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SECTION 13.0 FINE GUIDANCE SENSOR

2/15/84

Sect. 13.4.8 Blazek's memo
not attached

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SECTION 13.1 INTRODUCTION

The purpose of this document is to summmarize the operation of the fine guidance sensors (FGSs), their use in attitude initialization and the algorithms to be used for attitude determination with FGS data. The primary function of the three FGSs is to operate in conjunction with the support system module (SSM) pointing control system (PCS) to provide on board fine pointing control and stabilization. Two FGSs are actively used; one FGS is a standby. The secondary function is the operation of the standby FGS in the astrometry mode.

The intent of this document is to provide a sufficiently detailed design characteristics definition of the FGS to support implementation of PASS requirements related to the FGS.

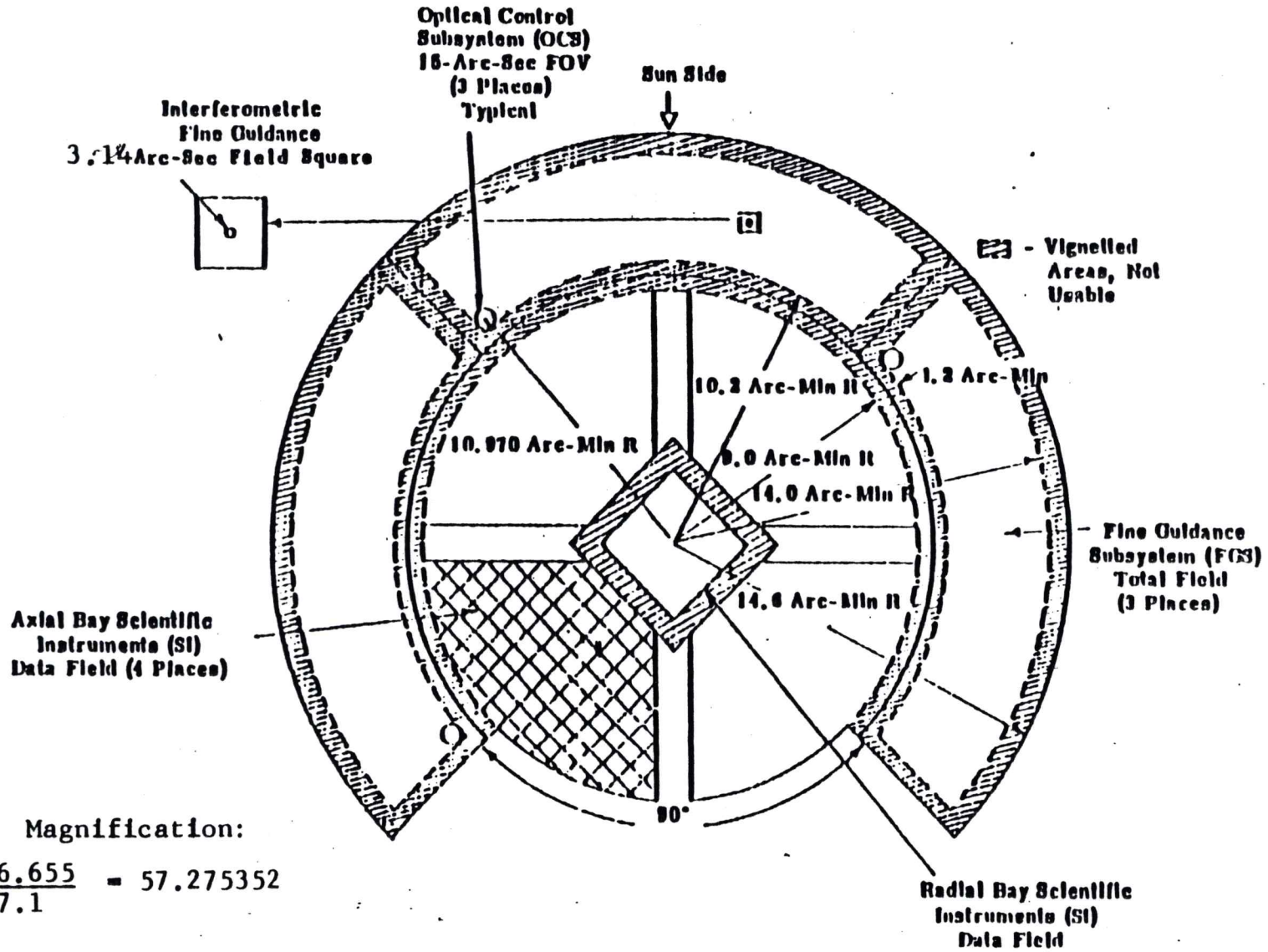
SECTION 13.2 GENERAL OPERATION

The FGS provides guide star positional information in its total field of view (TFOV) by two methods: 1) a coarse measurement accurate to ±0.1 arc-second, root mean square (rms), at 0.025 second update intervals per axis (Reference 1, Sect. 4.2.2) and 2) a fine measurement. Although the fine measurement accuracy required is omitted in Reference 1, Section 4.2.3, it is assumed to be on the order of 0.0028 arc-seconds, rms, which is the error allocated to the FGS for image stability (Reference 1, Sect. 5.1). The TFOV of an FGS is one-quarter of the outer 4 arc-minute annulus of the optical telescope assembly (OTA) field of view (FOV) (Fig.13-1). The unvignetted FOV covers 72.2 square arc-minutes. The TFOV is scanned by the instantaneous field of view (IFOV), which is a 3.14-by-3.14 arc-second-square reticle. Two star selectors position the IFOV, provide coarse measurements from their readouts and reorient the incoming light beam so that the emergent light beam falls on an interferometric device called the koesters prism. Photometric measurements of the beams emergent from the koesters prism provide the fine measurements of displacements from the null position. Fig. 13-2 shows a diagram of the FGS optical system.

13.2.1 STAR SELECTOR~~S~~ operation

The two star selectors position the IFOV, orient the light from the IFOV onto the base of the Koesters prisms, and provide a method of determining the star observation vector. Fig.13-3 illustrates the action of the two star selectors in object space. Each star selector deflects the incoming light beam by 7.1 arc-minutes in object space. The magnification of the FGS is 57.275. The deflection is 6.777 degrees in FGS pupil space. (Object space is defined by the projection on the celestial sphere. Pupil space is collimated space at which an image of the entrance pupil is located.) The direction of the deflection is determined by the amount of rotation of the star selector. An object in the IFOV lies on a circle of radius 7.1 arc-minutes centered on the image, I_B (circle B in Fig. 13-3.) The first star selector images the IFOV onto I_B. I_B lies on a circle of radius 7.1 arc-minutes (circle A in Fig. 13-3) from the OTA optical axis. I_B is imaged by the second star selector onto the OTA optical axis. The position of the object in the IFOV on circle B and its image, I_B, on circle A are defined by the star selector rotations θ_B and θ_A. θ_A and θ_B are positive rotations about the +T1 axis from the +T2 axis (see Fig. 13-3). The position of the IFOV is therefore described by the values (θ_A, θ_B) or can be converted into spherical polar coordinates (R, ϕ) centered about the optical axis.

Conversion of angular displacements in object space to angular displacements in FGS pupil space requires correction not only for magnification, or plate scale, as mentioned above, but also for optical field angle distortion. Optical field angle distortion is caused both by the design configuration of the optics and by manufacturing errors. FGS design distortion is described in



Magnification:

$$\frac{406.655}{7.1} = 57.275352$$

Figure 13-1 Space Telescope f/24 Focal Plane (Reference 2)

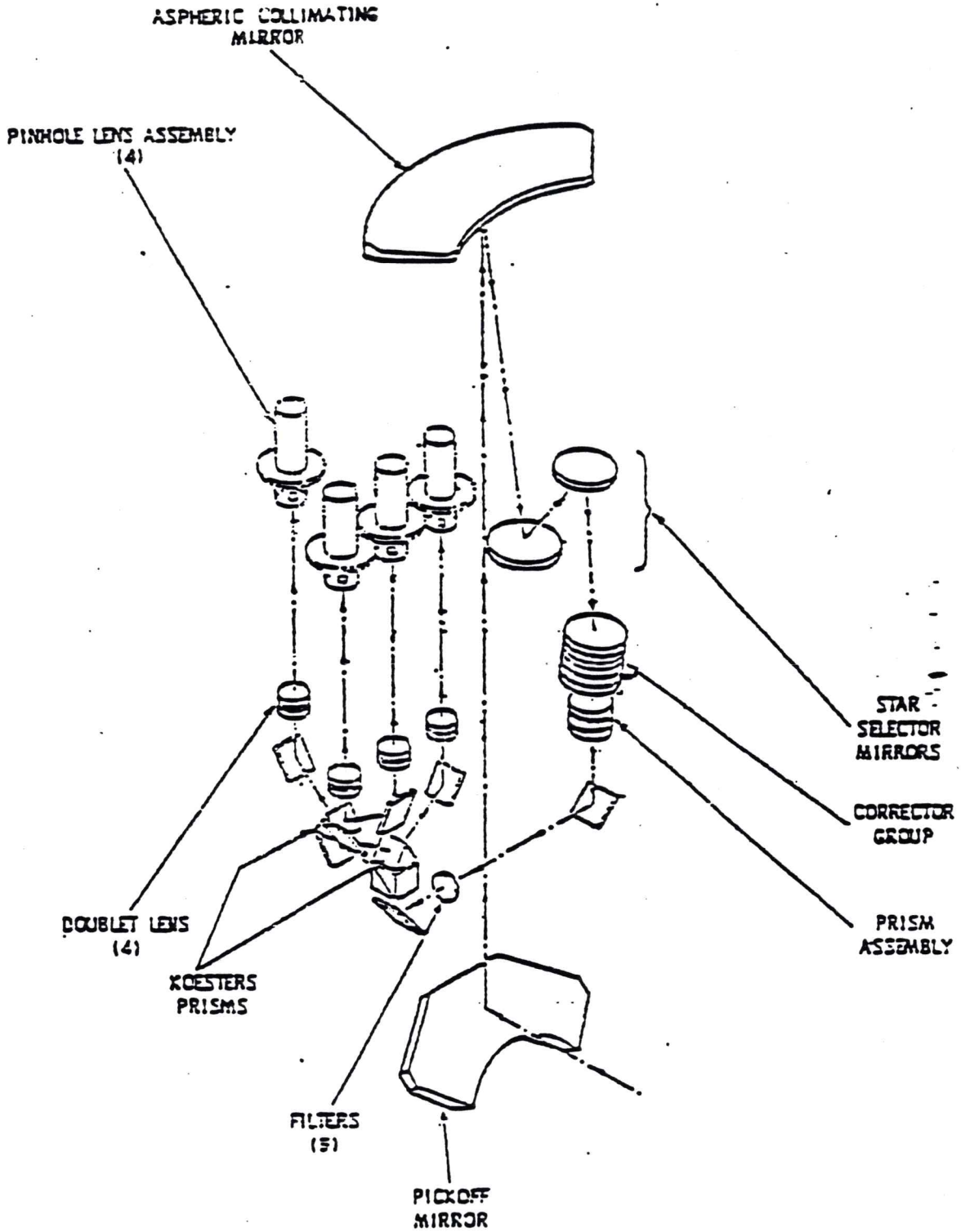
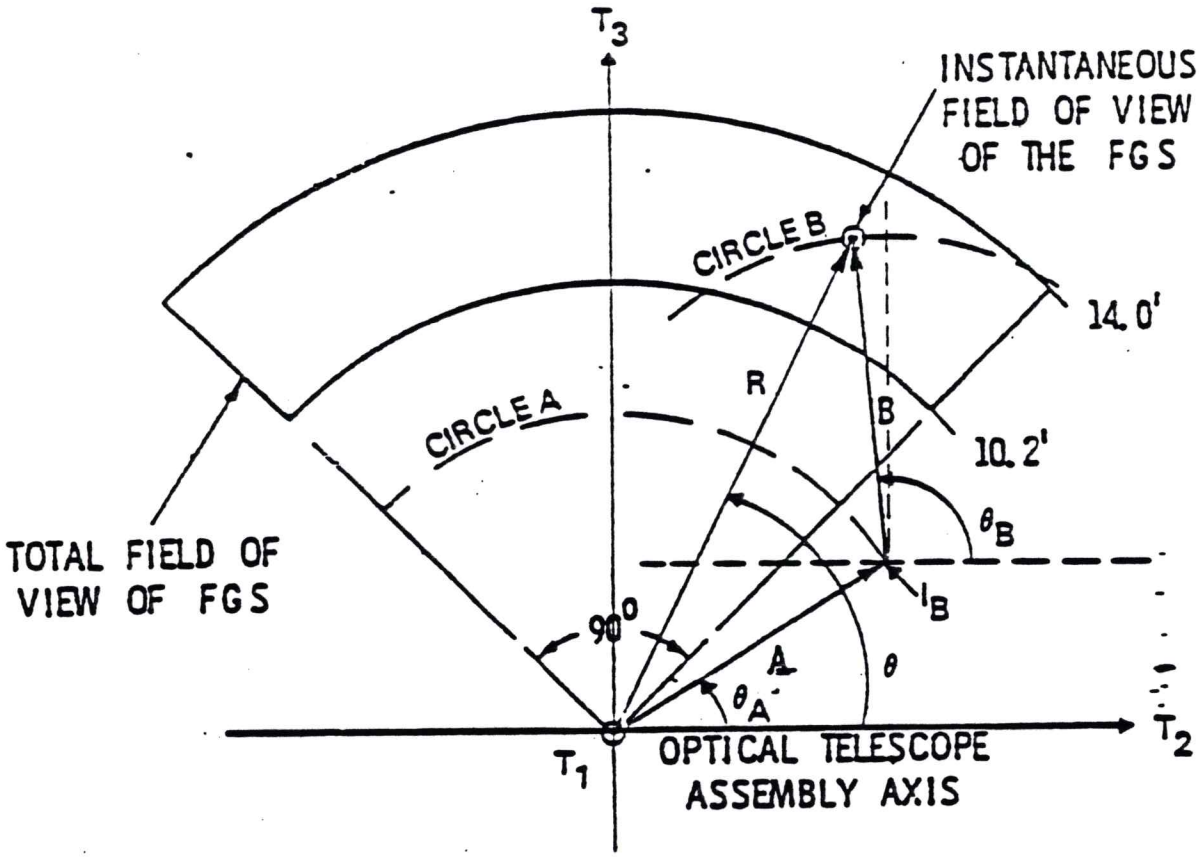


Figure 13-2 FGS Optical System (Reference 3)



	A	B
OBJECT SPACE	7.1'	7.1'
PUPIL SPACE	6.777°	6.777°

Figure 13-3 Positioning of IFOV of TFOV by Two Star Selector Assemblies (Adapted From Reference 2)

Appendix Section 13.4.1.

After telescope optical wavefront errors are minimized in orbit, it will be necessary to conduct calibration operations to establish optical field angle distortion corrections and plate scale values required for angle conversions between object space and FGS pupil space. These calibration operations and their ground software requirements are described in Appendix Sections 13.4.3 and 13.4.4.

13.2.2 KOESTERS PRISM Operation

A refinement of the positional information from the two star selectors is achieved by the signal from a koesters prism. The signal from a koesters prism is a measure of the tilt of the incident wavefront from the null position in one direction parallel to the base of the prism. Two prisms are used to measure the offset in orthogonal directions.

A beam splitter produces two separate beams from the beam emergent from the star selectors. Each beam is directed toward a koesters prism. The two koesters prisms are rotated so that they are orthogonal to each other. Fig.13-4 is a schematic of the beam splitter and the two koesters prisms. Fig. 13-5 illustrates the operation of a koesters prism interferometer.

The koesters prism contains a 50/50 beam splitter along its central interface. A wavefront incident on the base of the prism is reflected internally by one side of the prism. At the beam splitter, a portion of the beam is transmitted; the remainder is reflected. At the beam splitter surface, there is a quarter wave phase retardation of the transmitted beams. The primed letters represent the transmitted wavefront and the double-primed letters the reflected wavefront. At null (no wavefront tilt), the transmitted wavefront exhibits equal retardation in both exit faces. Thus, both exit faces will have uniform and equal intensity.

When a $\lambda/4$ tilt is present, as shown in Part b of Fig.13-5, a' is advanced by $\lambda/8$, and c" is retarded by $\lambda/8$. Thus, constructive interference will occur at the upper edge of the left-hand face. The left-hand face will have a gradual increase in intensity from the bottom to the top. At the right-hand face, c' will be retarded by $\lambda/8$, and a" will be advanced by $\lambda/8$. Thus, destructive interference will occur at the upper edge of the right-hand face. The right-hand face will have a gradual decrease in intensity from the bottom to the top. Thus, with the tilt as shown in Fig.13-5, the total integrated illumination of the left-hand face will be greater than on the right-hand face. (Note: All angles in the Fig. 13-5 are in FGS pupil space.) The intensity of the total integrated illumination from one side of the interferometer is measured by a photomultiplier tube (PMT). Let A be the intensity from PMT A; B be the intensity from PMT B. The difference A - B measures the average phase difference between the two portions of the incident beam. It is an indirect

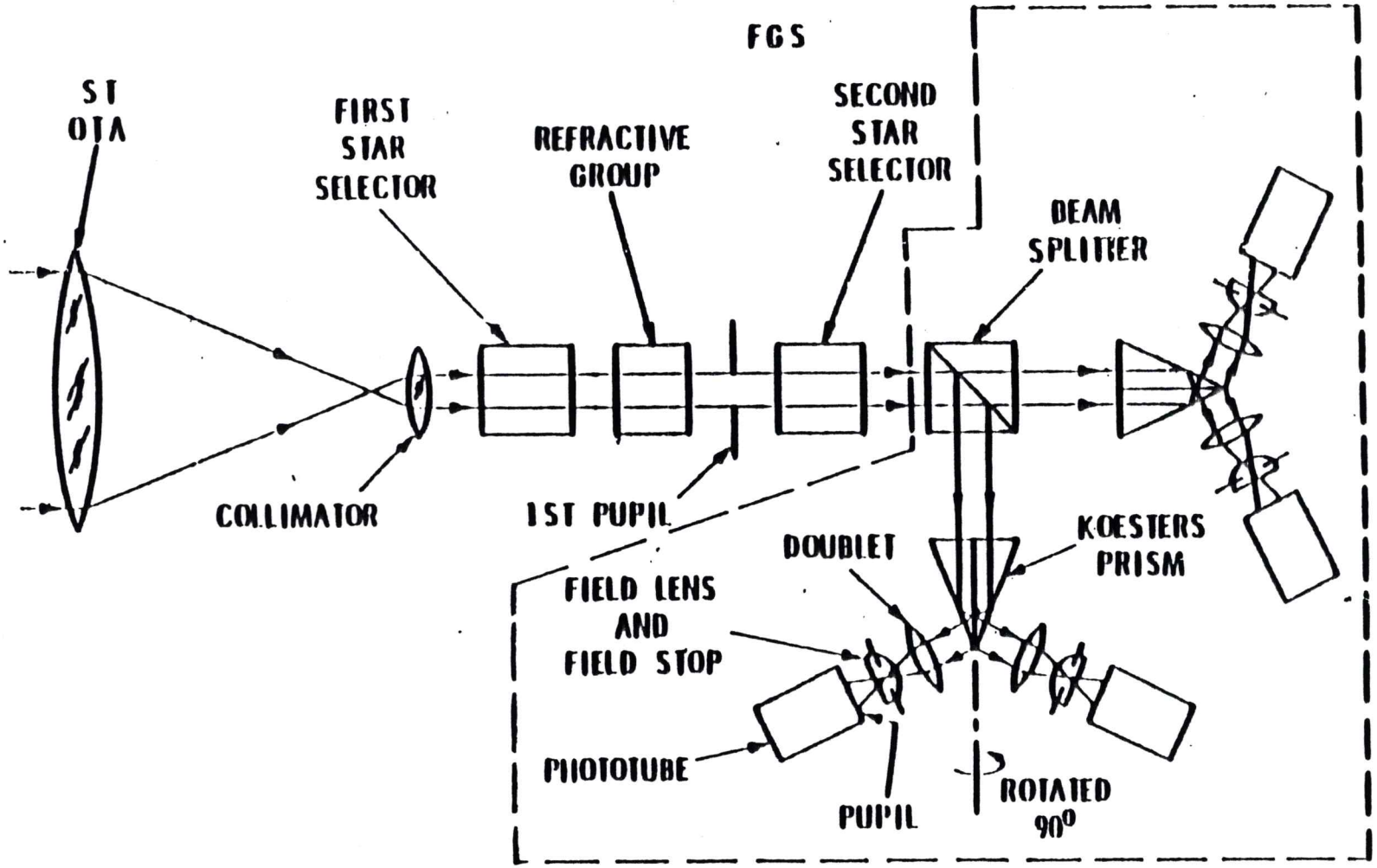


Figure 13-4 Simplified FGS Optical Schematic, BEAM SPLITTER & KOESTERS PRISM (Reference 2)

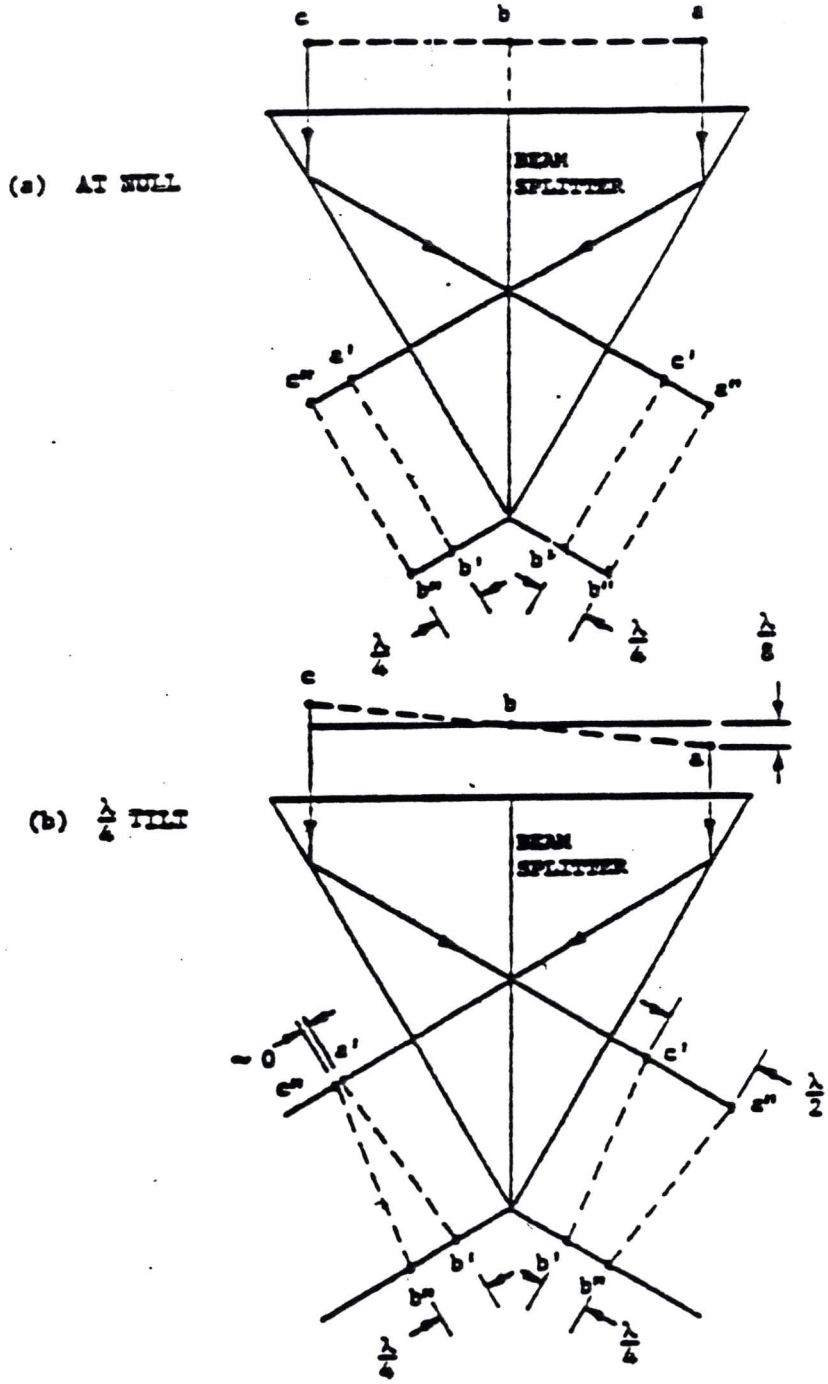


Figure 13-5 Köester's Prism Interferometer (Reference 2)

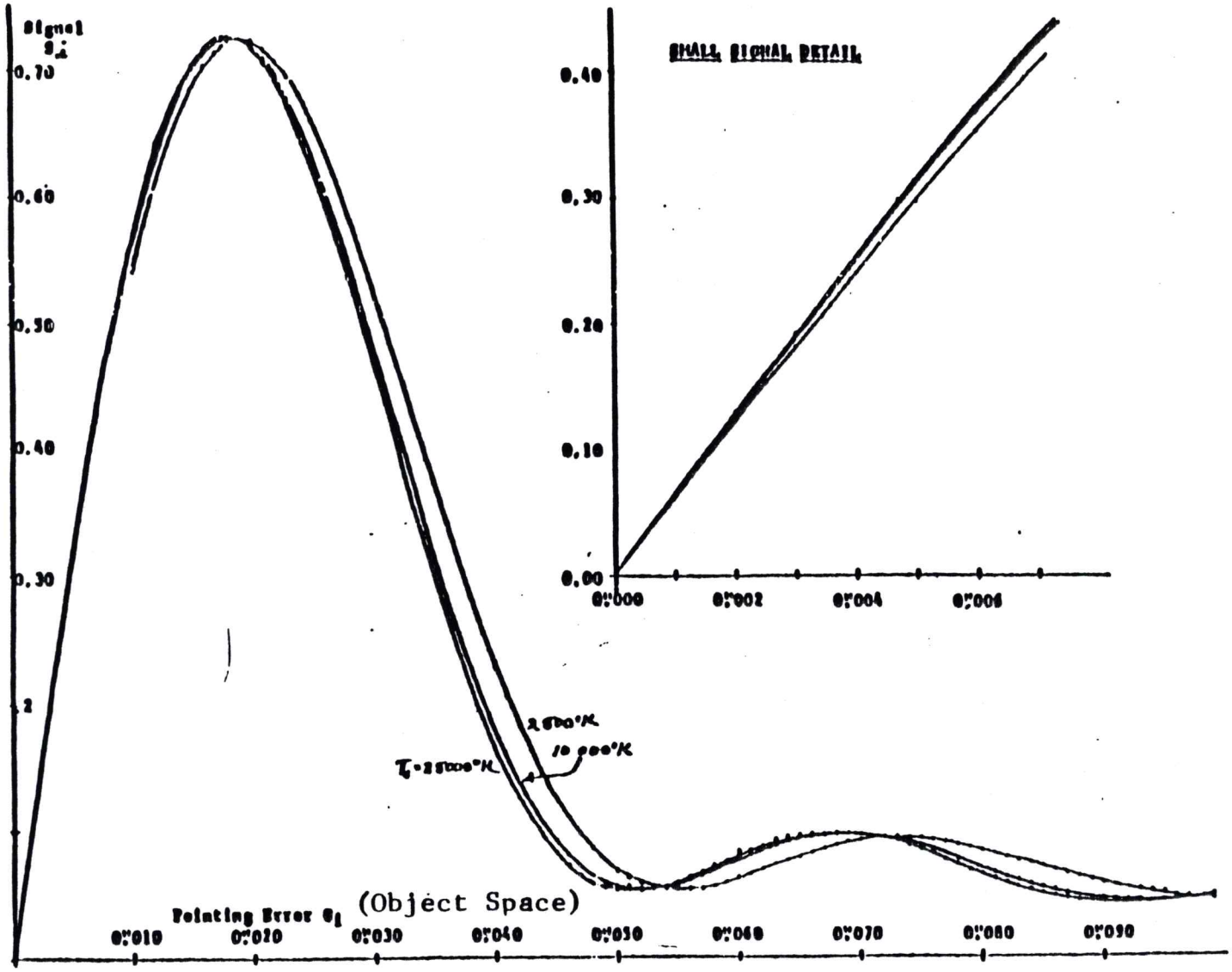


Figure 13-6 Polychromatic Interferometer Transfer Function (Reference 4)

measure of the angle of incidence. The sum A + B equals the total energy flux (less absorptive and scattering losses) incident on the koesters prism and is used to normalize the difference signal. Thus, the measure of the pointing error in the "i"th direction is

$$S_i = \frac{A_i - B_i}{(A_i + B_i) - k_4}$$

where k is a constant that compensates for the PMT dark current. Fig. 13-6 is a plot of the signal, S , as a function of pointing error for incident radiation for three blackbody distributions. The function is antisymmetric about the null. The transfer function is required to be linear within ± 5 per cent (Ref. 1, Sect. 4.2.1). The normalized and linearized fine error signal (pointing error) is determined from the transfer function by the relation

$$\theta_i = k_0 + k_1 S_i (1 + k_3 S_i^2)$$

where θ = pointing error in the ith direction (i = x,y) and k_0, k_1, k_3 = calibration constants.

13.2.3 FINE GUIDANCE ELECTRONICS operation

A functional block diagram of the FGE, showing the interrelationships of the various sections, is shown in Fig. 13-7. The function of the unit is to receive command signals, establish configuration and generate control signals for the FGS Assembly and the Servo Unit. The FGE processes data generated by the FGS Assembly and the Servo Unit and makes it available at the data output.

The major unit power and configuration control is performed in the command relay section which provides four basic functions.

- o Selection of one of the two redundant power bus interfaces
- o Power in-rush control
- o Selection of one of two DIMs
- o Power supply on/off control

The FGE's four modes of operation are Start Up, Shut Down, SSM Control, and Search & Track .

13.2.3.1 MODES

13.2.3.1.1 START UP MODE

A flow diagram is shown in Fig. 13-8. While in the configuration sequence, the FGE accepts the commands that select Power Bus 1 or 2 and DIM 1 or 2.

