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IMP F AND G PHASE I MAGNETIC FIELD ANALYSIS

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GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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PART I

ABSTRACT

This paper describes the Phase I Analysis Program developed to analyse the magnetic field data from the GSFC magnetic field experiment flown on IMP F and to be flown on IMP G.

The Phase I Analysis converts the raw X, Y, Z sensor data as received on the Magnetic Field Experiment Tape into vector measurements of the ambient magnetic field observed by the experiment. These data are computed for four frames of reference — Apparent, Payload, Solar Ecliptic and Solar Magnetospheric. In addition 20.45 second (sequence) statistics are computed for the last three coordinate systems and SC 4020 plots of these statistics as a function of time can be obtained. Finally a summary tape is produced containing detailed data and sequence statistics as well as the output from the autocorrelation computer, trajectory data and identification information. This summary tape provides the input to the Phase II analysis which is described in a companion document (X-612-68-125).

PART II

INTRODUCTION

1. INSTRUMENTATION

IMP F was launched from the Western Test Range May 24, 1967 at 1405:54Z into a "Polar" orbit (Apogee = 214,382 Km; Perigee = 242 Km; Inclination = 67.12°). The magnetic field experiment consists of fluxgate magnetometer sensors mounted remotely from the spacecraft on two booms in a triaxial configuration such that the ambient magnetic field can be measured in three orthogonal directions. The Z sensor is located on a separate boom opposite the X-Y set. A flipper mechanism is included to rotate the Z sensor by 180° approximately every 4 days to provide in-flight zeros for this axis. The spin modulation which appears in the X and Y sensor data provides the necessary information to determine the zero levels of these sensors. In addition approximately every hour a 10γ on-board calibration field is applied to each of the sensors to calibrate sensitivity. Each sensor has a dual range of $\pm 32\gamma$ and $\pm 128\gamma$.

The second portion of the experiment is an autocorrelation computer which performs direct computations of the first nine lagged products of the autocorrelation function with a sampling rate of 0.080 seconds. This permits the study of magnetic field fluctuations extending to 12.5 cps. The autocorrelation computer operates separately for one sequence on one axis of data from the triaxial magnetometers. The axes are alternately switched between parallel to the spin axis and perpendicular to the spin axis every sequence so that the complete directional spectrum of the magnetic field fluctuations can be studied.

2. TELEMETRY

The telemetry from the spacecraft is coherent digital PFM. The basic unit of telemetry is a 20.45 second sequence consisting of a 16 channel by 16 frame array with a channel length of .080 seconds. Commutated in the odd numbered frames* are the detail measurements from the X, Y and Z magnetometers each digitized to a precision of 8 bits. These data appear in channels 1, 2 and 3. In addition frame 8 uses channels 1 through 15 for transmission of 120 bits of output from the autocorrelation computer. The telemetry is digitized by the F-9A Data Processing System using correlation detectors for the detection of the PFM signals. (See Reference 4.)

*Frames and channels are numbered from 0 through 15.

3. PHASE I ANALYSIS

The primary purpose of the Phase I analysis is to convert the raw X, Y, Z sensor data as received on the Magnetic Field Experimenter Tape into vector measurements of the ambient magnetic field observed by the experiment. These data are computed for four different frames of reference — Apparent, Payload, Solar Ecliptic and Solar Magnetospheric. In addition sequence (20.45 second) statistics are computed for the last three coordinate systems. The program has been written so that a great deal of flexibility is available in the calculation and display of these data both on the printer and plotting on the SC 4020 plotter as shown in Table 1. (Check marks (✓) indicate what is available in the different frames of reference.)

Table 1

Frame of Reference	Detail Printed Output	Sequence Printed Output	SC 4020 Sequence Plots
Raw	✓		
Apparent	✓		
Payload	✓	✓	✓
Solar Ecliptic	✓	✓	✓
Solar Magnetospheric	✓	✓	✓

The above options are selected through the use of a switching vector card.

In addition to the various printed outputs and SC 4020 displays, a binary summary tape is generated which contains the detail data and sequence statistics for the frames of reference as well as identification information, trajectory and the output from the autocorrelation computer.

4. PROGRAM DESIGN

The Program is designed such that the data from an entire file (approximately 2 hours of data) are read into core storage before any rotations are performed. The Main Program computes the Apparent Coordinates from the raw data for the file, stores the autocorrelation computer output, trajectory and identification information on the disk, rotates the apparent data into three different coordinate systems and performs all the printing of these rotated data. All the rotated detailed data for the file remain in core storage after they are computed.

The statistical computations for the three different coordinate systems use this detail data, and are performed by the Statistics Subroutine. These statistics are stored in three different files (one per coordinate system) on the disk as they are computed. However, the statistics for the particular coordinate system currently being computed also remain in core storage so that they will be available to the SC 4020 plot routines, which can be called by the Statistics Subroutine. All printing of the statistics is done by the Statistics Subroutine. Finally, the detail data and statistics for the three coordinate systems, the apparent coordinates, trajectory, autocorrelation computer output, and ID information are gathered together and written on a Binary Summary Tape. There is one file of data on the Binary Summary Tape for each file of data on the Experimenter Tape.

This Summary Tape provides the input to the Phase II Analysis.

In preparation for subsequent analysis of these data by other investigators Appendix H, Characteristics of the IMP F Spacecraft and Magnetic Field Experiment That Should Be Considered in Subsequent Analysis, should be reviewed to aid in the interpretation of the results.

PART III

GENERAL DESCRIPTION OF PROCESSING

The following explanation is broken into 8 numbered sections whose numbers correspond to the numbering in the upper left hand corner of the blocks in the flowchart which is located at the end of Part III.

1. INPUT ROUTINE

a. The following control cards are read in at the beginning of the program. Formats are described in Appendix B.

