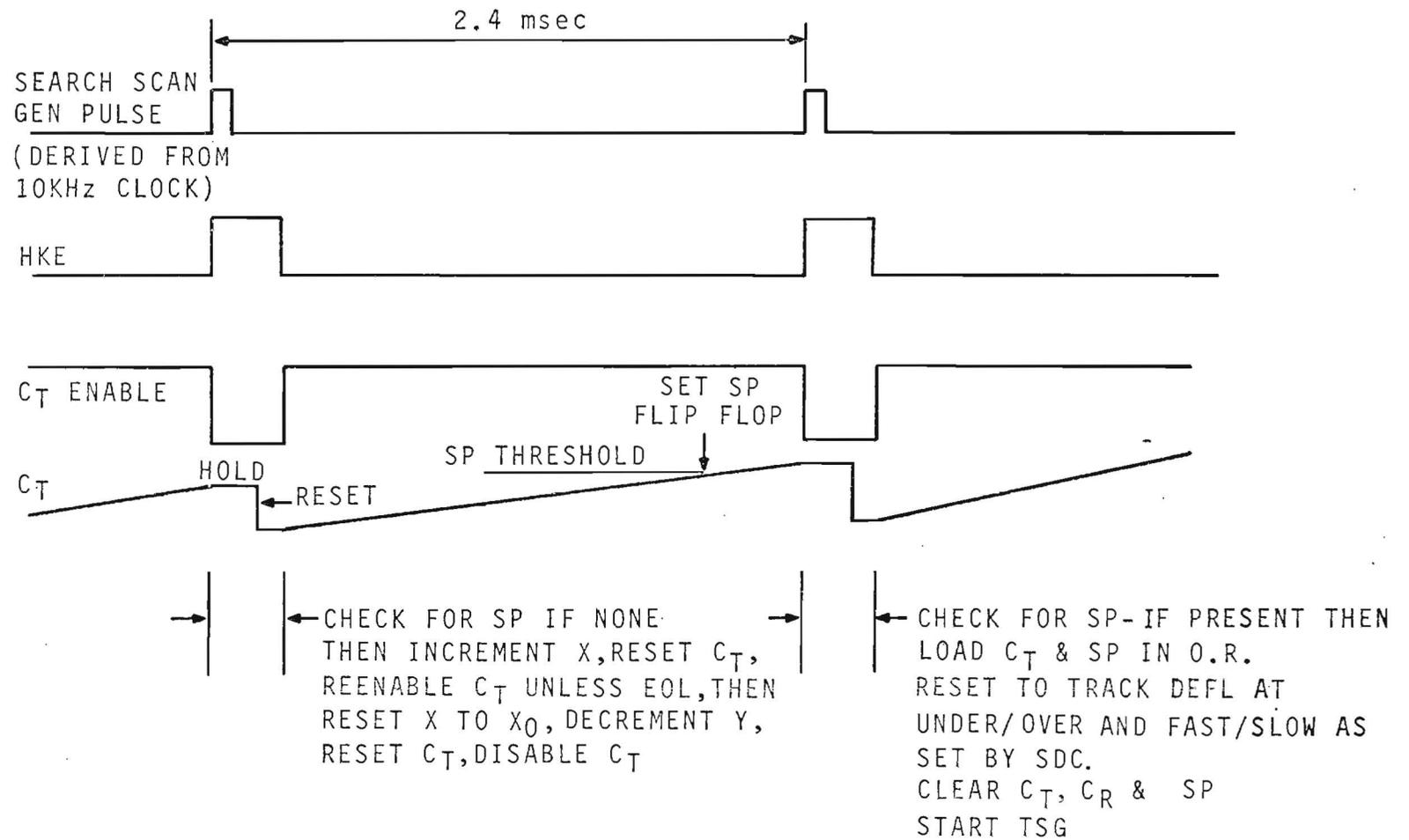


Figure 3-17. FES Event Sequencing Search & Track Mode IUE-FES

this interval the SP flip-flop is checked for star presence. If there is none, the X axis is incremented by one count unless there is an EOL. In this event X is reset to X_0 and Y is decremented one count. As in FCM, the C_T counter is disabled for one period for retrace. In the event that the C_T count exceeds the SP threshold during the dwell, the SP flip-flop will be set. At the following HKE, the C_T and SP will be loaded into the output register, the deflection will be set from search to track with track pattern parameters as set by the underlap/overlap and fast/slow bits in the SDC; the counters and SP flip-flop are reset and the TSG is enabled.

Control logic operation during HKE, while the FES is in track deflection, is somewhat more complex. Basic timing is provided by the TSG up/down signal with an HKE triggered by the rising of the up/down signal. The SP flip-flop must be examined to ensure that star presence was maintained, and the measure X signal is checked to determine whether the previous computation period involved error determination in X or Y. C_T and SP are loaded in the output register and the error generator is run at a 6.25 μ sec cycle rate for 300 μ sec (3 pulse widths of 0.1 msec each). The new ϵ_{ix} or ϵ_{iy} is summed to produce an update E_x or E_y which is loaded into the X or Y track loop. Finally, all registers are cleared.

During the computation period, both the C_T counter and the star offset (C_R) counter are enabled. For the first half of the period, while the aperture is at $-\Delta X$ (or $-\Delta Y$) C_T and C_R count upward. When the up/down signal changes from up to down, both counters are halted, while the aperture is slewed to $+\Delta X$ (or $+\Delta Y$). The counters are enabled and C_T continues to count upward, reaching and exceeding at some point the selected threshold count and setting the SP flip-flop. The C_R counter, however, is reversed and subtracts counts from the first half of the period. At the end of the measure X (or Y) interval, the residue in the C_R counter is a function of the center of star brightness, relative to the center of

track scan pattern. If C_R is positive, then more counts occurred during the $-\Delta$ aperture position and, thus, the pattern coordinates must be decremented to move the pattern in the negative direction. If C_R is negative, then the pattern is too negative and its coordinates must be incremented to move it in the positive direction. Figure 3-18 illustrates the FES events occurring during track deflection, in either primary mode or the track of search and track mode.

The HKE or housekeeping envelope brackets nine separate pulses each occurring as the previous pulse ends. The entire envelope is triggered by one of three signals depending on system or deflection modes. These are:

- a. DMU DWG in FCM, search deflection.
- b. 2.4 msec clock in S & TM, search deflection.
- c. TSG in FCM, track deflection; S & TM, track deflection; or PM, track deflection.

System and deflection modes will also govern the events triggered by the nine housekeeping pulses. Figure 3-19 shows the pulses while their mode sensitive functions are listed in table 3-3. These functions have been simplified, and do not give the entire depth of the logic and logic equations.

The pulse widths are a function of deflection mode, which selects either the 160-kHz or 10-kHz clock. In search deflection, the 160-kHz clock is used, pulse widths are 6.25 μ sec wide and the total HKE is 56.25 μ sec. In track deflection, the 10-kHz clock is used, pulse widths are 100 μ sec and the HKE is 0.9 msec.

While table 3-3 shows some unique mode-dependent action, the various pulses tend to perform the same function in any mode. P1 basically loads star magnitude data and star presence in a register for telemetry. P2 is operable if an SDC has been received and it then functions to load data and clear other flags. P3 also operates primarily as a result of an incoming command and it clears various registers and sets deflection mode to search in the absence of star presence. P4 clocks the SSG in search deflection and this causes the X coordinate to increment. P3 and P5 are used to

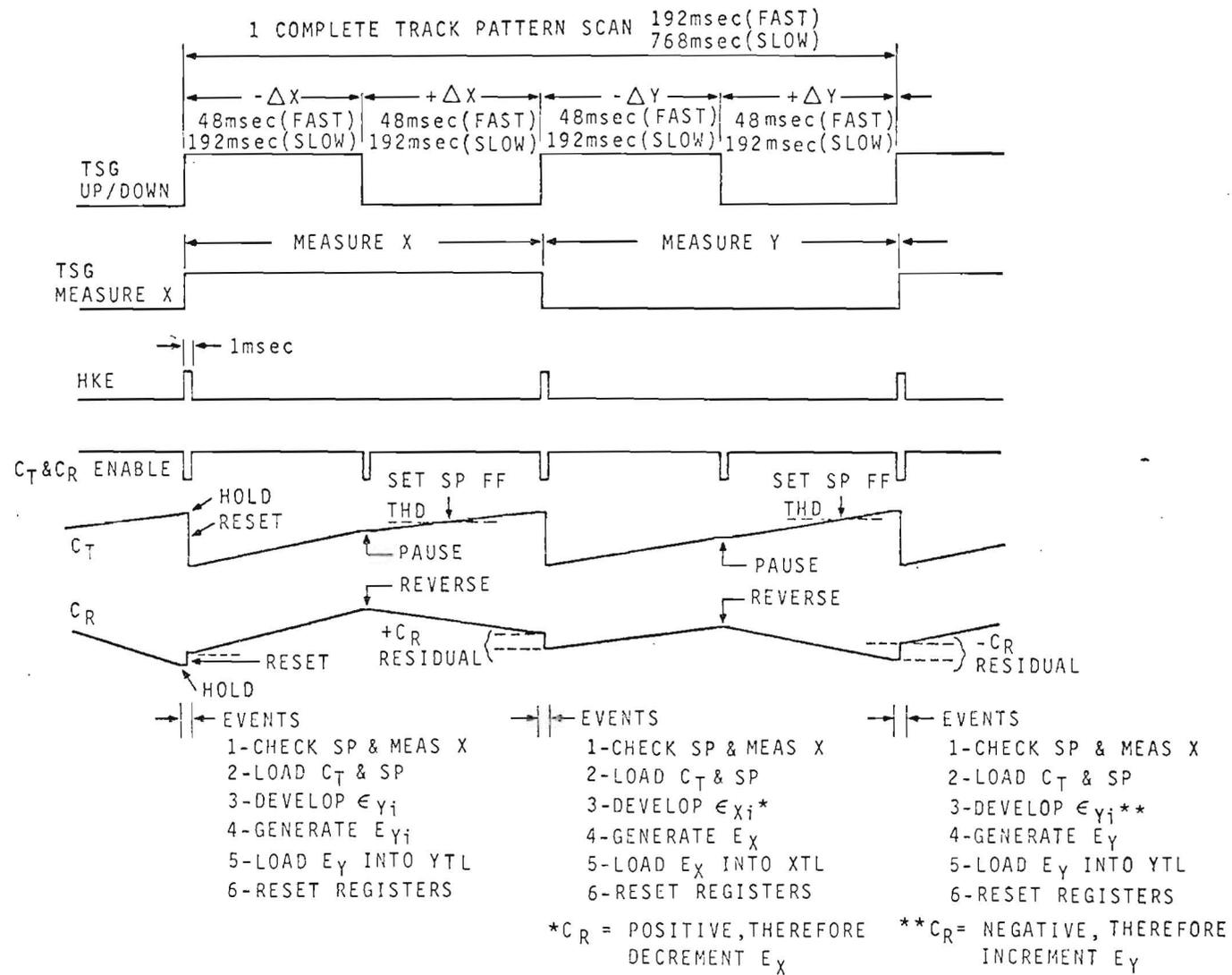
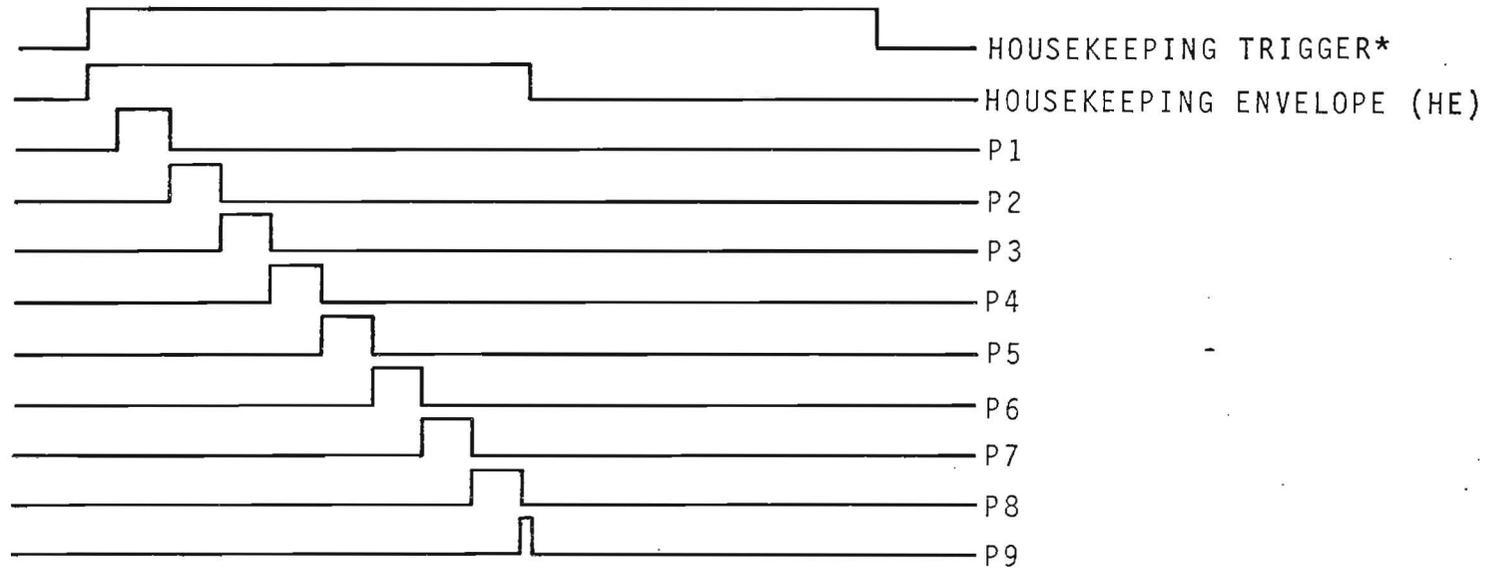