13.2.3.1.2 SHUT DOWN MODE

A flow diagram is shown in Fig. 13-9. This mode will consist of responses to a Shut Down Command, a High Voltage (HV) Off Command

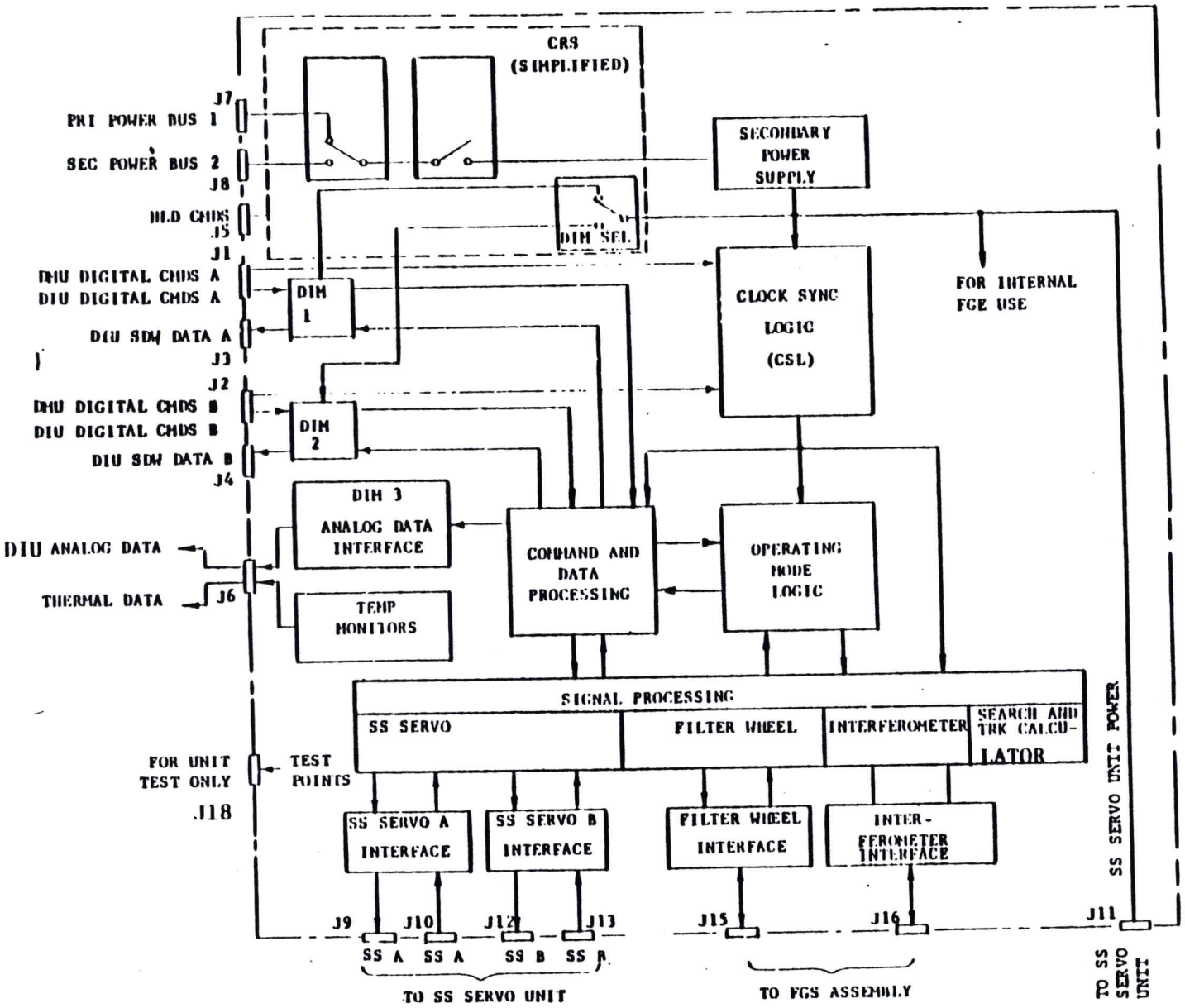


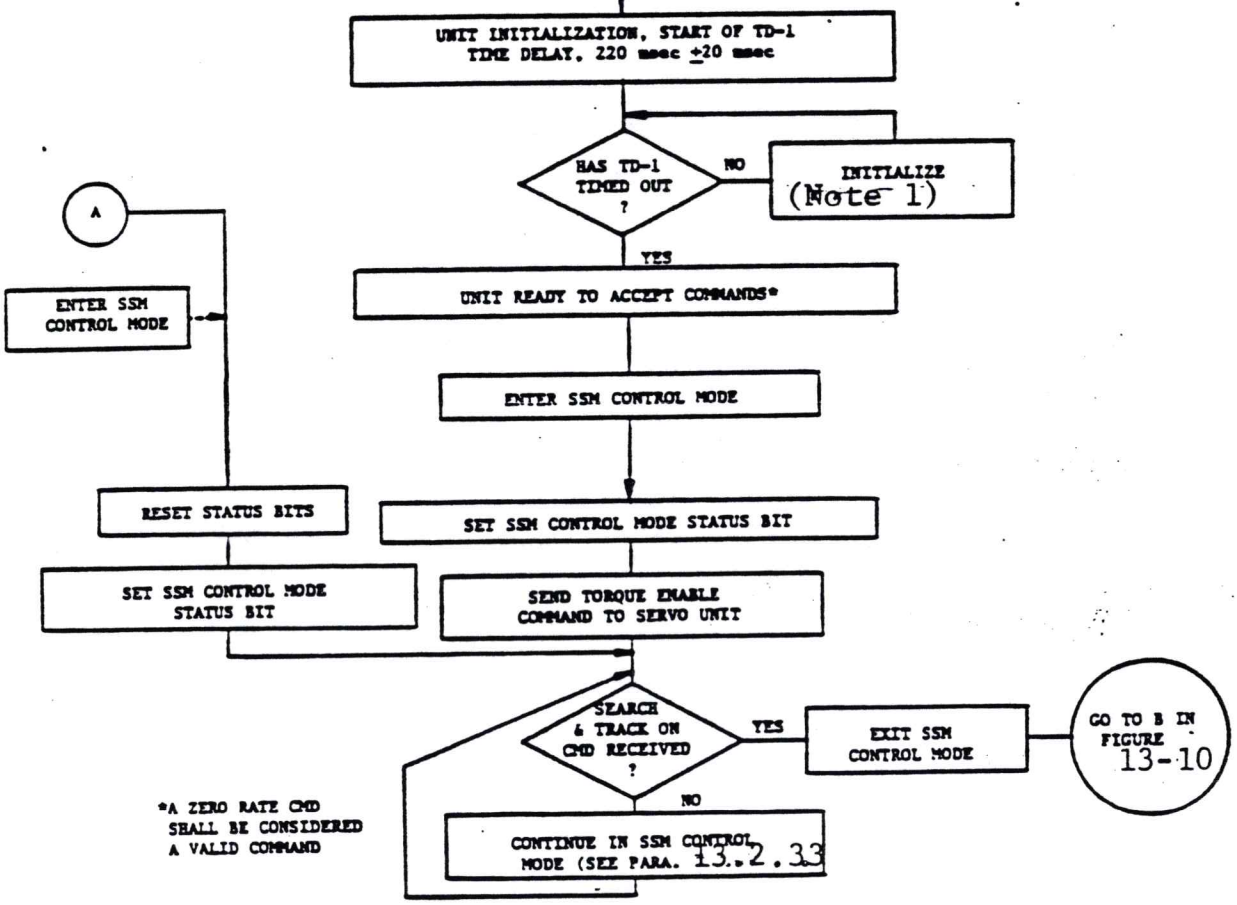
Figure 13-7 FGE Functional Block Diagram

Configuration Sequence:

Power Supply Disabled
In-Rush Resistor Unshunted
Power Bus Select (Prior knowledge of which bus is/will be active is assumed)
DIMSelect
In-Rush Resistor Shunted

Power Turn-On Sequence:

Power Supply Enable



Note 1: The start of time delay, TD-1 shall be measured from the start of power turn-on. The start of power turn-on is defined as the leading edge of the HLD Command pulse applied to enable its power supply.

Figure 13-8 Start Up Mode, Flow Diagram

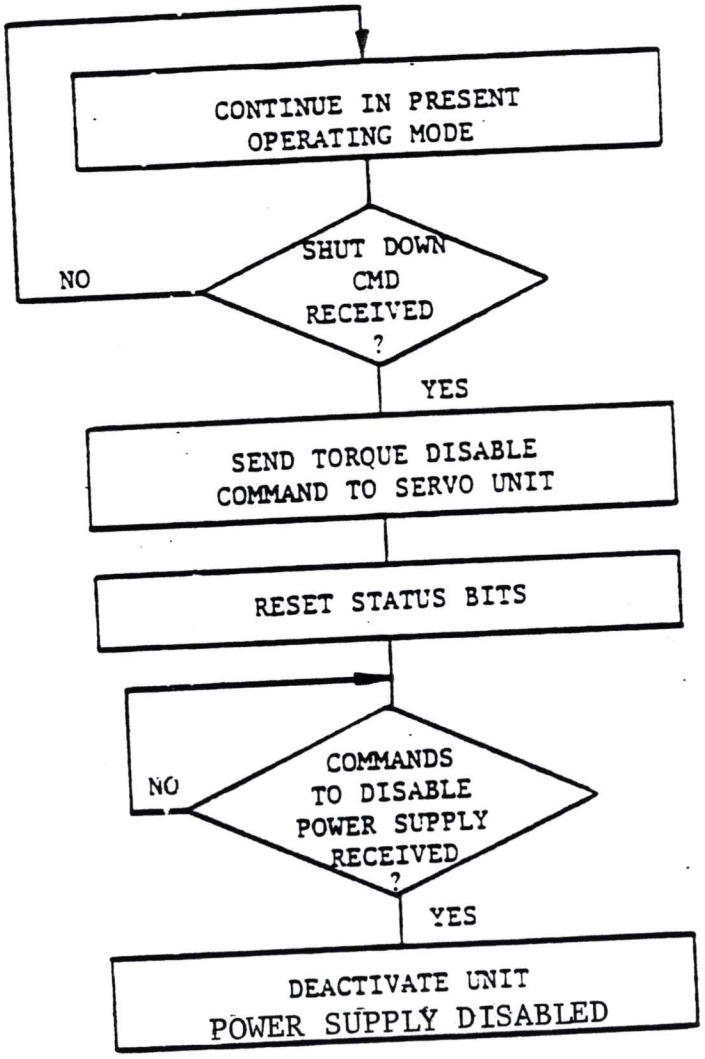


Figure 13-9 Shut Down Mode, Flow Diagram

and a Power Supply Disable Command. The Shut Down Command and HV Off Command can be received in either order.

13.2.3.1.3 SSM CONTROL MODE

Upon entering the SSM Control Mode, the SSM Control Mode Status bit shall be set; all other status bits shall be reset. The flag bits shall not be affected. The FGE enters the SSM Control Mode following start up and remains in this mode if no Search & Track On Command is received; the FGE also enters the SSM Control Mode from the Search & Track Mode whenever a Search & Track Off Command is received.

The FGE's major function in the SSM Control Mode is to receive, format and transmit signals between the DIU and the FGS Assembly and Servo Unit.

In the SSM Control Mode, the SSM sends to the FGS conditioning commands for the star magnitude window (upper and lower limits), search radius limit, fine error averaging time, filter position, and required on control bits. The SSM then orients the ST to place the guide star in the proper location in the FOV of the FGS. Then the SSM sends star selector rate commands to position the star selectors at the start of the search position (search center.) After positioning the star selector, the SSM sends a Search Track On command.

13.2.3.1.4 SEARCH & TRACK MODE

The FGE will enter the Search & Track Mode upon receipt of the Search & Track On Command. The Search and Track is divided into the following operations:

a)	Search	Flow Diagram, Fig. 13-10
b)	Coarse Track	Flow Diagram, Fig. 13-11
c)	Resume Search	Flow Diagram, Fig. 13-12
d)	Fine Lock	Flow Diagram, Fig. 13-13
e)	Stop	Flow Diagram, Fig. 13-14
f)	LOS Scan	Flow Diagram, Fig. 13-15

A table of parameters associated with the computational requirements is shown in Table 13-1.

Figures 13-16a through 13-16f illustrate the action of the FGS through search, coarse track and fine lock modes.

13.2.3.1.4.1 SEARCH

During Search, the FGE computes rate commands for the A and B Servos causing them to generate a spiral scan pattern. The rate commands continue to be issued for this purpose, until

1) The scan parameter, ρ, exceeds the commanded search radius limit, or

Fig. 13-10
Search mode, Flow Diagram

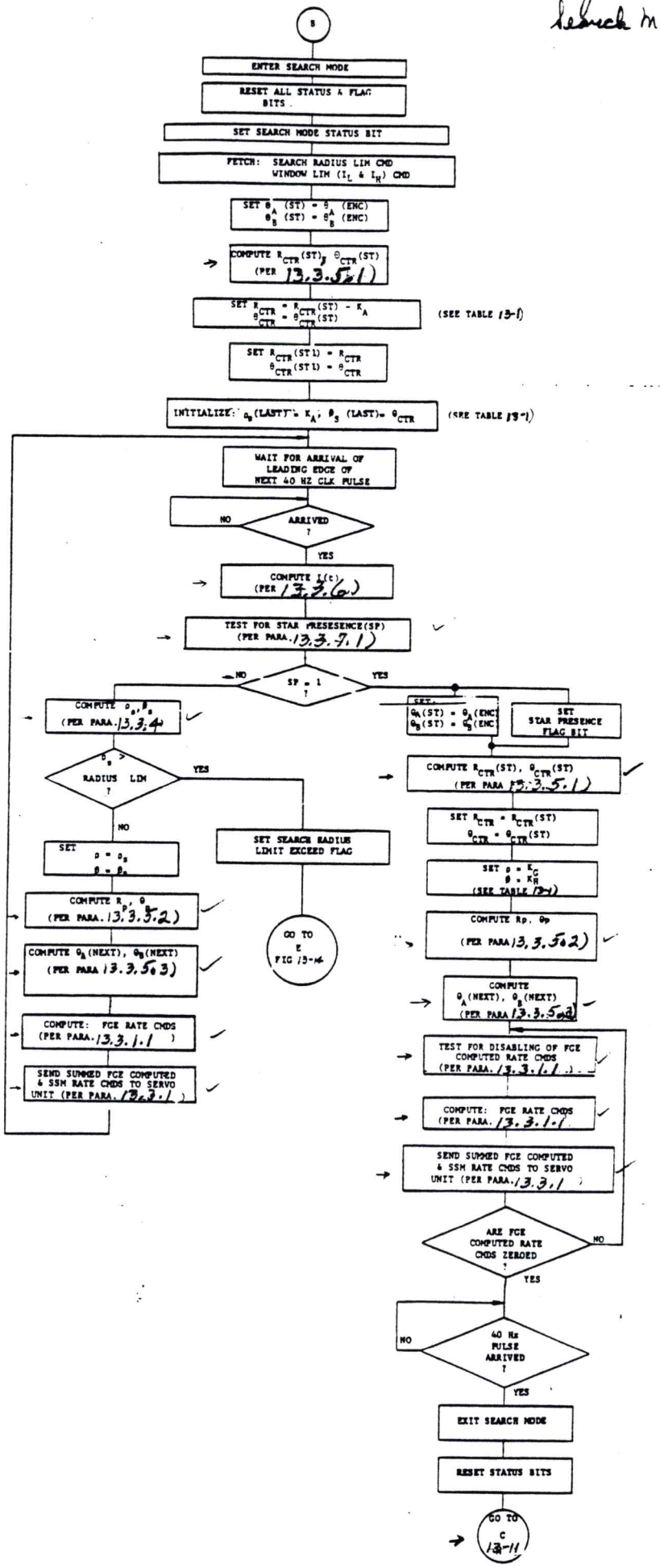


Fig. 13-16
Coarse Track mode
Sheet 1 of 2

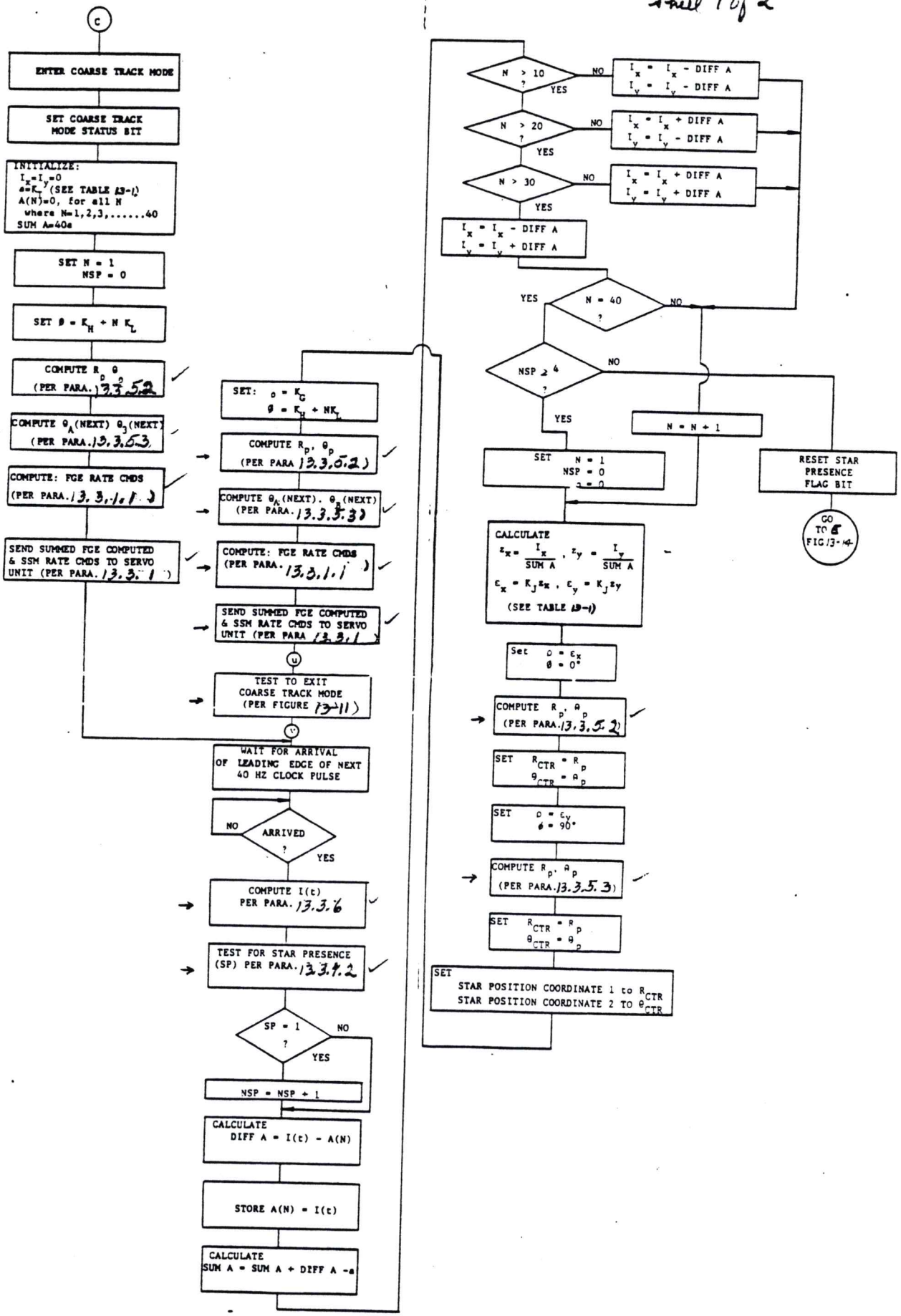
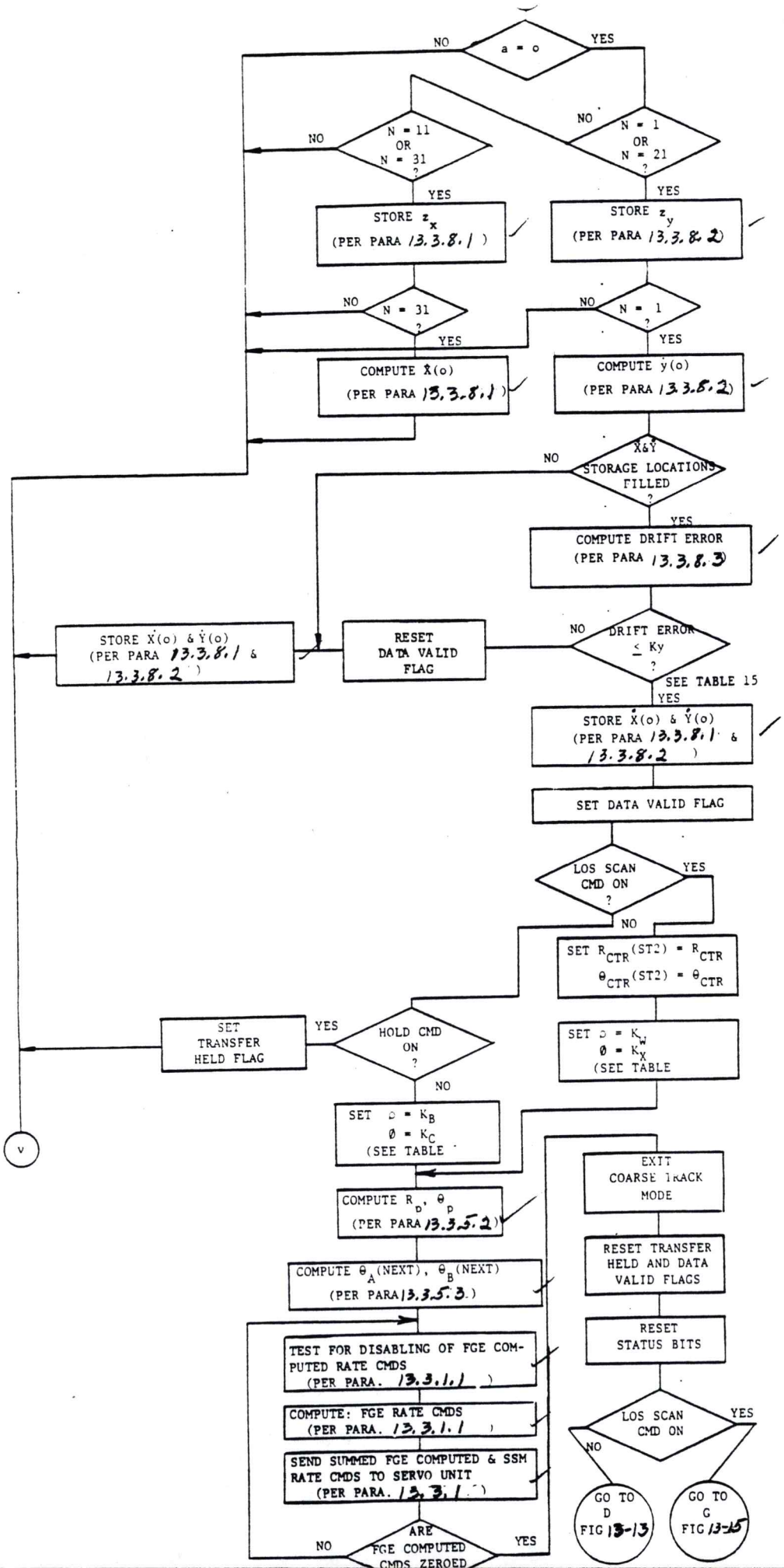
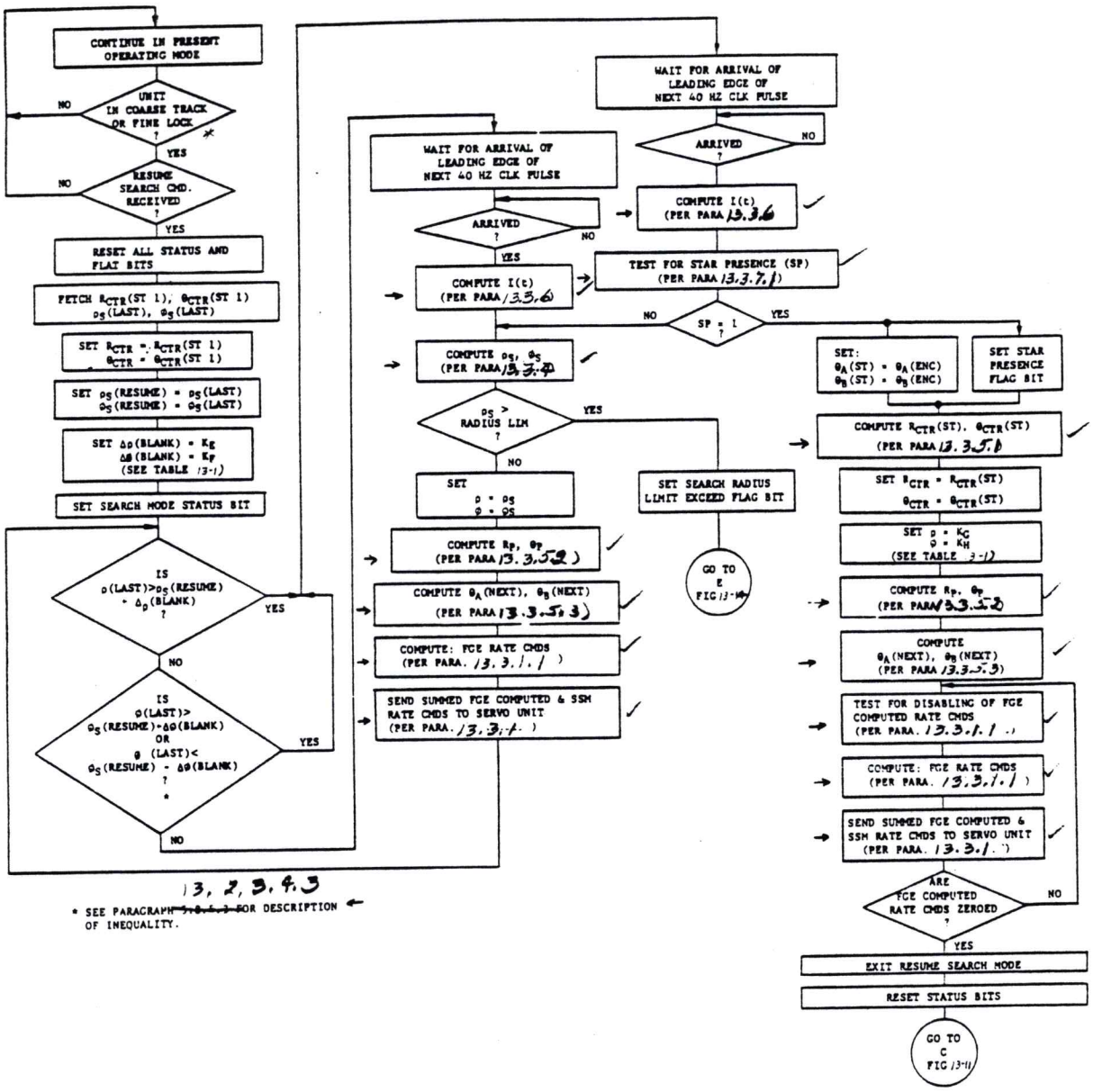


Fig 13-11
Coarse Track Mode
Sheet 2 of 2



(Add)
*"or STOP mode"?

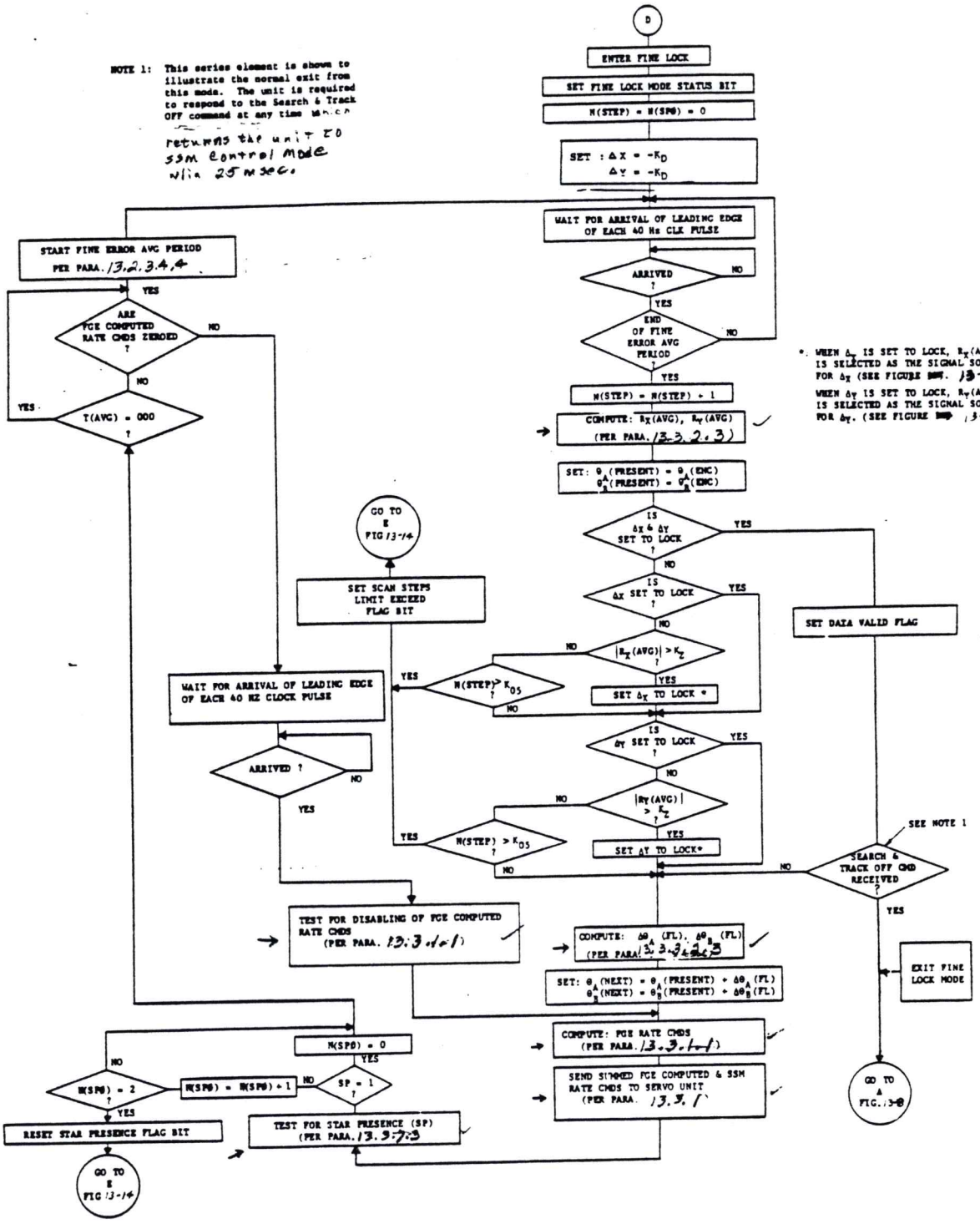
Fig. 13-12
Resume Search Mode



13.2.3.4.3

* SEE PARAGRAPH ~~5.8.5.3~~ FOR DESCRIPTION OF INEQUALITY.

Fig. 13-13
Fine Lock Mode



NOTE 1: This series element is shown to illustrate the normal exit from this mode. The unit is required to respond to the Search & Track OFF command at any time which returns the unit to SSM control mode w/in 25 msec.