CARD #	FUNCTION	VARIABLES
A	Experimenter tape # and analysis date	EXTNO, ANADTE
B	Switching vector	S(I), I = 1,80
C	Calibration coefficients for low range	AI(1,I), I = 1,3 BI(1,I), I = 1,3 CI(1,I), I = 1,3
D	Calibration coefficients for high range	AI(2,I), I = 1,3 BI(2,I), I = 1,3 CI(2,I), I = 1,3
E	Correction to zero and Z dependent zero for low range	ZDZ(1,I), I = 1,2 ZDS(1,I), I = 1,2
F	Correction to zero and Z dependent zero for high range	ZDZ(2,I), I = 1,2 ZDS(2,I), I = 1,2
G	File interval to be processed	IFLBG, IFLEND
H	Right Ascension and Declination in Celestial Interial Coordinates of the spin axis of the spacecraft	RACI, DECCI

b. The XCI, YCI and ZCI components of the spin axis unit vector are computed using the following equations.

$$XCI = Cos\ (DECCI) * Cos(RACI)$$

$$YCI = Cos\ (DECCI) * Sin(RACI)$$

$$ZCI = Sin\ (DECCI)$$

c. The header record for the file is now read from the experimenter tape (See Appendix C) and pertinent definitions and the file count are printed out. The switching vector card controls the degree of analysis performed and determines printing and SC 4020 plotting status.

2. CALIBRATION TO APPARENT FIELD VALUES (PROCESS ONE FILE)

The Phase I Analysis performs the following operations as it makes a pass through each file on the experiment tape.

a. A physical record is read from the experimenter tape containing three telemetry sequences (see Appendix C) along with the trajectory data* associated with channel zero frame zero of the middle sequence.

b. If S_2 is equal to zero the raw data from these three sequences are printed otherwise the printing of the raw data is suppressed.

c. The theoretical magnetic field which is included as part of the trajectory information in Solar Ecliptic Coordinates is rotated to Solar Magnetospheric Coordinates and is converted to a two angle presentation.

$$\begin{bmatrix} XT \\ YT \\ ZT \\ \ \end{bmatrix}_{SM} = \begin{bmatrix} \text{Rotation Matrix to} \\ \text{go from SE to SM} \\ \text{coordinates from} \\ \text{Experimenter Tape} \end{bmatrix} \begin{bmatrix} XT \\ YT \\ ZT \\ \ \end{bmatrix}_{SE}$$

*In the case of quick-look data no trajectory data is included on the Experimenter Tape.

$$\text{PSI} = \tan^{-1} \frac{\text{YT}}{\text{XT}}$$

$$\text{FPER} = (\text{XT}^2 + \text{YT}^2)^{1/2}$$

$$\text{ALPHA} = \tan^{-1} \frac{\text{ZT}}{\text{FPER}}$$

This angle presentation is calculated for both coordinates systems.

d. Computes a refined spin period for each of the three telemetry sequences in the physical record using the following algorithm:

$$\Delta T = \left[\left(t_3 + t_{s/s_3}\right) - \left(t_1 + t_{s/s_1}\right)\right]$$

$$N = \left[\frac{\Delta T}{\text{AVSPIN}} + 0.5\right]^{\text{Truncated to an integer}}$$

$$\text{Refined Spin Period} = \frac{\Delta T}{N}$$

Where

t_3 = Time for channel zero frame zero of the older sequence in the physical record

t_{s/s_3} = See sun time for the older sequence

t_1 = Time for channel zero frame zero of the younger sequence in the physical record.

t_{s/s_1} = See sun time for the younger sequence

AVSPIN = Average spin period for the file.

This results in a spin period that is averaged over approximately 16 spacecraft revolutions. If the refined spin period differs by more than 5 milliseconds from AVSPIN the average spin period for the file is used, since the t_{s/s_3} or t_{s/s_1} may be in error.

e. Checks whether the magnetometers are in the low or high range and converts the sensor outputs D_1, D_2, and D_3, to field values using the following set of equations. (Where I = 1 for the low range and I = 2 for the high range.)

$$ZA = AI(I,3) + BI(I,3)*D_3 + CI(I,3)*D_3^2$$

If the Z axis is in the "down" position the sign of ZA is reversed (this rotates ZA to Payload Coordinates)

$$ZA = -ZA$$

$$YA^* = AI(I,2) + BI(I,2)*D_2 + CI(I,2)*D_2^2 + ZDZ(I,2) + ZDS(I,2)*ZA$$

$$XA = AI(I,1) + BI(I,1)*D_1 + CI(I,1)*D_1^2 + ZDZ(I,1) + ZDS(I,1)*ZA$$

The calibration coefficients AI(I,K), BI(I,K), CI(I,K) for the three axes (K) and two ranges (I) have been determined by performing least squares parabolic fits to the pre-launch calibration data, i.e., counts vs gammas. This calibration data is contained in Appendix G.

The zero corrections, ZDZ(I,K) for the X and Y axes (both ranges) are calculated each orbit by a calibration program that is run separately prior to the Phase I Analysis (see Reference 2). The values of ZDZ(I,K) represent an adjustment applied to the calibration coefficients AI(I,K), which are the zero levels of the instruments.

The zero correction to the Z axis is made by direct adjustment of the AI(I,3) coefficients.

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*If D_2 > 170 counts, and the sensors are in the High Range YA is computed as:

$$YA = AI(I,2) + BI(I,2)*170.0 + CI(I,2)*170.0^2 + ZDZ(I,2) - 1.3583*(D_2 - 170.0) + ZDS(I,2)*ZA$$

The Z dependent zeros, ZDS(I, K) for the X and Y axes (both ranges) are also calculated each orbit by the above mentioned Program. This correction compensates for the fact that the X-Y sensor set, which is mounted on a separate boom from the Z sensor, is not quite perpendicular to that sensor thus a small Z dependence is observed in the X and Y sensor data which must be compensated.

The constants AI, BI, CI, ZDZ, and ZDS are read in on Control Cards C, D, E, and F.

f. XA is now adjusted to compensate for the fact that D_1 and D_2 are not sampled orthogonally using the following equation XA = (XA - YA Sin Δ)/Cos Δ where Δ= (0.080/Refined Spin Period)* 2π. In addition if the 10γ calibration field was on during this sequence it is removed from XA, YA and ZA. If the calibration field is on:

$$XA = XA + 10.85\gamma$$

$$YA = YA + 10.97\gamma$$

$$\left.\begin{array}{l} ZA = ZA + 10.32\gamma \\ ZA = ZA - 10.32\gamma \end{array}\right\} \begin{array}{l} \text{if Z axis is ``up''} \\ \text{if Z axis is ``down''} \end{array}$$

As XA, YA, and ZA are computed they replace D_1, D_2, and D_3 in the Experimenter Tape record which is written on the disk along with the refined spin period for the sequence as the file is processed.