Figure 3-18. FES Event Sequencing Track Deflection Primary Search & Track Modes IUE-FES



* DMU DWG OR SSG 2.4 msec. PULSE OR TSG UP/DOWN SIGNAL

Figure 3-19. Housekeeping Pulses

Table 3-3. Housekeeping Pulse Functions

Pulse	Track	Search	Field Camera
P1	Load HR2 If EOL or EOF, Set F2	Load HR2 If DMFF, Initialize TSG If EOL or EOF, Set F2	Load HR2 If DMFF, Initialize If EOL or EOF, Set F2
P2	If SDC, Load HR1 Clear EOL, EOF	If SDC, Load HR1 Clear EOL, EOF	If SDC, Load HR1 Clear EOL, EOF If DMFF, Load OR
P3	If S1, Clear HR2, XHR & YHR If S3, Set to DMFF If S2, Set EOL, EOF If $\overline{S1}$, start EG If $CSC \cdot \overline{P}$, Continue Search Decrement Y	If S1, Clear HR2 XHR & YHR If S3, Set to DMFF If S2, Set EOL, EOF If $CSC \cdot \overline{P}$, Continue Search Decrement Y	If S1, Clear HR2 XHR & YHR If S3, Set to DMFF If S2, Set EOL, EOF If $CSC \cdot \overline{P}$, Continue Search Decrement Y
P4		If $\overline{S1} \cdot \overline{SP} \cdot \overline{F2}$, Clock SSG	If $\overline{S1} \cdot (\overline{SP} + \overline{TE}) \cdot \overline{F2}$, Clock SSG
P5	If $CSC \cdot \overline{P}$, Continue Search Decrement Y	If $CSC \cdot \overline{P}$, Continue Search Decrement Y	If $CSC \cdot \overline{P}$, Continue Search Decrement Y
P6	If EOL, then Line PS If EOF, then Frame PS If MX, then Load YHR If \overline{MX} , then Load XHR	If $EOL \cdot \overline{CE}$, then Line PS If $EOF \cdot \overline{CE}$, then Frame PS If $EOL \cdot CE$, Set F3	If $EOL \cdot \overline{CE}$, then Line PS If $EOF \cdot \overline{CE}$, then Frame PS If $EOL \cdot CE$, Set F3
P7	If $SMC \cdot P$, Set \overline{DMFF} If $SDC \cdot P7$, Reset F3	If SP, Set \overline{DMFF} If $SDC \cdot P7$, Reset F3	If $SP \cdot TE$, Set \overline{DMFF} If $SDC \cdot P7$, Reset F3
P8	Clear Pulse CLR C_T, C_R, SMC SPFF, $F2, CSC$ & SDC	Clear Pulse CLR C_T, C_R, SMC SPFF, $F2, CSC$ & SDC	Clear Pulse CLR C_T, C_R, SMC SPFF, $F2, CSC$ & SDC
P9	Reset Housekeeping Control	Reset Housekeeping Control	Reset Housekeeping Control

decrement the Y coordinate one count each if a CSC has been received. This produces the double decrement required to move the search pixel far enough from the undesired coordinate that the pixel overlap no longer senses photons. If a bright star is being tracked, CSC may have to be issued several times to get adequate separation so that reacquisition does not occur. P6 is primarily the line or frame reset signal. P7 is used to set the track deflection mode if there is a star present, or to reset the EOL flag if an SDC envelope is present. P8 is a reset pulse for the various counters, registers, and event flags, while P9 resets the housekeeping pulse generator and conditions the logic to accept a new trigger.

The interconnection between the EP and the IUE is listed in table 3-4. Table 3-5 lists the pin number and signals available on the FES test connector and table 3-6 is the interconnection between the FES, EP, and FES sensor head. The sensor head connector is pin identical with the EP connector.

Table 3-4. FES System Interconnect Electronic Package, Connector P1

Pin Number	Designation	Destination
1	Power Return	LVSW
2	Power Return (Red)	LVSW
3	+15 Vdc -1	LVSW
4	Spare	
5	Data -1	DMU-1
6	Data -2	DMU-2
7	Star Presence Discrete -1	MSD-1
8	Star Presence Discrete -2	MSD-2
9	IDT Temp -1	MSD-1
10	IDT Temp -2	MSD-2
11	Frame Ground	
12	Spare	
13	Frame Ground	
14	160 kHz clock -1	DMU-1
15	160 kHz clock -2	DMU-2
16	+15 Vdc -2	LVSW
17	-15 Vdc -1	LVSW
18	-15 Vdc -2	LVSW
19	Spare	
20	Cmd Env -1	CDU-1
21	Cmd Env -2	CDU-2
22	Cmd Clock -1	CDU-1
23	Cmd Clock -2	CDU-2
24	SDC -1	CDU-1
25	SDC -2	CDU-2
26	Spare	
27	Spare	
28	Serial #ID Bit 1	BBRC
29	Serial #ID Bit 2	In-House Reference
30	Serial #ID Bit 3	
31	+8 Vdc -1	LVSW
32	+8 Vdc -2	LVSW
33	Command Shield	N/C
34	CSC -1	CDU-1
35	CSC -2	CDU-2
36	Spare	
37	DWG -1	DMU-1
38	DWG -2	DMU-2
39	Shift Pulses -1	DMU-1
40	Shift Pulses -2	DMU-2
41	Spare	
42	Spare	
43	10 kHz clock -1	DMU-1
44	10 kHz clock -2	DMU-2

Table 3-5. FES System Interconnect, Connector S2 (FES Test)

Pin Number	Signals
1	Main Electronics Chassis
2	Signal Return
3	High Voltage Monitor
4	Focus Current Monitor
5	Spare
6	Housekeeping Envelope (HKE)
7	Spare
8	Serial Digital Cmd (SDC)
9	Continue Search Cmd (CSC)
10	Serial Mode (SMC)
11	X - Deflection
12	Y - Deflection
13	DAC Reference
14	EOL
15	EOF
16	Load X HR
17	Load Y HR
18	Measure X
19	Up/Down
20	High Voltage Disable
21	High Voltage Reference
22	Spare
23	Spare
24	Spare
25	Spare
26	-15 Vdc

Table 3-6. FES System Interconnect, Connector S3 (FES EP/FES SH)

Pin Number	Designation
1	Power Return -1
2	+15 Vdc
3	-15 Vdc
4	+5 Vdc
5	Spare
6	High Voltage Monitor
7	High Voltage Reference
8	High Voltage Return
9	High Voltage Shield
10	High Voltage Disable
11	Focus Current Monitor
12	X - Deflection
13	X - Deflection Return
14	X - Deflection Shield
15	Y - Deflection
16	Y - Deflection Return
17	Y - Deflection Shield
18	Positive Offset Reference
19	Negative Offset Reference
20	X - Deflection Test Point
21	Y - Deflection Test Point
22	Spare
23	Power Return -2
24	Sensor Head Chassis -1
25	Sensor Head Chassis -2
26	Photo Events Digital
27	Temperature Sense -1
28	Temperature Sense -2
29	Spare
30	Spare
31	+15 Vdc (Unfiltered)
32	-15 Vdc (Unfiltered)
33	-15 Vdc Test Point
34	Spare
35	Spare
36	Spare
37	Spare
38	Spare
39	Photo Events Shield
40	Photo Events Return
41	Spare
42	Spare
43	Spare
44	Spare

SECTION 4. FES OPERATIONAL MODES

SECTION 4. FES OPERATIONAL MODES

4.1 INTRODUCTION

The IUE FES has three operating modes. These modes are primary mode, search and track mode, and field camera mode. The purpose of this section is to describe how these modes operate and any FES limitations which may affect operations. The first three sections 4.2, 4.3, and 4.4 will discuss each mode individually and how they are commanded and the significant telemetry outputs. In each of these sections, examples of a particular operation will be described in detail.

Section 4.5 describes how to switch between these normal modes. This will include all commands to the FES which are necessary to successfully switch between modes.

Section 4.6 will describe forbidden modes of operation and discuss any limitations in the FES which may affect the operation of the instrument.

Section 4.7 will describe the operational techniques associated with using the FES. It will discuss how to operate the FES to successfully perform the scientific objectives of the IUE. It will also discuss the use of the FES for operations with other subsystems parts within the IUE spacecraft. Examples of this are: use of the FES to focus the scientific instrument and use of the FES telemetry to update OBC algorithms.

4.2 PRIMARY MODE

4.2.1 INTRODUCTION

Primary mode will be used to track a guide star in the FOV of the FES. This mode utilizes the track deflection mode and is used to track guide stars from +14m to +2m. To track these different magnitudes a combination of commanded underlap/overlap and track scan rate is needed. Other inputs for this mode using the serial digital command are the approximate star position from the center of the tracker field and the modes selection (primary mode).

Significant output telemetry for primary mode includes the coarse X, Y coordinates of the command offset from the center of the field of view; the star magnitude count, star presence indicator bit, and the present position of the star with respect to the initially commanded offset from the center of the FOV.

4.2.2 COMMANDS FOR PRIMARY MODE

Assuming the sensor is off, the first command which must be sent is FES power on. This command will turn both the low voltage and high voltage on. A delay of approximately 10 seconds should be observed to allow for the high voltage to settle out from any initial turn on transient. The command word should come up zero, but it will routinely be initialized to all zeros using a serial digital command. After this has been accomplished a serial digital command must be sent which includes the following parameters:

- a. $X_0/x_0, Y_0/y_0$. The X and Y position of the star.
- b. UL/OL. The underlap/overlap bit which is used as a function of the magnitude of the star to be tracked.
- c. TSR. The track scan rate must be chosen, again, as a function of the magnitude of the star to be tracked.
- d. Mode Selection. Primary mode must be commanded.

Upon completion of the uplink of this serial digital command a continue search command must be sent. Once this has been uplinked the serial digital command will be acted upon.

The serial digital command inputs X_0/x_0 , Y_0/y_0 are offsets from the center of the field of view. Each step is approximately 0.27 arc-sec and there are 12 bits allocated for this offset. These are broken up into 7 bits (X_0 , Y_0) of coarse offset each being 8.64 arc-sec nominally and 5 bits of fine offset (x_0 , y_0) each being 0.27 arc-sec nominal. The MSB in X_0 , Y_0 is a sign bit and for positive numbers this bit is "0". For positive numbers X_0 , Y_0 counts up from the center of the field of view and for negative numbers this is computed as 2's complement. The x_0 , y_0 registers always count positive. The UL/OL bit if set to "1" is underlap and "0" is overlap. Overlap puts the track scan at ± 5.94 arc-sec from the center and is used to track 7m or dimmer stars. The underlap puts the track scan at ± 15.66 arc from center and is used to track 7m or brighter stars (see figure 3-8). Another part of this command is the track scan rate bit. If the track scan rate bit is set to "0" the tracker will be in fast track which has an update rate of 5.2 updates/second. If the track scan rate bit is set to "1" the tracker will be in slow track which has an update rate of 1.3 updates/second.

Table 4-1 shows the UL/OL and track scan rates that are acceptable for various star magnitudes.

Table 4-1. UL/OL and Track Scan Rates for Primary Mode

Star Magnitude Range	Calibration Conditions
+14m to +12m $A_0 V$	Slow Track, Overlap
+13m to +6m $A_0 V$	Fast Track, Overlap
+7m to +2m $A_0 V$	Fast Track, Underlap

These are not absolute numbers and there is a finite probability that for a given calibration condition the FES will track stars which are outside the limits set up in the table.

4.2.3 TELEMETRY FOR PRIMARY MODE

The telemetry output is on a 56-bit serial output which for primary mode will contain the following parameters:

- a. SM. The system mode (PM) into which the tracker has been commanded.
- b. X,Y. The seven most significant bits of the X,Y FOV coordinate to which the FES was commanded.
- c. C_T . The 15-bit magnitude count which is a measure of the star intensity.
- d. SP. 1-bit star presence.
- e. E_x, E_y . The 12-bit X,Y star position relative to the coordinates at which the star was acquired.

The seven most significant bits of X,Y coordinates are a direct telemetry output of the seven most significant bits commanded to coarse offset each being resolved to 8.64 arc-sec nominal. No output of the fine offset exists; therefore, operationally it will be necessary to remember the last fine offset commanded. Generally the fine offset will be set to zero. The 15-bit star magnitude count (C_T) for calibration will be provided with each tracker. The 12-bit E_x, E_y is calibrated so that the LSB is equal to 0.27 arc-sec nominally.

4.2.4 EXAMPLES OF COMMANDING PRIMARY MODE

The next step in this document is to show examples of how to command the tracker into the primary mode from tracker shutoff for a given set of initial conditions.