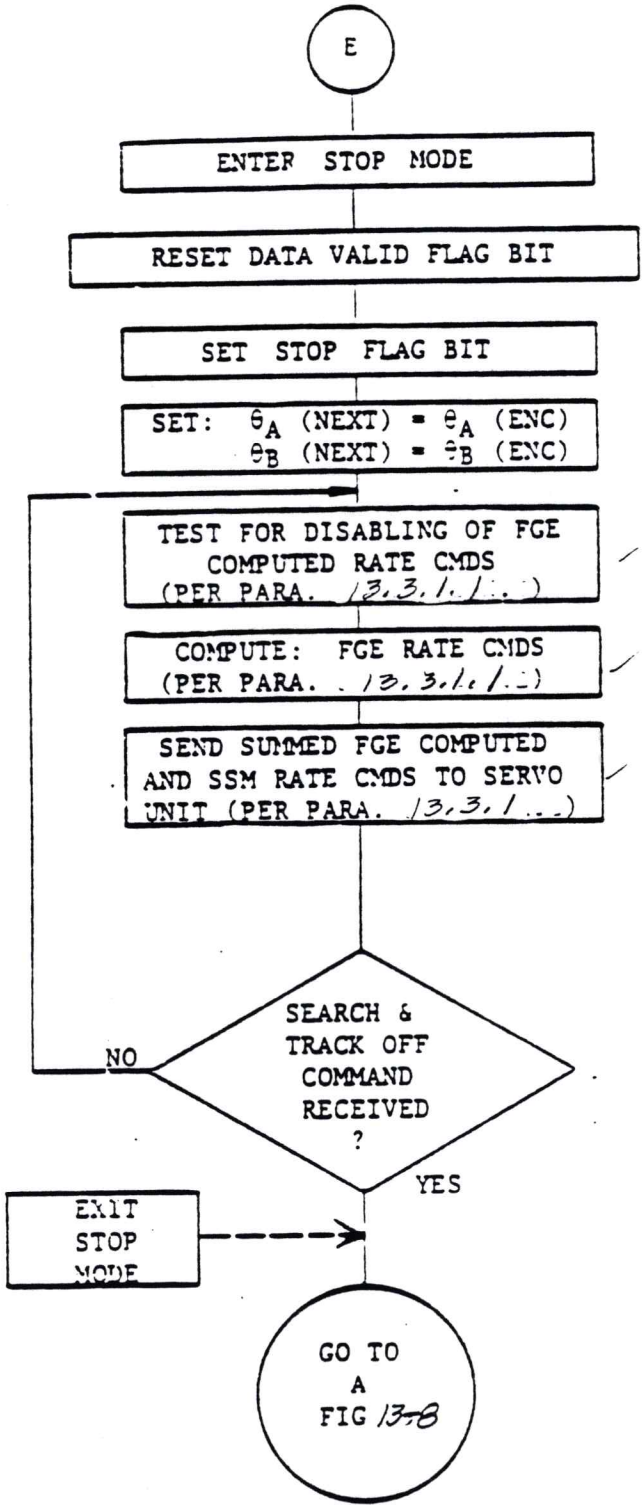


Figure 13-14 Stop Mode, Flow Diagram

Fig 13-15
LOS Scan Mode

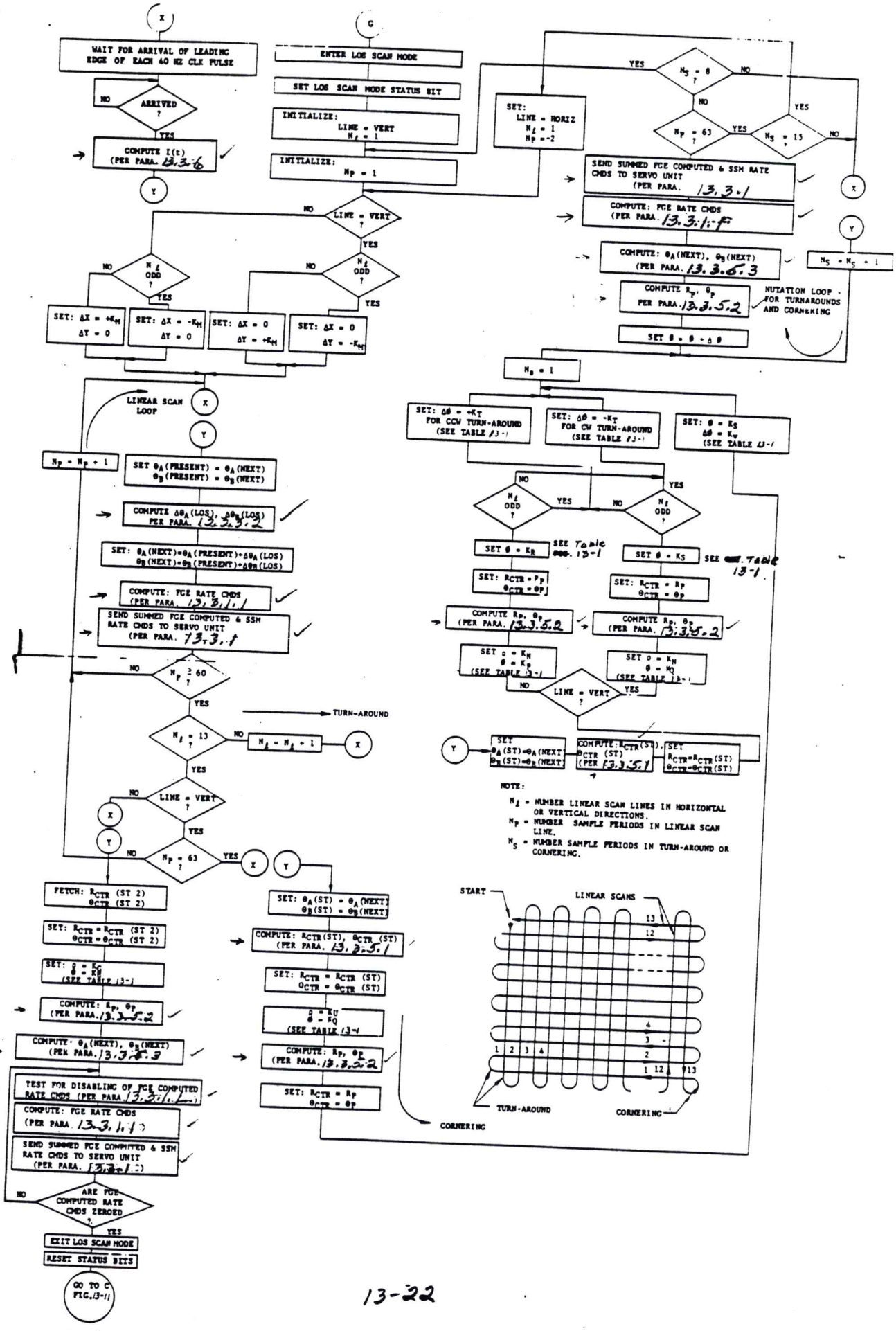


TABLE 13-1

TABLE OF PARAMETERS

(K_*) PARAMETER NAME	APPLIED TO	$(K_*)_I$ INITIAL VALUE (LSB UNITS)	$(K_*)_F$ FIXED VALUE (LSB UNITS)	LSB WEIGHT (ENG. UNITS/LSB)	$(K_*)_u$ UP LINK MODIFIER (See Note 1)	MODE	PURPOSE
K_A	R_{CTR} & $\rho S(LAST)$	1000	1000	0.001 arc-min	SDW 1-7	Search	Sets inner spiral radius at start of search.
K_B	ρ	566	566	0.001 arc-min	SDW 3-0	Coarse Track	Establishes position for start of Fine Lock.
K_C	ϕ	131,068	N/A	1.236 arc-sec	None	Coarse Track	Establishes position for start of Fine Lock.
K_D	$\Delta x, \Delta y$	113	113	80×10^{-6} arc-min	SDW 3-1	Fine Lock	Establishes size of linear scan steps.
K_E	$\Delta\rho$(BLANK)	16,384	16,384	0.001 arc-min	SDW 3-6	Resume Search	Establishes radial distance of blanking segment.
K_F	$\Delta\phi$(BLANK)	32,768	32,768	1.236 arc-sec	SDW 3-7	Resume Search	Establishes angular distance of blanking segment.
K_G	ρ	-1,546	-1,546	.001 arc-min	SDW 2-0	Search & LOS Scan	Establishes Coarse Track radius of nutation.
K_H	ϕ	0	N/A	1.236 arc-sec	None	Search, Coarse Trk & LOS Scan	Establishes position for start of each Coarse Track nutation cycle.
K_I	a	2^{14}	N/A	1 PMT Count	None	Coarse Track	Affects gain of position error computation during first nutation cycle.
K_J	I_x, I_y	20	20	0.001 arc-min	SDW 2-1	Coarse Track	Sets Coarse Track gain (i.e., scale factor for star pos. errors, ϵ_x and ϵ_y)
K_L	$\Delta\phi$	26,214	N/A	1.236 arc-sec	None	Coarse Track	Establishes size of steps during nutation cycles.
K_M	$\Delta x, \Delta y$	1,248	1,248	80×10^{-6} arc-min	SDW 3-4	LOS Scan	Establishes size of linear scan steps.

NOTE 1: The Uplink Modifiers, $(K_*)_u$ are defined in Paragraph 13-3-9 and Table 13-3

TABLE 13-1

TABLE OF PARAMETERS (Continued)

(K_A) PARAMETER NAME	APPLIED TO	$(K_A)_I$ INITIAL VALUE (LSB UNITS)	$(K_A)_F$ FIXED VALUE (LSB UNITS)	LSB WEIGHT (ENG UNITS/LSB)	$(K_A)_U$ UP LINK MODIFIER (See Note 1)	MODE	PURPOSE
K_N	ρ	250	250	0.001 arc-min	SDW 3-5	LOS Scan	Sets spacing of LOS Scan lines (i.e. establish center and radius of turn-around).
K_P	∅	262,144	N/A	1.236 arc-sec	None	LOS Scan	Establishes center for turn-around for horizontal scan lines.
K_Q	∅	0	N/A	1.236 arc-sec	None	LOS Scan	Establishes center for turn-around for vertical scan lines and center for cornering.
K_R	∅	786,432	N/A	1.236 arc-sec	None	LOS Scan	Establishes angle for start of nutation for turn-around (horizontal scan lines only).
K_S	∅	524,288	N/A	1.236 arc-sec	None	LOS Scan	Establishes angle for start of nutation for turn-around (vertical scan lines only) and for cornering.
K_T	Δ∅	65,536	N/A	1.236 arc-sec	None	LOS Scan	Establishes size of nutation steps for turn-around
K_U	ρ	300	N/A	0.001 arc min	None	LOS Scan	Establishes center of cornering and radius of nutation for cornering.
K_V	Δ∅	52429	N/A	1.236 arc-sec	None	LOS Scan	Establishes size of nutation steps for cornering.
K_W	ρ	4243	N/A	0.001 arc-min	None	Coarse Track	Establishes position for start of LOS scan.
K_X	∅	393,216	N/A	1.236 arc-sec	None	Coarse Track	Establishes position for start of LOS Scan.
K_Y	$\dot{X}, \dot{Y}$	39	39	$256 \times 10^{-6} \left(\frac{\text{arc-min}}{\text{sec}}\right)^2$	SDW 2-2	Coarse Track	Sets Coarse Track completion condition.
K_Z	$\lvert R_X(AVG)\rvert$, $\lvert R_Y(AVG)\rvert$	128	128	80×10^{-6} arc min	SDW 3-2	Fine Lock	Sets the Fine Lock detection threshold (i.e., ΔX and ΔY set to lock)

NOTE: The Uplink Modifiers, $(K_A)_u$, are defined in Paragraph 3.3.9 and Table 3.3.

TABLE 13-1

TABLE OF PARAMETERS (Cont'd)

(K_*) PARAMETER NAME	APPLIED TO	$(K_*)_I$ INITIAL VALUE (LSB UNITS)	$(K_*)_F$ FIXED VALUE (LSB UNITS)	LSB WEIGHT (ENG UNITS/LSB)	$(K_*)_u$ UP LINK MODIFIER (See Note 1)	MODE	PURPOSE
K_{0x}, K_{0y}	Q_x, Q_y	0	32	80×10^{-6} arc-min	SDW's 4-3 & 4-5	Fine Lock & SSM Control (SP =1)	Listed for processing of interferometer signal.
K_{1x}, K_{1y}	Q_x, Q_y	256	256	80×10^{-6} arc-min	SDW's 1-0 & 1-2	Fine Lock & SSM Control (SP =1)	Same as Above
K_{3x}, K_{3y}	Q_x^2, Q_y^2	160	160	2^{-8}	SDW's 1-1 & 1-3	Fine Lock & SSM Control (SP =1)	Same as Above
K_{4x}, K_{4y}	$\langle A+B \rangle_x$ $\langle A+B \rangle_y$	0	32	1 PMT Count	SDW's 4-4 & 4-6	Fine Lock & SSM Control (SP =1)	Same as Above
K_{05}	N(Step)	96	96	1 Step	SDW 3-3	Fine Lock	Sets limit for number scan steps. If exceeded unit enters stop mode.
K_{06}	ρ_S	2756	2756	2^{-7}	SDW 1-4	Search	Used as torque-limited coefficient in scan period equation for ρ_t.
K_{07}	ρ_S	152	152	2^{-8}	SDW 1-5	Search	Used as photometry-limited coefficient in scan period equation for ρ_v.
K_{08}	ρ_S	205	205	2^{8}	SDW 1-6	Search	Sets basic radial rate component in equation for $\Delta\rho$.
K_{09}	ρ_S	0	4	2^{*}	SDW 4-7	Search	Sets adaptive radial rate component in equation for $\Delta\rho$.
K_{10}	ρ_C	384	384	2^{-4}	SDW 2-3	Search, Coarse Trk, LOS Scan Fine Lock (D^V = 0)	Sets proportional gain in PID function for position to rate conversion.
K_{11}	TBD	0	TBD	TBD	SDW 5-6	TBD	K_{11} is a spare parameter
K_{12}	TBD	0	TBD	TBD	SDW 5-7	TBD	K_{12} is a spare parameter

NOTES: 1. The Uplink Modifiers $(K_*)_u$, are defined in Paragraph 13-3-9 and Table 13-4.
2. Wherever an engineering unit has not been assigned to an LSB weight, the parameter value given is dimensionless and the value of the LSB weight indicates binary point position.

TABLE 13-1

TABLE OF PARAMETERS (Continued)

(K_A) PARAMETER NAME	APPLIED TO	$(K_A)_I$ INITIAL VALUE (LSB UNITS)	$(K_A)_F$ FIXED VALUE (LSB UNITS)	LSB WEIGHT (ENG UNITS/LSB)	$(K_A)_u$ UP LINK MODIFIER (See Note 1)	MODE	PURPOSE
K_{13}	P_F	256	256	2^{-4}	SDW 2-4	Fine Lock (DV = 1)	Sets proportional gain in PID function for position to rate conversion.
K_{14}	I_F	102	102	2^{-7}	SDW 2-5	Fine Lock (DV = 1)	Sets integral gain in PID function for position to rate conversion.
K_{15}	D_F	64	64	2^{-7}	SDW 2-6	Fine Lock (DV = 1)	Sets differential gain in PID function for position to rate conversion.
K_{16}	$\dot{\theta}_A, \dot{\theta}_B$	3096	3096	0.5 arc-sec/sec	SDW 2-7	All Search & Track Modes	Sets maximum acceleration of $\dot{\theta}_A$ and $\dot{\theta}_B$ Signals
K_{20}	C_1	0	96	0.618 arc-sec	SDW 5-0	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{21}	$C_6+C_7-C_1$	0	96	0.618 arc-sec	SDW 5-1	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{22}	C_2	0	8192	2^{-23}	SDW 5-2	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{23}	C_3	0	1024	2^{-23}	SDW 5-3	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{24}	C_4	0	8192	2^{-23}	SDW 5-4	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{25}	C_5	0	1024	2^{-23}	SDW 5-5	Search Coarse Trk LOS Scan	Used in Vector Resolver Equations
K_{30}	P_t	64	64	2^{-4}	SDW 4-0	Mode Transitions	Sets proportional gain in PID function for position to rate conversion
K_{31}	I_1	4112	4112	0.5 arc-sec/sec	SDW 4-1	All Search & Track Modes	Sets limit for integrator in K_1 (PID)
K_{32}	TBD	TBD (See Note 4)	TBD	TBD	SDW 4-2		K_{32} is a spare parameter

NOTES:
1. The Uplink Modifiers, $(K_A)_u$, are defined in Paragraph 13.3.9. and Table 13-3
2. Wherever an engineering unit has not been assigned to an LSB Weight, the parameter value given is dimensionless and the value of the LSB weight given indicates binary point position.
3. $(K_{31})_I$ must be equal to $(K_{31})_F$, per Paragraph [illegible]
4. $(K_{32})_I$ must be equal to $(K_{32})_F$, per Paragraph 13.3.9.7.2 .

Figures 13-16a -- 13-16f

STAP Acquisition Sequence

13-27 thru 13-32

2) The star count, I(t), falls within the commanded upper and lower window limits, I_L and I_H.

If condition 1 occurs, the FGS enters the Stop Mode. (Fig. 13-14). If condition 2 occurs, the star presence flag is set. The A and B SS Servo encoder positions, corresponding to the instant that the in-limit condition is detected, are stored. The stored encoder positions are then used to determine the values of the next scan center, R_{CTR}(ST) and θ_{CTR}(ST), and the next SS Servo encoder postions, θ_A(NEXT) and θ_B(NEXT). Rate commands are then computed, using θ_A (NEXT) and θ_B (NEXT), and sent to the Servo Unit. The FGE will be able to enter the Coarse Track Mode once the disabling conditions have been met and the FGE computed rate commands have been zeroed.

13.2.3.4.2

- COARSE TRACK

Refer to Fig. 13-11 in conjunction with the following Coarse Track Mode explanation. Upon entering the Coarse Track Mode, the Coarse Track Mode Status bit, available at the SDW Data Output ports, shall be set. The first 40 Hz clock pulse appearing the initialization sequence shall be used to synchornize the start of the first nutation cycle. Since one nutation cycle will consist of 40 clock periods, the duration of each nutation cycle will be 1 second. Each of the clock periods in a nutation cycle will be assigned a number, N, in sequence from one to forty. A storage location, A(N), will be assigned to each clock period in the nutation cycle. Each location will store the most recent star count data, I(t), as indicated in Fig. 13-11. At the start of coarse track these storage locations will be initialized as defined in Fig. 13-11.

o START OF FIRST CLOCK PERIOD IN FIRST NUTATION CYCLE

The start of the first nutation cycle after entry into Coarse Track, will be synchronized to the first clock pulse appearing after the initialization sequence is completed. θ_A (NEXT) and θ_B (NEXT) positions will be computed and rate commands will be subsequently sent to the A and B SS servos.

o END OF FIRST CLOCK PERIOD IN FIRST NUTATION CYCLE

The arrival of the leading edge of the very next clock pulse following the above snychronizing pulse, will mark the end of the first clock period in the nutation cycle. It is also the end of a PMT count integration period. The four PMT counts, therefore, are totalized to provide the first I(t) intensity count in the nutation cycle. Next, a Star Presence test is performed. If SP = 1, indicating that I(t) is within the upper and lower commanded limits, the Number of Star Presences (NSP) counter will be incremented from zero to one. Otherwise the counter remains unchanged.

A difference value, DIFFA, is then computed. Since I(t) was obtained from the first clock period in the first nutation cycle,

the A(N) location will be A(1) and equal to the initialized value. (Throughout the first nutation cycle all A(N) terms in the DIFFA calculation will be the initialized value.) After DIFFA is calculated, the I(t) value will replace the initialized A(1). The Sum A term is next computed.

o POSTION ERROR CALCULATION

The next four inequality tests will result in the calculation of the I_x and I_y values depending upon the number of clock periods that have elapsed in the nutation cycle. For N = 1, I_x and I_y are simply the inversion of the DIFFA value since I_x and I_y were initialized to zero. Next, the clock period counter, N, will be incremented to two in anticipation of completion of the next clock period. The actual star position errors, ϵ_x and ϵ_y, are then computed. From these errors, a new center of nutation, R_{CTR} and θ_{CTR}, is computed and the star position coordinates 1 and 2 are set equal to these updated values.

o FOR N <40

As the nutation cycle continues, the generation of each new set of θ_A(NEXT) and θ_B(NEXT) values will occur at the 40 Hz rate. The arrival of the leading edge of each clock pulse will initiate another star presence test, new star position errors will be computed, and the best estimate star position coordinates will be updated. The NSP counter will be incremented after each clock pulse if a star presence condition (SP = 1) was detected. As the nutation proceeds and N continues to increment by one for each clock period, each initialized A(N) value will be replaced with an I(t) value. By the time the 40th clock period is reached, all the A(N) initialized values will have been replaced by I(t) values.

o WHEN N = 40

When N = 40 is detected (see flow diagram, Fig. 13-11), a test of the NSP counter is made. If the stored count is not above the specified limit, transition to the STop Mode will be made. Otherwise, the NSP counter will be reset to zero and the N counter will be reset to one in anticipation of the completion of the first clock period in the next nutation cycle. Also the "a" value, initialized to K_I for the first nutation cycle only, will be zeroed. At the 40th clock period, the term "SUM-a" would be zero if the effect of the DIFFA term were to be excluded. Thus, the initializing function of "a" will no longer be needed once the first nutation cycle is completed. Throughout the second nutation cycle and all subsequent ones, the DIFFA value will be the difference between the present I(t) value and the I(t) value stored in the A(N) location. This A(N) location will be indexed to the same clock period in the present nutation cycle except it will hold the I(t) value obtained one nutation cycle earlier.

o FOR N > 40

The nutation cycles and the associated events will keep repeating as described above. The number of nutation cycles that must elapse before the first DRIFT ERROR computation is performed and the subsequent frequency of these computations is defined in Fig. 13-11.

EXIT FROM COARSE TRACK

The FGE will be ready to exit the Coarse Track Mode if the Data Valid Flag is set (i.e., the computed Drift Error is $\leq K_Y$). If the LOS Scan and Hold commands are off, the next servo encoder positions, θ_A(NEXT) and θ_B(NEXT), will be calculated based on a vector which has been referenced to the best estimate star position.

Rate commands will be computed using θ_A(NEXT) and θ_B(NEXT) and sent to the Servo Unit.

The FGE will enter the Fine Lock Mode after the disabling conditions have been met and the FGE computed rate commands have been zeroed.

If the LOS Scan command is on, the unit will enter the LOS Scan Mode after similar computations and zeroing of the FGE computed rate commands have been accomplished. In addition, the best estimate star position is stored as R_{CTR}(ST2) and θ_{CTR}(ST2) for subsequent return from the LOS Scan Mode back into Coarse Track.

13.2.3.1.4.3

o RESUME SEARCH MODE

The FGE shall resume search from either the Coarse Track, Fine Lock Modes, or stop mode upon receipt of a Resume Search On command as shown in Fig. 13-12. The stored spiral center parameters, R_{CTR}(ST1) and θ_{CTR} (ST1), and the last stored spiral radius and angle ρ_S (LAST) and θ_S(LAST), will be fetched. These parameters will then be used as the beginning point for the resumption of the spiral scan. Once the spiral scan resumes, the algorithm for the sprial generation will be similar to that for the original Search Mode (Fig. 13-10) except that a star blanking function will be employed. The blanking function is active at the beginning of the search resumption. A blanking segment of arc iis established so as to prevent a re-acquisition of an unwanted star following resumption of search. The blanking segment is fixed by the stored constants, $\Delta\rho$ (BLANK) for radial distance and $\Delta\phi$(BLANK) for angular distance. The $\Delta\phi$(BLANK) shall be processed so that the angular distance of the blanking segment will be equal to twice $\Delta\phi$(BLANK). The ϕ_S(RESUME) angle shall always be centered within this angular distance of the blanking segment. The blanking function bypasses the Star Presence Test whenever the scanning point, defined by ρ_S and ϕ_S, is within the blanking segment.

13.2.3.1.4.4

o FINE LOCK MODE

Referring to Fig. 13-13, the ~~unit~~ FGE shall send a mode status bit via the SDW data outputs to indicate operation in the Fine Lock Mode. The counter, N (STEP) = N (STEP) + 1, totalizes the number of averaging periods and will be initialized by setting N (STEP) = 0. The incremental terms, Δ X and Δ Y, are used to establish the step size in anticipation of the start of the linear scan in the 225 degree direction. Δ_X and Δ_Y are determined by a common uplinkable value, K_D. The averaging of the normalized fine error signals, R_X(AVG) and R_Y(AVG), will be calculated following receipt of the leading edge of that 40 Hz clock pulse that marks the end of the commanded averaging period. For the special case where the Fine Error Averaging Time Command bits are all zeroes (i.e., T(AVG) = 000), this averaging period is the 40 Hz clock period. The averaged normalized Fine Error Signals, R_X(AVG) and R_Y(AVG) will then be simply the normalized fine error signals, R_X and R_Y, which are calcuated at the end of each clock cycle.

The computed R_X(AVG) and R_Y(AVG) magnitudes will be compared to threshold limits following the end of the first averaging period. This will occur since both Δ_X and Δ_Y were set to constant values at the start of the Fine Lock Mode. If neither limits are exceeded, the unit will be ready to start a 225 degree linear scan. the next calculated positions θ_A (NEXT) and θ_B (NEXT), will be used to derive the A and B FGE computed rate commands for producing this scan. Unless an exit is made out of the Fine Lock Mode, the next positions θ_A (NEXT) and θ_B (NEXT), will always be updated after each averaging period (which is after each clock period if the Averaging Time Command = 000). Each updated position is based on the present encoder positions, θ_A (PRESENT) and θ_B (PRESENT), and the computed incremental steps, $\Delta\theta_A$ and $\Delta\theta_B$. The start of another normalized FES averaging period will always be synchronous with the 40 Hz clock pulses. If the Averaging Time Command bits are all zeroes, the averaging time will start with the trailing edge of the same clock pulse whose leading edge marked the end of the previous averaging period. A non-zero Averaging Time Command requires that the A and B FGE-computed rate commands are both zeroed before the start of another averaging period. The start of averaging will still be coincident with the trailing edge of the 40 Hz clock pulse.

The fine lock sequence of events described above now repeats itself if neither R_X(AVG) nor R_Y(AVG) exceeds the specified limits. Following the end of each averaging period, the N(STEP) counter is incremented and new R_X (AVG) and R_Y (AVG) values are computed. The values of Δ_X and Δ_Y are as previously defined for calculating $\Delta\theta_A$ (NEXT) and $\Delta\theta_B$ (NEXT). Thus the 225 degree linear scan continues until one of four events occur:

1) The magnitude of the X-axis average normalized FES, R_X(AVG), exceeds the specified limit.

2) The magnitude of the Y-axis average normalized FES, R_Y (AVG), exceeds the specified limit.

3) The counter, N(STEP) exceeds a specified limit.

4) The counter, N(SPO) equals a specified value (i.e., star presence is lost).

If event 3 or 4 occurs, the unit exits the Fine Lock Mode and enters the Stop Mode.

If R_X (AVG) is the first to exceed its limit, Δ_X is set to R_X (AVG) while Δ_Y continues to be set to a constant value.

The next calculated positions, θ_A (NEXT) and θ_B (NEXT), will now change the scan from the 225 degree to a nominal 270 degree direction. The SS Servos will maintain the scan in this latter direction while simultaneously remaining locked on the R_X (AVG) signal. If R_Y (AVG) is the first to exceed its limit, Δ_Y is then set to R_Y (AVG) and Δ_X remains set to a constant. The scan changes to a nominal 180 degree direction but simultaneously remains locked to the R_Y (AVG) signal. Assuming that either Δ_X has been set to R_X (AVG), or Δ_Y to R_Y (AVG) (but not both), then the sequence of events will repeat as previously described except that the direction of scan has been changed. The new scan direction continues until one of the following events occur:

1) Both R_X (AVG) and R_Y (AVG) exceed their specified limits.

2) The counter, N(STEP), exceeds the limit.

3) The counter N(SPO) equals a specified value.

If both R_X (AVG) and R_Y (AVG) have exceeded their limits, both Δ_X and Δ_Y are set to R_X (AVG) and R_Y (AVG), respectively, and the Fine Locking Process is complete. The Data Valid Flag is then set and the A and B SS Servo will lock onto both axes. The best estimate star position in this locked condition will be represented by the A and B Star Selector Positions instead of the Star Position Coordinates used in the Coarse Track Mode. The Star Position Coordinates will not have any significance in the Fine Lock Mode.

With the locking process complete the $\Delta\theta_A$ and $\Delta\theta_B$ values will be a function of R_X (AVG) and R_Y (AVG) only. If the Averaging Time Command is non-zero, the start of the next fine error averaging period cannot begin until the A and B FGE computed rate commands have been zeroed. If the Averaging Time Command is zero, the averaging period shall start with the trailing edge of the same clock pulse whose leading edge marked the end of the previous averaging period. The unit remains in this locked condition until one of two events occur:

1) A Search and Track Off Command is received.

2) The counter N(SPO) equals a specified value.

13.2.3.1.4.5

STOP MODE

The unit will exit the Search, Resume Search, Coarse Track or Fine Lock modes and enter the Stop Mode if either one of the following conditions occurs:

a) The Commanded Search Radius Limit is exceeded during Search or Resume Search modes.

b) The Star Presence detection test performed in either Coarse Track or Fine Lock indicates loss of star.

c) The scan step (N(STEP) in Fig. 13-13) limit is exceeded during Fine Lock.

A flow diagram of the Stop Mode is shown in Fig. 13-14. As soon as conditions to stop have been met as defined above, the θ_A (ENC) and θ_B (ENC) encoder positions shall be stored and used as the next encoder postiions, θ_A (NEXT) and θ_B (NEXT), respectively. The unit will then perform the rate command disabling test, derive the next FGE computed rate commands (which could be zero depending on the outcome of the disabling test) and send the summed rate commands to the Servo Unit. This sequence of events shall be repeated until a Search and Track Off command is received.

13.2.3.1.4.6

LOS SCAN MODE

The unit shall enter the LOS Scan Mode from the Coarse Track Mode only. The following conditions are required in order for this mode change to occur (see Coarse Track flow diagram, Fig.13-11):

1) The Data Valid Flag must be set.

2) The LOS Scan Command must be on.

If these conditions are present, the A and B SS Servo will be positioned for the start of the LOS Scan.

Refer to Fig. 13-15 in conjunction with the following LOS Scan Mode description. Upon entering this mode, the LOS Scan Mode status bit, available at the SDW Data Output ports, shall be set. This status bit is reset when the LOS Scan Mode is exited.

The LOS Scan produces an orthogonal grid pattern consisting of equally spaced vertical and horizontal scan lines. (This scan pattern is produced externally by an optical system when appropriate rate commands are sent to the A and B SS Servos.) The scan pattern is shown as an insert in Fig. 13-15. The pattern consists of 13 vertical and horizontal scan lines. All 180 degree changes in direction from one scan line to another are similar and are referred to as "turn-arounds". The transition from the last vertical line (#13) to the first horizontal line

(#1) is referred to as the 270 degree "cornering" maneuver. Except for the two scan lines associated with the cornering, the length of all other scan lines will be determined by the constant assigned to Δy for vertical scans (or Δ X for horizontal scans) and sixty sample periods of the 40 Hz clock. That is, when N_p = 60 the repetitive linear scan loop is exited. Vertical line #13 (N_ℓ = 13 and LINE = VERT) requires additional length to account for the 270 degree cornering. Accordingly, the linear scan loop for this line will be exited when 63 sample periods (N_p = 63 and LINE = VERT) have been totalized. Similarly, the first horizontal scan line requires additional length. This is accomplished by initializing the sample period counter at $N_p = -2$ upon exiting the cornering nutation loop. Normally, N_p is initialized at 1 for the start of all other linear scan lines.

The number of vertical and horizontal lines are totalized by the N_ℓ counter. The algorithm for the linear scan line generator must taken into account the direction of scan. This is accomplished by sensing whether the number assigned to each scan line is odd or even. When N_ℓ is even, positive Δy and Δx constants are selected for the vertical and horizontal scan lines before the linear scan loop is entered. A similar polarity selection is made in the turn-around algorithm. For all counter-clockwise turn-arounds, a positive $\Delta\phi$ is selected. This selection is based on determining whether an odd or even numbered scan line follows the turn-around.

The algorithm for turn-around and cornering will be similar to that used in the Coarse Track nutation, Fig. 13-11. The center of nutation for either turn-around or cornering will be the last R_{CTR} and θ_{CTR} computed before the nutation loop is entered. The nutation algorithm is generated by setting ρ equal to a constant and changing ϕ by the quantity $\Delta\phi$ at the start of each sample period. New values of θ_A (NEXT) and θ_B (NEXT) are then calculated for each sample period based on the incrementing ϕ value. The nutation loop is exited when N_S = 8 for the π radian turn-around and when N_S = 15 for the 3/2 π radian cornering.

Following completion of the 13th horizontal line (N_ℓ = 13 and LINE $\neq$ VERT), the LOS Scan pattern will have arrived back at the starting point. The next sequence of events will prepare the unit for exiting the LOS Scan Mode. The stored R_{CTR}(ST2) and θ_{CTR} (ST2) parameters represented the last best estimate star position in Coarse Track. These values will be fetched and vectorially added to ρ and ϕ constants. θ_A (NEXT) and θ_B (NEXT) positions will then be computed. Once the FGE computed rate commands have been zeroed, the unit will automatically transfer back to the Coarse Track Mode.