A printout of XA, YA, and ZA will also be produced if S_3 has been set to zero. Note that at the end of Section 2 all information originally on the Experimenter Tape in this file, with the exception of D_1, D_2, and D_3 has been transferred to the disk. (D_1, D_2, and D_3 have been replaced with XA, YA and ZA.) The refined spin period (or the average spin period for the file) for each sequence is also on the disk.

3. ROTATION TO PAYLOAD COORDINATES (PROCESS ONE FILE)

The Program now rotates XA, YA, and ZA into the nonrotating (fixed) Payload Coordinate System using the following rotation matrix. The derivation of this matrix is found in Appendix D.

$$\begin{bmatrix} XP \\ YP \\ ZP \end{bmatrix} = \begin{bmatrix} -\sin\gamma_i & +\cos\gamma_i & 0 \\ \cos\gamma_i & +\sin\gamma_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} XA \\ YA \\ ZA \end{bmatrix}$$

the angle γ_i has been computed in Section 2 and is defined by the following formula:

$$\gamma_i = \left[\frac{(t_i - t_{s/s})}{\text{Refined Spin Period}}\right] * 2\pi + \psi_o - \psi_1$$

where

t_i is the time for ith vector measurement of the field.

$t_{s/s}$ is the time the OA sensor saw the sun. (See Sun Time.)

ψ_o is the angular offset of sensor from the OA sensor and is equal to -22.5°.

ψ_1 is the phase shift of the sensors at the spin frequency. (ψ_1 is approximately the same for all three sensors but is a function of the range that the sensor is in)

Range	ψ_1 in degrees
Low	$7.153 \log_{10}\left[\frac{1}{\text{Refined Spin Period}}\right] + 6.108$
High	0.5

After rotation to payload coordinates it is necessary to make an adjustment to the measured field in the ZP direction resulting from the fact that the Z sensor is not quite perpendicular to the X-Y sensor set. This adjustment is made by solving the following equation for F_z.

$$F_z' = F_z \cos\beta + F_\perp \sin\beta \cos\left[\gamma_i - (\psi + \phi_o)\right]$$

where

$F_z' \equiv$ field measured by Z sensor.

$F_\perp \sin\beta = (XP^2 + YP^2)^{1/2} \sin\beta \equiv$ the projection of the perpendicular field on the Z axis. β is a function of the Z axis position.

$\cos\left[\gamma_i - (\psi + \phi_o)\right] \equiv$ Demodulates the projection of the perpendicular field on the Z axis.

$\psi \equiv$ Azimuthal angle of F_I.

$\phi_o \equiv$ Correction. This correction is a function of the Z axis position.

4. DATA EDIT ON 2250 DISPLAY AND PRINTING OF PAYLOAD DATA

XP, YP, and ZP for the file are stored in core so that these data can be displayed on the 2250 Display and edited (this feature is currently not implemented and is not included in the flow chart). These data can be printed if S_4 has been set to zero.

5. PAYLOAD COORDINATE STATISTICS

Next, sequence averages and variances can be computed for XP, YP, ZP, Total Field, α_p, ψ_p using the following formulas applied to the data from each telemetry sequence:

$$\overline{XP} = \frac{1}{n}\sum_{i=1}^{n} XP_i \text{ : similar expressions for } \overline{YP} \text{ and } \overline{ZP} \tag{5.1}$$

$$\overline{TFP1} = \frac{1}{n}\sum_{i=1}^{n}\left(XP_i^2 + YP_i^2 + ZP_i^2\right)^{1/2};\ \overline{TFP2} = \left(\overline{X}P^2 + \overline{Y}P^2 + \overline{Z}P^2\right)^{1/2} \tag{5.2a,b}$$

$$\hat{\sigma}_{XP} = \left[\frac{1}{(n-1)}\sum_{i=1}^{n}(XP_i - \overline{XP})^2\right]^{1/2} \text{ : similar expressions for } \hat{\sigma}_{YP} \text{ and } \hat{\sigma}_{ZP} \tag{5.3}$$

$$\hat{\sigma}_{TFP2} = \left[\frac{1}{n-1}\sum_{i=1}^{n}(TFP_i - \overline{TFP}2)^2\right]^{1/2};\ \hat{\sigma}_{TFP1} = \frac{1}{3}(\hat{\sigma}_{XP} + \hat{\sigma}_{YP} + \hat{\sigma}_{ZP}) \tag{5.4a,b}$$

$$\overline{\alpha}_P = \tan^{-1}\left(\frac{\overline{ZP}}{\sqrt{\overline{XP}^2 + \overline{YP}^2}}\right) \tag{5.5}$$

$$\overline{\psi}_p = \tan^{-1}\left(\frac{\overline{YP}}{\overline{XP}}\right) \quad (5.6)$$

Component Ratio:

$$CRATIO = (\hat{\sigma}_{XP} + \hat{\sigma}_{YP} + \hat{\sigma}_{ZP})/3(\overline{TFP}2) \quad (5.7)$$

Total Field Ratio:

$$TRATIO = \hat{\sigma}_{TFP1}/\overline{TFP}1 \quad (5.8)$$

Summations extend over the number of good data points in a sequence. If S_5 is set to zero printouts of payload sequence statistics will be produced otherwise no printout is produced.

If S_7 is set to zero plots of payload sequence statistics will be produced otherwise no plots are produced.