The first example is a +10m star which is $X = +3$ arc-min and $Y = +2$ arc-min away from the center of the FOV. The first step is to turn the tracker power

on. Wait ten seconds for high voltage settle out and send the serial digital command to track the +10m guide star. Figure 4-1 shows the set up and command configuration of X_0 , Y_0 , x_0 , y_0 , for this particular case. The next step is to set up the UL/OL and for this particular case the UL/OL bit should be set for OL or a "zero" state. The TSR bit must then be set for fast scan or a "0" state. The last step is to set the mode selection bits (2 bits) for primary mode of "0,0" state. Figure 4-2 shows the final configuration for the +10m star case. This command is then uplinked and followed (with a 1-second delay) by a continue search command. The FES will then move to the commanded offset and begin to track the guide star. Fine adjustments may be made in the output position number by using the x_0 , y_0 bits which will be acted on immediately upon FES receipt of the command.

The telemetry output for this case is shown in figure 4-3. The X and Y and SM are the same as the command coordinates X_0 , Y_0 , SM. The star presence bit will be set as a function of star magnitude and threshold. The C_T count will be an indication of the star magnitude and will be updated after each axis track deflection. The E_x , E_y are the position error of the star from the initial X_0/x_0 , Y_0/y_0 coordinates set up in the command and they are equal to $E_i = \sum \epsilon_i$ where ϵ_i is the error for one particular deflection.

The second example would be to go from the +10m star to a +14m star at $X = -3$ arc-min and $Y = -5$ arc-min. The first operation would be to compute the new X_0/x_0 , Y_0/y_0 , for the new position. X_0 and Y_0 are in 2's complement and x_0 y_0 are always positive. This procedure is shown in figure 4-4.

The next step is to again set up the UL/OL bit which for this case will be a "zero" state for OL. The TSR bit must be set for slow scan or a "1" state. The last step is to again set the SM for primary mode or "0,0" state. Figure 4-5 shows the final configuration for this command.

Before this command can be uplinked it is necessary to take the FES out of the control loop if it is being used to control the IUE. Upon issuance of

4-6

	X ₀ Y ₀						
X ₀	0	0	1	0	1	0	0
Y ₀	0	0	0	1	1	0	1
SIGN	276.48	138.24	69.12	34.56	17.28	8.64	
	32	16	8	4	2	1	

$X = +3'$ $X = 3' = 180''$
 $Y = +2'$ $X_0 = 172.8$
 $x_0 = 7.29$
 $X = 180.09$
 $\epsilon = 0.09$

	x ₀ y ₀				
x ₀	1	1	0	1	1
y ₀	1	1	1	0	0
	4.32	2.16	1.08	.54	.27
	16	8	4	2	1

$Y = 2' = 120''$
 $Y_0 = 112.32$
 $y_0 = 7.56$
 $y = 119.88$
 $\epsilon = .12$

Figure 4-1. Command Set Up of X₀/x₀, Y₀/y₀ for Primary Mode

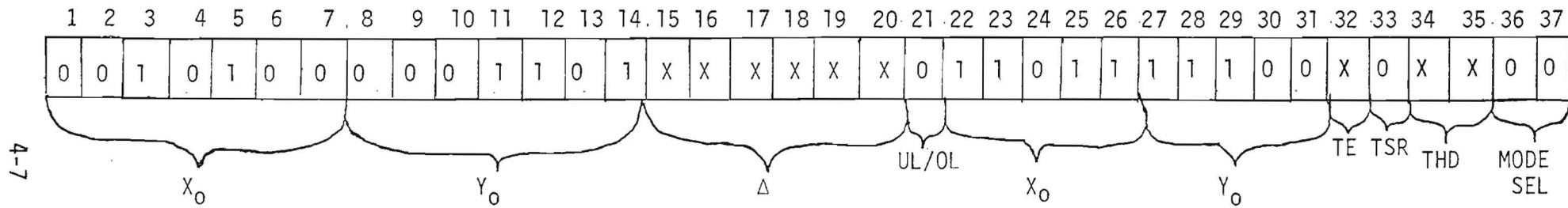


Figure 4-2. Command Configuration for Primary Mode

56 BIT TLM SERIAL OUTPUT

4-8

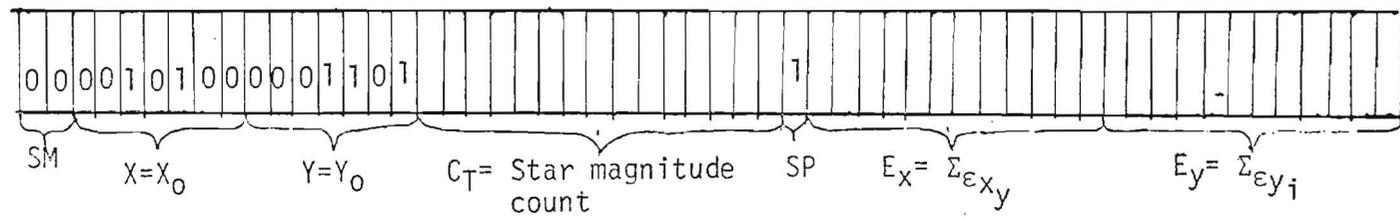


Figure 4-3. Telemetry Output for Primary Mode

4-9

X_0, Y_0 (2's Comp.)

X_0	1	1	0	1	0	1	0
Y_0	1	0	1	1	1	0	0

SIGN 276.48 138.24 69.12 34.56 17.28 8.64
32 16 8 4 2 1

$X = -3'$ $X = 1/2 \} = 9.07'$ center of FOV
 $Y = -5'$ $X = 1/2 \} = 9.07'$ $-3' = 6.07'$
 $X = 364.20''$
 $X_0 = 362.88''$
 $x_0 = 1.35''$
 $X = 364.23''$

x_0, y_0

x_0	0	0	1	0	1
y_0	0	1	0	0	1

4.32 2.16 1.08 .54 .27
16 8 4 2 1

$Y = 1/2 \} = 9.07'$ center of FOV
 $Y = 9.07'$ $-5' = 4.07'$
 $Y = 244.20''$
 $Y_0 = 241.92''$
 $y_0 = 2.43''$
 $y = 244.35''$

Figure 4-4. Command Set Up for $X_0/x_0, Y_0/y_0$ Primary Mode

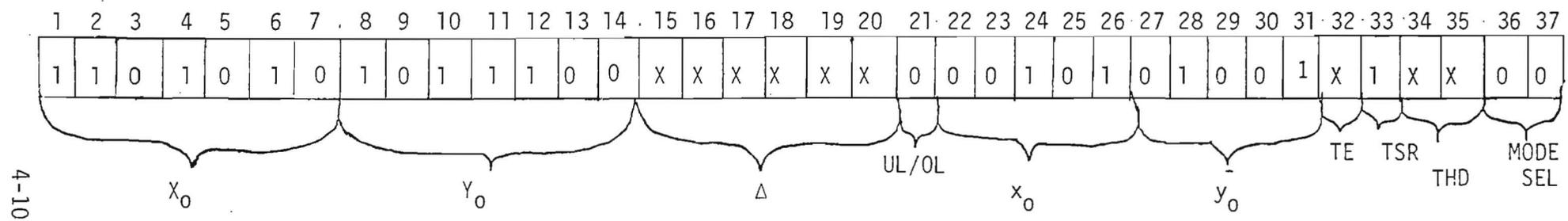


Figure 4-5. Command Configuration for Primary Mode

this command the FES will immediately change the X_0 , Y_0 fine offset and change the TSR. This would cause a large step error to the control system. All parameters will be loaded but not all will immediately be acted upon. After the serial digital command has been issued a continue search command must be sent. Once this has been issued the FES will then act on the rest of the command, the accumulated error E_x , E_y will be cleared, and the system will react as in example one. The telemetry for this case is shown in figure 4-6.

4.2.5 OPERATIONAL FLOW IN PRIMARY MODE

In the primary mode the continue search command can be used as it was in example two but in general when it is sent it will clear the accumulated error, setting the track deflection back to the commanded offset.

If the star presence bit drops to zero which is an indication that the star has been lost, the accumulated error will remain at the last value before the loss of star presence and track deflection. Therefore, if the FES is being used in the control loop these errors would remain fixed in the system and create a continuous offset. The SP bit may be regarded as a control/no control criteria to the OBC, thus assuring that the fixed accumulated error does not affect the control system.

Figure 4-7 shows the operational flow for tracker turn on. It shows the sequence which must be sent to assure proper operation.

Figure 4-8 shows the operational flow diagram of the primary mode. It shows how and what to command to accomplish all functions in that mode.

4.3 SEARCH AND TRACK MODE

4.3.1 INTRODUCTION

Search and track mode is used to search out a particular magnitude star (+11m to +2m) by forming a commanded square raster and proceeding to track