13.2.3.2 COMMANDS AND DATA

13.2.3.2.1 COMMAND INPUTS

Commands are grouped into one of the following categories:

a) High Level Discrete (HLD) Commands
b) DIU Digital Commands & Data Control Signals
c) DMU Digital Commands

DIU DIGITAL COMMANDS & DATA CONTROL SIGNALS

The digital commmand and data control interface refers to a class of signals input to a DIM from a DIU. These contain the following command and data handling types.

a) Serial digital word (SDW)
b) SDW command enable
c) SDW command gated clock
d) Low level discretes (LLD)
e) SDW data enable
f) SDW data gated clock

SDW COMMANDS, COMMAND ENABLES AND COMMAND GATED CLOCKS

To input a SDW into the FGE through either SDW CMD Port 1 or 2, three different command types are used:

a) SDW Command - a 16 bit bi-level serial word
b) SDW Command Enable - an enabling pulse that brackets the transmission of the SDW command.
c) SDW Command gated clock

Ports 1 and 2 shall each have the capability to handle 16 SDW command words, and are listed as SDW CMD Port 1 and SDW CMD Port 2 in Tables 13-2 and 13-3. The signal names in each SDW command numbered location for Ports 1 and 2 are listed in Tables 13-2 and 13-3. The LSB weightings are given in Table 13-4. The format for each SDW is also shown in Tables 13-2 and 13-3. Bits 1 through 4 in each SDW command is designated the address field. It defines a unique destination in the Signal Processing Electronics Section for each SDW command word in the particular port. The LSB weightings of each command, which may consist of more than one SDW command word, is defined in Table 13-4. During any 25 millisecond sync period, SDW commands will be sent through either SDW Command Port 1 or 2, but not both.

o PORT 1 SDW CMD RATE

SDW CMD NOS. 1 - 4: Each of these commands will be issued at a maximum rate of one per 40 Hz sync interval.

SDW CMD NOS. 5 - 16: A maximum of 16 of these commands will be issued in any 25 millisecond period.

TABLE 13-2

SDW COMMAND PORT 1

SDW CMD NO.	Signal Name	Address Field 1	2	3	4	Format Instruction 5	6	7	8	9	10	11	12	13	14	15	16
1	SSM 'A' Rate Command (MSB) & Sign	Ø	Ø	Ø	Ø	SIGN	MSB			Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
2	SSM 'A' Rate Command (LSB)	Ø	Ø	Ø	1												LSB
3	SSM 'B' Rate Command (MSB) & Sign	Ø	Ø	1	Ø	SIGN	MSB			Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
4	SSM 'B' Rate Command (LSB)	Ø	Ø	1	1												LSB
5	Star Magnitude Window (Upper Lim) I_H (MSB)	Ø	1	Ø	Ø	MSB				Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
6	Star Magnitude Window (Upper Lim) I_H (LSB)	Ø	1	Ø	1												LSB
7	Star Magnitude Window (Lower Lim) I_L (MSB)	Ø	1	1	Ø	MSB				Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
8	Star Magnitude Window (Lower Lim) I_L (LSB)	Ø	1	1	1												LSB
9	Search Radius Lim	1	Ø	Ø	Ø	MSB						LSB	Ø	Ø	Ø	Ø	Ø
10	Astro Filter Pos. and Fine Error Avg. Time	1	Ø	Ø	1	MSB AVG. TIME		LSB	Ø	Ø	Ø	Ø	Ø	Ø	MSB ASTRO FILTER POSITION		LSB
11	On Control Bits	1	Ø	1	Ø	HIGH VOLT	*	SEARCH TRACK	HALF RATE	HOLD	TEST SOURCE	LOS SCAN	Ø	Ø	Ø	Ø	Ø
12	Off Control Bits	1	Ø	1	1		Ø						DEF	Ø	Ø	Ø	SHUT DOWN
13	Spare Word Position	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
14	Spare Word Position	1	1	Ø	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
15	Spare Word Position	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
16	Spare Word Position	1	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø

* Resume Search

NOTE: Spare Bit Position will be zero (Ø) filled.

TAI 13-3

SDW COMMAND PORT 2

SDW CMD No.	Signal Name	Address Field				Format Instruction											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Uplink Modifiers 1-0 thru 1-7	Ø	Ø	Ø	Ø	See Table 13-3A											
2	Uplink Modifiers 2-0 thru 2-7	Ø	Ø	Ø	1	See Table 13-3B											
3	Uplink Modifiers 3-0 thru 3-7	Ø	Ø	1	Ø	See Table 13-3C											
4	Uplink Modifiers 4-0 thru 4-7	Ø	Ø	1	1	See Table 13-3D											
5	Uplink Modifiers 5-0 thru 5-7	Ø	1	Ø	Ø	See Table 13-3E											
6	Test Modifiers 6-0 thru 6-7	Ø	1	Ø	1	Not Applicable - Test by seller only											
7	Spare Word Position	Ø	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
8	Spare Word Position	Ø	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
9	Spare Word Position	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
10	Spare Word Position	1	Ø	Ø	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
11	Spare Word Position	1	Ø	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
12	Spare Word Position	1	Ø	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
13	Spare Word Position	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
14	Spare Word Position	1	1	Ø	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
15	Spare Word Position	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
16	Spare Word Position	1	1	1	1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø

NOTE: Spare Bit Positions will be zero (Ø) filled.

TABLE 13-3A

UPLINK MODIFIERS

SDW CMO NO.	SIGNAL NAME	SDW ADDRESS FIELD				FORMAT INSTRUCTION: UPLINK ADDRESS FIELD			FORMAT INSTRUCTION: UPLINK PARAMETER VALUE								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1-0	X-AXIS K_{1X} INTERFEROMETER COEFFICIENT	Ø	Ø	Ø	Ø	Ø	Ø	Ø	SIGN	MSB							LSB
1-1	X-AXIS K_{3X} INTERFEROMETER COEFFICIENT	Ø	Ø	Ø	Ø	Ø	Ø	1	SIGN	MSB							LSB
1-2	Y-AXIS K_{1Y} INTERFEROMETER COEFFICIENT	Ø	Ø	Ø	Ø	Ø	1	Ø	SIGN	MSB							LSB
1-3	Y-AXIS K_{3Y} INTERFEROMETER COEFFICIENT	Ø	Ø	Ø	Ø	Ø	1	1	SIGN	MSB							LSB
1-4	SEARCH TORQUE LIMITED COEF. K_{06}	Ø	Ø	Ø	Ø	1	Ø	Ø	SIGN	MSB							LSB
1-5	SEARCH PHOTOMETRY LIMITED COEF. K_{07}	Ø	Ø	Ø	Ø	1	Ø	1	SIGN	MSB							LSB
1-6	SEARCH BASIC RADIAL RATE K_{08}	Ø	Ø	Ø	Ø	1	1	Ø	SIGN	MSB							LSB
1-7	SEARCH INNER SPIRAL RADIUS K_A	Ø	Ø	Ø	Ø	1	1	1	SIGN	MSB							LSB

TABLE 13-3B

UPLINK MODIFIERS

SDW CMD NO.	SIGNAL NAME	SDW ADDRESS FIELD				FORMAT INSTRUCTION: UPLINK ADDRESS FIELD			FORMAT INSTRUCTION: UPLINK PARAMETER VALUE								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2-0	COARSE TRACK NUTATION RADIUS K_G	Ø	Ø	Ø	1	Ø	Ø	Ø	SIGN	MSB							LSB
2-1	COARSE TRACK GAIN K_J	Ø	Ø	Ø	1	Ø	Ø	1	SIGN	MSB							LSB
2-2	COARSE TRACK COMPLETION CONDITION K_Y	Ø	Ø	Ø	1	Ø	1	Ø	SIGN	MSB							LSB
2-3	P_C POSITION TO RATE CONV. K_{10}	Ø	Ø	Ø	1	Ø	1	1	SIGN	MSB							LSB
2-4	P_F POSITION TO RATE CONV. K_{13}	Ø	Ø	Ø	1	1	Ø	Ø	SIGN	MSB							LSB
2-5	I_F POSITION TO RATE CONV. K_{14}	Ø	Ø	Ø	1	1	Ø	1	SIGN	MSB							LSB
2-6	D_F POSITION TO RATE CONV. K_{15}	Ø	Ø	Ø	1	1	1	Ø	SIGN	MSB							LSB
2-7	ACCELERATION LIMITER K_{16}	Ø	Ø	Ø	1	1	1	1	SIGN	MSB							LSB

TABLE 13-3C

UPLINK MODIFIERS

SDW CMO NO.	SIGNAL NAME	SDW ADDRESS FIELD				FORMAT INSTRUCTION: UPLINK ADDRESS FIELD			FORMAT INSTRUCTION: UPLINK PARAMETER VALUE								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3-0	FINE LOCK INITIAL OFFSET K_B	Ø	Ø	1	Ø	Ø	Ø	Ø	SIGN	MSB							LSB
3-1	FINE LOCK STEP SIZE K_D	Ø	Ø	1	Ø	Ø	Ø	1	SIGN	MSB							LSB
3-2	FINE LOCK DETECTION THRESHOLD K_Z	Ø	Ø	1	Ø	Ø	1	Ø	SIGN	MSB							LSB
3-3	FINE LOCK STEP LIMIT K_{05}	Ø	Ø	1	Ø	Ø	1	1	SIGN	MSB							LSB
3-4	LOS STEP SIZE K_M	Ø	Ø	1	Ø	1	Ø	Ø	SIGN	MSB							LSB
3-5	LOS SCAN SPACING K_N	Ø	Ø	1	Ø	1	Ø	1	SIGN	MSB							LSB
3-6	RESUME SEARCH RADIAL BLANK K_E	Ø	Ø	1	Ø	1	1	Ø	SIGN	MSB							LSB
3-7	RESUME SEARCH TANGENTIAL BLANK K_F	Ø	Ø	1	Ø	1	1	1	SIGN	MSB							LSB

TABLE 13-3D

UPLINK MODIFIERS

SDW CMO NO.	SIGNAL NAME	SDW ADDRESS FIELD				FORMAT INSTRUCTION: UPLINK ADDRESS FIELD			FORMAT INSTRUCTION: UPLINK PARAMETER VALUE								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4-0	P_t POSITION TO RATE CONV K_{30}	Ø	Ø	1	1	Ø	Ø	Ø	SIGN	MSB							LSB
4-1	PID INTEGRATOR LIMIT K_{31}	Ø	Ø	1	1	Ø	Ø	1	SIGN	MSB							LSB
4-2	SPARE PARAMETER, K_{32}	Ø	Ø	1	1	Ø	1	Ø	SIGN	MSB							LSB
4-3	X-AXIS K_{OX} INTERFEROMETER COEFFICIENT	Ø	Ø	1	1	Ø	1	1	SIGN	MSB							LSB
4-4	X-AXIS K_{4X} INTERFEROMETER CORRECTION	Ø	Ø	1	1	1	Ø	Ø	SIGN	MSB							LSB
4-5	Y-AXIS K_{OY} INTERFEROMETER COEFFICIENT	Ø	Ø	1	1	1	Ø	1	SIGN	MSB							LSB
4-6	Y-AXIS K_{4Y} INTERFEROMETER CORRECTION	Ø	Ø	1	1	1	1	Ø	SIGN	MSB							LSB
4-7	SEARCH ADAPTIVE RADIAL RATE K_{09}	Ø	Ø	1	1	1	1	1	SIGN	MSB							LSB

TABLE 13-3E

UPLINK MODIFIERS

SDW CMO NO.	SIGNAL NAME	SDW ADDRESS FIELD				FORMAT INSTRUCTION: UPLINK ADDRESS FIELD			FORMAT INSTRUCTION: UPLINK PARAMETER VALUE								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5-0	C_1 STAR SELECTOR COOR. CONV. K_{20}	Ø	1	Ø	Ø	Ø	Ø	Ø	SIGN	MSB							LSB
5-1	$C_6 + C_7 - C_1$ STAR SELECTOR COOR. CONV. K_{21}	Ø	1	Ø	Ø	Ø	Ø	1	SIGN	MSB							LSB
5-2	C_2 STAR SELECTOR COOR. CONV. K_{22}	Ø	1	Ø	Ø	Ø	1	Ø	SIGN	MSB							LSB
5-3	C_3 STAR SELECTOR COOR. CONV. K_{23}	Ø	1	Ø	Ø	Ø	1	1	SIGN	MSB							LSB
5-4	C_4 STAR SELECTOR COOR. CONV. K_{24}	Ø	1	Ø	Ø	1	Ø	Ø	SIGN	MSB							LSB
5-5	C_5 STAR SELECTOR COOR. CONV. K_{25}	Ø	1	Ø	Ø	1	Ø	1	SIGN	MSB							LSB
5-6	SPARE PARAMETER K_{11}	Ø	1	Ø	Ø	1	1	Ø	SIGN	MSB							LSB
5-7	SPARE PARAMETER K_{12}	Ø	1	Ø	Ø	1	1	1	SIGN	MSB							LSB

TABLE 13-4

LSB WEIGHTING OF SDW COMMAND SIGNALS

Signal Description	LSB Weight
SSM 'A' Rate Command	0.5 arc-sec/sec
SSM 'B' Rate Command	0.5 arc-sec/sec
Star Magnitude Window (Upper Lim) I_H	1 PMT Count
Star Magnitude Window (Lower Lim) I_L	1 PMT Bount
Search Radius Limit	1.024 arc-min
Fine Error Avg. Time	Coded as per Table 16
Uplink Modifiers	See Paragraph 133.9.1.4

SDW CMD NOS. 1 - 16: These commands will be sent in any mixed combination that is is conformance with the above requirements .

o PORT 2 SDW CMD RATE

The maximum number of SDW commands issued in any 25 millisecond sync period will be 1 and will occur within 17 milliseconds collowing the leading edge of the 40 Hz sync pulse. If more than one Port 2 SDW Command is issued within the 17 millisecond interval defined above, the last SDW Command to arrive shall be processed by the FGE; the previous SDW Commands received within the same interval shall be ignored.

DMU DIGITAL COMMANDS

The DMU Digital Commands include Low Level Discretes (LLD) and Continuous Clock.

LOW LEVEL DISCRETE COMMANDS

The low level discrete commands from the DMU include the 40 Hz Sync signal and the Minor Frame Sync signal. There is no correlation between the active DMU (A or B) and the active DIU Section (A or B).

13.2.3.2.2. DATA INPUTS

The FGE will receive the following signals from the FGS Assembly:

Signal Description	Type
Filter Wheel Position*	Parallel digital word
X-axis PMT #1 Pulses	Discrete pulses
X-axis PMT #2 Pulses	Discrete pulses
Y-axis PMT #1 Pulses	Discrete pulses
Y-axis PMT #2 Pulses	Discrete pulses

*This signal will consist of a 3-bit parallel natural binary word indicative of the optical filter wheel position.

The FGEwill receive the following data signals from the Servo Unit:

Signal Description	Type
Encoder A Position	Parallel digital word
Encoder B Position	Parallel digital word
Compensated Error A	Analog
Compensated Error B	Analog

ENCODER A & ENCODER B POSITION

This signal will consist of a 21-bit parallel natural binary word indicative of shaft angle position from 0 to 360 degrees. A zero degree angle is represented by all logical zeroes in the 21-bit

word. The LSB weighting is equivalent to 0.618 arc second.

Signal type - parallel digital word, single ended

Update rate - 6.63 KHz rate with all bits updated simultaneously

13.2.3.2.3 DATA OUTPUTS

SDW Port 1 Output data will be retrieved from the active DIM in 16-bit bytes; data from Ports 2 and 3 will be retrieved from the active DIM in 8-bit bytes.

There are 3 DIMs as shown in Fig. 13-7. DIMs 1 and 2 are redundant and shall provide the interface buffering for all DIU low level digital (discrete and SDW) commands and SDW data outputs. Only one of the redundant DIMs shall be powered at any time. DIM 3 shall provide the buffering and signal conditioning for the non-redundant analog data to the DIUs.

13.2.3.2.4 COMMAND PROCESSING

The primary function of the command processing section, see Fig. 13-37, is to route commands received from the DIMs to proper destinations in the Signal Processing and Operating Mode Logic Sections. LLD commands are distributed without further processing, while commands originating at SDW CMD Ports 1 and 2 undergo serial-to-parallel conversion prior to distribution. The destination address for each of the Port 1 SDW command is contained in the address field, bit positions 1 - 4. Since Port 1 command information is contained in bit position 5 - 16, only these bits need to be routed to the destination. SDW CMD Port 2 also uses bit positions 1 - 4 as the address field, incorporates a sub-addressing scheme using bit positions 5 - 7 and positions 8 - 16 contain the command information.

13.2.3.2.5 DATA PROCESSING

The Data Processing Section, (Fig. 13-38), is divided into analog data handling and SDW data handling.

The LSB weighting of SDW Data Signals is shown in Table 13-5.

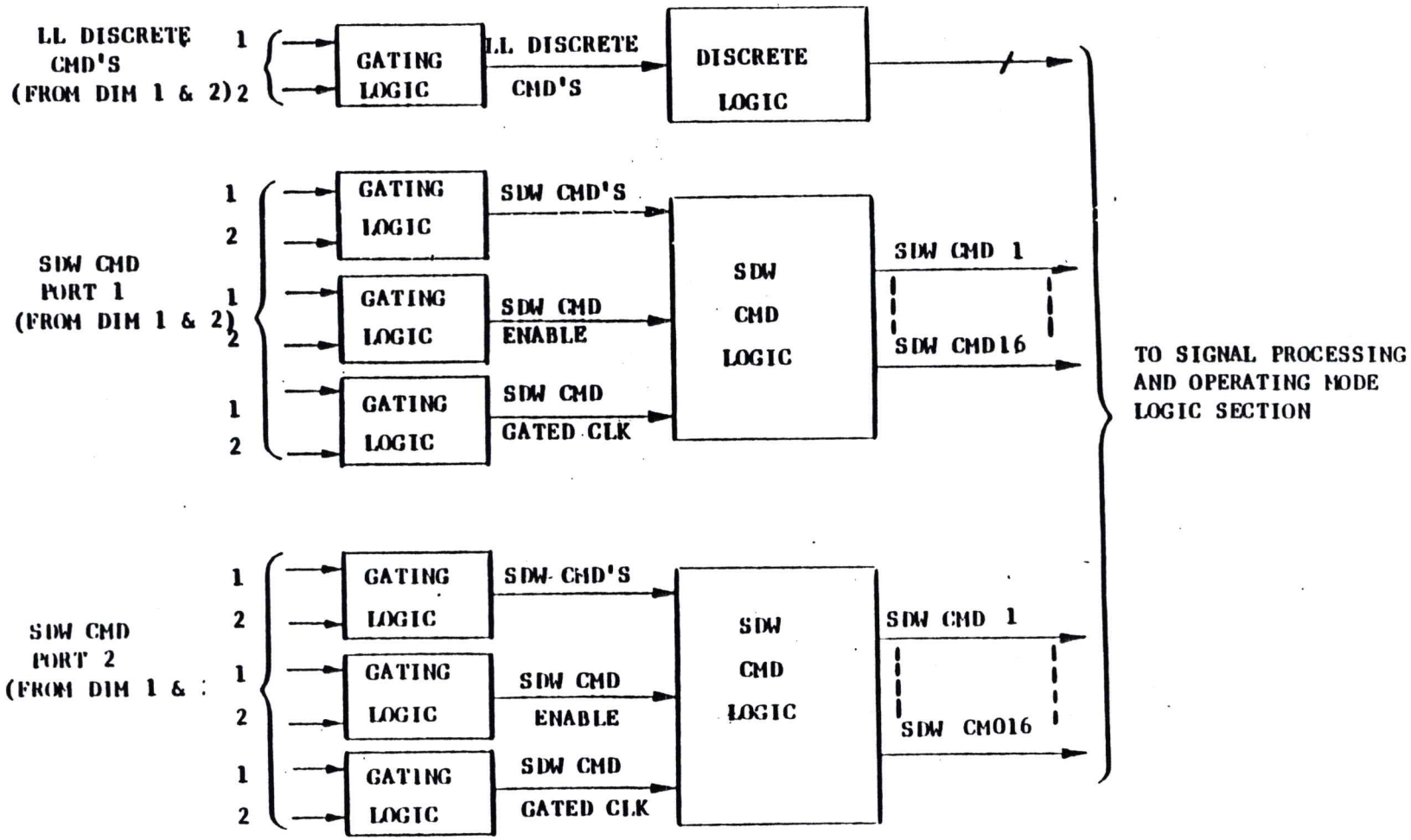


Figure 13-37 Command Processing Section, Functional Block Diagram

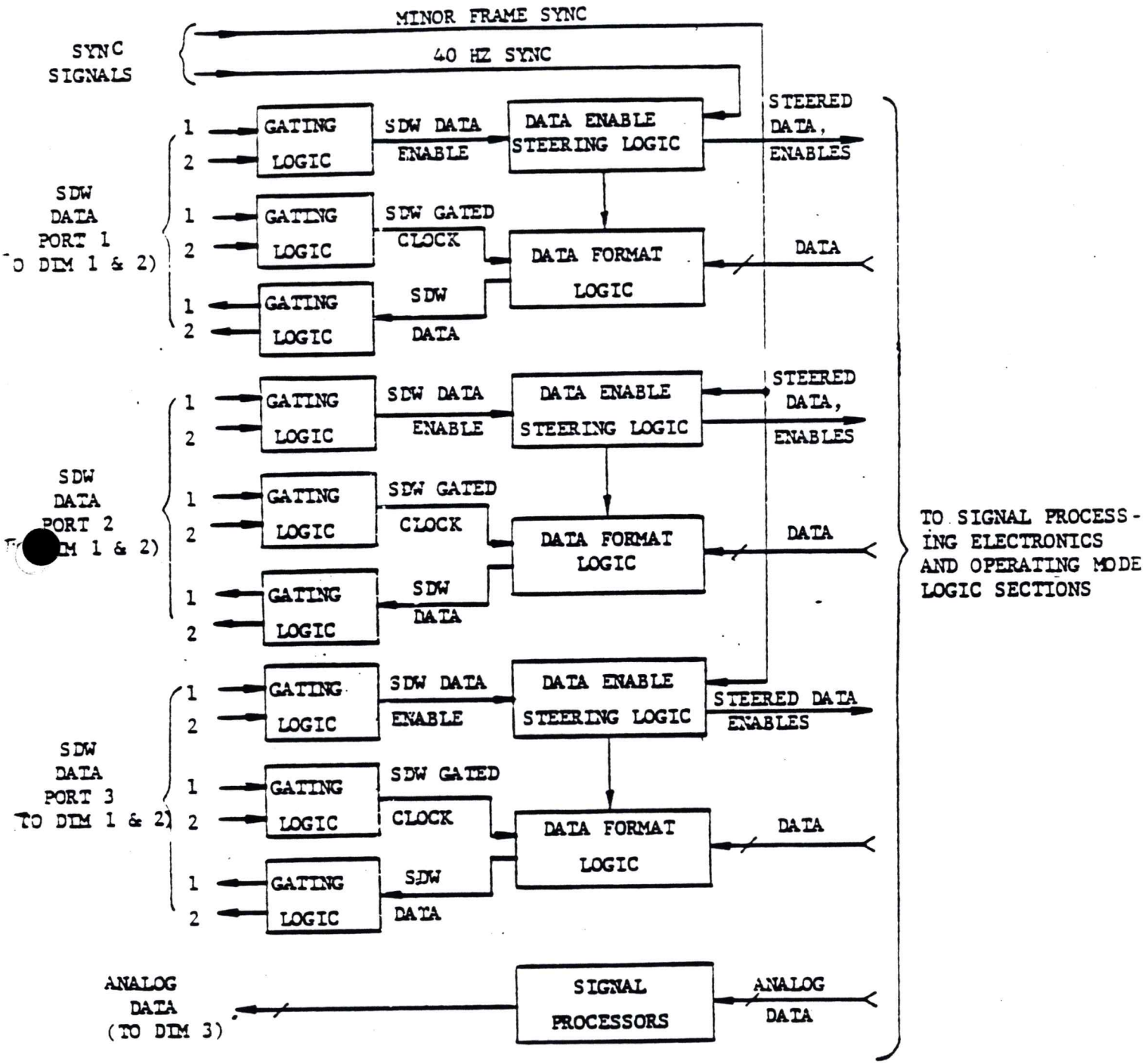


Fig 13-38 Data Processing Section Functional Block Diagram

TABLE 13-5

LSB WEIGHTING OF SDW DATA SIGNALS

Signal Description	LSB Weight
X-Axis Fine Count (PMT A and PMT B)	1 PMT Count
Y-Axis Fine Count (PMT A and PMT B)	1 PMT Count
X-Axis Fine Error (Normalized) and Sign	80×10^{-6} arc-min
Y-Axis Fine Error (Normalized) and Sign	80×10^{-6} arc-min
X-Axis Avg. Magnitude (A + B)	1 PMT Count
Y-Axis Avg. Magnitude (A + B)	1 PMT Count
A Star Selector Position	0.618 arc-sec
B Star Selector Position	0.618 arc-sec
Star Position Coordinate 1	0.001 arc-min
Star Position Coordinate 2	0.618 arc-sec
A Star Selector Avg. Position	0.077 arc-sec
B Star Selector Avg. Position	0.077 arc-sec
X-Axis Avg. Fine Error (Normalized) and Sign	80×10^{-6} arc-min
Y-Axis Avg. Fine Error (Normalized) and Sign	80×10^{-6} arc-min
$\dot{X}$ Star Position Drift	0.016 arc-min/sec
$\dot{Y}$ Star Position Drift	0.016 arc-min/sec

COMMAND TABLES & TELEMETRY TABLES - TBD

(These tables will be completed once DM-01, ST Command List, and DM-02, ST IP&CL, have been baselined.)

13.2.4 FGS Operation

NARRATIVE FLOW DIAGRAM

STOCC sends operation commands to SSM, giving type of operation, identification, address and characteristics as required of guide stars or astrometry target, time to commence operation, etc.

↓

FGS receives stored program commands for power turn-on sequence, through the commands to enable the FGE power supply.

↓ *p. 13-45

FGE initializes its logic (see *Note 1). After 220 millisecond time delay, FGE is ready to accept commands, enters SSM Control Mode with servo unit torque enabled, and sets SSM Control Mode Status bit.

↓

FGE receives uplink modifier stored program commands if required

↓

FGS receives conditioning commands:

- Star Magnitude Window (Upper Limit)
- Star Magnitude Window (Lower Limit)
- Search Radius Limit
- Filter Position/Fine Error Averaging Time
- ON Control Bits for Half Rate, Hold, Test Source and LOS Scan, as required

↓

(Initial conditioning of the FGS is now complete for the coming operation. The SSM orients the ST to place the target star in the proper location in the field of view of the FGS).

↓

SSM sends Star Selector Rate commands to position star selectors at start of search positions.

↓

(Next Page)

SSM sends High Voltage ON command and, 60 seconds later, Search Track ON command.

FGS enters Search Mode, resets status bits, sets Search Mode Status bit, and conducts spiral search

C

If FGS detects a star, sets Star Presence Flat bit, positions servos for start of Coarse Track, resets Search Mode Status bit, sets Coarse Track Mode Status bit, and enters Coarse Track Mode

D

If FGS fails to detect a star before reaching Search Radius Limit, sets Search Radius Limit Exceed Flag and Stop Flag, and enters Stop Mode until receipt of Search Track OFF command from SSM

E

Re-enters SSM Control Mode, resets status bits, and sets SSM Control Mode Status bit. FGS is ready for new operation commands from SSM or power-down by STOCC.

B

In Coarse Track Mode, FGS conducts circular scan (nutation) around star, continuing to test for star presence and attempting to center the scan about the star. When the FGS-computed drift error stabilizes within established criteria, FGS sets Data Valid Flag and tests for exit from Coarse Track Mode. SSM computes gyro drift rates from star position coordinate data supplied by FGS, and biases gyros to minimize drift. With LOS Scan OFF, if SSM had sent HOLD ON command prior to the Data Valid Flag being set, FGS sets Transfer Held Flag (after Data Valid Flag is set), remains in Coarse Track Mode until HOLD OFF or LOS Scan ON is commanded, or until star presence is lost.

If both LOS Scan OFF and HOLD OFF status exists, FGS drives its star selectors to a location offset in a known direction from FGE calculated star position, resets Transfer Held and Data Valid Flags, resets status bits, and enters Fine Lock Mode

(Next Page)

If LOS Scan ON command status exists, FGE positions its star selectors for the start of LOS Scan, resets Transfer Held and Data Valid Flags, resets status bits, and enters LOS Scan Mode

GO

If star presence is lost during coarse tracking, FGS resets Star Presence Flag bit and Data Valid Flag bit, sets Stop Flag bit, and enters Stop Mode until receipt of Search Track OFF command from SSM

GO TO E

In Fine Lock Mode, sets Fine Lock Mode Status bit, conducts a stepped scan search in the calculated direction of the star, tests for star presence and tests fine error magnitudes for readiness to lock.

If star remains present and readiness for lock occurs within a prescribed number of scan steps, locks SS servo to the fine error signals and sets Data Valid Flag. Science observations are performed while FGS operates in Fine Lock Mode. (For solar system object tracking requiring rate-feed-forward operation, SSM will send Star Selector Rate commands to be summed with FGE internally computed rate commands) Continues tracking star in Fine Lock Mode until Search Track OFF command is received from SSM, or until star presence is lost.

If scan steps exceed a prescribed number before readiness to lock occurs, sets Scan Steps Limit Exceed Flag bit and enters Stop Mode

If star does not remain present in the period before readiness for lock occurs, resets Star Presence Flag bit and enters Stop Mode

If star presence is lost after fine lock has occurred, FGS resets Star Presence Flag and Data Valid Flag bits and enters Stop Mode

Sets Stop Flag bit, stops servo motion, and disables SS rate commands

SSM sends Search Track OFF Command

(Next Page)

[redacted]

FGS re-enters SSM Control Mode, resets status bits, and sets SSM Control Mode Status bit. If Data Valid Flag was set during Fine Lock Mode, FGS continues to test for star presence, and Star Presence Flag remains set until the star is no longer present. Data Valid Flag remains set until ST drifts or is driven out of the fine lock orientation. FGS is ready for new operation commands from SSM or power-down by STOCC

A (Exit from Coarse Track Mode to LOS Scan Mode)

Enters LOS Scan Mode, sets LOS Scan Mode Status bit, and conducts LOS Scan. Star Presence Flag bit remains set. FGS transmits telemetry data on PMT counts and star selector positions to provide a map at STOCC of the size, shape and intensity of the target image. At the end of the LOS Scan pattern, FGS positions star selectors to the location to resume coarse tracking nutation around the star at the center of the LOS Scan pattern, resets status bits, enters Coarse Track Mode and sets Coarse Track Mode Status bit.

GO TO B

SHUT DOWN MODE

In any FGS operating mode, when SSM sends a Shut Down command FGS disables servo unit torque, resets status bits and enters Shut Down Mode

For FGS to exit Shut Down Mode, STOCC must send commands to disable the FGE power supply

[redacted]

RESUME SEARCH MODE

While in Coarse Track Mode or Fine Lock Mode, the FGS will respond to a Resume Search command from the SSM to ignore the star being tracked and search for another star

↓

FGS resets all status and flag bits and sets Search Mode Status bit. Resumes a spiral search about the original center location but continuing from the location of the star being tracked. Star presence is not tested in the vicinity of the star being tracked when Resume Search was commanded.