6. ROTATION TO SOLAR ECLIPTIC COORDINATES (PROCESS ONE FILE)

XP, YP, and ZP for the file are rotated to Solar Ecliptic Coordinates using the following rotation matrix. The derivation of this matrix is found in Appendix E.

$$\begin{bmatrix} XSE \\ YSE \\ ZSE \end{bmatrix} = \begin{bmatrix} \cos A & 0 & \sin A \\ -\sin A \sin D & \cos D & \cos A \sin D \\ -\sin A \cos D & -\sin D & \cos A \cos D \end{bmatrix} \begin{bmatrix} XP \\ YP \\ ZP \end{bmatrix}$$

To compute the matrix elements first compute the unit spin axis vector in Celestial Inertial Coordinates: (This computation has been performed in Section 1.)

$$XCI = \mathrm{Cos}\ (DECCI)^*\ \mathrm{Cos}\ (RACI)$$
$$YCI = \mathrm{Cos}\ (DECCI)^*\ \mathrm{Sin}\ (RACI)$$
$$ZCI = \mathrm{Sin}\ (DECCI)$$

Then rotate the spin axis to Solar Ecliptic coordinates:

$$\begin{bmatrix} SESX \\ \\ SESY \\ \\ SESZ \end{bmatrix} = \begin{bmatrix} \text{Rotation Matrix to go} \\ \text{from Celestial} \\ \text{Inertial to Solar} \\ \text{Ecliptic obtained from} \\ \text{Trajectory information on} \\ \text{Experimenter Tape} \end{bmatrix} \begin{bmatrix} XCI \\ \\ YCI \\ \\ ZCI \end{bmatrix}$$

Then compute:

$$\mathrm{COS}\ A = \left((SESY)^2 + (SESZ)^2\right)^{1/2}$$

$$\mathrm{SIN}\ A = SESX$$

$$\mathrm{COS}\ D = SESZ/\mathrm{Cos}\ A$$

$$\mathrm{SIN}\ D = SESY/\mathrm{Cos}\ A$$

S_8 and S_{10} determine printout and plot status for SE values.

Sequence averages and variances can be computed for XSE, YSE, ZSE, Total Field, θ_{se}, ϕ_{se}, CRATIO, and TRATIO using an analogous set of formulas to the set given in Section 5. S_9 and S_{11}, determine printout, and plot status for sequence statistics.

7. ROTATION TO SOLAR MAGNETOSPHERIC

XSE, YSE, and ZSE which are still in core are next rotated to Solar Magnetospheric Coordinates using the following rotation matrix:

$$\begin{bmatrix} XSM \\ YSM \\ ZSM \end{bmatrix} = \begin{bmatrix} \text{Rotation Matrix to go from SE to} \\ \text{SM obtained from Trajectory} \\ \text{Information on the Experimenter Tape} \end{bmatrix} \begin{bmatrix} XSE \\ YSE \\ ZSE \end{bmatrix}$$

S_{13} and S_{15} determine printout and plot status of SM values.

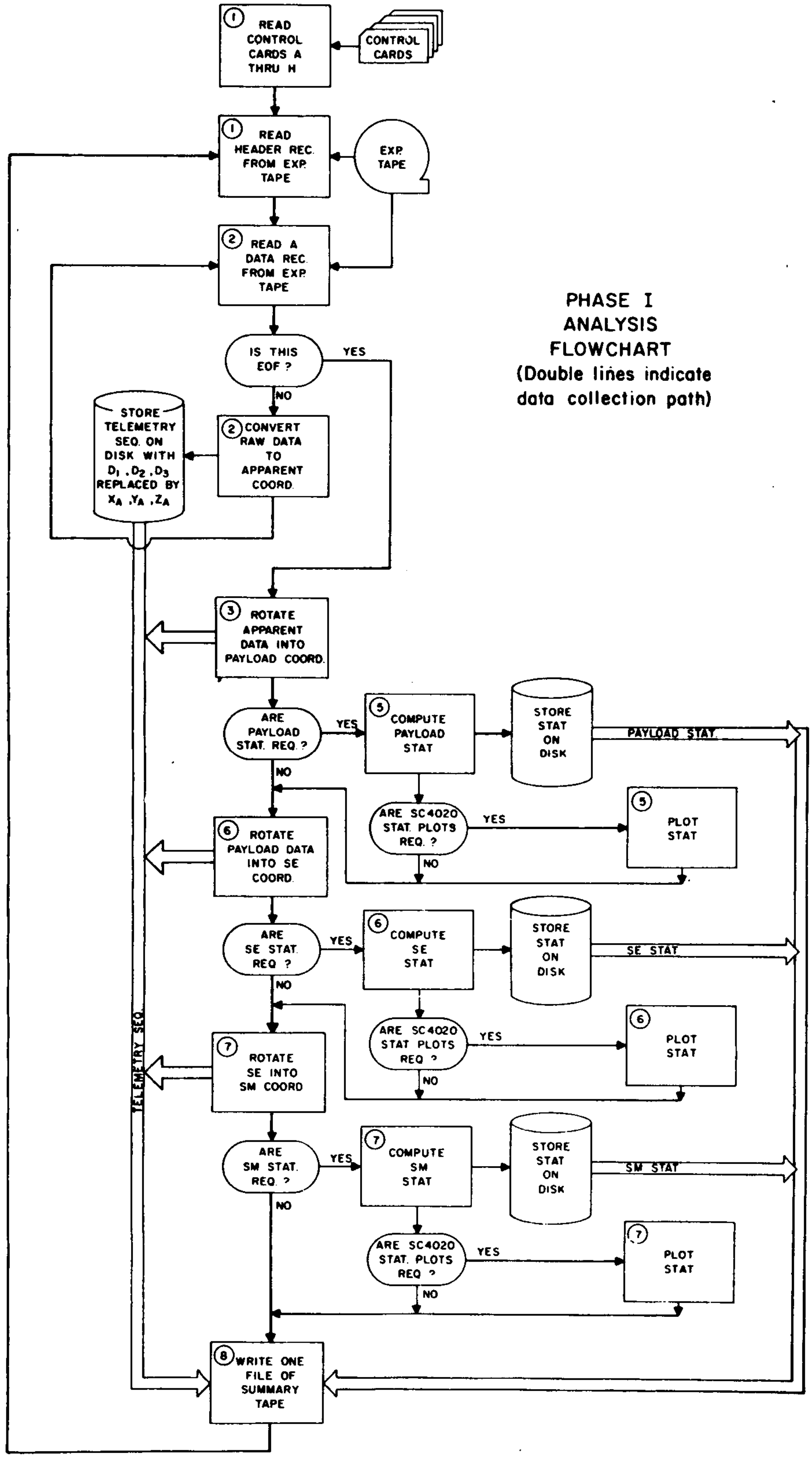
Sequence averages and variances are computed for XSM, YSM, ZSM, Total Field, θ_{sm}, ϕ_{sm}, CRATIO, and TRATIO using an analogous set of formulas to the set given in Section 5. S_{14} and S_{16}, determine printout, and plot status of SM sequence statistics.