56 BIT TLM SERIAL OUTPUT

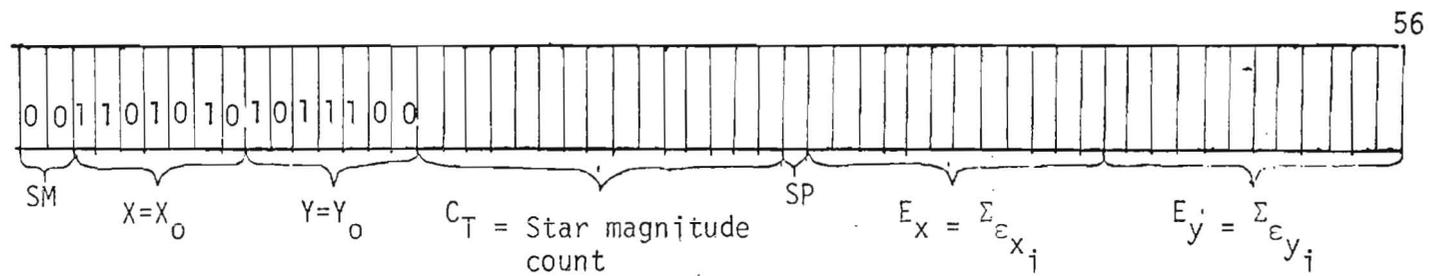


Figure 4-6. Telemetry Output for Primary Mode

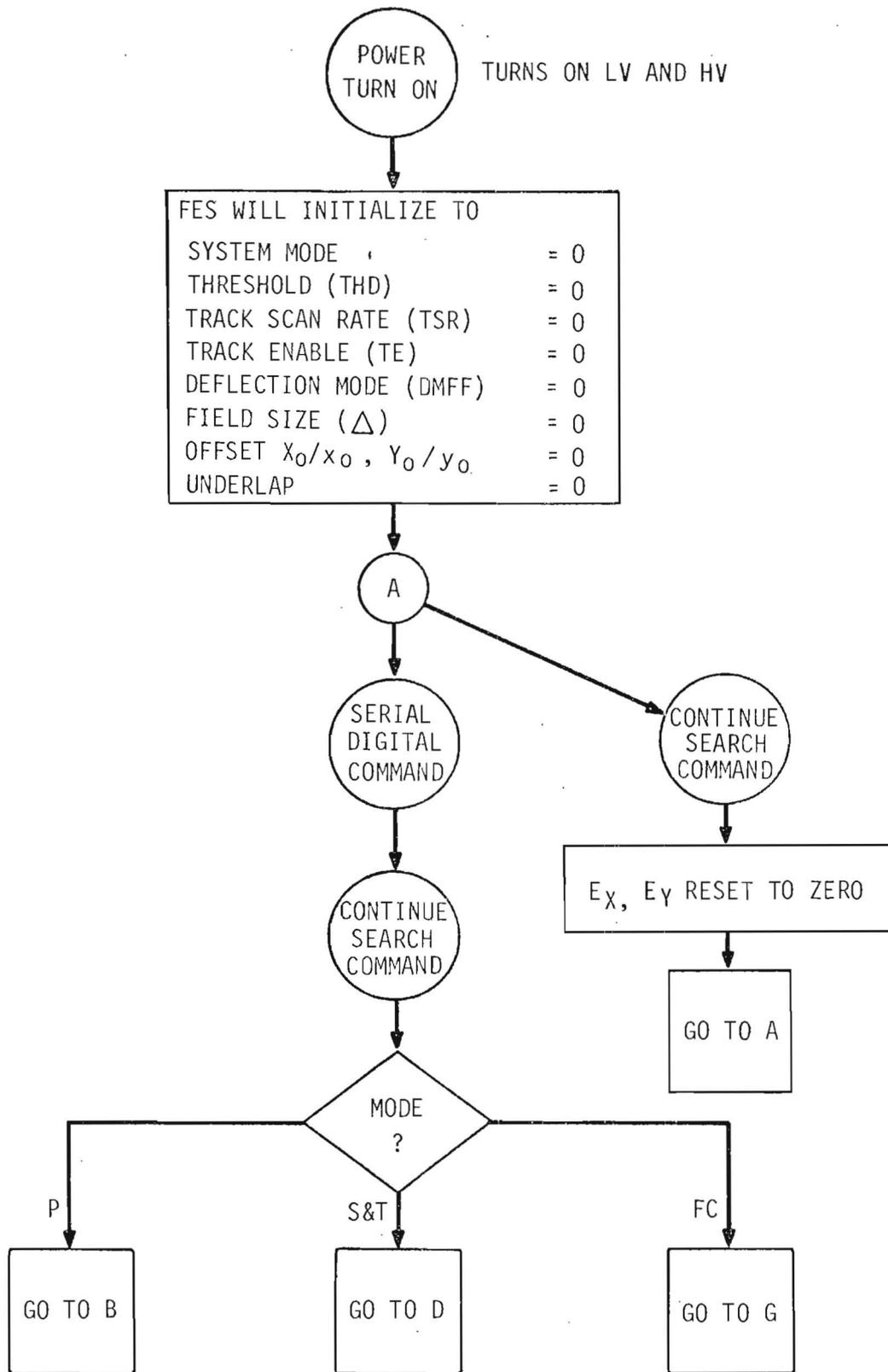


Figure 4-7 OPS Flow for FES Turn On

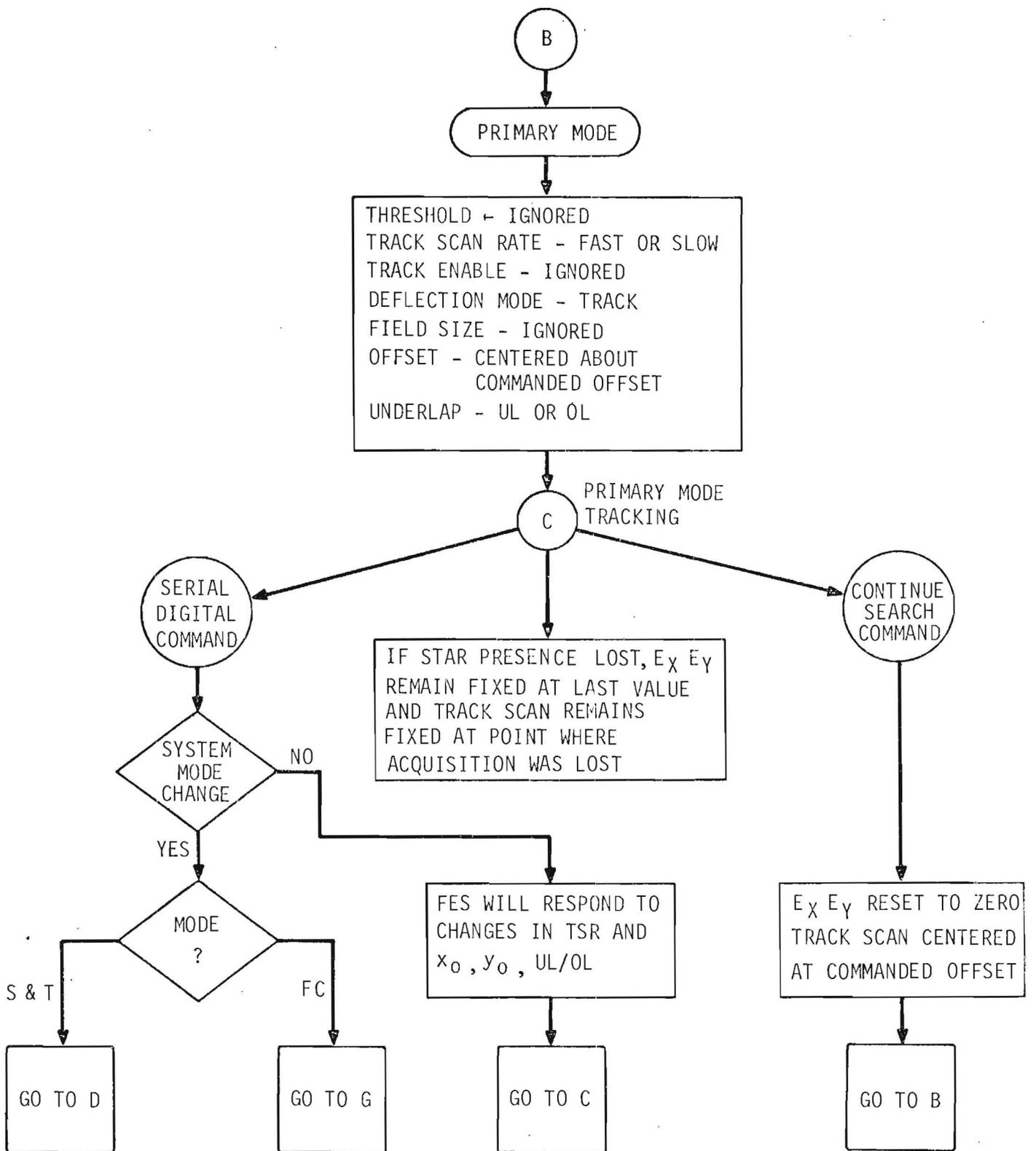


Figure 4-8. OPS Flow Primary Mode

the first star encountered which exceeds the commanded threshold. In this mode both search deflection and track deflection modes are utilized. The search deflection mode is used while the FES is searching out the commanded field of view. The dwell time for search deflection is internally set at 2.4 msec. Once the star magnitude threshold is exceeded the FES will switch to the track deflection mode.

To pick up different magnitude stars, two threshold bits exist. Table 4-2 shows the configuration of those bits for specific magnitudes. Assuming stars are present on the FOV, the probability of picking up any star in these ranges is greater than 0.9.

Table 4-2. Star Magnitude Configurations

Threshold Bit 1	Threshold Bit 2	Star Magnitude
0	0	+11.0mv A_0V & brighter
0	1	+10.0mv A_0V & brighter
1	0	+ 9.0mv A_0V & brighter
1	1	+ 8.0mv A_0V & brighter

Other inputs using the serial digital command for the search portion of the search and track mode are the start point of raster $X_0, X_0, Y_0/y_0$, the size of the raster and the mode selection (search and track mode). Inputs necessary for the track portion are the UL/OL and track scan rate (normally set to fast track) for the particular magnitude star to be tracked.

When in the track portion, the telemetry word includes the coordinates where the star presence was first indicated and the present position of the star with respect to the initial coordinates.

4.3.2 COMMANDS FOR SEARCH AND TRACK MODE

Assuming the sensor has been turned on, a serial digital command must be sent which includes the following parameters:

- a. $X_0/x_0, Y_0/y_0$. The X and Y position for the start of the raster in search mode.
- b. Δ . The number of dwells per line and lines per raster in search mode is $2\Delta + 1$.
- c. UL/OL. The underlap/overlap bit which is used as a function of the magnitude of the star to be tracked in track mode.
- d. TSR. The track scan rate must be set. Normally it will be set to fast track.
- e. THD. Star magnitude acquisition threshold.
- f. Mode Selection. Search and track mode must be commanded.

The serial digital command inputs $X_0/x_0, Y_0/y_0$ are offsets from the center of the field of view and define the start point of the raster scan for search deflection. Each step is approximately 0.27 arc-sec and there are 12 bits allocated for this offset. As in primary mode using track deflection, the weighting of X_0, Y_0 is 7 bits being 8.64 arc-sec nominally, while x_0, y_0 are 5-bit registers with a weighting of 0.27 arc-sec nominally. As discussed in primary mode, for negative numbers from the center of the FOV, the coarse (X_0, Y_0) register is computed as 2's complement, while for positive numbers the register counts up from the center of the field of view. The fine offset (x_0, y_0) always counts positive.

The raster size (Δ) is a 6-bit input where the dwells per line and lines per raster equal $2\Delta + 1$. A Δ set to zero will yield a single dwell point while all six bits set to "1" will yield a raster 18.432 arc-min square. The magnitude of the Δ LSB is 8.64 arc-sec.

The UL/OL bit is set to "1" for underlap and "0" for overlap. Overlap puts the track scan at +5.94 arc-sec from the center and is used to track +7m or

dimmer stars. The underlap puts the track scan at ± 15.66 arc-sec from center and is used to track +7m or brighter stars. Part of this command is the track scan rate. If the track scan rate bit is set to "0" the tracker will be in fast track which has an update rate of 5.2 updates/second. If the track scan rate bit is set to "1" the tracker will be in slow track which has an update rate of 1.3 updates/second.

4.3.3 TELEMETRY OUTPUT FOR SEARCH AND TRACK MODE

The telemetry output is a 56-bit serial output which for search and track mode will contain the following parameters. This data will be valid only after a suitable star has been acquired and the FES is in trade deflection mode.

- a. SM. The system mode (ST) into which the tracker has been commanded.
- b. X,Y. The seven most significant bits of the 12-bit FOV coordinate in search mode and in the track mode the X,Y FOV coordinate at which the star was acquired.
- c. C_T. The 15-bit star magnitude count which is a measure of the star intensity.
- d. SP. 1-bit star presence.
- e. E_x, E_y. In the track portion the 12-bit X,Y star portion as a function of the coordinates at which the star was acquired.

4.3.4 EXAMPLES OF SEARCH AND TRACK MODE SETUP

The next step is to show examples of how to command the tracker into the search and track mode assuming the tracker has been turned on and is operational.

The first example is to search out and track a +8 magnitude star with a 1 arc-min square raster beginning at $X = +2$ arc-min and $Y = +2$ arc-min. Figure 4-9 shows the set up of the X_0/x_0 , Y_0/y_0 and Δ for this case. Once this

X_0, Y_0

X_0	0	0	0	1	1	0	1
Y_0	0	0	0	1	1	0	1
	SIGN	276.48	138.24	69.12	34.56	17.28	8.64

x_0, y_0

x_0	1	1	1	0	1
y_0	1	1	1	0	1
	4.32	2.16	1.08	.54	.27

$X = +2'$	$X = +2' = 120''$	$Y = +2' = 120''$
$Y = +2'$	$X_0 = 112.32$	$Y_0 = 112.32$
	$x_0 = 7.83$	$Y_0 = 7.83$
	$X = 120.15''$	$Y = 120.15''$

Δ

0	0	0	0	1	1
---	---	---	---	---	---

Steps = $2\Delta + 1$
 Each Step = 8.64"
 $\therefore 2\Delta + 1 = 60 / 8.64 = 7$
 $\Delta = 3$

Figure 4-9. Command Setup of $X_0/x_0, Y_0/y_0, \Delta$ for Search & Track Mode

has been accomplished the raster has been defined. The next step is to set up the threshold for a +8m star or brighter which is a "1,1" for the two threshold bits. The FES will now search out a +8m star or brighter within the defined raster.

The next functions which must be set up are for the track portion of search and track mode. Since the star of interest is +8m the UL/OL bit must be set for overlap or a "0" state. The TSR bit must be set for fast scan or again a "0" state. The last part of the command word which must be accomplished is to set the SM bits for search and track mode or a "0,1" state. This final command set up is shown in figure 4-10.

After the command has been sent the raster will begin. The time of each dwell point is internally set at 2.4 msec and the steps are 8.64 arc-sec or one coarse offset step. At each dwell point the FES will check the C_T count and compare it with the threshold setting. The raster will step in X until end of line then return to beginning X, decrement one step in Y and resume stepping in X. At the end of each X line there will be one dwell time allotted for the scan to be repositioned and no C_T will be output for that dwell time. Figure 4-11 shows a typical raster. In figure 4-11 the raster will begin at PT 3,1, dwell there for 2.4 msec, move 8.64 arc-min to dwell at PT 2,1 and move again to point 1,1. The raster will then step to point X, note that it is outside the commanded raster, set $C_T = 0$, go to point 3,2 finishing the dwell time there with $C_T = 0$, then perform a full dwell at PT 3,2 with C_T reenabled.

When the threshold has been exceeded the FES will set the star presence bit and go into track deflection mode and begin tracking that star. This operation will be the same as primary mode track deflection. The only difference is that the X,Y outputs will be the point at which the star was acquired and has no correlation with the command inputs of X_0 , Y_0 .

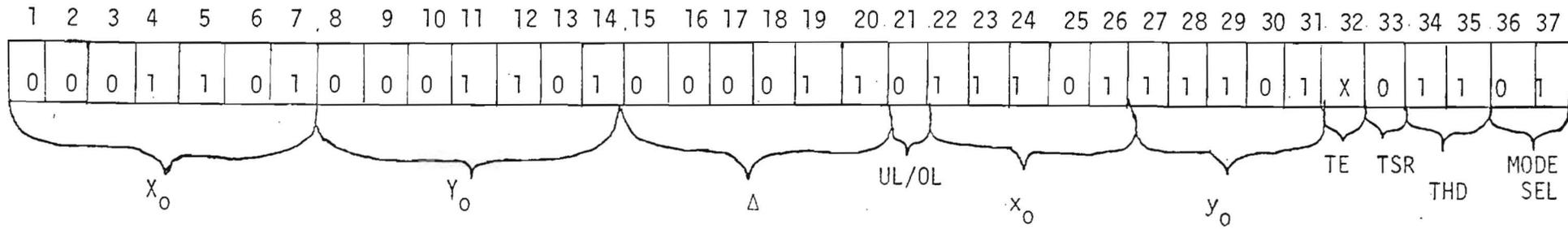


Figure 4-10. Command Configuration for Search & Track Mode

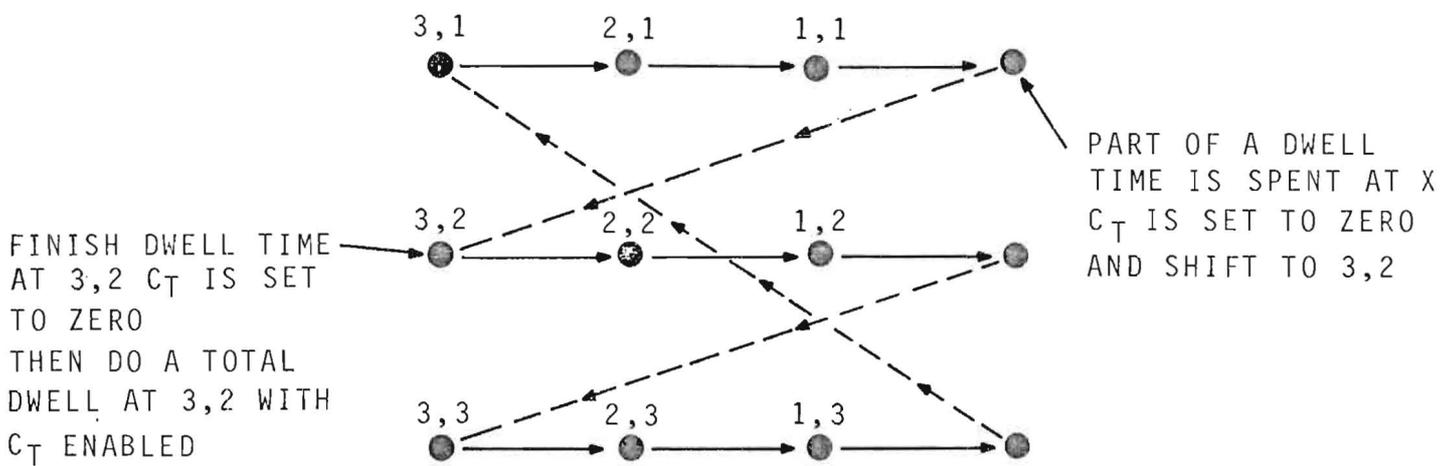


Figure 4-11. Typical Search Deflection Raster

The next example for search and track mode is to cease tracking and continue to search for another star in the predefined raster assuming that the star had been acquired at the beginning of the raster and that the only command which must be sent is the continue search command. When this command is sent, the FES will decrement two steps in Y from the point where the star was initially acquired and resume searching. If the star which had been acquired previously is sufficiently bright, the FES could reacquire and track it. If this occurs, another continue search command must be sent. This will again decrement the FES two steps in Y from the new acquisition point. These two commands have decremented the raster four steps in Y from the first acquisition point. If a new star is not acquired by the end of the raster the FES will go back to the start point and begin a new raster.