↓ GO TO C (Star Detected)

↓ GO TO D (Star Not Detected)

DEFAULT CONDITION

In any operating mode the FGS will respond to a Default command from the SSM by exiting the present operating mode

↓

FGS enters Default Condition, resets status bits, sets Default ON Status bit, drives the star selector servos to a position outside the FGS field of view to protect the PMT's, and remains latched in Default Condition

↓

In order to unlatch the FGS from the Default Condition, SSM simultaneously sends Search Track Off Command (Logic 1) and Default Command Reset (Logic 0)

↓

FGS re-enters SSM Control Mode, resets status bits, and sets SSM Control Mode Status bit. FGS is ready for new operation commands from SSM or shut down by STOCC

Note 1:

The FGE automatically initializes its input command latch circuits and output data circuits during the 220 millisecond time delay following power supply enable to the following command and bit states:

Input Command Latch Circuits

Search Track OFF	Hold OFF
High Voltage OFF	Test Source OFF
Not Shut Down	LOS Scan OFF
Not Resume Search	Default OFF
Half Rate OFF	

Input Command Word Latch Circuits	Initialized Value (Decimal Equivalent of Binary Word)	Engineering Units
Fine Error Averaging Time	0	0.025 sec
Search Radius Limit	31	31.744 arc sec
Star Magnitude Window (Lower Limit)	100	100 PMT Counts
Star Magnitude Window (Upper Limit)	65,535	65,535 PMT Counts
Star Selector A & B Rate Commands	0	0 arc sec/sec
Filter Wheel Position	0	No Op

Output Data Circuits	Logic State
All Mode Status bits	0
All Flag bits	0

All parameters subject to modification by uplink modifier commands are initialized to Initial Values $(K_*)_I$ given in Table 13-1.

After initialization, all of the above circuits will remain in these initial states until commanded to another state by appropriate input command stimuli, except for the SSM Control Mode Status bit which is automatically set to Logic 1 at the end of the 220 millisecond time delay.

[redacted]

13.3 FLOW DIAGRAM REFERENCE/EQUATION LIST

13.3.1 A & B STAR SELECTOR (SS) RATE CMDS IN SEARCH AND TRACK MODE

SS A and B Rate Commands sent to the Servo Unit in the Search and Track mode shall be the sum of the processed SSM rate commands and the FGE computed rate commands.

The summed SS A and B rate commands sent to the Servo Unit shall be prevented from overflowing. That is, the magnitude of the rate commands shall be clamped to $(2^{15}-1)$ LSB units for any rate summation that would result in an overflow of this command.

13.3.1.1 FGE COMPUTED RATE MAGNITUDE COMMAND IN SEARCH AND TRACK MODE

The FGE computed rate magnitude command shall be a function of the pointing error, ε, and the parameter, K_1. The command is defined as follows:

$$|\dot{\theta}_A| = |K_1 \varepsilon_A| \text{ , for A SS Servo}$$

$$|\dot{\theta}_B| = |K_1 \varepsilon_B| \text{ , for B SS Servo}$$

where, $\varepsilon_A = \theta_A \text{ (next)} - \theta_A \text{ (enc)}$

$\varepsilon_B = \theta_B \text{ (next)} - \theta_B \text{ (enc)}$

θ_A (next) = next desired encoder A position, defined in figures 13-8 thru 13-15.

θ_B (next) = next desired encoder B position, defined in figures 13-8 thru 13-15.

θ_A (enc) = encoder A position.

θ_B (enc) = encoder B position.

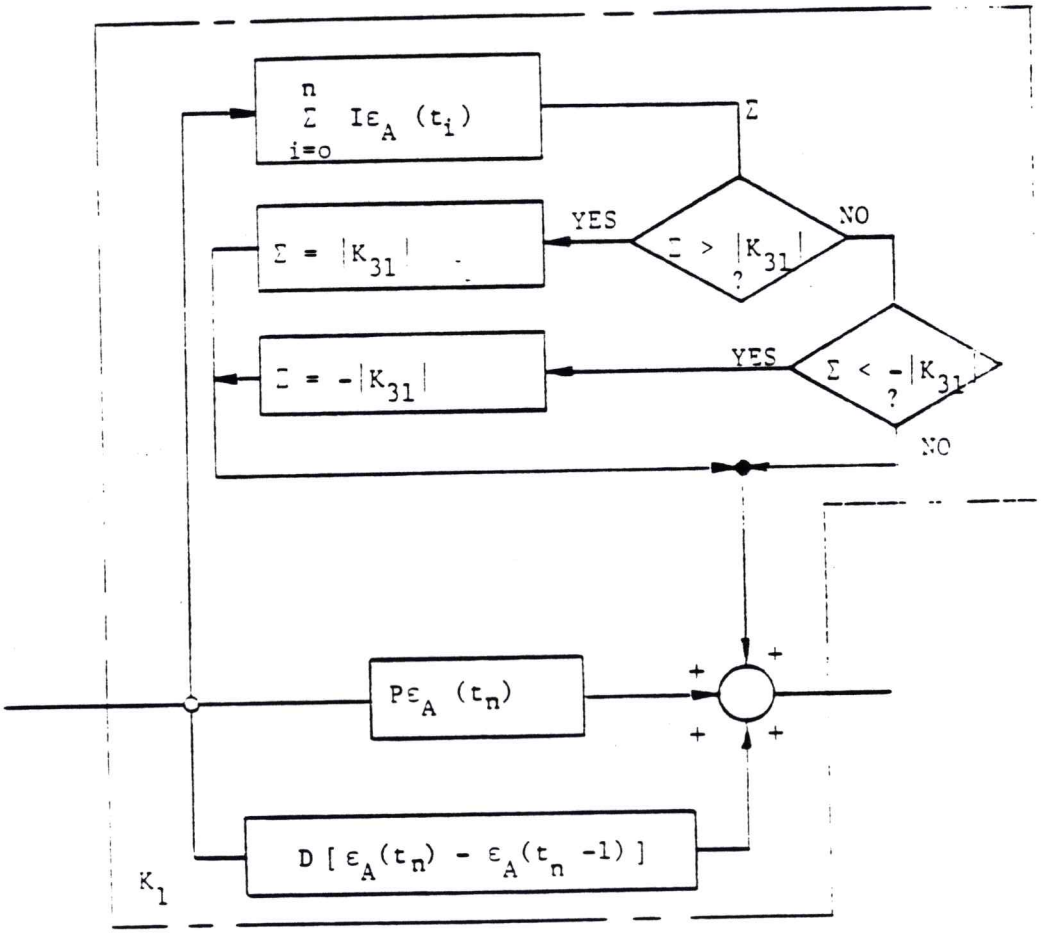
K_1 = a gain term consisting of a proportionality constant, an integration term and a derivative term. The PID coefficients of these terms shall be as follows:

<u>For all Search & Track Modes, Except Fine Lock, where Disabling Of FGE Computed Rate Cmds Not Required</u>:

$P = P_c = K_{10}$

$I = 0$

$D = 0$



NOTE: This K_1 block diagram is the same for ε_B, except that A is replaced by B.

PID Block Diagram

For all Search & Track Modes, Except Fine Lock, where Disabling Of FGE Computed Rate Cmds Is Required:

$P = P_t = K_{30}$

$I = 0$

$D = 0$

For Fine Lock Mode (DV=1)

$P = P_F = K_{13}$

$I = I_F = K_{14}$

$D = D_F = K_{15}$

For Fine Lock Mode (DV=0)

$P = P_C = K_{10}$

$I = 0$

$D = 0$

The K parameters are defined in Table 13-1 and Paragraph 13-3-9.

Additional requirements related to the A or B SS Servo rate magnitude commands shall be as follows:

a. Acceleration limit - the FGE computed rate command changes between the 40 Hz clock pulses shall be limited in the unit to K_{16}, a parameter defined in Paragraph 13-3.9 & Table 13-1. This limitation applies to either increasing or decreasing changes in the rate command.

b. Word length - 15 bits.

c. Disabling of FGE Computed Rate Commands (for nulling) - A test for disabling of the rate commands is required in the various operating modes of the unit (as defined in the flow diagrams) whenever nulling of the pointing error is required. When the test for disabling of the rate commands is specified, the following shall apply:

The FGE computed rate commands shall be simultaneously zeroed (i.e., all rate command bits set to logical "0") when the pointing error magnitudes are:

$|\varepsilon_A| < 3$ LSB's and $|\varepsilon_B| < 3$ LSB's

The acceleration limit requirement shall still apply to the above. That is, the disabling of the rate commands will be delayed until the acceleration limit is no longer exceeded and the pointing error magnitudes are less than the above defined values.

The FGE-computed rate commands shall be kept disabled until a new set of θ_A(NEXT) and θ_B(NEXT) values have been computed or a Search and Track Off command has been received.

d. Disabling of FGE Computed Rate Commands (for Search and Track Off)

Whenever a Search & Track Off command has been received, the FGE computed rate commands shall be disabled. These commands will be enabled again when the Search and Track mode is re-entered and a new set of θ_A(next) and θ_B (next) values have been calculated.

e. Resetting of PID Term

Following transition from coarse Track to Fine Lock, the following shall apply:

1. The contribution of the derivative term for the calculation of the first set of A and B rate commands shall be zero. Thereafter, the derivative term contribution shall be as defined in the PID Block Diagram.

f. Rate Command Overflow

The FGE computed rate commands shall be prevented from overflowing. That is, the magnitude of the rate commands shall be clampled to $(2^{15} - 1)$ LSB units for any rate computations that would result in an overflow of this command.

13.3.1.2 FGE-COMPUTED RATE SIGN COMMAND

The rate sign command for the FGE computed rate commands shall be defined as follows:

Rate Sign Cmd. = Logical '0' for positive values at Acceleration Limiter output.

Rate Sign Cmd. = Logical '1' for negative values at Acceleration Limiter output.

13.3.2 INTERFEROMETER SIGNAL PROCESSING ELECTRONICS

The following functions shall be performed using the pulse trains at the X-axis PMT #1 and #2 inputs, and the Y-axis PMT #1 and #2 inputs: integration, computation and DIM data transfer. The functions shall be performed concurrently and independently for each PMT pulse input.

13.3.2.1 INTERFEROMETER PMT PULSE INTEGRATION

Integration shall be defined as counting of pulses for a fixed time interval. PMT #1 and PMT #2 pulses for each axis shall be counted simultaneously but independently for a fixed time interval of 25 ms. The time interval shall be established by the period of the 40 Hz sync signal. Counting shall be performed to 16 bits of precision. The leading edge of the 40 Hz sync pulse shall cause the totalized counts in each counter to be frozen. The contents of each counter shall be stored and the counters reset to zero during the pulse duration time of the sync pulse. The trailing edge of the sync pulse shall initiate a new counting (integration) period. The stored contents of the counters shall be referred to simply as A and B (corresponding to PMT #1 and PMT #2 respectively).

The content of the counters shall be monitored during integration. When the contents reach the maximum capacity of the counter, the contents shall be frozen for the remainder of the integration period, after which it is stored as described above.

13.3.2.2 INTERFEROMETER DATA COMPUTATION

The following arithmetic computations shall be performed using the values A and B for the X and Y axes at the end of each 25 ms integration period. These computations are required only during the Fine Lock Mode and in the SSM Control Mode when the Star Presence Flag is set. In addition, the $\langle A + B \rangle_{16}$ average value shall be computed during the coarse track mode.

a. the difference $A - B$

b. the sum $A + B$

c. the average value $\langle A + B \rangle$ for 16 consecutive values $(A + B)$

d. The corrected average value $(\langle A + B \rangle - K_4)$

e. the quotient $Q = (A - B)/(\langle A + B \rangle - K_4)$

f. the function $R = K_o + K_1 Q(1 + K_3 Q^2)$

The values for the terms K_4, K_o, K_1 and K_3 for each axis are obtained from the remote DIU and shall be stored for use in these computations. The terms K_1, K_3, and K_4 will be unsigned integers: the term K_o, will be a signed integer.

13.3.2.2 INTERFEROMETER DATA COMPUTATION (cont'd)

The computation of <A + B> shall be done as follows. Initially, 16 consecutive values of A + B shall be accumulated as soon as they are computed at the end of each 25 ms integration period. The 16 values shall be added and the resultant sum divided by 16 to obtain the average value <A + B>. Thereafter, a running average shall be maintained. The running average shall be done as follows. At the end of each 25 ms integration period, a new value of A + B shall be added to the list of 16 previous values and the oldest value shall be deleted so that 16 entries remain on the list. An average shall be computed again. Thus, the value of <A + B> is updated at the end of each integration period. The value <A + B> shall be computed in 16 bit precision.

Computation of the function R shall be performed at the end of each 25 ms integration period and shall be completed before the leading edge of the SDW Data Enable DE5 pulse occurs. The value of R shall be computed to 8 bits of precision plus the sign bit. The value R shall be referred to as the Normalized Fine Error Signal. The X & Y axis values will be referred to as R_X and R_Y respectively.

13.3.2.3 NORMALIZED FINE ERROR SIGNAL (R) AVERAGING

Averaging of the X and Y Axis normalized Fine Error signals shall be performed during the Fine Lock Mode and in the SSM Control Mode when the Star Presence Flag is set. Although the data will not be meaningful, the Seller is not restricted from computing this average value in other operating modes.

13.3.3 $\Delta\theta_A$ / $\Delta\theta_B$ TRANSFORMATION CALCULATOR

13.3.3.1 X AND Y-AXIS TRANSFORMATION EQUATION

The following equations define the computations required to transform a rectangular coordinate incremental change, ΔX and ΔY, to a polar coordinate incremental change, $\Delta\theta_A$ and $\Delta\theta_B$:

$$\Delta\theta_A = 0.0657 \frac{(\Delta X \cos [2\pi \times 2^{-21} \times \theta_B] + \Delta Y \sin [2\pi \times 2^{-21} \times \theta_B])}{\sin [2\pi \times 2^{-21} (\theta_B - \theta_A)]}$$

$$\Delta\theta_B = -0.0657 \frac{(\Delta X \cos [2\pi \times 2^{-21} \times \theta_A] + \Delta Y \sin [2\pi \times 2^{-21} \times \theta_A])}{\sin [2\pi \times 2^{-21} (\theta_B - \theta_A)]}$$

These equations are used during different operating modes of the unit as defined below.

13.3.3.2 TRANSFORMATION COMPUTATIONS DURING LOS SCAN

The equations of Paragraph 13.3.3.1 shall be used for the coordinate transformation computations during the LOS Scan mode. These equations shall incorporate the parameters defined below.

13.3.3.2.1 PARAMETER DEFINITIONS FOR LOS SCAN MODE

a. θ_A DEFINITION: θ_A (PRESENT) expressed in digital format per Figure 13-15.

b. θ_B DEFINITION: θ_B (PRESENT) expressed in digital format per Figure 13-15.

c. θ_A RANGE: $0° \leq \theta_A \leq 135°$

d. θ_B RANGE: $45° \leq \theta_B \leq 180°$

e. $\theta_B - \theta_A$: $19° \leq \theta_B - \theta_A \leq 90°$

f. ΔX and ΔY: $\pm$Km (see Table 13-1 and Fig 13-15.)

g. $\Delta\theta_A$ and $\Delta\theta_B$ REQUIREMENT:

Word length: 13 bits, including the sign bit.

LSB weighting: 0.618 arc-seconds

Fractions: The computed results shall be in whole numbers. Rounded off of fractions shall be utilized.

13.3.3.2.2 SCALE CORRECTED TRANSFORMATION VALUES

The scale correction factor has already been included in the transformation equation of Paragraph 13.3.3.1 for use in the LOS Scan mode. Thus, the following values shall be utilized in this mode in accordance with Fig 13-15.

$$\Delta\theta_A \text{ (LOS)} = \Delta\theta_A$$

$$\Delta\theta \text{ (LOS)} = \Delta\theta_B$$

13.3.3.2.3 SCALE CORRECTED TRANSFORMATION VALUES

The scale correction factor has already been included in the transformation equation of Paragraph 13.3.3.2 for use in the Fine Lock mode. Thus, the following values shall be utilized in this mode in accordance with Fig 13-13

$$\Delta\theta_A \text{ (FL)} = \Delta\theta_A$$

$$\Delta\theta_B \text{ (FL)} = \Delta\theta_B$$

13.3.4 SPIRAL SCAN CALCULATOR

The Scan Calculator creates the Vector $(\overrightarrow{\rho_s, \emptyset_s})$ by increasing the magnitudes of ρ_s and $\emptyset_s$ with the respective values of $\Delta\rho$ and $\Delta\emptyset$. During a spiral scan ρ_s and $\emptyset_s$ are incremented by $\Delta\rho$ and $\Delta\emptyset$, respectively.

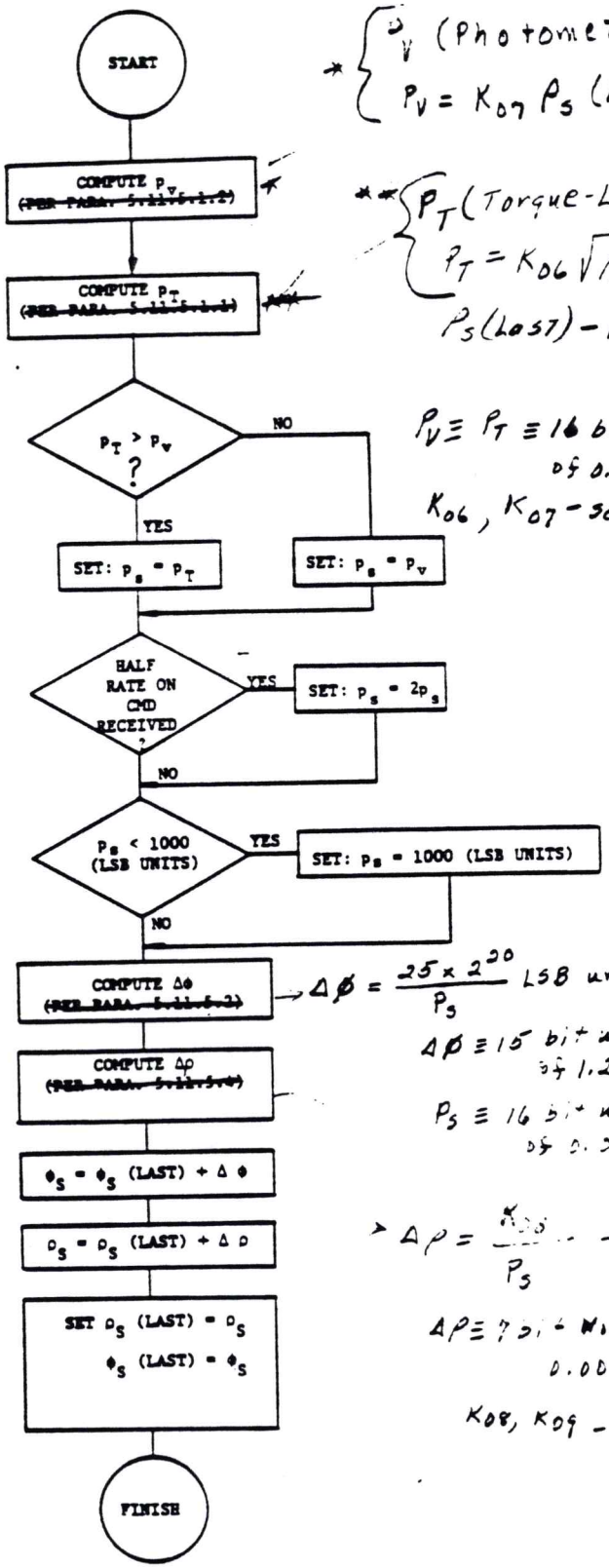
Both $\Delta\emptyset$ and $\Delta\rho$ are calculated as separate functions of the required period (p_s). p_s, in turn, is the largest of three values:

a. p_T, the period calculated as a function of torque limits

b. p_V, the period calculated as a function of photometry limits

c. 1000 milliseconds, the default period below which p_s is limited.

A flow diagram of the scan algorithm for calculating ρ_S and $\emptyset_s$ is shown in Figure 13-17.



p_V (Photometry Limited Period)
$P_V = K_{07} P_s$ (Last) LSB units

P_T (Torque-Limited Period)
$P_T = K_{06} \sqrt{P_s (Last)}$ LSB units

P_s (Last) – 17 bit word w/LSB value of 0.001 arc minute.

$P_V \equiv P_T \equiv$ 16 bit word with LSB value of 0.001 sec.

K_{06}, K_{07} – see Table 13-1

$$\Delta\phi = \frac{25 \times 2^{20}}{P_s} \text{ LSB units}$$

$\Delta\phi \equiv$ 15 bit word w/LSB value of 1.236 arc sec.

$P_s \equiv$ 16 bit word w/LSB value of 0.001 sec.

$$\Delta\rho = \frac{K_{08}}{P_s} - K_{09}$$

$\Delta\rho \equiv$ 7 bit word w/LSB value of 0.001 arc min.

K_{08}, K_{09} – see Table 13-1

FIG. 13-19 Spiral Scan Algorithm, Flow Diagram

13.3.5 VECTOR RESOLVER CALCULATOR

The Vector Resolver Calculator converts stored star selector encoder angles, $\{\theta_A(ST), \theta_B(ST)\}$, to spherical polar coordinates defined by a vector of arc length (R_{CTR}) at an angle (θ_{CTR}). The Vector Resolver also calculates a vector (R_p, θ_p), from the vector addition of $\overrightarrow{(R_{CTR}, \theta_{CTR})} + \overrightarrow{(\rho, \emptyset)}$.

The Vector Resolver performs an inverse calculation to yield a new (θ_A, θ_B), defined as θ_A(NEXT) and θ_B(NEXT). The inputs for this calculation are the values R_p and θ_p as defined above. The θ_A(NEXT) and θ_B(NEXT) are used to generate star selector rate commands in the SS Servo Rate Command Electronics.

13.3.5.1 VECTOR $\{\overrightarrow{R_{CTR}(ST), \theta_{CTR}(ST)}\}$

$$R_{CTR}(ST) = \cos^{-1}\left[C_3C_5 - C_2C_4 \cos\{[\theta_B(ST) - \theta_A(ST)] - (C_6 + C_7 - C_1)\}\right]$$

$$\theta_{CTR}(ST) = \theta_A(ST) - C_1 + \cos^{-1}\left[\frac{C_5 - C_3 \cos R_{CTR}(ST)}{C_2 \sin R_{CTR}(ST)}\right]$$

($\cos^{-1}$ is always positive in both equations).

13.3.5.1.1 $R_{CTR}(ST)$, $\theta_{CTR}(ST)$ Definition

$R_{CTR}(ST)$ is a 20 bit magnitude word with an LSB weight of 0.001 arc-minute.

$\theta_{CTR}(ST)$ is a 20 bit magnitude word with an LSB weight of 0.618 arc-seconds.

13.3.5.1.2 $\theta_A(ST)$, $\theta_B(ST)$ DEFINITION

$\theta_A(ST)$ is a 20 bit magnitude word with an LSB weight of 0.618 arc-seconds.

$\theta_B(ST)$ is a 20 bit magnitude word with an LSB weight of 0.618 arc-seconds.

$\theta_B(ST) > \theta_A(ST)$ at all times.

13.3.5.1.3 VALUES OF PARAMETERS

Parameter values used in this equation shall be as follows:

$$C_1 = K_{20}$$

$$C_6 + C_7 - C_1 = K_{21}$$

$$C_2 = \sin \theta_5 + K_{22}$$

$$C_3 = \cos \theta_5 + K_{23}$$

$$C_4 = \sin \theta_7 + K_{24}$$

$$C_5 = \cos \theta_7 + K_{25}$$

$$\theta_5 = \theta_7 = 406.655 \text{ arc-minutes}$$

See Paragraph 13.3.4 and Table 13-1 for definition of the K parameters.

C_2, C_3. C_4 and C_5 are 20 bit numbers.

13.3.5.2 VECTOR $(\overrightarrow{R_p, \theta_p})$

The defining equations are:

$$R_p = \cos^{-1} [\cos \rho \cos R_{CTR} - \sin \rho \sin R_{CTR} \cos (\emptyset - \theta_{CTR})]$$

$$\theta_p = \theta_{CTR} - \left[\pi/2 - \cos^{-1} \left(\frac{\sin (\theta_{CTR} - \emptyset) \sin\rho}{\sin R_p}\right)\right]$$

13.3.5.2.1 DEFINITION (R_p, θ_p)

Same as $R_{CTR}(ST)$ and $\theta_{CTR}(ST)$, respectively

See paragraph 13.3.5.1.1.

13.3.5.2.2 DEFINITION $(\rho, \emptyset)$

Defining equations are:

$$\rho_s = \rho_s(\text{LAST}) + \Delta\rho \text{ arc-minutes}$$

$$\emptyset = \emptyset_s(\text{LAST}) + \Delta\emptyset \text{ arc-seconds}$$

ρ_s & ρ_s(LAST) a 17 bit word w/LSB value of 0.001 arc minute.

$\emptyset$ is a 20 bit magnitude word with an LSB weight of 1.236 arc-seconds

13.3.5.3 θ_A(NEXT) AND θ_B(NEXT)

The defining equations are:

$$\theta_A(\text{NEXT}) = C_1 + \theta_p - \cos^{-1}\left[\frac{C_5 - C_3 \cos R_p}{C_2 \sin R_p}\right]$$

$$\theta_B(\text{NEXT}) = (C_6 + C_7 - C_1) + \theta_A(\text{NEXT}) + \cos^{-1}\left[\frac{C_3 C_5 - \cos R_p}{C_2\ C_4}\right]$$

13.3.5.3.1 DEFINITION OF θ_A(NEXT), θ_B(NEXT)

Same as θ_A(ST) and θ_B(ST), respectively.

See paragraph 13.3.5.1.2.

13.3.5.3.2 VALUES OF PARAMETERS

Parameter values used in this equation shall be as given in Paragraph 13.3.5.1.3

13.3.6 I(t) COMPUTATION

At the end of each PMT pulse integration period an I(t) value shall be computed,

$$I(t) = (A + B)_x + (A + B)_y$$

The values of A + B for both x and y axes are available from the interferometer computations in Paragraphs 13.3.2, 13.3.2.1 and 13.3.2.2.

The values $(A + B)_x$ and $(A + B)_y$ are statistical in nature and will vary randomly from sample to sample. The maximum value of I(t) will be 65,535. This shall be described as a 16 bit binary unsigned integer. The minimum value of I(t) is 12. I(t) may assume any integer value between these limits.

13.3.7.1 STAR PRESENCE DETECTION IN SEARCH

a. At the end of each 40 Hz sample interval, the computed I(t) value, obtained from Paragraph 13.3.6 shall be compared to the commanded I_L and I_H limits as follows:

$$I_L < I(t) < I_H$$

b. If I(t) falls within the above limits, set SP = "1". If outside, set SP = "0".

c. Once SP is set to "1" during Search, it shall remain in this state pending the outcome of subsequent star presence tests in Coarse Track and Fine Lock.

13.3.7.2 STAR PRESENCE DETECTION IN COARSE TRACK

a. At the end of each 40 Hz sample interval, the computed I(t) value shall be compared to the commanded I_L and I_H limits as follows:

$$I_L < I(t) < I_H$$

b. If I(t) falls within the above limits, SP remains in the "1" state. If outside, set SP = "0". If the SP = "1" condition occurs after each star presence test in Fig. 13-11 a counter is incremented. If the totalized counts in this counter at the end of each course track nutation cycle does not exceed a specified limit given in Fig 13-11, transition to the Stop Mode shall be made.

13.3.7.3 STAR PRESENCE DETECTION IN FINE LOCK

a) At the end of each 40 Hz sample interval, the computed I(t) value shall be compared to the commanded I_L and I_H limits as follows:

$$I_L < I(t) < I_H$$

b) If I(t) falls within the limits, set SP = "1". If outside, set SP = "0". If the SP = "0" condition occurs for the number of sample intervals (clock cycles) defined in Fig 13-13 transition to the Stop Mode shall be made.

13.3.8 COARSE TRACK DRIFT COMPUTATIONS

13.3.8.1 $\dot{X}$ COMPUTATION

The computation of $\dot{X}(o)$ shall be as follows:

$$\dot{X}(o) = 2 \sum_{n=1}^{16} z_x$$

where z_x is defined in Fig. 13-11.

Initially, 16 values of z_x shall be sampled and stored in conformance with Fig. 13-11. Thereafter, as each new value of z_x is sampled per Fig. 13-11, it shall be added to the list of 16 previously sampled values. The oldest value shall be deleted so that the 16 most recently sampled z_x values always remain in storage. The summation required in the above equation is the sum of these z_x values held in storage. A new value of $\dot{X}(o)$ shall be calculated after every second z_x value is sampled as per Fig 13-11.

Each new $\dot{X}(0)$ value is to be stored as shown in Fig 13-11. A total of 8 storage locations shall be provided. The location containing the most recent value shall be designated $\dot{X}(1)$ and the location with the oldest value as $\dot{X}(8)$. After the 8 storage locations have been filled, the storing of each $\dot{X}(0)$ value into the $\dot{X}(1)$ location shall cause the oldest value in the $\dot{X}(8)$ location to be deleted. The $\dot{X}(8)$ location shall then be replaced with the next oldest value from the $\dot{X}(7)$ location, the $\dot{X}(7)$ with the $\dot{X}(6)$ value, and so forth.

NOTE: The LSB of X is defined in Table 13-4.

13.3.8.2 $\dot{Y}$ COMPUTATION

The $\dot{Y}$ computation and storage shall be defined in Paragraph 13.3.8.1 except replace z_x and $\dot{X}$ with z_y and $\dot{Y}$, respectively.

13.3.8.3 DRIFT ERROR COMPUTATION

The Drift Error Computation shall be computed as follows:

$$\text{Drift Error} = [\dot{X}(0) - \dot{X}(8)]^2 + [\dot{Y}(0) - \dot{Y}(8)]^2$$

Since $\dot{X}(8)$ and $\dot{Y}(8)$ are lost when $\dot{X}(0)$ and $\dot{Y}(0)$ are stored in the stack, the Drift Error must be calculated before the stack is updated.

13.3.9 PARAMETER VALUE CALCULATOR

13.3.9.1 PARAMETERS ADJUSTABLE BY AN UPLINK MODIFIER

For those parameters (K_*) adjustable via an Uplink Modifier, the following definitions apply:

K_* = the operational value, selected by the unit as defined below.

$(K_*)_I$ = the initial value, a constant residing in the unit.

$(K_*)_F$ = the fixed value, a constant residing in the unit

$(K_*)_U$ = the Uplink Modifier, an SDW Command word.

Table 13-1 indicates which parameters can be adjusted by an Uplink Modifier.

13.3.9.1.1 K_* VALUE

The value of K_* shall be selected in accordance with Paragraphs 13.3.9.1.2 and 13.3.9.1.3 to be either,

$$K_* = (K_*)_I$$

or $$K_* = (K_*)_F \times (K_*)_U$$

The K_* value is the value used in the flow diagrams.

13.3.9.1.2 $(K_*)_I$ VALUE

The $(K_*)_I$ value is the initial operating value. $(K_*)_I$ will be equal to $(K_*)_F$ for SDW CMD No. is 1-0 through 4-2. $(K_*)_I$ will be equal to zero for SDW Cmd No. 4-3 through 5-7.

$(K_*)_I$ shall be the value used for K_* following Unit Initialization but prior to its modification by an Uplink Modifier.

If no Uplink Modifier is received by the unit, the operational value, K_*, shall continue to be equal to the initial value, $(K_*)_I$. The values for $(K_*)_I$ are given in Table 13-1.

13.3.9.1.3 $(K_*)_F \times (K_*)_U$ PRODUCT

The prevailing value of K_* shall be replaced by the product $(K_*)_F \times (K_*)_U$ within 25 milliseconds after the last arrival of $(K_*)_U$.

Each Uplink Modifier shall be dedicated to affect only one particular $(K_*)_F$ (e.g., $(K_L)_U$ can only affect K_L).

The values for $(K_*)_F$ and $(K_*)_U$ are given in Table 13-1.