8. GENERATION OF SUMMARY TAPE (PROCESS ONE FILE)

The Program now builds a summary tape record for each telemetry sequence which contains: (see Appendix C):

1. ID information.
2. The original telemetry sequence including the output from the autocorrelation computer with the exception that XA, YA, ZA has replaced D_1, D_2, D_3.
3. The trajectory data for the sequence.
4. The Payload, SE, and SM detail data and statistics for the sequence and refined spin period.

There is one file of data on this Summary Tape for every file of data on the original experimenter tape and all overlapping data are still present. There is one set of Summary Tapes for each Experimenter Tape.


PHASE I
ANALYSIS
FLOWCHART
(Double lines indicate data collection path)
CONTROL CARDS
1 READ CONTROL CARDS A THRU H
1 READ HEADER REC. FROM EXP. TAPE
EXP. TAPE
2 READ A DATA REC. FROM EXP. TAPE
IS THIS EOF ?
YES
NO
STORE TELEMETRY SEQ. ON DISK WITH D1, D2, D3 REPLACED BY XA, YA, ZA
2 CONVERT RAW DATA TO APPARENT COORD.
3 ROTATE APPARENT DATA INTO PAYLOAD COORD.
ARE PAYLOAD STAT. REQ. ?
5 COMPUTE PAYLOAD STAT
STORE STAT ON DISK
PAYLOAD STAT
ARE SC4020 STAT. PLOTS REQ. ?
5 PLOT STAT
6 ROTATE PAYLOAD DATA INTO SE COORD.
ARE SE STAT. REQ ?
6 COMPUTE SE STAT
SE STAT
6 PLOT STAT
7 ROTATE SE INTO SM COORD
TELEMETRY SEQ.
ARE SM STAT. REQ. ?
7 COMPUTE SM STAT
SM STAT
7 PLOT STAT
8 WRITE ONE FILE OF SUMMARY TAPE

PART IV

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APPENDIX A

DICTIONARY OF TERMS

1. S	Switching Vector
2. XCI	
3. YCI	Spin axis unit vector in Celestrial Inertial Coordinates
4. ZCI	
5. D_1	Detected output of X sensor
6. D_2	Detected output of Y sensor
7. D_3	Detected output of Z sensor
8. XA	D_1 rotated into the standard rotating coordinate system
9. YA	D_2 rotated into the standard rotating coordinate system
10. ZA	D_3 rotated into the standard rotating coordinate system
11. XP	XA in payload coordinates
12. YP	YA in payload coordinates
13. ZP	ZA in payload coordinates
14. AI	Constant term of calibration coefficients
15. BI	Linear term of calibration coefficients
16. CI	Second degree term of calibration coefficients
17. ZDZ	Correction to zero level
18. ZDS	Z dependent zero level
19. γ_i	$(t_i - t_{s/s})/$(Refined Spin Period)* $2\pi + \psi_o - \psi_1$

20. t_i Time for the orthogonal sample $D1_i$, $D2_i$, $D3_i$

21. $t_{s/s}$ Time the OA Sensor saw the sun

22. ψ_o The angular offset of sensor = -22.5°

23. $\overline{TFP1}$, $\overline{TFP2}$ Average total field in payload coordinates for a sequence

24. $\overline{\alpha_p}$ Average angle of field vector measured from Z axis for a sequence

25. $\overline{\psi_p}$ Average angle of field vector in X-Y plane for a sequence

26. $\hat{\sigma}_{XP}$ Variance of XP for a sequence

27. $\hat{\sigma}_{YP}$ Variance of YP for a sequence

28. $\hat{\sigma}_{ZP}$ Variance of ZP for a sequence

29. A See Appendix E

30. D See Appendix E

31. XSE XA in SE coordinates

32. YSE YA in SE coordinates

33. ZSE ZA in SE coordinates

34. RACI Rt. Ascension of spin axis in Celestial Interial Coordinates

35. DECCI Declination of spin axis in Celestial Interial Coordinates

36. $\overline{TFSE1}$, $\overline{TFSE2}$ Average total field in SE for a sequence

37. $\overline{\theta_{se}}$ Average angle of field vector measured from Z axis in SE for a sequence

38. $\overline{\phi_{se}}$ Average angle of field vector in X-Y plane in SE for a sequence

39. $\hat{\sigma}_{XSE}$ Variance of XSE for a sequence

40. $\hat{\sigma}_{YSE}$ Variance of YSE for a sequence

41. $\hat{\sigma}_{ZSE}$ Variance of ZSE for a <u>sequence</u>

42. XSM XA in SM coordinates

43. YSM YA in SM coordinates

44. ZSM ZA in SM coordinates

45. $\overline{TFSM1}, \overline{TFSM2}$ Average total field in SM for a <u>sequence</u>

46. $\overline{\theta_{sm}}$ Average angle of field vector measured from Z axis for a <u>sequence</u>

47. $\overline{\phi_{sm}}$ Average angle of field vector in X-Y plane for a <u>sequence</u>

48. $\hat{\sigma}_{XSM}$ Variance of XSM for a <u>sequence</u>

49. $\hat{\sigma}_{YSM}$ Variance of YSM for a <u>sequence</u>

50. $\hat{\sigma}_{ZSM}$ Variance of ZSM for a <u>sequence</u>

APPENDIX B

Card#	Fortran Format	Function
A	2 (A4)	Experimenter Tape# and Analysis Date
B	80 (I1)	Switching Vector (See rest of this Appendix for a functional breakdown.)
C	9 (F8.0)	Calibration Coefficients for low range
D	9 (F8.0)	Calibration Coefficients for high range
E	6 (F10.0)	Correction to zero and z dependent zero for low range
F	6 (F10.0)	Correction to zero and z dependent zero for high range
G	2 (I5)	File interval to be processed
H	2 (F10.0)	Right Ascension and Declination in Celestial Inertial Coordinates of the spin axis of the spacecraft

APPENDIX B (Cont.)