The next example is to change the commanded raster while in the search portion of search and track mode.

While searching, if a continue search command is sent, the FES will decrement two steps in Y and continue to search the predefined raster. It would be used to cease tracking a star and continue to search the raster.

Sending a serial digital command will accomplish changes in the raster. These changes will occur in this fashion. If x_0 , y_0 have been changed the FES will immediately respond to this and the next raster dwell point could shift by as much as 8.37 arc-sec from where it would have dwelled. This would only be useful if there were a reason to shift by this small amount. If X_0 , Y_0 , Δ were changed the FES would implement the new X_0 , Δ at the end of the X line and would respond to the new Y_0 , Δ at the end of the field. Therefore, the totally new raster would not begin until the total initial raster had been completed. The only way to change the raster without waiting for the finish of the previous raster is to send a serial digital command which changes modes and then send the serial digital command defining the new raster along with the mode change back to search and track mode.

4.3.5 OPERATIONAL FLOW IN SEARCH & TRACK MODE

If a continue search command is given as previously described, the FES will decrement two steps in Y and continue to search. This can be used to cease tracking a star and resume searching. If a serial digital command had been sent previously to change X_0 , Y_0 , Δ , these will be incorporated as follows: X_0 , Δ at the EOL and Y_0 , Δ at the EOF.

If a serial digital command is sent, the TSR and x_0 , y_0 , UL/OL will change immediately. No other changes will be incorporated.

If while in the track mode, the star presence is lost, both the track scan and E_x , E_y will remain fixed at the last value.

Figure 4-12 shows the operational flow diagram for the search and track mode. It describes how and what to command to accomplish all functions in that mode.

4.4 FIELD CAMERA MODE

4.4.1 INTRODUCTION

The field camera mode is used to map the star field within a commanded FOV. Search deflection, synchronized with the telemetry system is used to accomplish this search. The Data Word Gates (DWG), which precedes the shift pulses which are used to send out the sensor data, directly controls the stepping through the raster. The spacing between DWG's therefore controls the dwell time.

Field camera mode can be broken up into two different submodes. The first is totally a mapping mode and is accomplished when the Track Enable (TE) bit is low. The second mode is also a mapping mode but when the TE bit of the serial digital command is high, the star magnitude count is compared to the commanded threshold as well and, when it is found to exceed the threshold, the FES automatically switches to the internally controlled track deflection, just as in the search and track mode.

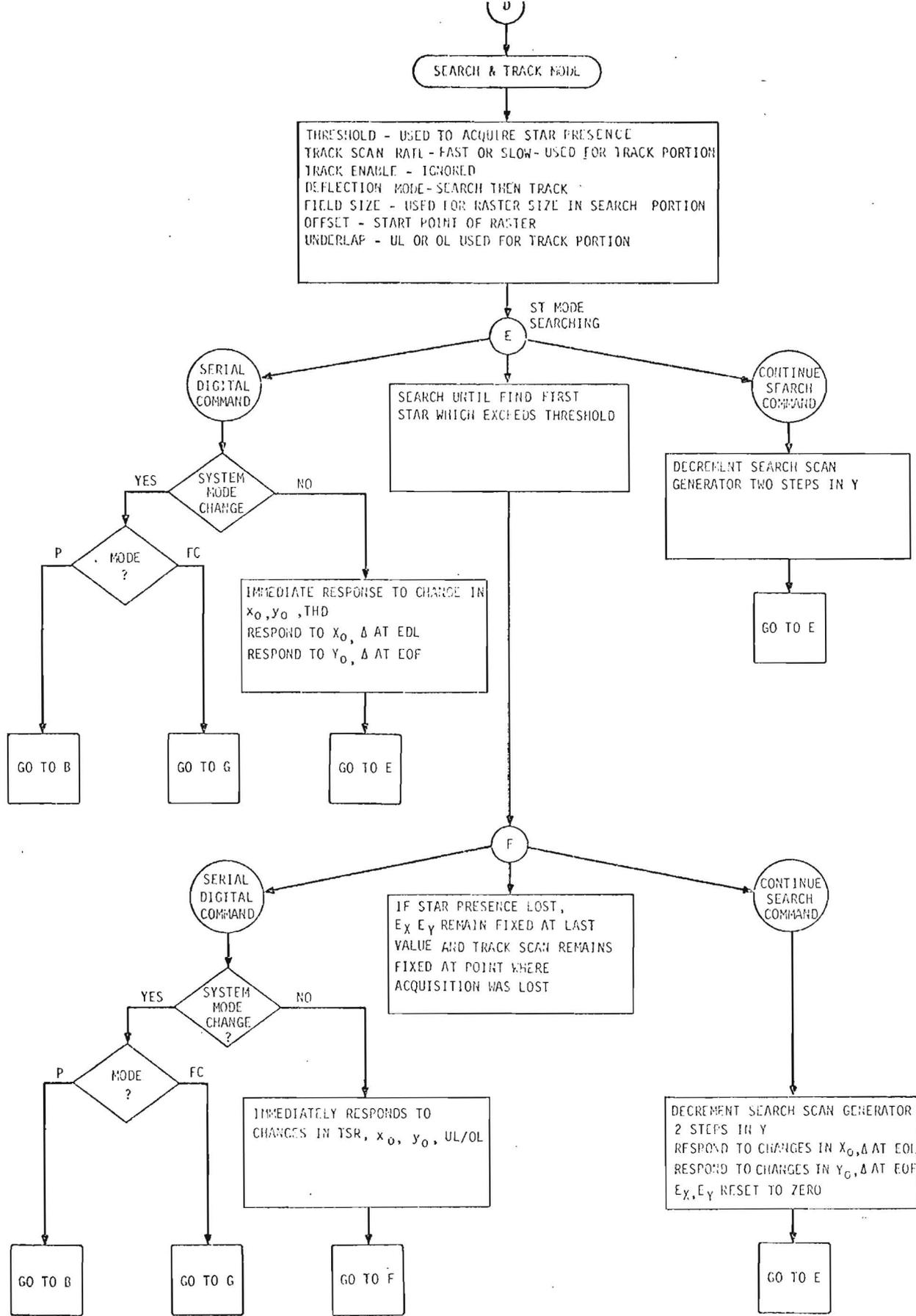


Figure 4-12. Operational Flow for Search and Track Mode

4.4.2 FIELD CAMERA MODE-MAP ONLY

For the mapping only mode, the inputs, using the serial digital command, are the start point of the raster X_0/x_0 , Y_0/y_0 (upper left hand corner), the steps for the raster, Δ , the TE bit set is set to "zero" and the mode selection (FCM).

The significant output telemetry is the position of the raster and the star magnitude counter. The calibration in the ground computer for this magnitude count will be different for each DWG dwell time chosen.

4.4.2.1 Command for Field Camera Mode-Map Only. Assuming the sensor has been turned on, a serial digital command must be sent which includes the following parameters:

- a. X_0/x_0 , Y_0/y_0 . The X and Y positions for the start of the mapping raster.
- b. Δ . The number of dwells per line and lines per raster equals $2\Delta + 1$.
- c. Track Enable. Set to disable.
- d. SM. Field camera mode must be commanded.

The serial digital command inputs X_0/x_0 , Y_0/y_0 are offsets from the center of the field of view and define the start point of the raster scan for search deflection. Each step is approximately 0.27 arc-sec and there are 12 bits allocated for this offset. As for primary mode using track deflection the weighting of X_0 , Y_0 is 7 bits each being 8.64 arc-sec nominally while x_0 , y_0 are 5-bit registers with a weighting of 0.27 arc-sec nominally. As discussed in primary mode, the computation of negative numbers for the coarse (X_0 , Y_0) registers must be done using the 2's complement technique. The fine (x_0 , y_0) register is always a positive number. Therefore, the maximum negative count is 2016 and occurs only when the sign bit and LSB of the coarse register are set to one and the fine register is all zeros. The maximum positive count is 2047 and occurs when all bits, except the

sign bit, in the coarse register are set to one and all bits in the fine register are set to one.

The raster size (Δ) input is a 6-bit input where the dwells per line and lines per raster equal $2\Delta+1$. A Δ set to zero will yield a single dwell point while setting all bits to "1" will yield a raster 18.432 arc-min square.

4.2.2.2 Telemetry Output for Field Camera Mode-Map Only. The telemetry output is a 56-bit serial output which for field camera mode contains the following parameters:

- a. SM. The system mode (FC) into which the tracker has been commanded.
- b. X,Y. The seven most significant bits of the 12-bit FOV coordinate.
- c. C_T. The 15-bit star magnitude count which is a measure of the star intensity.

The dwell time for the search scan generator is controlled in the field camera mode by the DWG's issued from the DMU. This can be set up for a variety of different times as a function of data rate and telemetry format.

4.4.2.3 Examples of Field Camera Mode-Map Only. The next step is to show an example of how to command the tracker into the field camera mode assuming the tracker has been turned on, the tracker is operational and the DWG has been properly timed. The example is to map an area beginning at $X = -3$ arc-min and $Y = +4$ arc-min and encompassing a 10 arc-min square. Figure 4-13 shows the set up of X_0/x_0 , Y_0/y_0 and Δ for this case. In most cases, the X_0/x_0 , Y_0/y_0 and Δ values will not correspond exactly with the desired start point and raster size. If this occurs, the X_0/x_0 , Y_0/y_0 and Δ values should be chosen to encompass the desired start point and raster size. Once this has been accomplished the raster size has been defined and the only thing left to do is to command field camera mode with TE disabled. This set up is

		X_o, Y_o						
X_o		1	1	0	1	0	1	0
Y_o		0	0	1	1	0	1	1
SIGN		276.48	138.24	69.12	34.56	17.28	8.64	

		x_o, y_o				
x_o		0	0	1	0	1
y_o		1	1	0	0	1
		4.32	2.16	1.08	.54	.27

$X = -3'$ $X = \frac{1}{2} + 19.07'$ center of FOV
 $Y = +4'$ $x = 9.07' - 3' = 6.07$
 $x = 364.20''$
 $X_o = 362.88$
 $x_o = 1.35$
 $X = 364.23$

$Y = 4' = 240''$
 $Y_o = 233.28$
 $y_o = 6.75$
 $Y = 240.03$

4-27

Δ					
1	0	0	0	1	1
32	16	8	4	2	1

Steps = $2\Delta + 1$
Each Step = $8.64''$
 $\therefore 2\Delta + 1 = \frac{600}{8.64} = 70$
 $\Delta = 35$

Figure 4-13. Command Setup of $X_o/x_o, Y_o/y_o, \Delta$ for FCM-Map Only

either at "1,0" or "1,1" state in the mode select bits and a "0" state for the TE bit. The final command set up is shown in figure 4-14.

After the command has been sent the raster will begin. The time of each dwell point is again determined by the timing of the DWG's and the steps are 8.64 arc-sec or one coarse offset step. The operation of this raster is explained in the search and track mode operation.

The telemetry output for field camera mode includes X,Y, SM and C_T . Raster configuration changes are explained in the search and track mode section of this document.