13.3.9.1.4 $(K_*)_U$ FORMAT AND CHARACTERISTICS

Each $(K_*)_U$ value is obtained from an SDW command word via SDW Command Port 2. The format for each $(K_*)_U$ shall be as defined in Table 13-3.

$(K_*)_U$ shall be assigned the following characteristics:

$(K_*)_U$ Magnitude: 8 bits total, 5 bit binary fraction
LSB = 1/32
MSB = 4

$(K_*)_U$ Sign: Logic '1' = negative value
Logic '0' = positive value

$(K_*)_U$ range: $-7\frac{31}{32} \leq (K_*)_U \leq +7\frac{31}{32}$

13.3.9.2 PARAMETERS NOT ADJUSTABLE BY AN UPLINK MODIFIER

Whenever a parameter, K_*, is not adjustable by an Uplink Modifier as indicated in Table 13-1 the following shall apply:

$$K_* = (K_*)_I$$

The value for K_* is simply an unalterable constant equal to $(K_*)_I$. Values for $(K_*)_I$ are given in Table 13-1.

App. 13.4.1

13.4 Appendix

13.4.1 FGS Catalog Design Optical Distortion

Attachment 1

OPTICAL TECHNOLOGY DIVISION

SPACE TELESCOPE PROGRAM

MEMORANDUM

80-D&D-1455
13 May 1980

TO: Distribution

FROM: Ken Selger

SUBJECT: FGS CATALOG DESIGN OPTICAL DISTORTION

REF:
1. PR-264, "Star Selector Analysis of Fine Guidance System (SE-03)", March, 1979.
2. PR-403, "Star Selector Coordinate Conversion", March 1980.
3. ST-SE-873, "Information for SSM Flight Software", December 10, 1979.

Star coordinates in the FGS system are specified by the encoder shaft angles θA and θB. Star coordinates in the space telescope are given in Polar coordinates, a radial angle and an azimuthal angle. The conversion from one set of coordinates to the other requires two transformations. The first converts a star's object space coordinates to image space coordinates. The second uses the image space coordinates to convert to encoder shaft angle coordinates θA and θB. The latter transformation is given by Vollaro in Reference 1 and derived by Tsiang in Reference 2. This memorandum addresses the former transformation.

The values given in Table 1 would enable the user to convert star angles in object space to image space for the catalog optical design. A catalog optical design is one using the catalog values for the indices of the glass elements. For the FGS design this represents the theoretical design. Actual glass indices have not been included nor have manufacturing errors been considered. Manufacturing errors have been described in general terms by two 14-term polynominal in Reference 3.

In a perfect telescope the object space radial* angles can be converted to image space angles by simply multiplying those angles by a constant called the magnification. In a real optical system, however, the magnification changes with field angle. The variation can be mathematically described through the use of an odd power series expansion. The form of this equation is as follows:

(Image Space) = (Object Space) X (Magnification) + (Object Space)^3 X (a coefficient) + (Object Space)^5 x (second coefficient) + ...

Table 1 gives the coefficients that were determined for the Space Telescope's catalog design.**

The coefficients were determined by least-squares fitting polynominals of varying order to a set of measured object space and image space angles. The angles were determined through the use of the optical design program MEXP. Object space angles were inputted into the program, the program then calculated the output angles in image space. Double precision mathematics was used throughout, however, only eight significant digits are printed. This limitation produces a round-off error of approximately .0002 arc seconds.

The magnfication used for the calculations is the paraxial magnification as reported by the optical design program MEXP. The numerical value of the magnification is equal to 57.249715. In the four cases considered this number was held constant. A total of 40 measured points were used. Eighty-one points in all were used by including the mirror image points at negative field angles and a center point at 0.

* Azimuthal angles are the same in object space and image space and there is no aximuthal design distortion.

**All angles expressed in degrees unless otherwise specified.

Table 1 below gives the maximum error determined using 0, 1, 2 or 3 coefficients. The errors are given in object space angles. One approach that was not tried would be to allow the magnification to change. The magnification would still be a constant for any particular polynomial but would be a different constant for different polynomials. This procedure should have the effect of reducing the residuals from those given in Table 1.

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$$\theta_p = \theta_0 M + \theta_0^3 k_3 + \theta_0^5 k_5 + \theta_0^7 K_7$$

$$= \theta_0 \left(M + \theta_0^2 k_3 + \theta_0^4 K_5 + \theta_0^6 K_7 \right)$$

$$\frac{M'}{M}(\theta_0) = 1 + \theta_0^2 \frac{k_3}{M} + \theta_0^4 \frac{k_5}{M} + \theta_0^6 \frac{K_7}{M}$$

$$\frac{M'}{M}(12') = 1 + (0.2)^2 \frac{-8.0507687}{57.249715} + (0.2)^4 \frac{10.7689768}{57\ldots} + (0.2)^6 \frac{-3.336329}{57\ldots}$$

$$= 1 - 0.005328$$

$$= 0.994672$$

$\Rightarrow$ 6.4" over 20'

TABLE 1

MAXIMUM DISTORTION VS. # OF TERMS IN THE POLYNOMIAL FIT

# OF TERMS	MAG	3RD	5TH	7TH	MAX ERROR ARC SEC OB. SP.
1	57.249715	-	-	-	6.0929
2	57,249715	-7.5674782	-	-	0.0827
3	57.249715	-8.04468604	10.4795606	-	0.0003
4	57.249715	-8.0507687	10.7689968	-3.336329	0.0002 *

* ERROR IS LIMITED BY INPUT DATA USED FOR FIT I.E. NOISY DATA.

13-80

App 13.4.1

App. 13.4.2

F. Hemenway Writeup
on
Initial Calibration

App. 13 A.3

OTA SYSTEMS
ENGINEERING
27 JULY 1982

OTA ORBITAL VERIFICATION AND MISSION OPERATIONS SOFTWARE REQUIREMENTS DESCRIPTION FOR OTA OPTICAL FIELD ANGLE DISTORTION CALIBRATIONS

I. Software Package Group Name - OTA OFF-LINE OPERATIONS

II. Software Package Name - OTA OPTICAL FIELD ANGLE DISTORTION CALIBRATIONS

III. INTRODUCTION

The detailed requirements for OTA Optical Field Angle Distortion Calibrations to satisfy the need for astrometric measurements to an accuracy of ±0.002 arc seconds rms, and to satisfy the ST Astrometry Team that the calibration procedures will provide the most accurate calibration results, have not yet been fully established. Dr. Paul Hemenway, of the Astrometry Team and the University of Texas at Austin, has been most helpful in explaining some of the possible alternative provisions which may appear in the final requirements of the Astrometry Team, and in providing technical guidance and suggestions to Perkin-Elmer in the preparation of this description.

OTA Optical Field Angle Distortion calibration results have two uses, and the accuracy requirements differ greatly between the two. The greater accuracy is required to support ST astrometry measurements, and the Astrometry Team will conduct its own data processing to develop calibration corrections for those measurements. The other use is to provide corrected pointing commands for the FGS's for guide star acquisition and vehicle pointing to support science observations. The software to support this application is described herein and is expected to be a great deal simpler

than that to be developed by the Astrometry Team. However, the ST orbital operations required to provide data are expected to be the same for both purposes, so a single set of orbital calibration operations will probably be used for both.

The reader should keep in mind that this description of software requirements is preliminary in nature and is subject to significant change as the calibration requirements and procedures are developed and as the algorithms to be programmed are developed over the next year or so. It is provided at this time for use by the PASS contractor in planning its software development effort and in preliminary estimates of software size.

IV. Calibration Objective

The objective of the OTA Optical Field Angle Distortion Calibration is, for each FGS field of view, to map the differences, as a function of FGS field position, between a perfect projection of points in object space onto a spherical surface in OTA image space (using the design value of plate scale), and the location of those points in image space indicated by the FGS star selector encoder readings and distorted by the OTA and FGS optics. This is to be done to an accuracy consistent with the measurement of the relative angular positions of three or more objects within the FGS field of view to an accuracy of ±0.002 arc seconds rms. A secondary objective is to verify FGS photometric precision.

V. Calibration Method

Each FGS will be calibrated independently, while the other two FGS's are locked onto guide stars to control the OTA/ST line of sight. The following discussions are written for FGS 3 calibration—FGS 1 and 2

calibrations will be performed in the same way as FGS 3.

1. FGS 3 will be pointed to a star field in which there are at least 25 (TBD-See Note below) stars of m_v = 9 to 13 within its field of view with roughly uniform distribution. While the OTA line of sight is held fixed, FGS 3 will be commanded to acquire each of the 25 stars in succession and to collect position data on each for 51.2 (TBD) seconds while in Fine Lock Mode. One or more of the 25 star positions may be measured a second time for confirmation of stability of measurements during this period of observations.

   NOTE: The number of stars and the number of positions of the FGS field of view to be used for astrometry calibration purposes will be analyzed by the Astrometry Team. Likewise, Perkin-Elmer will be analyzing the numbers from the viewpoint of optimizing the calibration process for the less stringent requirements imposed by guide star and astrometry target acquisition and by Scientific Instrument pointing. Since the orbital calibration operations should probably be common to the two purposes, and since it may be desirable to use the PASS calibration software for a quick look at astrometry calibration data collection results, the PASS software may be based on the same numbers of stars and field of view positions as the astrometry calibration software. The numbers of stars and field of view positions ultimately selected may vary significantly from those used in this initial description of requirements. The product of the number of stars and number of field of view positions will be subject to much less variation than each of its components.

2. The OTA line of sight will be repositioned in yaw so that the stars at the center of the FGS 3 field of view in Step 1 move radially outward approximately 0.9 (TBD) arc minutes (object space) from their Step 1

positions, and the position measurements described in Step 1 will be repeated for those members of the 25 stars which are still within the FGS 3 field of view.

3. The OTA line of sight will be repositioned in pitch relative to its Step 1 position so that the stars at the center of the FGS 3 field of view in Step 1 move tangentially clockwise approximately 0.9 (TBD) arc minutes (object space) from their Step 1 positions, and the position measurements described in Step 1 will be repeated for those members of the 25 stars which are still within the FGS 3 field of view.

4. The OTA line of sight will be repositioned equally in pitch and yaw relative to its Step 1 position so that the stars at the center of the FGS 3 field of view in Step 1 move radially outward and tangentially counter-clockwise approximately 0.9 (TBD) arc minutes (object space) from their Step 1 positions, and the position measurements described in Step 1 will be repeated for those members of the 25 stars which are still within the FGS 3 field of view.

5. The OTA line of sight will be repositioned equally in pitch and yaw relative to its Step 1 position so that the stars at the center of the FGS 3 field of view in Step 1 move radially outward and tangentially clockwise approximately 0.9 (TBD) arc minutes (object space) from their Step 1 positions, and the position measurements described in Step 1 will be repeated for those members of the 25 stars which are still within the FGS 3 field of view.

Figure 1 shows the five positions of the FGS field of view relative to the 25-star field as described in Steps 1-5 above. The numbers in the outer corners of the field of view positions represent the applicable Step numbers. The "+" marks are intended to represent stars, and their distribution is probably much more uniform than will be the case in the actual calibration.

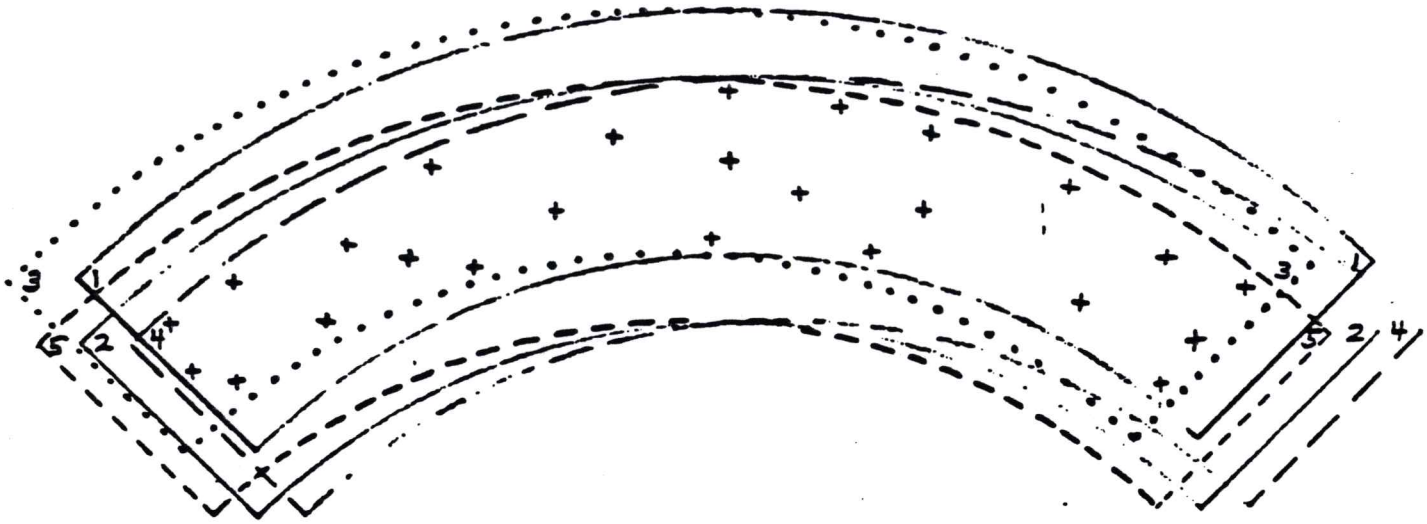


Figure 1. FGS Field of View Positions Relative to 25-Star Field.

VI. Software Package Objectives

To perform the data processing and computations to determine the detailed form of, and values of the constants in, two polynomial equations required to define the corrections which must be applied to image space position measurements derived from FGS star selector position readings to compensate for OTA and FGS optical field angle distortions. A secondary objective is to perform the data processing to confirm OTA photometric precision.

VII. Software Output Requirements

Output requirements are summarized below, and described in further detail in Section IX below in the descriptions of software functional requirements.

1. Printer Outputs - results of intermediate calculation steps and of final calibration results.
2. X-Y Plotter and Graphic Display Outputs - display of field of view of the FGS being calibrated showing reference star locations and identities in their calibration Step 1 position, and with the Step 2-5 positions of the FGS overlaid on the Step 1 position similar to the sketch in Figure 1. The graphic routines should be capable of vector residual plots.

VIII. Data Inputs

1. The number designations and names of current OTA telemetry measurements to be monitored and analyzed are given in Section IX below in the descriptions of software functional requirements. Sample rates for each measurement in the 32 kbps telemetry format to be used for astrometry operations are given in Perkin-Elmer Specification SG 679-1087B General

Specification for OTA Instrumentation Program Component List (DM-02) of 11-17-81.

2. Data required from the engineering data base will include the OTA and SSM telemetry calibration data to convert binary counts into engineering units, telemetry format data to permit decommutation of telemetry data streams to acquire specified measurements, SDW command definitions to convert binary counts into engineering units, and the "Initial Values" of FGS Uplink Modifier parameters used by the FGE in the absence of Uplink Modifier Commands.

3. Results of prior data processing which will be required to support these requirements include the following:

   a. Astrometry headers giving the identity of each of the reference stars and guide stars used in the FGS Optical Field Angle Distortion Calibrations, together with the time period, predicted Star Selector Position measurements and SDW command values applicable to FGS operation for each astrometric observation or guide star tracking.

   b. Post-facto ST orbit, to provide accurate ST position in orbit (definitive orbit) versus UTC, and velocity aberration corrections.

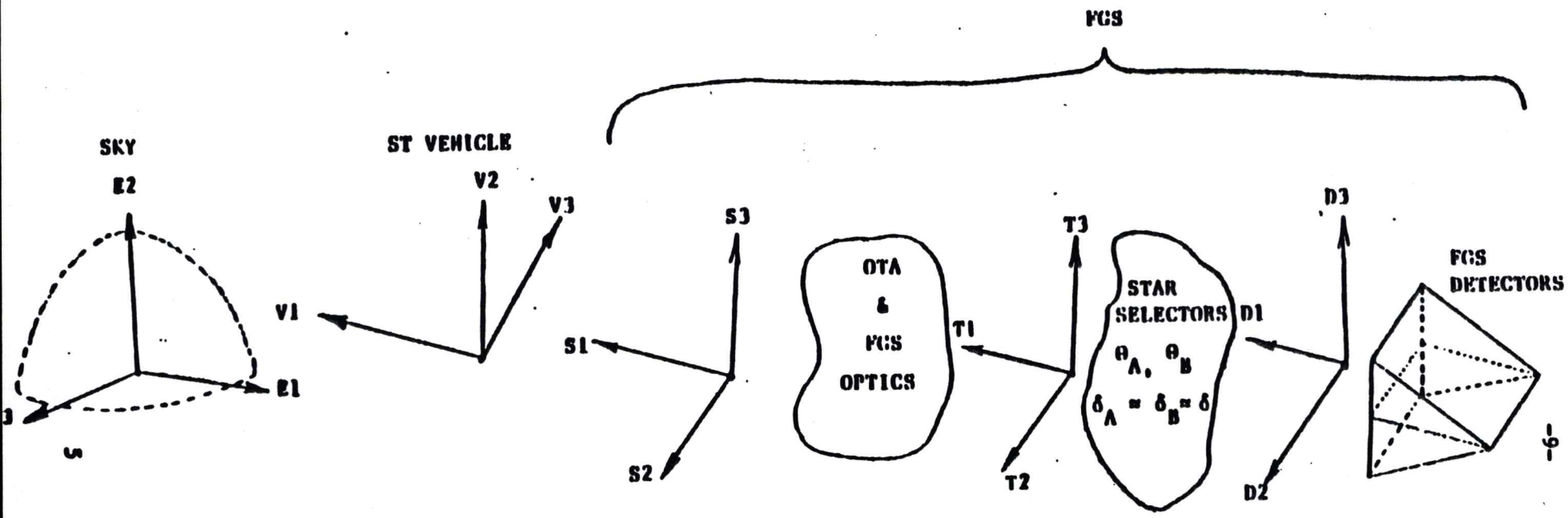
   c. Accurate ephemeris of Earth.

IX. Software Functional Requirements

In this preliminary description of software requirements, a description of the data processing and computations required to support the Optical Field Angle Distortion Calibrations is substituted in place of flow diagrams and algorithms.

(Telemetry Measurement designations are for FGS 3).

1. For each of the five positions of the FGS FOV relative to the star field, record the A and B Star Selector Average Position measurements (F03H649M-654M) for each of the star observations. (See Note at the end of Section IX). For each measurement, calculate the UTC time for the mid-point of the averaging time period using the Vehicle Time word in each telemetry minor frame and SSM-supplied timing information for the applicable telemetry format. Print out the object identity, average position and mid-point time for each of the observations.
2. For each of the star observations in Step 1 above, calculate the average position of the guiding FGS star selectors by averaging the A and B Star Selector Position measurements (F03H609M-614M) over the observation time period. Print out the results with the data from Step 1 above.
3. Convert all A and B star selector average position sets into image space spherical polar coordinates ($\hat{R}_{ip}$ and $\hat{\theta}_{ip}$) relative to the FGS Ti coordinate system, assuming zero alignment error between the FGS and the OTA optical axes. (See Figure 2 for Ti and Si coordinate system descriptions.)
4. Correct each of the calculated average position sets ($\hat{R}_{ip}$ and $\hat{\theta}_{ip}$) for orbital aberration computed from definitive orbit data.
5. Conduct a statistically rigorous mathematical process to establish the best fit of the values for the constants in the following equations to accurately correct star selector average position data collected in the calibration operations to measure angular separations of the stars in object space:



Coordinate System Name	Equatorial Inertial	Vehicle Control Axes	Fine Guidance Sensor	FGS Star Selector Pupil	FGS Detector
Letter Designation	E →	V →	S →	T →	D
Conversion Process	ST Attitude (SSM)	Alignment (Rotation, Translation)	Optical Distortion & Scale	Star Selector Rotation	

Figure 2. Relationships among the Five Coordinate Systems that Relate the Fine Guidance Sensor to the Sky.

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$$R_{ip} = F(\hat{R}_{ip}, \hat{\theta}_{ip}) = D_{i1} + (1 + D_{i2})\hat{R}_{ip}$$
$$+ D_{i3}\hat{R}_{ip}^2 + D_{i4}\hat{R}_{ip}\hat{\theta}_{ip} + D_{i5}\hat{R}_{ip}^3 + D_{i6}\hat{R}_{ip}^2\hat{\theta}_{ip}$$
$$+ D_{i7}\hat{R}_{ip}\hat{\theta}_{ip}^2 + D_{i8}\hat{R}_{ip}^4 + D_{i9}\hat{R}_{ip}^3\hat{\theta}_{ip} + D_{i10}\hat{R}_{ip}^2\hat{\theta}_{ip}^2$$
$$+ D_{i11}\hat{R}_{ip}\hat{\theta}_{ip}^3 + D_{i12}\hat{R}_{ip}^5 + D_{i13}\hat{R}_{ip}^7$$

$$\theta_{ip} = G(\hat{\theta}_{ip}, \hat{R}_{ip}) = D_{i14} + (1 + D_{i15})\hat{\theta}_{ip}$$
$$+ D_{i16}\hat{\theta}_{ip}^2 + D_{i17}\hat{\theta}_{ip}\hat{R}_{ip} + D_{i18}\hat{\theta}_{ip}^3 + D_{i19}\hat{\theta}_{ip}^2\hat{R}_{ip}$$
$$+ D_{i20}\hat{\theta}_{ip}\hat{R}_{ip}^2 + D_{i21}\hat{\theta}_{ip}^4 + D_{i22}\hat{\theta}_{ip}^3\hat{R}_{ip} + D_{i23}\hat{\theta}_{ip}^2\hat{R}_{ip}^2$$
$$+ D_{i24}\hat{\theta}_{ip}\hat{R}_{ip}^3 + D_{i25}\hat{\theta}_{ip}^5 + D_{i26}\hat{\theta}_{ip}^7$$

Where: $\hat{R}_{ip}$ = radial component of image space spherical polar coordinates relative to the FGS Ti coordinate system, calculated from A and B star selector average position of a star, assuming zero optical field angle distortion and zero alignment error between the FGS and OTA optical axes, and corrected for orbital aberration.

$\hat{\theta}_{ip}$ = azimuthal component of image space spherical polar coordinates relative to the FGS Ti coordinate system, calculated from A and B star selector average position of a star, assuming zero optical field angle distortion and zero alignment error between the FGS and OTA optical axes, and corrected for orbital aberration.

R_{ip} = radial component of object space spherical polar coordinates relative to the FGS Si coordinate system, after correction of $\hat{R}_{ip}$ for optical field angle distortion and magnification.

θ_{ip} = azimuthal component of object space spherical polar coordinates relative to the FGS Si coordinate system, after correction of $\hat{\theta}_{ip}$ for optical field angle distortion and magnification.

The known facts are (1) the values of $\hat{R}_{ip}$ and $\hat{\theta}_{ip}$ derived from star selector position data for each star position observation, (2) that the angular separations in object space between each pair of reference stars remain constant throughout the calibration data collection period, and (3) that the two equations above will accurately correct for field angle distortions and alignment errors in the optical system when the best set of constants is chosen.

The unknowns are the best values for the Di(n) coefficients and the values for R_{ip} and θ_{ip} for each of the star position observations.

6. To evaluate the photometric precision of each FGS individually, for each star whose position is measured by that FGS, calculate the mean value, standard deviation and maximum deviation from the mean value of all photometric measurements made of the star. A photometric measurement for the purpose is defined as the average value during the period of measurement of its A and B star selector average positions of the sum of the X and Y Fine Count (PMT A) and (PMT B) telemetry measurements (F03Q601M through 608M). Also calculate the standard deviations and maximum deviations as percentages of the mean values. Group stars according to visual magnitude values, and calculate standard deviations and maximum deviations as a percentage of mean values for each group.

Note: On the Use of Star Selector Average Position Data.

For each position observation of a reference star in the field of view of the FGS being calibrated, in addition to providing raw A and B Star Selector Position measurements 40 times per second in telemetry, the FGE automatically averages the positions of the A and B Star Selectors over a 51.2 second, or shorter, period following the time that fine lock tracking operation is achieved. For both A and B Star Selectors, it averages the star selector positions for 32 of the integration periods (fine error averaging times) of the fine lock tracking operation. With the fine error averaging time commanded to be 1.6 seconds, the 32 samples require 51.3 seconds to accumulate, plus another 0.2 second maximum to transmit via telemetry (32 kbps format). Each of these measurements should represent relative positions of the observed bodies to an accuracy of ±0.001 (TBD) arc seconds in object space, assuming the design value for plate scale and neglecting optical field angle distortion.

This method of measuring the positions of reference stars is presently planned to be used for determining optical field angle distortion calibration corrections in the MOGS for use in correcting FGS pointing commands for acquiring guide stars and astrometry targets. More accurate optical field angle distortion calibration results are required for the purpose of processing operational astrometry measurements in order to measure relative positions to an accuracy of ±0.002 arc seconds rms. Such accuracy is required for astrometry, and it is understood that the Astrometry Team will perform its own processing of optical field angle distortion calibration data, using raw rather than FGE-averaged data, in order to achieve the required astrometry calibration accuracies. Therefore, it is assumed that the MOGS software requirements are based on the use of FGE-averaged position measurements. The actual use of this technique in the final software depends upon continued favorable results of error analyses as the procedures and algorithms are developed during the next year.

Astrometry
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28 June 1982
OTA SYSTEMS
ENGINEERING

OTA ORBITAL VERIFICATION AND MISSION OPERATIONS SOFTWARE REQUIREMENTS DESCRIPTION FOR PLATE SCALE CALIBRATIONS

I. Software Package Group Name - OTA OFF-LINE OPERATIONS

II. Software Package Name - PLATE SCALE CALIBRATIONS

III. INTRODUCTION

The detailed requirements for Plate Scale Calibrations to satisfy the need for astrometric measurements to an accuracy of ±0.002 arc seconds rms, and to satisfy the ST Astrometry Team that the calibration procedures will provide the most accurate calibration results, have not yet been fully established. Dr. Paul Hemenway, of the Astrometry Team and the University of Texas at Austin, has been most helpful in explaining some of the possible alternative provisions which may appear in the final requirements of the Astrometry Team, and in providing technical guidance and suggestions to Perkin-Elmer in the preparation of this description.

Plate scale calibration results have two uses, and the accuracy requirements differ greatly between the two. The greater accuracy is required to support ST astrometry measurements, and the Astrometry Team will conduct its own data processing to develop calibration corrections for those measurements. The other use is to provide corrected pointing commands for the FGS's for guide star acquisition and vehicle pointing to support science observations. The software to support this application is described herein and is expected to be a great deal simpler than that to be developed by the Astrometry Team. However, the ST orbital operations required to provide data are the same for both purposes, so a single set of calibration operations should be used for both.

III. (Continued)

The reader should keep in mind that this description of software requirements is preliminary in nature and is subject to significant change as the calibration requirements and procedures are developed and as the algorithms to be programmed are developed over the next year or so. It is provided at this time for use by the PASS contractor in planning its software development effort and in preliminary estimates of software size.

IV. Calibration Objective

The objective of the Plate Scale Calibration is to measure the OTA effective focal length and plate scale for each FGS field of view, to an accuracy consistent with the measurement of the relative angular positions of three or more objects within the FGS field of view to an accuracy of ±0.002 arc seconds rms. A FGS Optical Field Angle Distortion Calibration must be performed before or in conjunction with the Plate Scale Calibration to provide the data for correcting plate scale measurements for the effects of field angle distortions.

V. Calibration Method

Each FGS will be calibrated independently by making repetitive position measurements over a one day to several day period of an asteroid with well known ephemeris while the ST is pointed at a fixed point and with a fixed roll angle relative to the celestial sphere. The orientation of the ST will be chosen so that the asteroid will move from one outer corner of the FGS field of view to the other, which represents approximately 19 arc minutes of relative angular movement, as shown in Figure 1.

The method for calculating the effective focal length and plate scale will be to measure, in essence, the linear distance traversed across the

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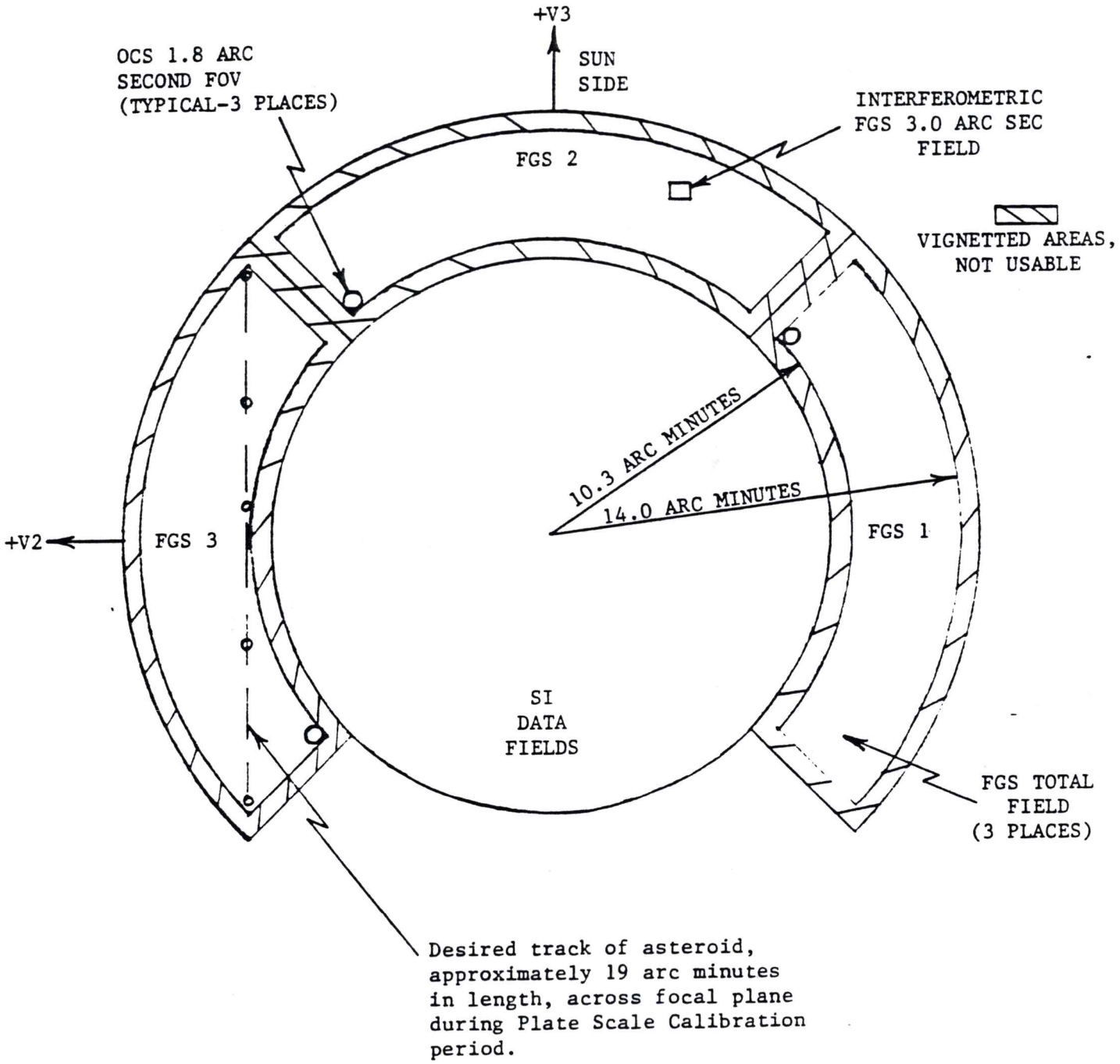

Figure 1. Asteroid Track in OTA Focal Plane During Plate Scale Calibration

V. (Continued) FGS field at the OTA focal plane by the asteroid's image during the time that the asteroid traverses a known angular displacement relative to the ST. Effective focal length and plate scale will be calculated by the following equations:

$$\text{EFL} = \frac{y \text{ (mm, linear displacement in the image plane)}}{\tan\theta \text{ (arc seconds, angular displacement in object space)}}$$

$$\text{Plate Scale} = \frac{\theta \text{ (arc seconds)}}{y \text{ (mm)}}$$

The required characteristics of the asteroid used for each FGS calibration will be as follows:

1. Its image in the FGS will be an unresolved disk.
2. Its ephermeris shall be well known to provide predictions of its angular position changes in the FGS field of view to an accuracy of ±0.0005 (TBD) arc seconds rms per 20 arc minutes.
3. Its brightness shall be between m_v = 15 (TBD) and m_v = 10 (the brighter asteroids within this range are preferred).
4. Its apparent motion shall be within the "Quasi-Static" range, i.e., less than 0.020 arc seconds per second.
5. Its apparent motion shall be great enough to move across 19 arc minutes within several days.
6. Its location relative to Earth and Sun at the time of the calibration shall permit orientation of the ST during the observations so that sun angle restrictions are not violated. (See Figure 2).
7. Its relative orbital path at the time of the calibration shall pass through a star field with many (on the order of 10 to 20) reference stars suitable for astrometric measurement in the same FGS field of view as the asteroid, and with several potential guide stars in each of the fields of view of the other two FGS's.