SWITCHING VECTOR CONTROL CARD B

Card Column & Subscript of s	State	Action
1	0 1	Reserved
2	0	Printout of the Detail Raw Data
	1	No Printout of Detail Raw Data
3	0	Printout of the Detail Apparent Field Values
	1	No Printout of Detail Apparent Field Values
4	0	Printout of the Detail Payload Field Values
	1	No Printout of Detail Payload Field Values
5	0	Printout of Sequence Statistics in Payload Coordinates
	1	No Printout
6	0	4020 Plots of Detail Payload Coordinates
	1	No Plots
7	0	4020 Plots of Sequence Statistics in Payload Coordinates
	1	No Plots
8	0	Printout of the Detail SE Field Values
	1	No Printout

Card Column & Subscript of s	State	Action
9	0	Printout of the SE Sequence Statistics
	1	No Printout
10	0	Reserved
	1	
11	0	4020 Plot of SE Sequence Statistics
	1	No Plot
12	0	Reserved
	1	
13	0	Printout of Detail SM Field Values
	1	No Printout
14	0	Printout of SM Sequence Statistics
	1	No Printout
15	0	Reserved
	1	
16	0	4020 Plot of SM Sequence Statistics
	1	No Plot
17	0	Reserved
	1	

Card Column & Subscript of s	State	Action
18	0	
	1	
19	0	
	1	
20	0	
	1	
21	0	
	1	
22	0	
	1	
23	0	
	1	
24	0	
	1	
25*	0	RACI, DECCI To Be Used
	1	RACI, DECCI Are Not To Be Used
26	0	
	1	

*S_{25} must be set equal to zero if rotation to SE and/or SM is desired.

APPENDIX C

IMP F EXPERIMENTER BINARY TAPE ID RECORD FORMAT

Word No.	Identification		Format
1	Experimenter ID		I
2	Satellite ID		I
3	Orbit number		I
4	Telemetry Recording Station Number		I
5	Analog tape number		I
6	Analog-to-digital line ID		I
7	Day of Year	start time	I
8	Milliseconds of Day	for this file	I
9	Day of Year	stop time	I
10	Milliseconds of Day	for this file	I
11	Average sequence time (milliseconds) for this file		I
12	Quick look data flag		I
13	Orbit/no orbit data flag		I
14	Decom process date year		I
15	Decom process date month		I
16	Decom process date day		I
17	Decom process date hour		I
18	Orbit tape ID reel number		I
19	Orbit tape date of generation year		I
20	Orbit tape date of generation month		I
21	Orbit tape date of generation day		I
22	Average spin period in milliseconds		I
23	Year of start time of file		
24	Year of stop time of file		
25 - 40	Room for expansion		

Orbit/No Orbit Data Flag for Experimenter Tape ID Records

0 = no orbit data included on this file. Fill characters are used in orbit item locations.
1 = "final" orbit data included on this file.
2 = preliminary orbit data included on this file.
3 = predicted orbit data included on this file.

Quick-Look Data Flag for Experimenter Tape ID Records

0 = no sequence clock corrections, no frame time corrections

applied to this file, there data is "quick-look".

1 = Phase I sequence clock corrections and frame time corrections have been applied to this file, but final correction have not been made, therefore, data is "quick-look".

2 = Phase I and Phase II sequence and frame time corrections have been made to data on this file.

Sequence Data Quality Flag

The F9 program uses the computed signal-to-noise ratio to determine the probability of error per sequence. The sequence data quality flags on F9 digitized intermediate data tapes have these meanings:

Flag	Data Quality
0	Probability of one or more errors in each 100 samples, category 1.
1	Probability of one or more errors in each 100 samples, category 2.
2	Probability of one or more errors in each 100 samples, category 3.
3	Probability of one or more errors in each 330 samples.
4	Probability of one or more errors in each 500 samples.
5	Probability of one or more errors in each 1000 samples.
6	(fill character) Data quality is undetermined for this partial sequence.

Data quality flags on a sequence basis are computed by the F8 processing program. From the number of errors in the satellite clock and in the sync oscillator, an assumption is made about the quality of the entire sequence. The F8 assigned sequence quality flags have these meanings:

Flag	Data Quality
0	Undetermined
1	Poor quality
2	Fair quality
3	Good Quality
6	Fill character, undetermined data quality

APPENDIX C (Cont.)

MAGNETIC FIELD IMP F EXPERIMENTER TAPE FORMAT

Item No.	Identification	Fortran Name	Format
1	Satellite I.D.	ID(I)	I
2	Acquisition station I.D.	IDAS(I)	I
3	Analog tape I.D.	IDAT(I)	I
4	Analog-to-digital line indicator	IDAL(I)	I
5	Year of frame 0, channel 0	IYR(I)	I
6	Day of frame 0, channel 0	INTDAY(I)	I
7	Milliseconds of day	MSEC(I)	I
8	Time quality flag	ITQF(I)	I
9	Data quality flag for this sequence	IDQF(I)	I
10	Experimenter on/off flags (frame 4, channel 2)	IXF(I)	I
11	Orbit data flag	IODF(I)	I
12	Analog calibration flag (channel 1, frame 4)	IACF(I)	I
13	Pseudo-sequence count quality flag	IPSQF(I)	I
14	Pseudo-sequence count	IPSC(I)	I
15	Sequence I.D. quality flag	IDSQF(I)	I
16	Sequence I.D.	IDS(I)	I
17	Satellite clock	ISC(I)	I
18	Average frame time in milliseconds	IAFP(I)	I