4.4.3 FIELD CAMERA MODE-MAP AND TRACK

For the second mode where the TE bit is set for track, the inputs as in the map only mode are the same for X_0/x_0 , Y_0/y_0 , Δ and mode selection. The TE bit must now be set to "1" and as in the search and track mode, the tracking inputs UL/OL, TSR, threshold must be properly set. In this mode both the search deflection and the track deflection modes are used. As in search and track mode, search deflection is used for searching out the commanded field of view and once a star presence is indicated the FES will switch to track deflection mode. The primary difference between this mode and the search and track mode is that during the search deflection portion the dwell time is set up by the DMU DWG's. Table 4-2 indicates the range of magnitude thresholds as a function of DWG timing. The following equation shows the relationship of dwell time to magnitude:

$$\chi = 2.4 (2.51)^n \text{ millisecc}$$

where:

+11 requires 2.4 millisecc

n = number of magnitudes dimmer than +11m desired.

For a dwell time of 25.6 msec, stars up to +13.5m may be acquired with a probability greater than 0.9. Stars of +14m may also be captured, but with a lower probability.

4-29

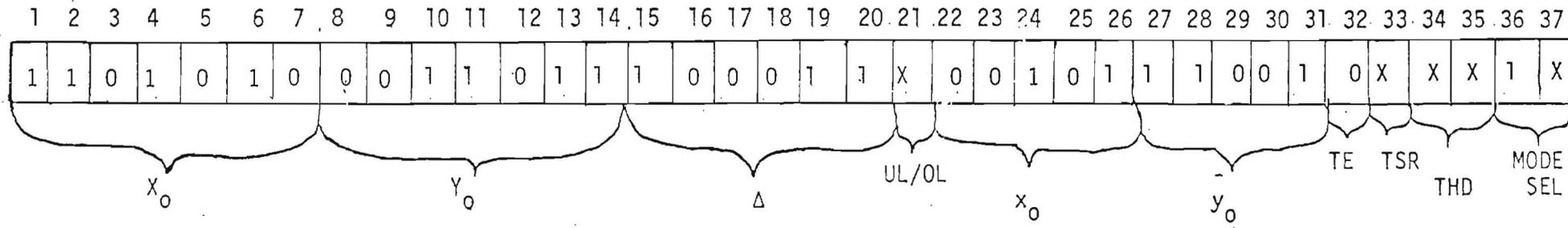


Figure 4-14. Command Configuration for FCM-Map Only

Inputs using the serial digital command for the search portion of field camera mode are the start point of the raster, $(X_0/x_0, Y_0/y_0)$ the size of the raster, (Δ) , the threshold (THD) and the mode selection (FCM). Inputs necessary for the track portion are the UL/OL, and the TSR for the particular magnitude star to be tracked.

In the search deflection portion the significant telemetry output is the position of the raster and the star magnitude counter. For the track deflection portion, telemetry includes, the coordinates where the star was acquired, star magnitude count per axis, star presence indication and the present position of the star with respect to its initial acquisition point.

4.4.3.1 Commands for Field Camera Mode-Map and Track. As in search and track mode, a serial digital command containing the following parameters must be sent along with the TE bit set to a "1":

- a. $X_0/x_0, Y_0/y_0$. The X and Y positions for the start point of the raster in search mode.
- b. Δ . The number of steps in the raster in search mode.
- c. UL/OL. The underlap/overlap bit which is used as a function of the magnitude of the star to be tracked while in track deflection mode.
- d. TSR. The track scan rate must be chosen, again, as a function of the magnitude of the star to be tracked in track deflection mode.
- e. TE. The track enable bit must be set to enable.
- f. SM. Field camera mode must be commanded.

The definition of these functions are presented in the search and track mode section.

4.4.3.2 Telemetry Outputs for Field Camera Mode-Map and Track. The telemetry output for this mode will be the same as in search and track mode after star presence has been indicated.

4.3.3.3 Examples of Field Camera Mode-Map and Track. The next step is to show an example of how to command the tracker into field camera mode with the TE bit enabled. The example is to search out and track a +12 magnitude star within a 4 arc-min raster beginning at $x=+2$ and $Y=+1$. To search out a +12 magnitude star the DWG timing could be 25.6 msec, which will allow the FES to detect a star of that magnitude. Figure 4-15 shows the set up of X_0/x_0 , Y_0/y_0 and Δ for this case. The raster and start point are now defined. These inputs should be set up to encompass the actual start point and the total field of view if the conversion does not work out to the exact numbers.

The next step is to set up the threshold for this case. Since the threshold limits are set up for a 2.4 msec dwell time and the dwell time in this example is a 25.6 msec, it is not necessary to set up a threshold of +12m. All that is needed is to set up a threshold of +10m or a configuration of "0,1" for the two threshold bits.

The next functions must be set up for the track deflection mode portion of field camera mode. The TE bit must be set to allow the FES to track in field camera mode. Since the star of interest is +12m the UL/OL bit must be set for overlap or a "0" state. The TSR bit should be set for fast scan or again a "0" state. The last parameter to be entered is the SM set for field camera mode which is either at "1,0" or "1,1" state for the two SM bits. The final command configuration for this example is shown in figure 4-16.

Once the command has been sent the FES will respond as defined in the search and track mode portion of this section.

4.4.4 OPERATIONAL FLOW IN FIELD CAMERA MODE, MAP ONLY

For field camera mode map only, the continue search command is used as in the search portion of the search and track mode, to decrement the raster

4-32

X_0, Y_0

X_0	0	0	0	1	1	0	1
Y_0	0	0	0	0	1	1	0
	SIGN	276.48	138.24	69.12	34.56	17.28	8.64

x_0, y_0

x_0	1	1	1	0	1
y_0	1	1	1	1	1
	4.32	2.16	1.08	.54	.27

$X = +2'$ $X = +2' = 120''$ $Y = 1' = 60''$
 $Y = +1'$ $X_0 = 112.32''$ $Y_0 = 51.84''$
 $x_0 = 7.83$ $y_0 = 8.37$
 $X = 120.15''$ $Y = 60.21''$

Δ

0	0	1	1	1	0
32	16	8	4	2	1

Steps = $2\Delta + 1$
 Each Step = $8.64''$
 $2\Delta + 1 = \frac{240}{8.64}$
 $2\Delta = 28$
 $\Delta = 14$

Figure 4-15. Command Setup of $X_0/x_0, Y_0/y_0, \Delta$ for Field Camera Mode-Map & Track

4-33

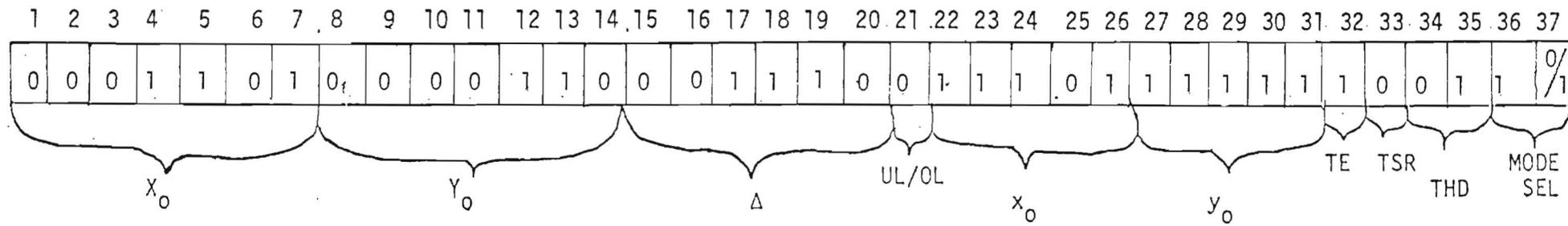


Figure 4-16. Command Configuration for Field Camera Mode-Map & Track

two steps in Y. If a serial digital command is sent, when neither the mode nor the TE bit status has changed, the FES will respond immediately to changes in x_0 and y_0 and continue to map. The tracker will respond to changes in X_0, Δ at the next EOL, and to changes in Y_0, Δ at the next EOF. If a serial digital command had been sent which now enabled the TE bit, the tracker will again respond as previously only now the proper inputs for the track deflection portion of this mode must be input. These include THD, UL/OL, and TSR. Figure 4-17 shows the operational flow diagram for the field camera mode, map only.

4.4.5 OPERATIONAL FLOW IN FIELD CAMERA MODE-MAP AND TRACK

For field camera mode map and track and the tracker is in the search deflection portion, the continue search command will decrement the raster two steps in Y. If a serial digital command is sent where neither the mode nor the TE bit have been changed the FES will respond immediately to changes in THD, x_0 and y_0 and continue to search. The tracker will respond to changes in X_0, Δ at the EOL and changes to Y_0, Δ at the EOF. If a serial digital command is sent, which changes the TE bit to disable, the FES will respond immediately to changes in x_0, y_0 . It will respond to changes in X_0, Δ at the EOL and to Y_0, Δ at the EOF. The tracker will now go to map only mode and respond as shown in figure 4-17.

When the tracker is in the track deflection portion and a continue search command is sent, the raster size and starting point changes are incorporated. The tracker will then go to the point where the star was initially acquired, decrement Y by two steps, and continue the search raster. The tracker will then respond to the X_0, Δ changes at EOL and the Y_0, Δ changes at EOF. If a serial digital command is sent, the tracker will respond immediately to changes in the TSR, UL/OL, and x_0, y_0 . No other changes will be incorporated.

If the star presence is lost while in the track deflection mode, both the track scan and E_x, E_y will remain fixed at the last value before star presence was lost.

Figure 4-17 shows the operational flow diagram of the field camera mode map and track. It describes how to command all functions in that mode.

The final point to be made on field camera mode map and track is that if the tracker is in the search portion and a serial digital command is sent which changes the TE bit to disable, the tracker will immediately go to a map only mode. In the track portion of this mode to get back to a map only mode the serial digital command must be sent first with the disable bit set. Then a continue search command must be sent. This will move the Y scan down two steps, the disable bit will be acted upon and the tracker will go to a map only mode.

4.5 MODE SWITCHING

The mode switching hinges on changing the system mode. Once the system mode has been changed the only operation which must be accomplished is to make sure the inputs to the serial digital command are proper for that particular mode. This section will present the operations necessary to command between modes. This will be somewhat redundant but will be presented to make sure there is no confusion as to what has to be done.

4.5.1 SWITCHING TO PRIMARY MODE FROM THE OTHER MODES

Switching to primary mode from any other normal mode requires the following inputs to the serial digital command:

- a. $X_0/x_0, Y_0/y_0$. The X and Y position of the star to be tracked.
- b. UL/OL. The underlap/overlap bit, which is used as a function of the magnitude of the star to be tracked.
- c. TSR. The track scan rate is chosen as a function of the magnitude of the star to be tracked.
- d. SM. The system mode must be primary mode.

The SDC bits for Δ , TE, and THD are ignored by the FES in primary mode.

All changes within primary mode can be handled by use of the serial digital command and the continue search command. This is covered in the primary mode section of this document.

4.5.2 SWITCHING TO SEARCH AND TRACK MODE FROM THE OTHER MODES

Switching to search and track mode from any other normal mode requires the following inputs to the serial digital command:

- a. $\underline{X_0/x_0}, \underline{Y_0/y_0}$. The X and Y position for the start of the raster in search deflection mode.
- b. $\underline{\Delta}$. The number of steps in the raster in search deflection mode.
- c. $\underline{UL/OL}$. The underlap/overlap bit which is used as a function of the magnitude of the star to be tracked in track deflection mode.
- d. \underline{TSR} . The track scan rate must be chosen as a function of the magnitude of the star to be tracked in track deflection mode.
- e. \underline{THD} . Star magnitude acquisition threshold.
- f. \underline{SM} . System mode must be search and track mode.

All operations within search and track mode can be handled by using the serial digital command and the continue search command. The only type of operation within search and track mode which may be done more efficiently by switching between modes is when a raster must be changed and completion of the first raster is not necessary. If the change is made within the mode, the raster will not change until the total raster is complete. To shorten the time, the most efficient way is to change the mode to another normal mode then switch back to search and track mode with all the necessary inputs for the new raster incorporated. This will immediately start the new raster.

4.5.3 SWITCHING TO FIELD CAMERA MODE (MAP ONLY) FROM THE OTHER MODES

Switching to field camera mode map only, from any other mode requires these inputs to the serial digital command:

- a. $X_0/x_0/Y_0/y_0$. The X and Y positions for the start of the raster in search deflection mode.
- b. Δ . The number of steps in the raster in search deflection mode.
- c. TE. Track enable bit set to disable.
- d. SM. System mode must be field camera mode.

All operations within field camera mode map only, may be handled by using the serial digital command and the continue search command. As in search and track mode, for more efficient use of the raster, switching out of field camera mode and back into it can quickly change the raster.

Particular examples of this switching are not necessary. The examples given in the operation of the three modes provides all that is necessary to set up the necessary parameters.

4.5.4 SWITCHING TO FIELD CAMERA MODE (MAP AND TRACK) FROM THE OTHER NORMAL MODES

Switching to field camera mode map and track from any other normal mode requires these inputs to the serial digital command.

- a. $X_0/x_0/Y_0/y_0$. The X and Y positions for the start of the raster in search deflection mode.
- b. Δ . The number of steps in the raster in search deflection mode.
- c. UL/OL. The underlap/overlap bit which is used as a function of the magnitude of the star to be tracked in track deflection mode.
- d. TSR. The track scan rate must be chosen as a function of the magnitude of the star to be tracked in track deflection mode.
- e. THD. Star magnitude acquisition threshold.
- f. TE. Track enable bit set to enable.
- g. SM. System mode must be field camera mode.

All operations within field camera mode (map and track) may be handled by using the serial digital command and the continue search command. As in search and track mode, for more efficient use of the raster, switching out of field camera mode and back into it can quickly change the raster.