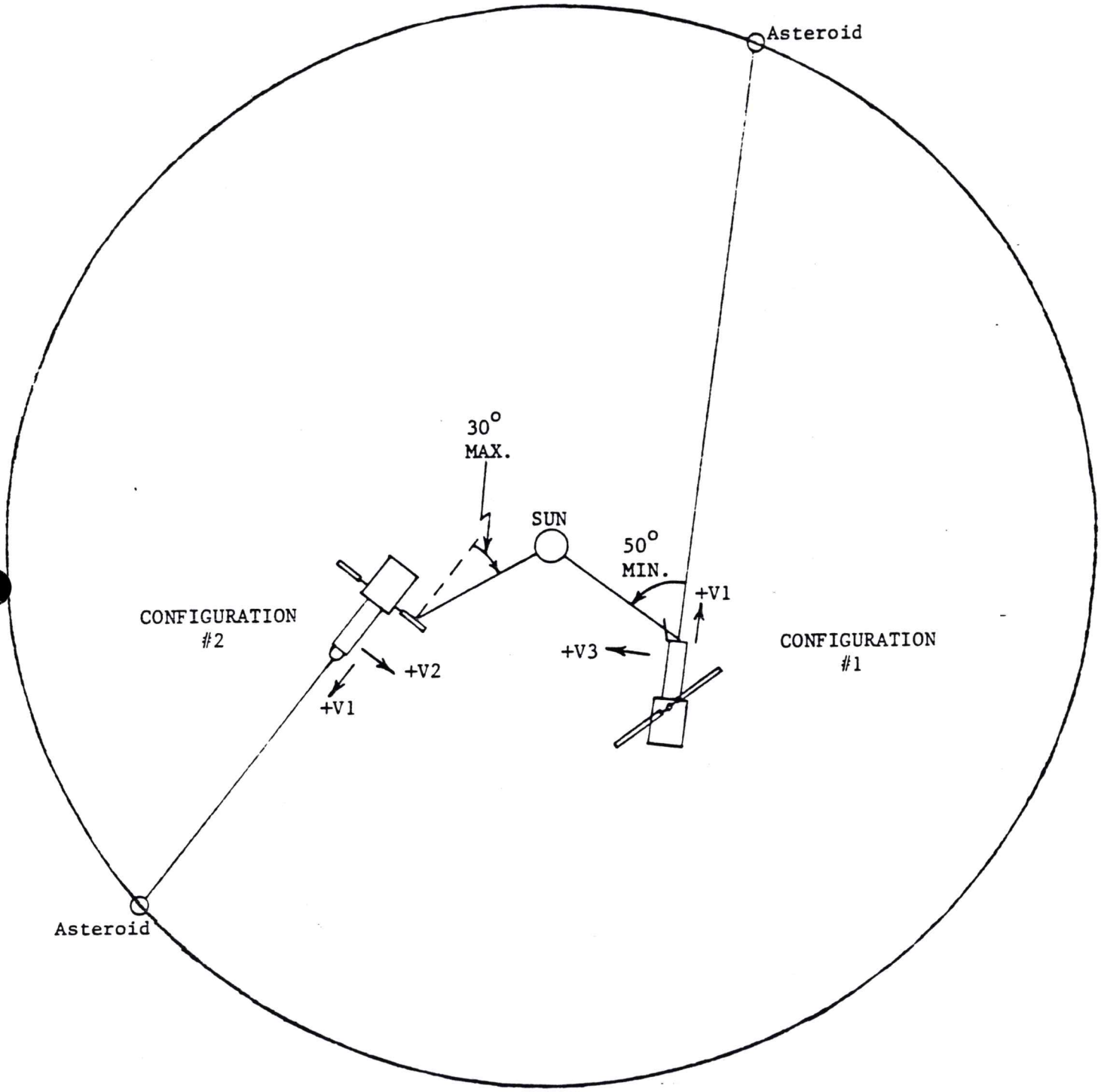

Figure 2. Relative Orbital Orientations for Plate Scale Calibrations

There are somewhat over 2000 named and numbered asteroids. Almost all known asteroids satisfy characteristics 4 and 5 above. A few hundred known asteroids are small enough and bright enough to satisfy characteristics 1 and 3. Perhaps only 20 asteroids have been observed well enough to date to satisfy characteristic 2. However, orbits of all known asteroids are known well enough to determine their satisfaction of characteristics 6 and 7 once the date of calibration has been set within a month. For any asteroids which will satisfy all required characteristics except ephemeris accuracy, a modest ground based observation campaign can provide data to satisfy that characteristic.

The probable need for such a ground based observation campaign can be visualized from the following discussion. The probability that one or two of the 20 asteroids which presently satisfy the first five characteristics listed above will also satisfy the sixth and seventh characteristics at the particular time a calibration operation is desired is small because of the operational restrictions regarding sun angle. This can be seen in Figure 2, which is a sketch showing two possible configurations of relative positions among sun, ST and asteroid for conducting plate scale calibrations. Most asteroid orbits lie reasonably close to the plane of the ecliptic, so, for simplicity of figures and discussion, the configurations in Figure 2 and the following discussion assume coplanarity. For actual calibration planning, of course, the asteroid orbit inclinations must be taken into account.

To significantly decrease the probable need to violate the operational sun angle restrictions, and the degree of such violations, a modest ground based observational campaign seems to be a very attractive solution when and if required. However, even with that potential solution, some restrictions may still be encountered at some desired times of calibration.

Configuration 1 is applicable to that required for plate scale calibrations for FGS 1 and FGS 3. For these, the vehicle V1-V3 plane must be parallel to the asteroid orbit plane in order to achieve the required motion of the asteroid image across the FGS fields. For calibration with FGS 2, the vehicle V1-V2 plane must be parallel to the asteroid orbit plane, and so Configuration 2 applies.

In Configuration 1, an asteroid can be observed through about 70 percent of its orbit, so the probability of having at least one asteroid which satisfies all requirements at any time should be quite high. Violation of the 50 degree minimum pointing angle to the sun does not appear to be a feasible means of increasing asteroid availability because the increased stray light in the OTA, while it may not impede bright asteroid observations, would impede the making of accurate astrometric measurements on reference stars during the calibration process.

In Configuration 2, an asteroid can be observed only through about 17 percent of its orbit because of the requirement to keep the sun within 30 degrees of the V1-V3 plane. At any particular time, the probability of having a suitable member of the 20 asteroids available for this case is low, particularly when the requirements of both characteristics 6 and 7 are considered. Without adding to the population of suitable asteroids through additional ground based observations, it will probably be necessary to violate the 30 degree restriction occasionally. This can probably be done for short periods of time and/or by minimizing ST power consumption during this period without serious impact on electrical power management. Another possible partial solution may be that some asteroids with orbits inclined as much as 30 degrees from the ecliptic plane may be found to be suitable for the calibration with FGS 2, with less deviation required from the 30 degree restriction.

Given the availability of a suitable asteroid for the period of the calibration operation, the calibration procedure will be as follows:

1. Acquire guide stars with the two guiding FGS's. Position the guide stars at star selector positions in the two FGS's so that the long axis (through the outer corners) of the field of view of the FGS to be calibrated is parallel to the orbit plane of the asteroid, and the asteroid is 30 arc seconds (TBD) from one end of the long axis of the field, from which its relative motion will cause it to traverse to the other end.

   NOTE: This, and all subsequent observations for the duration of this calibration operation for this FGS, will be performed with the Pointing Control Subsystem controlling vehicle orientation to hold the four star selector position angles in the two guiding FGS's approximately centered on these same readings. This will insure that the OTA optical axis will be pointed very close to the same position on the celestial sphere for each observation.

2. Acquire the asteroid with the third FGS. After Fine Lock Mode has been achieved, collect position data for one minute (TBD).

3. Immediately shift the third FGS to acquire the first of 10 to 20 (TBD) reference stars. Each reference star shall be sufficiently distant from Earth that the parallax error in measuring its position will be negligible for the duration of the calibration period (i.e., annual parallax less than ±0.0045 arc second), or else corrections should be made for known parallactic shifts. Collect position data for one minute (TBD) of Fine Lock Mode operation.

4. Repeat Step 3 above for the remainder of the reference stars.

5. Repeat Step 2 above with the asteroid. This completes one of 3 to 5 (TBD) sets of observations of the asteroid and reference stars for this calibration of one FGS.
6. Repeat Steps 1 through 5 above for the first FGS. This can probably be done using the same asteroid, provided that suitable reference and guide stars exist at the slightly modified OTA pointing direction.
7. Repeat Steps 1 through 5 above for the second FGS. This may require a different asteroid to minimize reductions in solar array power output.
8. When relative motion of the asteroid has caused its image to traverse one-quarter to one-half (TBD) of the distance along the FGE field major axis, conduct the second set of observations of the asteroid and reference stars for each FGS, by repeating Steps 1 through 7 above.
9. At appropriate times, conduct the third, fourth and fifth (TBD) sets of observations by repeating Steps 1 through 7 above each time.

   NOTE: The time required for the asteroid to traverse the 19 arc minutes across each FGS field will vary among FGS's if different asteroids are used. Therefore, timing between observation sets may vary among FGS's.

VI. Software Package Objectives

To perform the data processing and computations to determine the effective focal length of the OTA in each FGS field of view from the telemetry data collected during the Plate Scale Calibration operations, using the results of the FGS Optical Field Angle Distortion Calibrations to correct star selector position measurements.

VII. Software Output Requirements

Output requirements are summarized below, and described in further detail in Section IX below in the descriptions of software functional requirements.

1. Printer Outputs - results of intermediate calculation steps and of final calibration results.
2. X-Y Plotter Outputs - display of field of view of the FGS being calibrated showing reference star locations and identities, asteroid observed positions and appropriate calculation results.

VIII. Data Inputs

1. The number designations and names of current OTA telemetry measurements to be monitored and analyzed are given in Section IX below in the descriptions of software functional requirements. Sample rates for each measurement in the 32 kbps telemetry formats to be used for astrometry operations are given in Perkin-Elmer Specification SG 679-1087B General Specification for OTA Instrumentation Program Component List (DM-02) of 11-17-81.
2. The number designations, names and sample rates of non-OTA telemetry measurements are TBD.
3. Data required from the engineering data base will include the OTA and SSM telemetry calibration data to convert binary counts into engineering units, telemetry format data to permit decommutation of telemetry data streams to acquire specified measurements, SDW command definitions to convert binary counts into engineering units, and the "Initial Values" of FGS Uplink Modifier parameters used by the FGE in the absence of Uplink Modifier Commands.
4. Results of prior data processing which will be required to support these requirements include the following:
   a. FGS Optical Field Angle Distortion Calibration results giving for each FGS the errors in Star Selector Position telemetry measurements in defining FGS line of sight in object space caused by optical field angle distortion.

VIII. 4. (Continued)

b. Astrometry headers giving the identity of each of the asteroids, reference stars and guide stars used in the Plate Scale Calibrations, together with the time period, predicted Star Selector Position measurements and SDW command values applicable to FGS operation for each astrometric observation or guide star tracking.

c. The actual commands transmitted to the OTA from the SSM affecting FGS search and track operations and the precise times of their transmission to the OTA.

d. Accurate asteroid ephemeris based on full solar system integration plus ground based support.

e. Post-facto ST orbit, to provide accurate ST position in orbit versus UTC (definition orbit).

f. Accurate ephemeris of Earth.

IX. Software Functional Requirements

In this preliminary description of software requirements, a description of the data processing and computations required to support the Plate Scale Calibrations is substituted in place of flow diagrams and algorithms.

A. For each position observation of an asteroid or reference star in the field of view of the FGS being calibrated, in addition to providing raw A and B Star Selector Position measurements 40 times per second in telemetry, the FGE automatically averages the positions of the A and B Star Selectors over a 51.2 second period (see note below) following the time that fine lock tracking operation is achieved. For both A and B Star Selectors, it averages the star selector positions for 32 of the integration periods (fine error averaging times) of the fine lock

IX. A. (Continued) tracking operation. With the fine error averaging time commanded to be 1.6 seconds, the 32 samples require 51.3 seconds to accumulate, plus another 0.2 second maximum to transmit via telemetry (32 kbps format). When each of these measurements has been corrected for combined optical alignment, plate scale and field angle distortion errors, the results should represent relative positions of the observed bodies to an accuracy of ±0.002 arc seconds, assuming the design value for plate scale.

This method of measuring the positions of asteroids and reference stars is presently planned to be used for determining plate scale calibration corrections in the MOGS for use in correcting FGS pointing commands for acquiring guide stars and astrometry targets. More accurate plate scale calibration data are required for the purpose of processing operational astrometry measurements in order to measure relative positions to an accuracy of ±0.002 arc seconds rms. Such accuracy is required for astrometry, and it is understood that the Astrometry Team will perform its own processing of plate scale calibration data, using raw rather than FGE-averaged data, in order to achieve the required astrometry calibration accuracies. Therefore, it is assumed that the MOGS software need not duplicate the Astrometry Team software capability, and the following MOGS software requirements are based on the use of FGE-averaged position measurements. The actual use of this technique in the final software depends upon continued favorable results of error analyses as the procedures and algorithms are developed during the next year.

NOTE: The 51.2 second averaging period is the calculated time required to achieve astrometric measurement accuracies of ±0.002 arc seconds rms

for the dimmest astrometry targets (m_v = 17), so that averaging period has been assumed initially herein for all astrometric measurements. For bright asteroids and stars it may prove to be sufficient to use shorter averaging periods, such as 25.6 seconds or 12.8 seconds.

B. Description of Requirements

(Telemetry Measurement designations are for FGS 1).

1. For each quasi-static observation position of the asteroid, record the A and B Star Selector Average Position measurements (F01H049M-054M) for each of the reference stars and for the two observations of the asteroid position. For each measurement, calculate the UTC time for the mid-point of the averaging time period using the Vehicle Time word in each telemetry minor frame and SSM-supplied timing information for the applicable telemetry format. Print out the object identity, average position and mid-point time for each of the observations.

2. For each of the asteroid and reference star observations in Step 1 above, calculate the average position of the guiding FGS star selectors by averaging the A and B Star Selector Position measurements (F01H009M-014M) over the observation time period. Print out the results with the data from Step 1 above.

3. Convert all A and B star selector average position sets into focal plane polar coordinates (R_{ip} and Θ_{ip}) relative to the OTA optical axis.

4. Calculate corrected average positions ($\hat{R}_{ip}$ and $\hat{\Theta}_{ip}$) for each of the measurements in Steps 1 and 2 above by applying corrections for combined alignment, plate scale and optical field angle distortion derived from the OTA calibration for FGS Optical Field Angle Distortion, and for orbital aberration computed from definitive orbit data.

IX. B. 5. Convert corrected average positions ($\hat{R}_{ip}$ and $\hat{\Theta}_{ip}$) from focal plane polar coordinates to focal plane rectilinear (gnomonic) coordinates $\hat{x}_i$ and $\hat{y}_i$ (hereinafter referred to as x and y).

> The following description, for one FGS, is based on performing four (4) observation sets of the positions of ten (10) reference stars and the asteroid (two asteroid position observations per set). As mentioned in Section V, the numbers of reference stars and observation sets are TBD.

6. Using the first observation set of the ten (10) reference stars as an arbitrary "standard", calculate the displacements of the latter three observation sets relative to the "standard" by a statistically rigorous method, for the purpose of accurately referencing each of the eight (8) asteroid position measurements to the same "standard" background frame.
7. From the 8 observations of asteroid position, calculate the asteroid positions in x and y coordinates relative to the "standard" background frame.
8. Using a statistically rigorous method, calculate the x and y components of asteroid velocity relative to the "standard" background frame from the 8 sets of x and y data calculated in Step 7 and using the times of observations calculated in Step 1.
9. Using asteroid ephemeris data, and assuming the design value of plate scale, calculate expected values of the x and y components of asteroid velocity.

IX. B. 10. Compare ephemeris predictions versus observed values of asteroid velocity and calculate the plate scale correction and the OTA effective focal length.

11. Print out appropriate results of intermediate steps as well as the results of plate scale and effective focal length calculations.

12. Present an x-y plotter display of the field of view of the FGS being calibrated showing the reference star locations and identities,. asteroid observed positions and times of observation, and appropriate results of position calculations.

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OTA SYSTEMS
ENGINEERING
27 July 1982

OTA ORBITAL VERIFICATION AND MISSION OPERATIONS SOFTWARE REQUIREMENTS DESCRIPTION FOR FGS/SI ALIGNMENT CALIBRATIONS

I. Software Package Group Name - OTA OFF-LINE OPERATIONS

II. Software Package Name - FGS/SI ALIGNMENT CALIBRATIONS

III. INTRODUCTION

This description of requirements for software to support the FGS/SI Alignment Calibrations after ST deployment in orbit is based on the current plan for conducting the calibrations and processing the data. This description is provided for use by the PASS contractor in planning its software development effort and in preliminary estimates of software size. The reader should keep in mind that this description of software requirements is preliminary in nature and is subject to significant change as the calibration plans and procedures, and the algorithms to be programmed, are developed over the next year or so.

IV. Calibration Objective

The objective of the FGS/SI Alignment Calibration is to measure the alignment of each FGS and SI to the optical V1, V2, V3 coordinate system to permit accurate calculation of guide star pointing angles for efficient acquisition of science targets in the centers of SI apertures.

V. Calibration Method

The calibration will consist of two sets of steps: (1) the determination

of the orientation of the optical V1, V2, V3 axes relative to the three FGS on-axis lines of sight, and (2) the measurement of the angular position of each SI aperture relative to the V1, V2, V3 axes.

The definition of the V1, V2, V3 axes is given in the SSM to OTA ICD-01C in Section 3.3.5.5 as follows:

"The (on-axis*) line of sight of each FGS is defined as the projection of interferometer error nulls into object space for star selector settings of $\theta_A = 0^\circ$ and $\theta_B = 180^\circ$. The OTA V1 axis is the line of sight equidistant from the 3 FGS (on-axis*) lines of sight. The V3 axis is the line perpendicular to V1 in the plane containing the V1 axis and the line of sight of FGS 2, with its star selection settings at $\theta_A = \theta_B = 90^\circ$. The V2 axis is the cross product of V3 and V1."

*"on-axis" is added to the ICD definition for added clarity.

When $\theta_A = 0^\circ$ and $\theta_B = 180^\circ$, the FGS line of sight is nominally aligned parallel to the OTA optical axis (and is, therefore, outside the FGS field of view). When $\theta_A = \theta_B = 90^\circ$, the FGS line of sight is nominally displaced 14.2 arc minutes (object space) from the OTA optical axis and is on the line from the OTA optical axis which bisects the FGS field of view.

The alignment calibration will be conducted after the Optical Field Angle Distortion and Plate Scale Calibrations, so that star selector position data can be corrected for the effects of distortion and plate scale to calculate FGS line of sight positions in object space.

For the first part of the calibration procedure, which is that of determining the orientation of the optical V1, V2, V3 axes relative to the three FGS lines of sight, the OTA will be pointed toward a star field in

which there are several (about five) stars in each FGS field of view whose relative positions (among the fifteen stars) are known with high astrometric accuracy (astrometric standard stars). Then, with two FGS's controlling vehicle pointing direction, the third FGS will be used to make astrometric position measurements of the five (TBD) astrometric standard stars in its field of view. The process will then be repeated so that each of the other two FGS's will also make astrometric position measurements of the five (TBD) astrometric standard stars in its own field of view.

After these data are used to calculate the orientation of the V1, V2, V3 axes relative to the FGS star selector readings, a suitable SI target and pair of guide stars will be used to perform line of sight raster or dwell scan maneuvers for each SI to determine the angular orientation of its field of view relative to the V1, V2, V3 axes.

VI. Software Package Objectives

To perform the data processing and computations to determine the orientation of the V1, V2, V3 axes relative to the three FGS lines of sight, and to determine orientations of the fields of view of the five Scientific Instruments relative to the V1, V2, V3 axes.

VII. Software Output Requirements

Software outputs shall be in the form of printer displays of the results of intermediate calculation steps and final calibration results. They are described in further detail in Section IX below in the descriptions of software functional requirements.

VIII. Data Inputs

1. The number designations and names of current OTA telemetry measurements to be monitored and analyzed are given in Section IX below in the descriptions of software functional requirements. Sample rates for each measurement in the 32 kbps telemetry formats to be used for astrometry operations are given in Perkin-Elmer Specification SG 679-1087B General Specification for OTA Instrumentation Program Component List (DM-02).

2. Data required from the engineering data base will include the OTA and SSM telemetry calibration data to convert binary counts into engineering units, telemetry format data to permit decommutation of telemetry data streams to acquire specified measurements, SDW command definitions to convert binary counts into engineering units, and the "Initial Values" of FGS Uplink Modifier parameters used by the FGE in the absence of Uplink Modifier Commands.

3. Results of prior data processing which will be required to support these requirements include the following:

   a. Astrometry headers giving the identity of each of the reference stars and guide stars used in the FGS/SI Alignment Calibrations, together with the time period, predicted Star Selector Position measurements and SDW command values applicable to FGS operation for each astrometric observation or guide star tracking.

   b. Optical Field Angle Distortion Calibration results giving, in effect, for each FGS the errors in Star Selector Position telemetry measurements in defining FGS line of sight in object space caused by optical field angle distortion.

   c. Plate Scale Calibration results giving for each FGS the relationship between object space and image space angles.

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d. Results of analysis of SI scanning maneuver data giving the orientation of each SI field of view as a function of star selector positions of the two guiding FGS's. (This is assumed to be provided by Science Operations Ground System).

e. Post-facto ST orbit, to provide accurate ST position in oribt (definitive orbit) versus UTC, and velocity aberration corrections.

f. Accurate ephemeris of Earth.

IX. Software Functional Requirements

In this preliminary description of software requirements, a description of the data processing and computations required to support the FGS/SI Alignment Calibrations is substituted in place of flow diagrams and algorithms. (Telemetry Measurement designations are for FGS 3).

1. For each FGS, record the A and B Star Selector Average Position measurements (F03H649M-654M) for each of the astrometric standard star observations. For each measurement, calculate the UTC time for the mid-point of the averaging time period using the Vehicle Time word in each telemetry minor frame and SSM-supplied timing information for the applicable telemetry format. Print out the object identity, average position and mid-point time for each of the observations. Why?

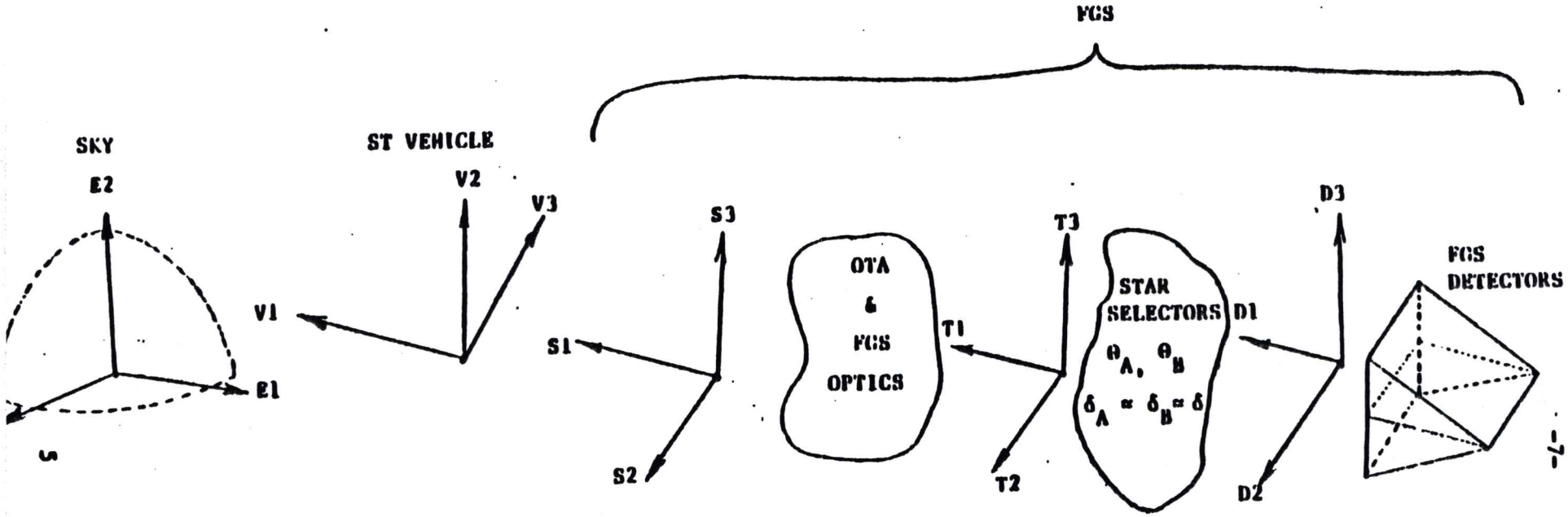
2. For each of the star observations in Step 1 above, calculate the average position of the guiding FGS star selectors by averaging the A and B Star Selector Position measurements (F03H609M-614M) over the observation time period. Print out the results with the data from Step 1 above.

3. Convert all A and B star selector average position sets into image space polar coordinates ($\hat{R}_{ip}$ and $\hat{\theta}_{ip}$) relative to the FGS Ti coordinate system. (See Figure 1).

4. Correct each of the calculated average position sets ($\hat{R}_{ip}$ and $\hat{\theta}_{ip}$) for optical field angle distortion and plate scale, and for orbital aberration computed from definitive orbit data, to provide corrected spherical polar coordinate data in object space relative to the FGS Si coordinate system. (FGS optical axis is the S1 axis).

5. Conduct a statistically rigorous mathematical process to compare the angular displacements measured between each star pair whose positions were observed simultaneously (between each astrometric standard star and each guide star) against the known astrometric separations for those stars, and, from the apparent errors in the measured values, to calculate the mean position of each of the FGS "on-axis lines of sight" relative to the V1 (mid-point), V2, V3 axes. (The orientation of each FGS line of sight must be determined to a one sigma accuracy of ±0.002 (TBD) arc second).

6. Using the results of prior data processing giving orientations of the SI apertures as a function of star selector positions of the two guiding FGS's (Section VIII. 3. d.), and the known angular separations among guide stars and SI targets, calculate the orientation of each SI aperture relative to the V1, V2, V3 axes.



Coordinate System Name	Equatorial Inertial	Vehicle Control Axes	Fine Guidance Sensor	FGS Star Selector Pupil	FGS Detector
Letter Designation	E →	V →	S →	T →	D
Conversion Process	ST Attitude (SSM)	Alignment (Rotation, Translation)	Optical Distortion & Scale	Star Selector Rotation	

Figure 1. Relationships among the Five Coordinate Systems that Relate the Fine Guidance Sensor to the Sky.

13.4.6

1 December 1982
OTA Systems
Engineering

OTA ORBITAL VERIFICATION AND MISSION OPERATIONS SOFTWARE REQUIREMENTS DESCRIPTIONS

FGS INTERFEROMETER TRANSFER FUNCTION ANALYSIS

I. SOFTWARE PACKAGE GROUP NAME -- OTA OFF-LINE OPERATIONS

II. SOFTWARE PACKAGE NAME - FGS INTERFEROMETER TRANSFER FUNCTION ANALYSIS

III. INTRODUCTION

This description of requirements for ground system software to conduct on-orbit measurements of the FGS interferometer transfer functions is provided for use by the PASS contractor in planning its software development effort and for preliminary estimates of software size. The reader should keep in mind that this description of software requirements is preliminary in nature and is subject to significant change when the algorithms to be programmed are developed at a future date.

IV. MEASUREMENT OBJECTIVE

The objective of this software package is to measure the transfer functions* of the FGS interferometers on orbit. The reasons for making these measurements are as follows:

- To ascertain whether any changes took place as a result of handling, launch, and injection.
- To detect any changes in the quantum efficiency of the photomultipliers. (Degradation of the performance of a single photomultiplier would result in an asymetrical transfer function).
- To determine whether there are any effects attributable to target color temperature.

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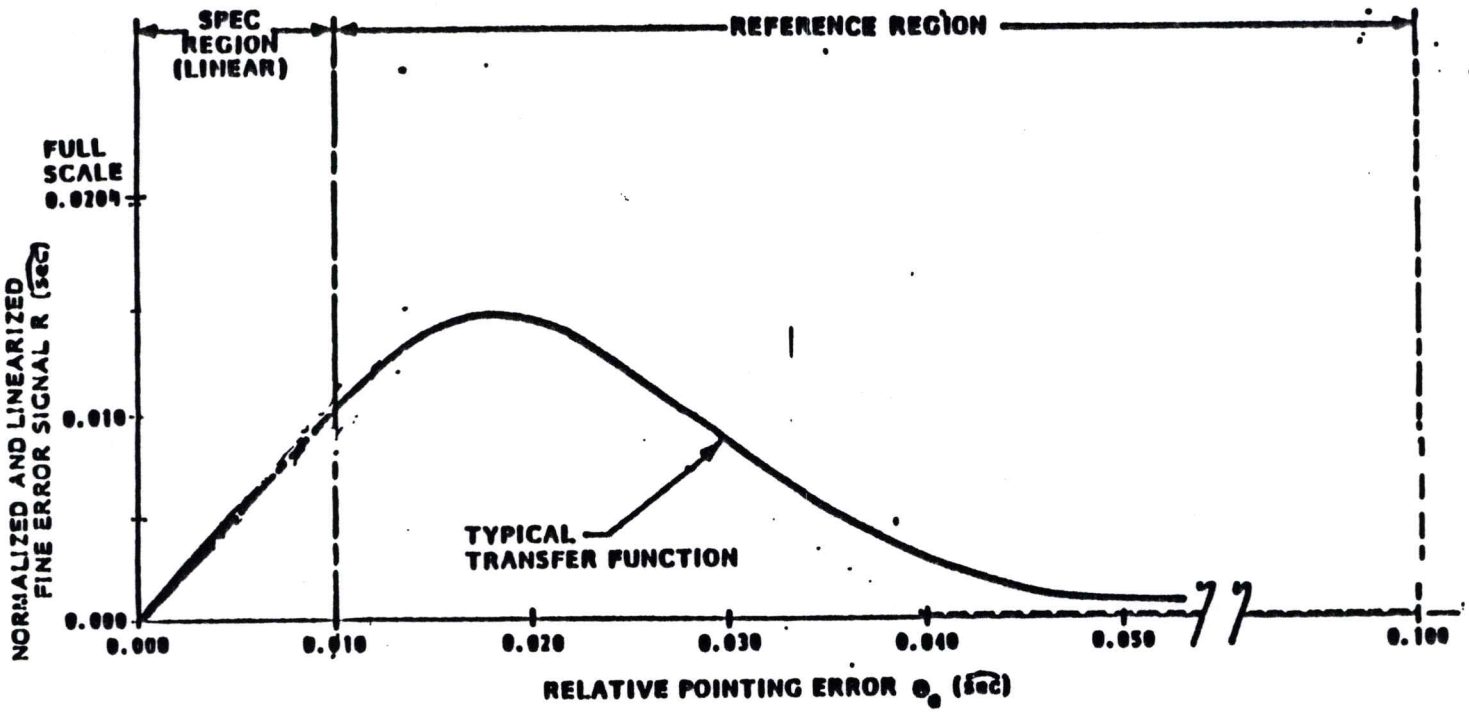
*A typical transfer function (from ICD-01) is shown in Figure 1. The equations which convert PMT counts to the normalized/linearized Fine Error Signal (R) are shown in Figure 2. A complete description of the required processing is in the FGS Design Specification, SD 679-1006.