Item No.	Identification	Fortran Name	Format
19	PP 21 (Bellows temperature)	PP21(I)	F
20	PP 7 (+11.7 volt line)	PP7(I)	F
21	Frame number (1)	NF (I,J)	I
22	Mag X	D1(I,J)	I
23	Mag Y	D2(I,J)	I
24	Mag Z	D3 (I,J)	I
25	Frame number (3)		I
26	Mag X		I
27	Mag Y		I
28	Mag Z		I
29-52	Magnetometer values for frames 5, 7, 9, 11, 13, and 15 (items 25-28 repeated six times)		
53	Frame 8, channel 1a, 1b, 2a	IAVG(I)	I
54	Frame 8, channel 2b	L8EX(I)	I
55	Frame 8, channel 3a, 3b	L8FR(I)	I
56	Frame 8, channel 4a	L7EX(I)	I
57	Frame 8, channel 4b, 5a	L7FR(I)	I
58	Frame 8, channel 5b	L6EX(I)	I
59	Frame 8, channel 6a, 6b	L6FR(I)	I
60	Frame 8, channel 7a	L5EX(I)	I
61	Frame 8, channel 7b, 8a	L5FR(I)	I

IMP G	IMP F	Item No.	Identification	Fortran Name	Format
		62	Frame 8, channel 8b	L4EX(I)	I
		63	Frame 8, channel 9a, 9b	L4FR(I)	I
		64	Frame 8, channel 10a	L3EX(I)	I
		65	Frame 8, channel 10b, 11a	L3FR(I)	I
		66	Frame 8, channel 11b	L2EX(I)	I
		67	Frame 8, channel 12a, 12b	L2FR(I)	I
		68	Frame 8, channel 13a	L1EX(I)	I
		69	Frame 8, channel 13b, 14a	L1FR(I)	I
		70	Frame 8, channel 14b	LZEX(I)	I
		71	Frame 8, channel 15a, 15b	LZFR(I)	I
		72	OA SCAN (spin-axis-sun-angle)	OAS(I)	F
		73	OA1 (sun time)	TSS(I)	F
		74	OA2 (spin period)	SPIN(I)	F
		75	OA3 (earth time)	ET(I)	F
		76	OA4 (earth width)	EW(I)	F
		77-228	Data from two more telemetry sequences (items 1-76 repeated twice)		
		229	Day or orbit data	JDOD	I
		230	Milliseconds of day of orbit data	JSEC	I
87	100	231	Geomagnetic latitude satellite position	TRAJ(N),	F
88	101	232	Geomagnetic longitude satellite position	N = 1, 43	F

IMP G	IMP F	Item No.	Identification	Fortran Name	Format
89	102	233	X solar ecliptic satellite position		F
90	103	234	Y solar ecliptic satellite position		F
91	104	235	Z solar ecliptic satellite position		F
92	105	236	Radial distance to satellite from earth center		F
93	106	237	X solar magnetosphere satellite position		F
94	107	238	Y solar magnetosphere satellite position		F
95	108	239	Z solar magnetosphere satellite position		F
96	109	240	X solar ecliptic moon position		F
97	110	241	Y solar ecliptic moon position		F
98	111	242	Z solar ecliptic moon position		F
99	112	243	X solar magnetosphere moon position		F
100	113	244	Y solar magnetosphere moon position		F
101	114	245	Z solar magnetosphere moon position		F
102	115	246	Distance from satellite to moon		F
103	116	247	Distance from satellite to the moon which is parallel to the X axis		F
104	117	248	Geomagnetic latitude sun position		F
105	118	249	Geomagnetic longitude sun position		F
106	119	250	X theoretical geomagnetic field in solar ecliptic		F
107	120	251	Y theoretical geomagnetic field in solar ecliptic		F

IMP G	IMP F	Item No.	Identification	Fortran Name	Format
108	121	252	Z theoretical geomagnetic field in solar ecliptic		F
109	122	253	Magnitude of the theoretical geomagnetic field in solar ecliptic		F
110-118	123-131	254-262	Rotation matrix from solar ecliptic to solar magnetosphereic		F
119-127	132-140	263-271	Rotation matrix from celestial inertial to solar ecliptic		F
128	141	272	Geocentric latitude satellite position		F
129	142	273	Geocentric longitude satellite position		F

This is a seven-track, 556 BPI, binary mode tape. All items (both integer and floating) are 32-bit, IBM 360 notation words. One four-byte control word (which gives the number of bytes in the logical record) is at the beginning of each record. Missing data is indicated by having all bits except sign bit set to "1".

APPENDIX C (Cont.)

IMP F SUMMARY TAPE FORMAT

Item No.	Identification	Format
1	Satellite I. D.	I
2	Orbit Number	I
3	Telemetry Recording Station Number	I
4	Analog Tape Number	I
5	Analog-To-Digital Line I. D.	I
6	Day of Year (Start)	I
7	Milliseconds of Day	I
8	Day of Year (Stop)	I
9	Milliseconds of Day	I
10	Average Sequence Time (Milliseconds) This File	I
11	Quick Look Data Flag	I
12	Orbit/No Orbit Data Flag	I
13	Decom Process Date Year	I
14	Decom Process Date Month	I
15	Decom Process Date Day	I
16	Decom Process Date Hour	I
17	Orbit Tape I. D. Reel Number	I
18	Orbit Tape Date of Generation Year	I
19	Orbit Tape Date of Generation Month	I

Item No.	Identification	Format
20	Orbit Tape Date of Generation Day	I
21	Average Spin Period in Milliseconds	I
22	Year of Start Time	I
23	Year of Stop Time	I
24	Experimenter Tape Number	A4
25	Analysis Date	A4
26	Year of beginning of Frame 0, Channel 0	I
27	Day of beginning of Frame 0, Channel 0 (Decimal Day)	I
28	Milliseconds of Day	I
29	Time Quality Flag	I
30	Data Quality Flag for this Sequence	I
31	Experimenter On/Off Flags (Frame 4, Channel 2)	I
32	Orbit Data Flag	I
33	Analog Calibration Flag (Channel 1, Frame 4)	I
34	Pseudo-Sequence Count Quality Flag	I
35	Pseudo-Sequence Count	I
36	Sequence I. D. Quality Flag	I
37	Sequence I. D.	I
38	Satellite Clock	I
39	Average Frame Time in Milliseconds	I
40	PP21 (Bellows Temperature)	I

Item No.	Identification	Format
41	PP7 (+11.7 Volt Line)	I
42	Frame Number (1)	I
43	X Apparent	F
44	Y Apparent	F
45	Z Apparent	F
46	Frame Number (3)	I
47	X Apparent	F
48	Y Apparent	F
49	Z Apparent	F
50	Frame Number (5)	I
51	X Apparent	F
52	Y Apparent	F
53	Z Apparent	F
54	Frame Number (7)	I
55	X Apparent	F
56	Y Apparent	F
57	Z Apparent	F
58	Frame Number (9)	I
59	X Apparent	F
60	Y Apparent	F
61	Z Apparent	F