Particular examples of this switching are not necessary. The examples given in the operation of the three normal modes provides all that is necessary to set up the necessary parameters.

4.6 FORBIDDEN MODES

Within the FES there are no forbidden modes. The system mode bits have been defined so that the two bits will always describe a particular normal mode. This was accomplished by making the "1,0" and "1,1" configurations of these bits to both mean field camera mode.

The only two operational constraints are:

- a. When inputting into the serial digital command in X_0/x_0 , Y_0/y_0 do not input a negative zero. This will not cause any damage to the FES but will cause the tracker to go to a limit position. This is due to the X_0 , Y_0 input being in a 2's complement form.
- b. Do not command a serial digital command at a rate greater than 1/second. This may cause erroneous command information due to the fact that a serial digital command may not be acted upon for as long as one second after the FES has received the command.

Other operational constraints which should be considered such as linearity and calibration are discussed in section 3 of this document.

4.7 OPERATION TECHNIQUES ASSOCIATED WITH USING THE FES

The preceding portion of section 4 has described the normal modes, their operation and particular examples of their use. It has also shown how to switch between modes and the operational constraints of the FES. The purpose of this section is to discuss how the sensor may be used for particular operational needs and problems associated with its use. This will not only include the use of one FES but the possible use of two FES's to accomplish certain operations.

4.7.1 USE OF FES TO ACQUIRE A STAR

One of the major purposes of the FES is to enable the IUE to place the target star in the aperture and to acquire guide stars to keep it there.

As a function of the normal mode of the FES the tracker can search and track stars between +2m and +14m. In determining how to operate the FES to accomplish this goal certain problems must be looked at carefully.

The first problem is that of attitude determination to assess the IUE pointing. The IUE can use DSS and the panoramic attitude sensor to determine approximate attitude. This determination will not be good enough to assure that the +X axis is pointing toward a designated target star. The solution to this problem is to use the FES in FCM to obtain a star pattern. This is compared on the ground with star maps to develop a more precise attitude determination.

Another problem which must be addressed is that of near neighbor stars which may be too close to a desired guide star. It will be necessary to assess how far away a particular magnitude guide star has to be from a near neighbor so that there is no interference. As a function of the magnitude of the near neighbor star, this affect may not exist or be very pronounced. Tests must be run to see the affect of near neighbor stars, as a function of magnitude, to assess their operational impact.

One way of acquiring a star, assuming there is no near-neighbor problem, is to slew the spacecraft to the region of interest. A coarse attitude determination using the panoramic attitude sensor, DSS, and known ephemeris data is then accomplished.

After this has been completed, the FES should be put into FCM and map the total FOV. Once the map has been received on the ground, it is compared to ground charts for pattern recognition. When there is pattern recognition, the IUE can then be slewed to further refine the attitude. Once it is felt that the attitude is close to the desired search and track mode, it may be used to acquire the star.

This is accomplished by setting up the correct parameters for the track portion and setting up the raster size to encompass an area about the predicted star position. The size of this raster would be a function of the expected attitude error about that point. Once search and track mode has been commanded the star has been acquired, and the scan has settled out on the star, the acquisition point coordinates (X,Y) and the errors (E_x, E_y) can be used to determine the star position with respect to the roll axis pointing.

Using these values, $X+E_x$, $Y+E_y$, the offset from the roll axis (+X) can be assessed. Slews may then be generated which can position the IUE so that the guide star is positioned properly with respect to the experiment slits. Once this has been accomplished the proper inputs for the primary mode may be uplinked and the guide star should be picked up.

When the guide star is picked up in primary mode, the E_x and E_y would be the errors between where the star is and where it should be in relation to the experiment slits. If this angle is great, slews can be generated to take out these errors. At this point the target star should be within the experiment aperture. The FES can now be used in a monitor mode, while the IUE is under gyro control. By looking at the E_x, E_y of the FES operations can ascertain gyro drift and compensate accordingly as the situation warrants. If the FES is in fast track, the FES could be put into control along with the IRA to maintain IUE pointing.

For this operation search and track mode would be used over FCM because the raster will take a shorter time for final acquisition. The only time FCM should be used for this final raster is if the guide star of interest has a magnitude lower than +11m.

The search and track mode can be used to define the coordinates of two or three bright stars in the commanded raster or to acquire a star quickly within a particular raster. The major drawback in using the search and

track mode is that the dwell time is internally fixed at 2.4 msec. This means that the dimmest star which can be picked up by the FES is +11m and that the telemetry downlink rate is not synchronized with the 2.4 msec update; therefore, much of the raster is lost. Unless the DMU can provide a telemetry frame which updates at 2.4 msec, this can never be used for mapping.

4.7.2 FOCUSING THE SI USING THE FES AS A REFERENCE

The SI can be focused by using the FES in the FCM, map only, by setting the initial point of the raster on a particular star and setting the Δ to zero. This will permit the raster to stay at that particular point and update the magnitude counter after each dwell time. Since the FES output is synchronized to telemetry, each dwell will give a C_T count.

In this mode, FES will be used as a photometer to assist in focusing the scientific instrument.

4.7.3 USING THE FES TO UPDATE OBC ALGORITHMS

The FES will be used by the OBC in certain algorithms necessary to update attitude information. For this purpose the FES must be tracking a star in track deflection mode where the TSR is fast track or 5.2 samples per second. Slow track may also be used but fast track is preferred. The way the OBC would get this information is to have the DMU extract this information from the FES using a special format solely for the OBC assigned to the DMU for getting not only FES data to the OBC but also other sensor data. To accomplish this task, the DMU is set up not only with a telemetry format but set up with a format to bring data into the DMU and send it to the OBC. A typical telemetry format in the DMU is shown in figure 4-18. This format shows in figure 4-18 the FES data once in the 128-word format. The time between each update is 25.6 msec assuming a data rate of 40 kb/sec. A typical computer format is

shown in figure 4-19. This format shows the FES data four times in the 128 word format. Therefore, the time for each update is 6.4 msec, assuming a data rate of 40 kb/sec.

There are many rates at which data may be given to TLM and the OBC. These will be functions of the format used and the data rate chosen. Data rates from 1.25 to 40 kb/sec may be chosen and a variable format may be chosen in the DMU for OBC and TLM update using the FES.

A particular example of how to get data into the OBC would be to use FES No. 1 for both telemetry and to update the OBC. The first operation is, assuming the telemetry has been set up as in figure 4-18, and the data rate is 40 kb/sec, to set up the OBC format such as that shown in figure 4-19.

These formats will not be suitable for use in accomplishing the two tasks simultaneously, but are used as examples only.

This would set up a data rate to the ground of 40 kb/sec and to the OBC of 40 kb/sec assuming the ratio between the OBC data and telemetry is 1 to 1.

When this is set up, the DMU will sample FES data for telemetry every 25.6 msec and for OBC every 6.4 msec.

In this mode when the time is correct, each of these formats will issue a DWG to the FES to sample its data. The OBC will pole the DMU every 6.25 msec. Since the FES in fast track only updates every 192 msec, the OBC will be sampling the same data 30 times before the FES data will actually change. The OBC has been set up to use a sample approximately every 204 msec; therefore, it will use new data each time. The total system is run asynchronously and no attempt has been made to synchronize the operation.

BIT RATE - 40.0 kb/SEC.

OBC FORMAT 3A

TRANSFER & MISSION ORBIT

AVERAGE SAMPLE TIME		
MF	25.6	MSEC

4-45

ACCEL A	ACCEL B	PITCH CMD C&M	PAS1/2 SUN PULSE	SMSS SUN PULSE	DMU RAD MON	GYRO 1A	GYRO 1B	GYRO 2A	GYRO 2B	GYRO 3A	GYRO 3B	GYRO 4A	GYRO 4B	GYRO 5A	GYRO 5B
GYRO 6A	GYRO 6B	FINE ERROR SENSOR DATA NO. 1						ROLL RATE 1		PITCH RATE 1	YAW RATE 1	ROLL RATE 2	PITCH RATE 2	YAW RATE 2	D2
ACCEL A	ACCEL B	YAW CMD C&M	PAS1/2 SUN PULSE	SMSS SUN PULSE	A2	GYRO 1A	GYRO 1B	GYRO 2A	GYRO 2B	GYRO 3A	GYRO 3B	GYRO 4A	GYRO 4B	GYRO 5A	GYRO 5B
GYRO 6A	GYRO 6B	FINE ERROR SENSOR DATA NO. 1						CSS PITCH ERROR		CSS ROLL ERROR	D18	CMD EX COUNTER 1	CMD EX COUNTER 2	ANALOG SUBCOM 1	ANALOG SUBCOM 2
ACCEL A	ACCEL B	ROLL CMD C&M	PAS1/2 SUN PULSE	SMSS SUN PULSE	DMU 2.5V CAL @ 2M	GYRO 1A	GYRO 1B	GYRO 2A	GYRO 2B	GYRO 3A	GYRO 3B	GYRO 4A	GYRO 4B	GYRO 5A	GYRO 5B
GYRO 6A	GYRO 6B	FINE ERROR SENSOR DATA NO. 1						ROLL RATE 1		PITCH RATE 1	YAW RATE 1	ROLL RATE 2	PITCH RATE 2	YAW RATE 2	ANALOG SUBCOM 3
ACCEL A	ACCEL B	D8	PAS1/2 SUN PULSE	SMSS SUN PULSE	BUS VOLT (27-29V)	GYRO 1A	GYRO 1B	GYRO 2A	GYRO 2B	GYRO 3A	GYRO 3B	GYRO 4A	GYRO 4B	GYRO 5A	GYRO 5B
GYRO 6A	GYRO 6B	FINE ERROR SENSOR DATA NO. 1						CSS PITCH		CSS ROLL	DMU 2.5V CAL.	S/C BUSS V	S/C BUSS I	ANALOG SUBCOM 1	ANALOG SUBCOM 2

■ = WORD GATE

Figure 4-19. Typical OBC Format

4.7.4 PROBLEMS ASSOCIATED WITH USING ONE FES FOR BOTH TLM AND OBC UPDATES

The major problem in trying to use one FES to provide both telemetry and OBC updates is that both the TLM format and the OBC format will send DWG's for update. If the formats are not set up properly, the TLM portion may send a DWG to the FES while the OBC portion is in the process of loading that data. This can cause erroneous data to be loaded into the OBC.

Since the OBC will be using this data in essence continuously, and the DMU data rates, formats, and ratios have so many combinations, setting up the case, in which DWG's used for one purpose will not cancel the other, will be a difficult task.

4.7.5 OBC AND TLM UPDATES USING FES NO. 1 AND FES NO. 2

A possible way to handle both operations is to use both FES's. One FES doing operations for the ground and the second FES sending data to the OBC for updates. As an example FES No. 1 would be used for ground operations in FCM mode with updates every 25.6 msec as in the previous case described in section 4.7.3, while FES No. 2 is in primary mode with updates every 6.4 msec to the OBC. A ratio of 1 to 1 is again chosen at the 40 kb/sec data rate.

The telemetry portion of the DMU time will, every 25.6 msec, send a DWG to FES No. 1 to update the downlink to the ground. For FCM this time is sufficient to operate for stars up to +14m.

The (OBC) computer portion of the DMU time will, every 6.4 msec, send a DWG to FES No. 2 to update the appropriate algorithms. This is the same operation as described in section 4.7.3.

4.7.6 PROBLEMS ASSOCIATED WITH DUAL FES OPERATION FOR OBC UPDATE

There seems to be no problems with operations in this dual FES mode. Since the DMU formats are independent, the problem of DWG's being issued to the same FES at improper times no longer exists.

4.7.7. FES USE BY THE DMU

The DMU sends the DWG's to the FES to update the telemetry and the OBC. Specific formats have been set up in the DMU for both these purposes. Two of these are shown in figures 4-18 and 4-19. Since these formats are variable, timing for DWG's can be made variable. TLM update rates from 1.25 to 40 kb/sec in steps of 1.25 kb/sec can be chosen while up to eight of the FES 56-bit telemetry can be put into a 128-word output with no timing problems. This will allow in the FCM mode to extend the capability for star mapping, to lower magnitudes than +14m; and may allow, by increasing the dwell time, the FES to map +14m stars as the sensitivity degrades.

Formats for the OBC can also be variable, but due to the update time of the FES and the cycle time of the OBC, the format shown in figure 4-19 is sufficient.

Figure 4-20 depicts a typical set up of the DMU for telemetry and computer mode. A ratio of 1 to 1 is shown which means that the DMU will send half a cycle (100 μ sec) for TLM and half a cycle for computer. The figure shows FES No. 1 in FCM used for TLM and FES No. 2 in primary mode used for computer data. The DWG to FES No. 1 occurs within the TLM half cycle and the DWG to FES No. 2 occurs within the computer half cycle. This also shows that if only one FES were used the separation of DWG's for TLM and computer would have to occur eight cycles apart and must never occur as shown in figure 4-21.

4.7.8 USE OF FES TO TRACK EXTENDED SOURCES OR BRIGHT STARS

The definition of an extended source for the FES is one whose half cycle is greater than one track deflection scan in underlap or approximately 15 arc-min.

A method for looking at extended sources is to use field camera mode and setting up the raster to encompass the extended source. An example of an extended source is shown in figure 4-21. In this case a raster is set up to encompass the extended source and the data sent to the ground in telemetry. The ground computer will select certain raster points and use them to form a pseudo E_x and E_y in a track scan type of deflection. The dwell time for this case would be a function of the magnitude of the extended source. In this figure, A_4 and G_4 would be used for Y information while D_1 and D_7 would be used for X information.