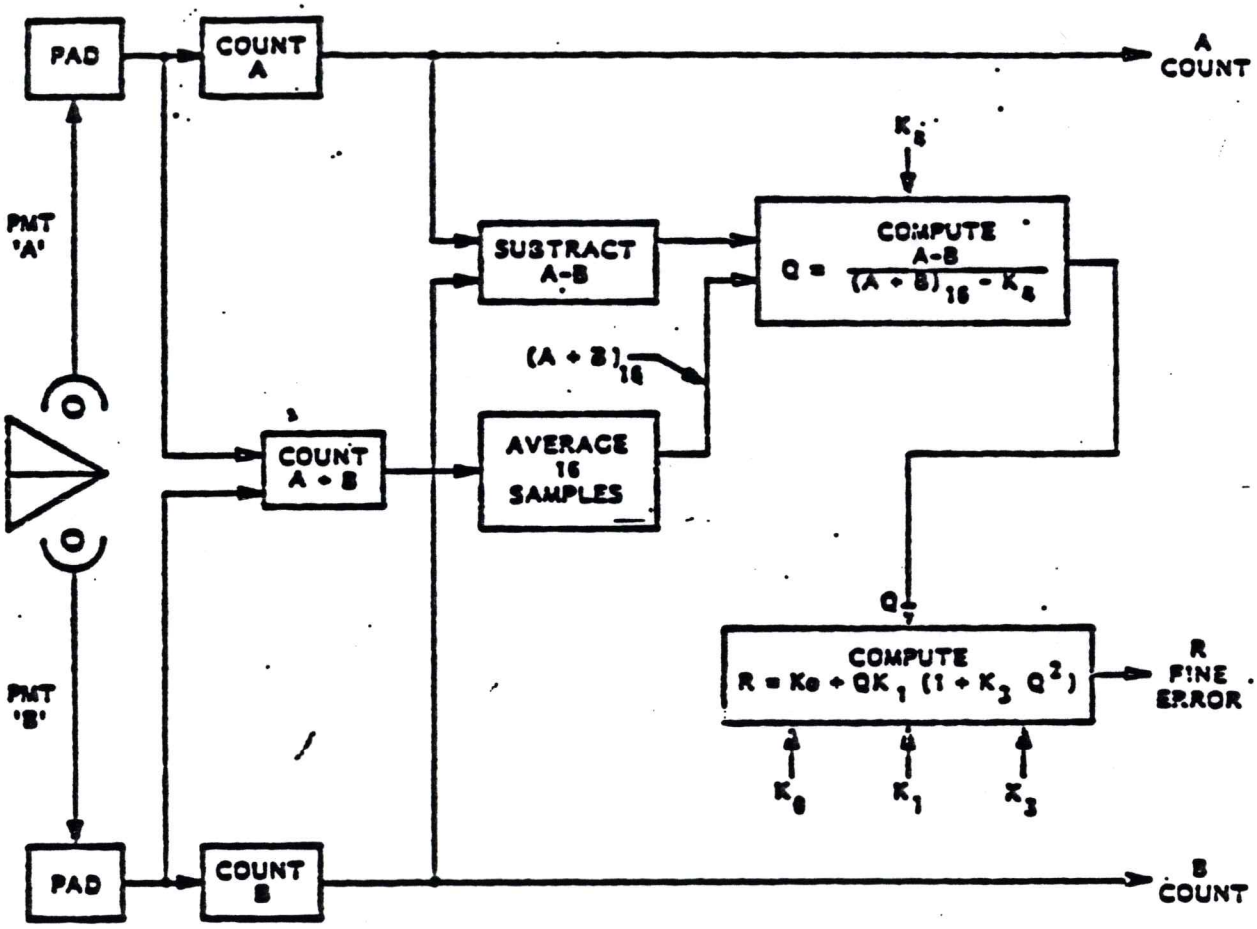
NOTE: LIMITS ARE AN ODD-SYMMETRIC FUNCTION AROUND ZERO
$R(-\theta_e) = -R(\theta_e)$

FIGURE 1. TYPICAL TRANSFER FUNCTION

13,418

13,476

B-2414



NOTE: Uplink Coefficients K_0, K_1, K_3, K_4 per ICD-01.

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FIGURE 2. FGS FINE ERROR SIGNAL OUTPUTS

V. MEASUREMENT METHOD

A. Operating Mode

The operating mode for these measurements will be a quasi-astrometric mode. Bright guide stars will be acquired by two FGS's in the normal manner. I.E., the FGS's will be slewed to the nominal guide star locations, enter the spiral search mode, acquire their stars, enter the coarse track mode, update the gyro drift rates, and finally enter the fine lock mode, so that the ST is held "stationary".* Next, the third FGS (which is the one whose transfer function is to be measured) will be slewed to a relatively bright star. It too, will go through the search, coarse track, and fine lock modes. The above operation will be monitored at the STOCC. The PASS software will utilize the downlinked star selector positions to generate commands for uplink to continue the following scenario. The third FGS is then commanded to the SSM Control Mode (Search/Track OFF). Next a set of commands will be sent to the star selector servos, causing the star image to be positioned in the "corner" of the first quadrant of the interferometer field. From this position, the star image will be commanded to traverse the interferometer field diagonally from the "corner" of the first quadrant to the "corner" of the third quadrant. While this is occurring, the star selector shaft encoders will be read periodically and synchronously with the outputs of all four photomultipliers. These data will be downlinked where the transfer functions in two directions will be calculated and plotted. The process will be repeated for each FGS in turn.

B. Detailed Parameters

1. Color effects will be evaluated through the selection of target stars as well as through the use of filters.
2. It is desirable to perform the star transit as rapidly as possible, so as to minimize the effect of relative motion. Bright target stars must therefore be used to maintain an adequate signal to noise ratio. The required star magnitude is Mv=9.0.

B-2914

*In the following discussion, it is assumed that the Target Star will be held fixed in the FOV of the third FGS. Relative motion must be eliminated by corrections to the ST LOS from the time of third FGS lock to the conclusion of the "traverse" described below.

3. The scan rate will be $0.001\sqrt{2} = 0.0014$ arc sec per 25 msec integration period. In addition to measuring the transfer function in the "control" region, the range must be adequate to check for spurious zero crossings in the large error region. (The software should include the capability of scanning the range $\pm 1.5\sqrt{2} = \pm 2.12$ arc seconds).

4. During this test, the 32 kilobit/sec telemetry mode must be used in order to obtain the raw data. (PMT counts and Star Selector Positions) at a 40 sample per second rate.

VI. SOFTWARE PACKAGE OBJECTIVES

- Generate the necessary commands to effect the star transits described above plus all ancillary star selector motions.
- Compute the transfer functions.
- Analyze the results.

VII. SOFTWARE OUTPUT REQUIREMENTS

Software output requirements are:

1. Printer outputs
   - Star magnitude selected
   - Star color temperature selected
   - Filter used if any
   - Star Selector Encoder Outputs
   - Star Location in FGS field
   - Outputs of all four PMT's. (Fine Counts)
   - Tables of values for both X and Y transfer functions.

2. X-Y Plotter Outputs
   - Plots of both transfer functions
   - PMT response Curves

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VIII DATA INPUTS

1. Data required from the engineering data base will include the OTA and SSM telemetry calibration data to convert PCM counts into engineering units, telemetry format data to permit docommutation of telemetry data streams to acquire specified measurements, SDW command definitions to convert binary counts into engineering units, and the "Initial Values" of FGS Uplink Modifier parameters used by the FGS in the absence of Uplink Modifier Commands.

2. Results of prior data processing which will be required to support these requirements include the following:

   a. All six FGS interferometer transfer functions as measured prior to launch.

   b. All twelve photomultiplier response curves as measured prior to launch.

   c. Measured spectral transmission curves for all filters on all FGS units.

   d. Astrometry headers giving the identity of each of the reference stars and guide stars to be used in the FGS Interferometer Transfer Function Analysis, together with the time period, predicted Star Selector Position measurements and SDW command values applicable to FGS operation.

   e. The actual commands transmitted to the OTA from the SSM affecting FGS search and track operations and the precise times of their transmission to the OTA.

   f. Accurate ephemeris of Earth.

   g. Results of Plate Scale and Optical Field Angle Distortion Calibration.

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IX. SOFTWARE FUNCTIONAL REQUIREMENTS

A. GENERAL

Most of the software for accomplishing the operations described in this section will be required for operation in other modes as well. The major effort here will be the calling up of appropriate programs and commands at the proper time. The following description is a

preliminary attempt to describe the required operations for each FGS and to put them in order. Telemetry measurement numbers shown below are those applicable to FGS 1.

B. Description of Requirements

1. Acquisition

The operations of slew, search, coarse track, and fine lock through which the two FGS's not being calibrated must pass are standard procedures used in all observational modes. Likewise, the acquisition of a star by the FGS under test is a standard procedure which is used in the astrometry mode.

2. Traverse

The traverse of the star image from the corner of the first quadrant to the corner of the third quadrant exercises all four PMT's and provides information for obtaining the transfer functions in two directions. The traverse is achieved by commanding the FGS to the SSM Control Mode (Search/Track-off) and then controlling star selector position by appropriate star selector rate commands.

The traverse commands consist of a set of rate commands designed to produce a scan of 45 degree slope. The scan rate is planned to be approximately .0014 arc sec per 25 msec interval. The position data to be recorded are the telemetered star selector encoder readings (F01Q009M through F01Q014M) as a function of time at 40 samples per sec (sps).

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3. Photomultipliers

The outputs of the four PMT's (Fine Counts - F01Q001M through F01Q008M) must be telemetered and recorded at 40 sps. These data must be time tagged to the star selector position readings.

4. Star Location

The location of the star whose image will be traversed as a function of FGS field position shall be determined and recorded

during Fine Lock Mode.

5. Telemetry

Telemetry mode is 32 kilobits/sec.

6. Computations

a. All numerical values to be converted to engineering units.

b. Both interferometer transfer functions are to be calculated, utilizing the star selector position data and the photomultiplier output data as inputs.

c. Transfer functions for different (extreme) color temperatures shall be compared.

d. The negative half of all transfer functions shall be compared with the positive half. (This is to check for quantum efficiency changes in the photomultipliers).

e. Except where indicated, all results shall be given in ST coordinates (V_1,V_2,V_3,)

7. Plots

The following curves shall be plotted.

- All FGS interferometer transfer functions. The abscissa shall be in milli-arc seconds off axis and the ordinate shall be the normalized, linearized Fine Error Signal computed from PMT counts, (As shown in Figure 2). The meaning of plus and minus in both coordinates shall be unambiguously labeled.

B-2914

App. 13.4.7

14 May 1982
OTA SYSTEMS
ENGINEERING

OTA ORBITAL VERIFICATION AND MISSION OPERATIONS SOFTWARE REQUIREMENTS DESCRIPTION FOR FGS BEHAVIOR MONITORING AND ANALYSIS

I. Software Package Group Name - OTA ON-LINE OPERATIONS

II. Software Package Name - FGS Behavior

III. Software Package Objectives:

To provide capability for near-real-time monitoring and analysis of each FGS to detect anomalous behavior in acquiring stars within its commanded search radius and in providing accurate and stable star selector position, tracking error and star magnitude data to the PCS during its various modes of operation for science observations and subsystem calibrations. Included will be provisions for monitoring and analyzing data relating to the following types of operations:

A. Star Search and Acquisition

B. Operation During Fine Lock Pointing Operations

1. Static pointing operations
2. Moving object science observations
3. Static astrometry observations
4. Moving object astrometry observations

C. Line-of-Sight (LOS) Scan operations

IV. Software Output Requirements

Output requirements are described in Section VI below in the descriptions of FGS operational functions to be monitored and analyzed. The permissible time delay from the availability of the telemetry data at the STOCC until

IV. (Continued) presentation of the printer outputs to Perkin-Elmer/OTA representatives shall be a maximum of two (TBD) minutes, and ten (TBD) minutes for X-Y plotter and analog recorder outputs.

Each of the output records shall be referred to Vehicle Time such that the Vehicle Time of each data item can be easily and quickly determined, and Vehicle Time shall be referred to UTC.

The output requirements are summarized as follows:

1. Printer Outputs -
   a. Results of limit check failures.
   b. Telemetry measurement values at specified events or for specified event-dependent time periods.
   c. Current values of SDW commands to the FGS.
   d. Results of off-line computer calculations in tabular form and narrative form.
   e. Lists of events and time of occurrence in tabular form and narrative form.
   f. Tables of values of telemetry measurements with time as may be requested from time to time for troubleshooting purposes.

2. X-Y Plotter Outputs - Tracks of the center of the FGS instantaneous field of view (IFOV) in pupil space during Search, Coarse Track, LOS Scan and Fine Lock Modes of operation.

IV. (Continued)

3. 8-Channel Analog Recorder Output - Analog strip charts of eight telemetry measurements and up to eight event signals, for specified event-dependent or time-dependent periods, in combinations as specified herein and as may be requested from time to time for troubleshooting purposes.

V. Data Inputs

1. The number designations and names of current OTA telemetry measurements to be monitored and analyzed are given in Section VI below in the descriptions of software functional requirements. Sample rates for each measurement in the 4 kbps and 32 kbps telemetry formats to be used for FGS operations are given in Perkin-Elmer Specification SG 679-0187B General Specification for OTA Instrumentation Program Component List (DM-02) of 11-17-81.
2. The number designations, names and sample rates of non-OTA telemetry measurements are TBD.
3. Data required from the engineering data base will include the OTA and SSM telemetry calibration data to convert binary counts into engineering units, telemetry format data to permit decommutation of telemetry data streams to acquire specified measurements, SDW command definitions to convert binary counts into engineering units, and the "Initial Values" of FGS Uplink Modifier parameters used by the FGE in the absence of Uplink Modifier Commands.
4. Results of prior data processing which will be required to support these requirements include the actual commands transmitted to the

V. 4. (Continued) OTA from the SSM affecting the FGS operations being analyzed, and the precise time of their transmission to the OTA, with the exception of the SSM-calculated A and B Star Selector Rate commands. For these commands, for each SSM-generated maneuver of the star selectors, information on the polarity and the time of transmission of the first and last command to each star selector will suffice.

VI. Software Functional Requirements

In this preliminary description of software requirements, a description of the FGS operational functions to be monitored and analyzed is substituted in place of a flow diagram and algorithms. The following descriptions are written for a single FGS - Number 1. Listings for FGS 2 and FGS 3 will be identical except for command and telemetry designators.

A. Functional Requirements Applicable to All Software Modules

1. Limit check DC/DC Converter Voltage (F01V070A). If it fails the limit check, print out all available samples of both DC/DC Converter Voltage and the bus voltage for the SSM power bus to which the FGS is connected for a three (TBD) minute period, but not to exceed 12 (TBD) samples, starting with the sample preceding the time at which the limit check failure occurred.
2. Print out the current value of each Uplink Modifier parameter commanded to be different than its FGE initialization value, in engineering units.
3. Print out the initial states of each of the FGS status and flag bits, and the Vehicle Time at which the Data Valid Flag was most recently set if its initial state is "ON".

VI. A. (Continued)

4. Print out the times, and identify the events, each time a status bit or flag bit changes state and each time a command is transmitted to the FGS (except for A and B Star Selector Rate Commands initiated by the PCS), in the order of occurrence.

5. Calculate and print out once every 10 (TBD) minutes the average temperature of the temperature sensors within the FGS radial bay module, the temperature of the FGE box, and the temperature readings of any other individual temperature sensors considered to be critical for proper FGS operation.

6. If the FGS transfers to the Stop or Shut Down Mode, check that the star selector servos are properly stopped.

7. If the FGS transfers to the Default Condition, check that the star selector servos are properly driven to their default positions.

B. Star Search and Acquisition Behavior

1. ST Operations Producing the Software Inputs

This routine may be employed each time an FGS is commanded to search for and track a star in the brightness range $4m_v$ to $17m_v$. It will include the SSM Control Mode operations preceding the Search Track ON command. It will apply both to acquisitions in which the FGS is commanded to "Hold ON" in Coarse Track Mode, and to those in which it is commanded to proceed into Fine Lock Mode.

2. See Section VI. A. above for functional requirements common to all software modules.

3. Functional Requirements for SSM Control Mode Operation

a. Limit check time from FGE Enable Control command to SSM Control Status bit (F01J032B).

VI. B. 3. (Continued)

b. If a filter position change is commanded, limit check Astro Filter Position (F01H037D). Print out Astro Filter Position at the end of SSM Control Mode.

c. Print out the current values of the following SDW commands at the end of SSM Control Mode: Star Magnitude Window (Upper Limit); and (Lower Limit); Search Radius Limit; Fine Error Averaging Time.

d. For each maneuver of either or both of the star selector servos, print out the initial and final values of A Star Selector Position (F01H009M-011M) and B Star Selector Position (F01H012M-014M). Calculate and print out FGS LOS position in polar coordinates (from the OTA optical axis) at the initial and final positions. Calculate and print out maximum and average star selector servo rates and maximum accelerations and decelerations during the movement. If both star selectors are accelerated simultaneously, calculate and print out the maximum torque imparted to the ST while accelerating and decelerating.

e. Limit check the calculated A and B star selector servo rates (should be zero) just prior to Search Track ON command.

f. Limit check time period between FGE HV ON and Search Track ON commands (should be 60 ± 1 second).

4. <u>Functional Requirements for Search Mode Operation</u>

a. Limit check time from Search Track ON command to SSM Control Status bit going low and Search Status bit (F01J029B) going

VI. B. 4. a. (Continued) high. Print out the time of execution of Search Track ON command.

b. Monitor Star Presence Flag (F01J023B) and Search Radius Limit Exceed Flag (F01J022B) and print out the time of occurrence and identity of whichever occurs first.

c. On an X-Y plotter, display a track of the FGS instantaneous field of view (IFOV) center in pupil space during the spiral search scan. Display time markers along the track. Present scales along the edges of the plot representing field position in pupil space. Flag all occurrences of the IFOV entering the vignetted areas at the edges of the FGS FOV or the OCS FOV area. At the end of the spiral scan, mark and identify the location at which the Star Presence Flag or Search Radius Limit Exceed Flag was set, and continue displaying the track while the star detector servos are driven to the starting location for coarse tracking or are stopped.

d. From A and B Star Selector Position and time data, calculate and limit check radial rate, and limit check total time to reach Star Presence Flag or Search Radius Limit Exceed Flag against values calculated from a theoretical model using the same sets of Uplink Modifier parameter values as those set in the FGE.

e. Monitor X and Y Fine Count (PMT A) and (PMT B) (F01Q001M thru 008M) and perform the following limit check to determine whether the FGS is detecting Star Presence (SP) properly:

VI. B. 4. e. (Continued)

If $I_L < I(t) < I_H$, then SP = 1

If outside, then SP = 0

$I(t) = (A + B)_X + (A + B)_Y$ = Summation of all 4 PMT fine counts

I_L = Star Magnitude Window (Lower Limit) command

I_H = Star Magnitude Window (Upper Limit) command

(Note: PMT fine counts are sampled 40 times per second in 32 kbps telemetry formats, but only once per second in the 4 kbps format. Star presence testing is performed 40 times per second in the FGE in Search Mode.)

f. When a star is detected, check that the commanded Search Radius Limit has not been exceeded, Search and Coarse Track Status bits are properly reset and set, the spiral scan is terminated and the star selector servos are properly positioned for starting coarse tracking.

g. If a star is not detected in Search Mode, check that the Search Radius Limit Exceed Flag and Stop Flag are set and the star selector servos are stopped at the commanded Search Radius Limit.

5. <u>Functional Requirements for Coarse Track Mode Operation</u>

a. Print out the time at which Coarse Track Status bit (F01J030B) is set and print the status of Hold and LOS Scan Commands at the same time. Limit check the time duration from Star Presence Flag going high to Coarse Track Status bit going high.

VI. B. 5. (Continued)

b. Continue to display the track of the center of the IFOV on the X-Y plotter during coarse tracking, superimposing the track over that plotted during Search Mode. Identify the locations at which significant events occur. Flag all occurrences of the IFOV entering the vignetted areas at the edges of the FGS FOV or the OCS FOV area. If HOLD ON and LOS Scan OFF command status exists, discontinue the X-Y plot five seconds after the Transfer Held Flag is set and restart the X-Y plot when the Star Presence Flag, Data Valid Flag and/or Transfer Held Flag is/are reset. Terminate the X-Y plot if the Stop Flag or Default ON Status bit is set or if a Shut Down command is sent to the FGS.

c. Using Star Position Coordinate 1 (F01H055M-057M) and Star Position Coordinate 2 (F01H058M-060M) data, calculate and print out star position drift rate once each TBD cycles of coarse track nutation as long as Coarse Track Mode continues. Limit check and print out star position drift rate at the time(s) the Data Valid Flag is set. Print out any apparent discrepancies between FGE X-DOT Star Position Drift (F01H061D) and Y-DOT Star Position Drift (F01H062D) and those calculated in the ground computer.

d. Monitor X and Y Fine Counts and limit check I(t) as described in Paragraph VI. B. 4. e. above. Duplicate the FGE test logic for resetting the Star Presence Flag Bit and print out any apparent discrepancies between FGE and ground computer results.

B. 5. (Continued)

e. Check that the coarse tracking nutation rate and radius of nutation are correct as determined from Uplink Modifier parameters and Star Selector Position data.

f. When conditions (command status, Data Valid, Star Presence) permit entry into Fine Lock Mode, check that status and flag bits change states properly and that the star selector servos are properly positioned for starting Fine Lock star acquisition.

g. While operating with a 32 kbps telemetry format, for a period of 10 (TBD) seconds following the initiation of Coarse Track Mode, duplicate the FGE computation of X(A + B) Average Magnitude (F01Q17M-18M) and Y(A + B) Average Magnitude (F01Q19M-20M) and print out any apparent discrepancies between FGE and ground computer results.

6. <u>Functional Requirements for Fine Lock Mode Operation</u>

a. Limit check the time duration between the occurrence of the logic state permitting transition from the coarse tracking nutation, and the Fine Lock Status bit (F01J031B) going high.

b. Continue to display the track of the center of the IFOV center on the X-Y plotter during Fine Lock Mode operation, superimposing the track over those plotted during Search and Coarse Track Modes. Identify the locations at which significant events occur. Flag all occurrences of the IFOV entering the vignetted areas at the edges of the FGS FOV or the OCS FOV area. Terminate the X-Y plot if the Stop Flag or Default ON Status bit is set or if a Shut Down command is sent to the FGS. Terminate the X-Y plot when the Data Valid Flag has been set and remains set for at least TBD seconds.

VI. B. 6. (Continued)

c. Monitor X and Y Fine Counts and limit check I(t) as described in Paragraph VI. B. 4. e. above. Duplicate the FGE test logic for resetting the Star Presence Flag bit and print out any apparent discrepancies between FGE and ground computer results.

d. During the Fine Lock star acquisition process, from the start of Fine Lock Mode to the time the Data Valid Flag is set, and for TBD seconds thereafter, display the IFOV center on the X-Y plotter, using a smaller scale factor than the prior plot, to show the stepped scan in X and Y directions toward the calculated star position. If the Data Valid Flag does not become set, terminate the plot two seconds after the Scan Steps Limit Exceed Flag (F01J026B) or the Stop Flag is set.

e. During the Fine Lock star acquisition process and for TBD seconds after the Data Valid Flag or Stop Flag is set, display the following telemetry signals on the 8-channel analog recorder, and sign and flag bits on event markers between analog channels:

(1) X Fine Count (PMT A) + (PMT B) (F01Q001M-004M)

(2) Y Fine Count (PMT A) + (PMT B) (F01Q005M-008M)

(3) X (A + B) Average Magnitude (F01Q017M-018M)

(4) Y (A + B) Average Magnitude (F01Q019M-020M)

(5) X Average Fine Error Normalized (F01H044M-045M)

(6) X Average Fine Error Normalized Sign (F01J043B)

(7) Y Average Fine Error Normalized (F01H047M-048M)

(8) Y Average Fine Error Normalized Sign (F01J046B)

VI. B. 6. e. (Continued)

(9) A Star Selector Position (Reduced Scale) (F01H009M-011M)

(10) B Star Selector Position (Reduced Scale) (F01H012M-014M)

(11) Star Presence Flag (F01J023B)

(12) Data Valid Flag (F01J024B)

(13) Scan Steps Limit Exceed Flag (F01J026B)

(14) Stop Flag (F01J021B)

In parallel with the analog recording, print out the value in engineering units of each of the measurements being recorded at the start of Fine Lock Mode, each time one of the flag bits being recorded changes state, and at the end of the recording. Also print out the chart scale calibration for the reduced scale recordings.

f. If the Scan Steps Limit Exceed Flag is set, calculate drift rate of the optical axis from SSM attitude and rate sensor data.

C. FGS Operation During Fine Lock Pointing Operations

1. ST Operations Producing the Software Inputs

This routine applies to operations of the FGS in its Fine Lock Mode, after the Data Valid Flag has been set signifying the accomplishment of fine lock. This applies to tracking both stars whose positions in the star field are not moving (static objects) and also stars or other objects whose positions are moving at rates sufficient to require controlled movement of the ST VI axis during science and astrometry observations. Therefore, it applies to Fine Lock Mode operations both with and without rate-feed-forward commands transmitted to the star selector servos from the SSM Pointing Control Subsystem (PCS).

The ST operations involving this type of FGS operation include science and astrometry observations of both static and moving

VI. C. 1. (Continued) targets, and some OTA calibration operations.

2. See Section VI. A. above for functional requirements common to all software modules.

3. Functional Requirements for Fine Lock Pointing Operations

a. Print out the current values of the following SDW commands: Star Magnitude Window (Upper Limit); and (Lower Limit); and Fine Error Averaging Time, in engineering units.

b. Monitor X and Y Fine Count (PMT A) and (PMT B) (F01Q001M thru 008M) and limit check I(t) as described in Paragraph IV. D. 2. e. above to determine whether it remains between commanded upper and lower limits of star magnitude. Duplicate the FGE test logic for resetting the Star Presence Flag bit and print out any apparent discrepancies between FGE and ground computer results.

c. For FGS static pointing operations with a 32 kbps telemetry format and in which the PCS is not expected to send rate-feed-forward commands (A & B Star Selector Rate commands intended to help the FGS remain locked on to moving targets, or to static targets during ST maneuvers) to the FGS, monitor A and B Star Selector Position (F01H009M-014M) and check that movements occur only in the intervals between Fine Error Averaging Periods, and not during Fine Error Averaging Periods. Check that the movements which occur between Fine Error Averaging Periods are of appropriate magnitude and polarity for the values of X and Y Average Normalized Fine Error (F01M044M, 045M, 047M, 048M and F01J043B, 046B) reported after each Fine Error Averaging Period. (With the planned telemetry

VI. C. 3. c. (Continued) sampling rate of 5 samples per second for X and Y Average Normalized Fine Error, this check will not be feasible for Fine Error Averaging Time commands of less than 0.2 seconds).

d. For moving target science or astrometry observations, and for FGS Fine Lock tracking during ST maneuvers, in which the PCS is expected to send rate-feed-forward commands to the FGS, monitor A and B Star Selector Position and check that star selector movements occurring during Fine Error Averaging Periods are of the appropriate magnitude and polarity for the movement of the ST LOS. Check that the movements which occur between Fine Error Averaging Periods are of appropriate magnitude and polarity for the values of X and Y Average Normalized Fine Error reported after each Fine Error Averaging Period. (The parenthetical note at the end of Paragraph VI. C. 3. c. above applies here also).

e. On an X-Y plotter, for selected time periods, display a track of the center of the FGS instantaneous field of view (IFOV) in pupil space, with a reduced scale to permit display of the small movements involved. Display time markers along the track. Present scales along the edges of the plot representing field position in pupil space. Flag all occurrences of the IFOV entering the vignetted areas at the edges of the FGS FOV or the OCS FOV area.

f. For selected time periods, display the following telemetry signals on the 8-channel analog recorder, and sign, status and flag bits on event markers between analog channels:

C. 3. f. (Continued)

(1) X Fine Count (PMT A) + (PMT B) (F01Q001M-004M)

(2) Y Fine Count (PMT A) + (PMT B) (F01Q005M-008M)

(3) X Average Fine Error Normalized (F01H044M-045M)

(4) X Average Fine Error Normalized Sign (F01J043B)

(5) Y Average Fine Error Normalized (F01H047M-048M)

(6) Y Average Fine Error Normalized Sign (F01J046B)

(7) A Star Selector Position (Reduced Scale) (F01H009M-011M)

(8) B Star Selector Position (Reduced Scale) (F01H012M-014M)

(9) A Star Selector Compensated Error Signal (F01V071A)

(10) B Star Selector Compensated Error Signal (F01V072A)

(11) Star Presence Flag (F01J023B)

(12) Data Valid Flag (F01J024B)

(13) Stop Flag (F01J021B)

(14) Fine Lock Status Bit (F01J031B)

In parallel with the analog recording, print out the value in engineering units of each of the measurements being recorded at both the start and completion of the recording period.

D. FGS Behavior During LOS Scan Operations

1. ST Operations Producing the Software Inputs

This routine applies to operations of the FGS in its LOS Scan Mode, which is used for a coarse determination of the best focus position of the OTA secondary mirror in bootstrap operations. This routine is used only to monitor FGS behavior-separate software to be provided by Perkin-Elmer will be used to process the star magnitude data for determining best focus position.

VI. D. 1. (Continued)

The FGS operational period covered is from the time the Data Valid Flag is set in Coarse Track Mode, when LOS Scan ON has been previously commanded, until LOS Scan Mode operation has been completed and the Coarse Track Status bit has again been set.

2. See Section VI. A. above for functional requirements common to all software modules.

3. Functional Requirements for LOS Scan Operations

a. Print out the current value of the Filter Position command (F01K011S) and limit check the Astro Filter Position measurement (F01H037D) against it.

b. Check that the A and B star selectors are properly positioned at the end of Coarse Track Mode to commence the LOS scan pattern.

c. Limit check the time period between setting of Data Valid Flag and setting of LOS Scan Status bit.

d. Check that the rate of scan and the dimensions of the LOS Scan pattern are correct as determined from star selector position data and current values of Uplink Modifier parameters.

e. Limit check the time duration of the LOS Scan operation.

f. At the end of the LOS scan pattern, check that the A and B star selectors are properly positioned to resume Coarse Track nutation about the same calculated star position as at the start of LOS Scan.

g. On an X-Y plotter, display a track of the center of the FGS instantaneous field of view (IFOV) in pupil space during the period from Data Valid Flag setting through the LOS Scan Mode.