4.7.9 USE OF FES TO TRACK BRIGHT STARS

The FES in track deflection mode may not be able to track stars whose magnitude is substantially greater than $+2m A_0 V$. If it is desired to track bright stars, FCM can be used in the same manner as depicted in section 4.7.8. The raster size and dwell times for this case are chosen as a function of the star magnitude. The only other consideration is the actual limitations of the instrument to accept light energy.

4.7.10 OPERATION OF THE FES IN A DEGRADED MODE

The FES over a period of time may degrade in sensitivity and certain functions within the FES may fail. If the sensitivity is degraded the FES will lose the ability to track dimmer stars. It is also a greater probability that the track deflection mode would fail rather than the search deflection mode. This is due to the greater complexity of circuitry used in the track deflection mode. This would mean that the tracker could not be used for control in primary mode. Because of the flexibility in FCM in the sense of dwell time and raster size, it can be used in combination with ground computers to continue the mission. Ground software and DMU formats which would allow for operations in FCM as a backup to track deflection mode for degraded operations must be developed. This FCM operation could also allow FES No. 2 to map and track very dim stars.

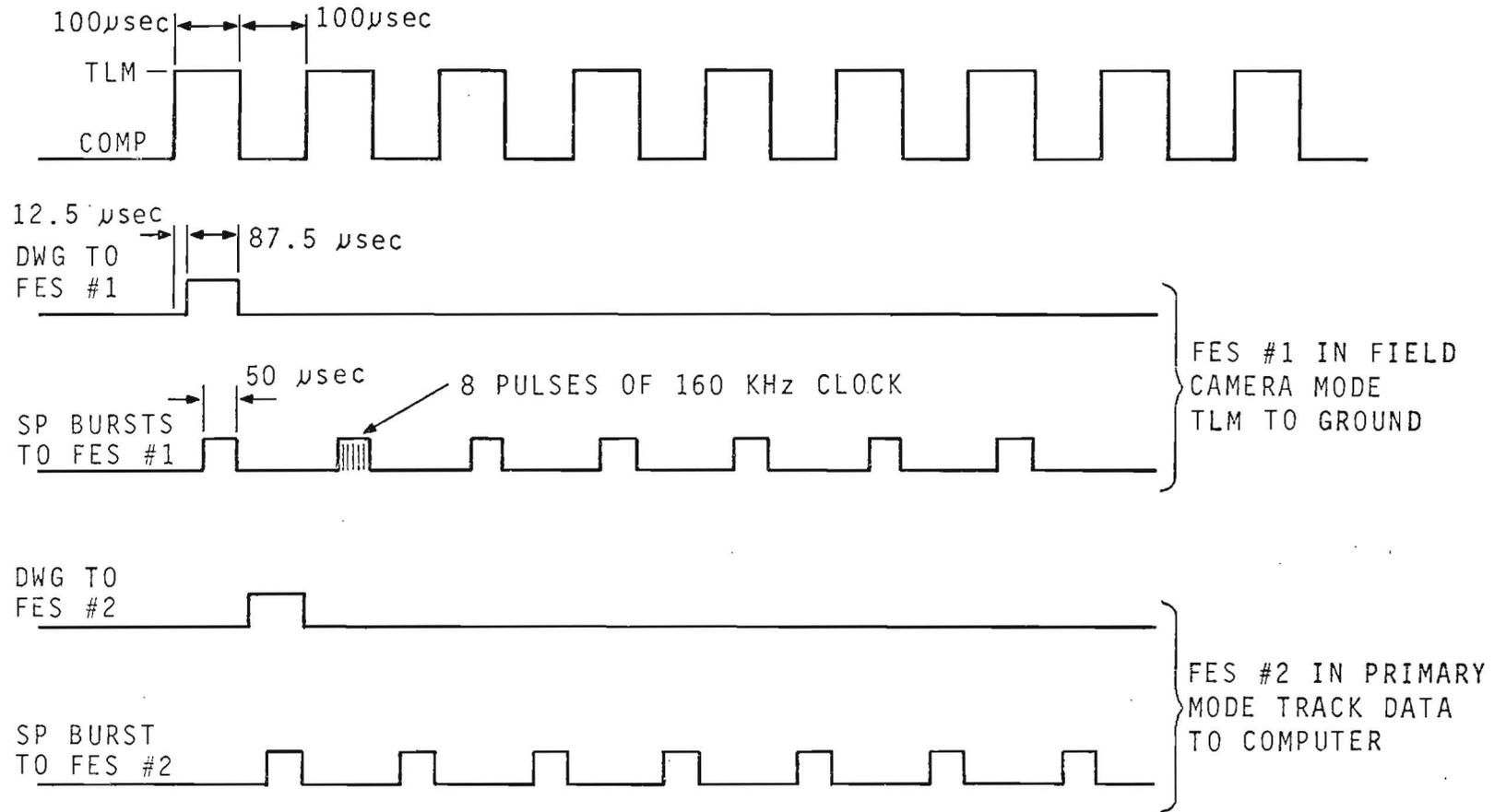
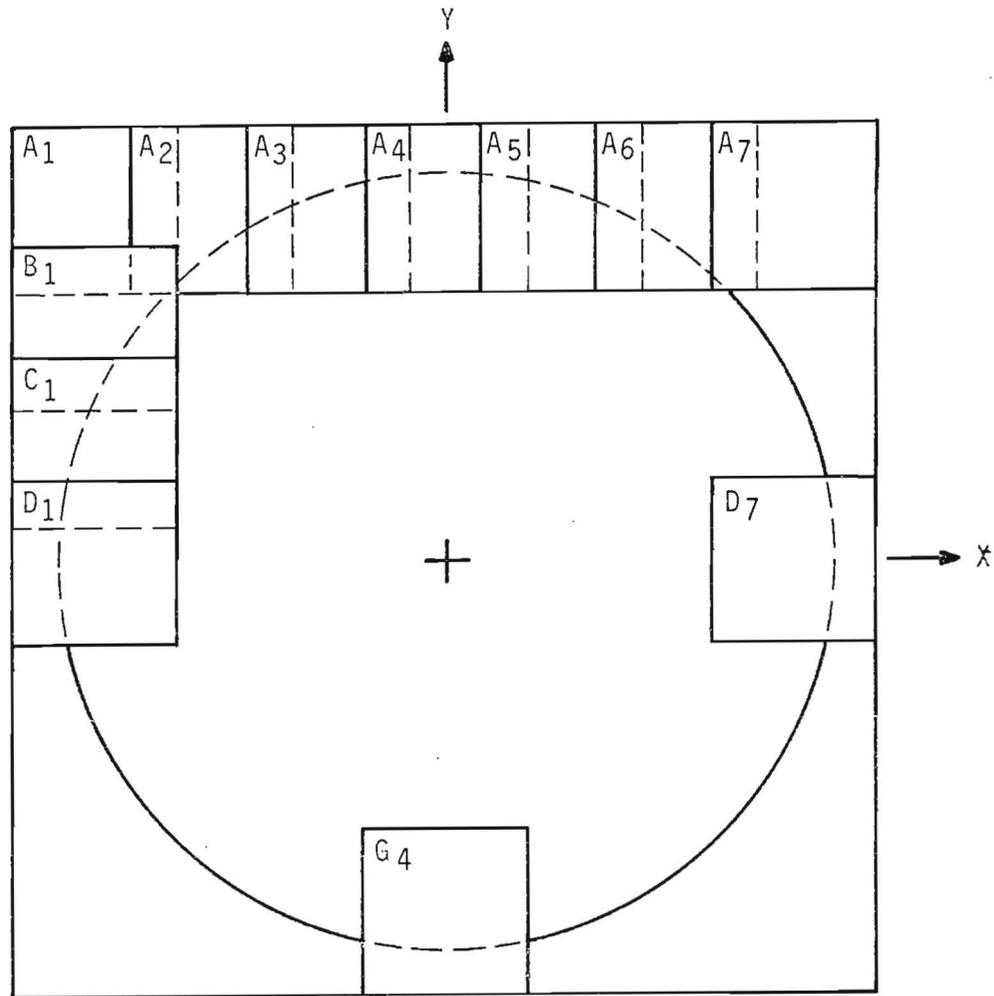


Figure 4-20. Dual FES Operation



A4, G4, & D1, D7 WOULD BE USED FOR CONTROL

Figure 4-21 Extended Source Tracking In Field Camera Mode

4.8 SUMMARY OF COMMANDS FOR SEARCH DEFLECTION AND TRACK DEFLECTION

Table 4-4 shows the proper configuration necessary for use in search deflection when used in field camera mode. It shows for both FES's the dwell time and threshold necessary to track particular magnitude stars. It also shows the dwell timing necessary for mapping stars up to the magnitudes shown.

Table 4-5 shows the UL/OL and TSR for both FES's necessary to track the magnitudes shown. In areas where both UL and OL are shown or where fast and slow track are shown, the probability of picking up that star is high in both cases.

Table 4-4. Command Configuration for Search Deflection

DWG Timing (ms)	Search Deflection (FCM) FES #1 TE = 1		Search Deflection (FCM) FES #1 TE = 0	
	THD	Star Magnitude (\geq)	DWG Timing (ms)	Star Magnitude (\geq)
3.2	8/9/10/11	8.31/9.31/10.31/11.31	3.2	11.31
6.4	8/9/10/11	9.06/10.06/11.06/12.06	6.4	12.06
12.8	8/9/10/11	9.82/10.82/11.82/12.82	12.8	12.82
25.6	8/9/10/11	10.57/11.57/12.57/13.57	25.6	13.57
51.2	8/9/10/11	11.32/12.32/13.32/14.32	51.2	14.32
102.4	8/9/10/11	12.08/13.08/14.08/15.08	102.4	15.08
	FES #2			
3.2	8/9/10/11	7.31/8.31/9.31/10.31	3.2	10.31
6.4	8/9/10/11	8.06/9.06/10.06/11.06	6.4	11.06
12.8	8/9/10/11	8.82/9.82/10.82/11.82	12.8	11.82
25.6	8/9/10/11	9.57/10.57/11.57/12.57	25.6	12.57
51.2	8/9/10/11	10.32/11.32/12.32/13.32	51.2	13.32
102.4	8/9/10/11	11.08/12.08/13.08/14.08	102.4	14.08

Table 4-5. Command Configuration for Track Deflection

Star Magnitude	Track Deflection FES #1		Track Deflection FES #2	
	UL/OL	TSR	UL/OL	TSR
+1	--	---	UL	Fast
+2	UL	Fast	UL	Fast
+3	UL	Fast	UL	Fast
+4	UL	Fast	UL	Fast
+5	UL	Fast	UL	Fast
+6	UL	Fast	UL/OL	Fast
+7	UL/OL	Fast	OL	Fast
+8	OL	Fast	OL	Fast
+9	OL	Fast	OL	Fast
+10	OL	Fast	OL	Fast
+11	OL	Fast	OL	Fast
+12	OL	Fast	OL	Slow/Fast
+13	OL	Slow/Fast	OL	Slow
+14	OL	Slow	--	--

Glossary:

- HR 2 = Hold Register 2, where Photon Event Count in C_T and Star Presence (SP) are stored.
- DMFF = Deflection Mode Flip-Flop. DMFF = Search $\overline{\text{DMFF}}$ = Track
- SPFF = Flag set during count period if C_T exceeds preset threshold.
SPFF = Star Presence $\overline{\text{SPFF}}$ = No Star
- SDC = Flag set by arrival of a Serial Digital Command during previous interval.
SDC = New Command $\overline{\text{SDC}}$ = Old Command
- CSC = Flag set by arrival of a Continue Search Command during previous interval.
CSC = Cmd Received $\overline{\text{CSC}}$ = No Command
- EOM = End of Measurement (X or Y) Track Deflection
- EOL = End of Line (X) - primarily Search Deflection
- EOF = End of Frame (Y) - primarily Search Deflection
- SMC = Flag set by arrival of an SDC containing a System Mode Change
SMC = Mode Change $\overline{\text{SMC}}$ = No Change
- F_2 = Flag set by P1 pulse if EOL or EOF condition exists. This flag is reset by P8 pulse.
- F_3 = Flag set by P6 pulse if EOL condition and a command envelope are present. This flag is reset by SDC (which occurs after command is completely loaded) and P7.
- HR 1 = Hold Register 1,
- EG = Error Generator - performs $\epsilon_i = K * \frac{C_R}{C_T}$ and $\sum \epsilon_i = E$
- C_T = Counter that counts photon events. Count represents magnitude.
- C_R = Reversible counter that indicates differential count between $+\Delta$ & $-\Delta$.

Glossary (cont):

S_7 = EOL

S_8 = EOF

S_9 = MX

S_{10} = MY = \overline{MX}

S_{11} = SMC · P

S_{12} = $\overline{S_1} \cdot \overline{SP} \cdot \overline{F_2} = \overline{\overline{S_1} \cdot \overline{SP} + F_2}$

S_{14} = $\overline{S_1} \cdot \overline{TE} \cdot \overline{SP} \cdot \overline{F_2} = \overline{S_1 + TE + SP + F_2}$

PM = Primary Mode

S&T = Search and Track Mode

FCM = Field Camera Mode

UL/OL = Underlap/Overlap

SM = System Mode