Item No.	Identification	Format
62	Frame Number (11)	I
63	X Apparent	F
64	Y Apparent	F
65	Z Apparent	F
66	Frame Number (13)	I
67	X Apparent	F
68	Y Apparent	F
69	Z Apparent	F
70	Frame Number (15)	I
71	X Apparent	F
72	Y Apparent	F
73	Z Apparent	F
74	Frame 8, Channel 1a, 1b, 2a	I
75	Frame 8, Channel 2b	I
76	Frame 8, Channel 3a, 3b	I
77	Frame 8, Channel 4a	I
78	Frame 8, Channel 4b, 5a	I
79	Frame 8, Channel 5b	I
80	Frame 8, Channel 6a, 6b	I
81	Frame 8, Channel 7a	I
82	Frame 8, Channel 7b, 8a	I

Item No.	Identification	Format
83	Frame 8, Channel 8b	I
84	Frame 8, Channel 9a, 9b	I
85	Frame 8, Channel 10a	I
86	Frame 8, Channel 10b, 11a	I
87	Frame 8, Channel 11b	I
88	Frame 8, Channel 12a, 12b	I
89	Frame 8, Channel 13a	I
90	Frame 8, Channel 13b, 14a	I
91	Frame 8, Channel 14b	I
92	Frame 8, Channel 15a, 15b	I
93	0A SCAN (Spin-Axis-Sun-Angle)	F
94	0A1 (Sun Time)	F
95	0A2 (Spin Period)	F
96	0A3 (Earth Time)	F
97	0A4 (Earth Width)	F
98	Day of Orbit Data	I
99	Milliseconds of Day of Orbit Data	I
100 - 142	Items 231-273 (Trajectory Data) from IMP F Experimenter Tape Format.*	F
143	X Payload	F
144	Y Payload	F
145	Z Payload	F

*Item 251 from experimenter tape has been converted to theoretical geomagnetic field latitude angle. Item 252 has been converted to theoretical geomagnetic field longitude angle on the Summary Tape.

Item No.	Identification		Format
146	ALPHA Payload	For Frames 1,3,5,7,9,11,13,15	F
147	PSI Payload		F
148	Total Field Payload		F
191	X Average Payload		F
192	Y Average Payload		F
193	Z Average Payload		F
194	TOTAL FIELD AVERAGE 1 Payload		F
195	TOTAL FIELD AVERAGE 2 Payload		F
196	ALPHA Average Payload		F
197	PSI Average Payload		F
198	Standard Deviation of X Payload		F
199	Standard Deviation of Y Payload		F
200	Standard Deviation of Z Payload		F
201	Standard Deviation of Total Field 1 Payload		F
202	Standard Deviation of Total Field 2 Payload		F
203	Component Ratio Payload		F
204	Total Field Ratio Payload		F
205	X Solar Ecliptic	For Frames 1,3,5,7,9,11,13,15	F
206	Y Solar Ecliptic		F
207	Z Solar Ecliptic		F
208	THETA Solar Ecliptic		F
209	PHI Solar Ecliptic		F

Item No.	Identification		Format
245	X Average Solar Ecliptic		F
246	Y Average Solar Ecliptic		F
247	Z Average Solar Ecliptic		F
248	THETA Average Solar Ecliptic		F
249	PHI Average Solar Ecliptic		F
250	Standard Deviation of X Solar Ecliptic		F
251	Standard Deviation of Y Solar Ecliptic		F
252	Standard Deviation of Z Solar Ecliptic		F
253	Component Ratio Solar Ecliptic		F
254	Total Field Ratio Solar Ecliptic		F
255	X Solar Magnetospheric	For Frames 1,3,5,7,9,11,13,15	F
256	Y Solar Magnetospheric	For Frames 1,3,5,7,9,11,13,15	F
257	Z Solar Magnetospheric	For Frames 1,3,5,7,9,11,13,15	F
258	THETA Solar Magnetospheric	For Frames 1,3,5,7,9,11,13,15	F
259	PHI Solar Magnetospheric	For Frames 1,3,5,7,9,11,13,15	F
295	X Average Solar Magnetospheric		F
296	Y Average Solar Magnetospheric		F
297	Z Average Solar Magnetospheric		F
298	THETA Average Solar Magnetospheric		F
299	PHI Average Solar Magnetospheric		F
300	Standard Deviation of X Solar Magnetospheric		F

Item No.	Identification	Format
301	Standard Deviation of Y Solar Magnetospheric	F
302	Standard Deviation of Z Solar Magnetospheric	F
303	Component Ratio Solar Magnetospheric	F
304	Total Field Ratio Solar Magnetospheric	F
305	Celestial Inertial Orientation of Spin Axis for X	F
306	Celestial Inertial Orientation of Spin Axis for Y	F
307	Celestial Inertial Orientation of Spin Axis for Z	F

End of tape is indicated by an EOF mark. Files are not separated by any logical type of EOF record. This is a 9 track IBM 360 binary tape (999.0 indicates bad data). All words are single precision (i.e. 4 bytes in length).

APPENDIX C (Cont.)

IMP G SUMMARY TAPE FORMAT

Item No.	Identification	Format
1	Satellite I. D.	I
2	Orbit Number	I
3	Telemetry Recording Station Number	I
4	Analog Tape Number	I
5	Analog-To-Digital Line I. D.	I
6	Day of Year (Start)	I
7	Milliseconds of Day	I
8	Day of Year (Stop)	I
9	Milliseconds of Day	I
10	Average Sequence Time (Milliseconds) This File	I
11	Quick Look Data Flag	I
12	Orbit/No Orbit Data Flag	I
13	Decom Process Date Year	I
14	Decom Process Date Month	I
15	Decom Process Date Day	I
16	Decom Process Date Hour	I
17	Orbit Tape I. D. Reel Number	I
18	Orbit Tape Date of Generation Year	I
19	Orbit Tape Date of Generation Month	I

Item No.	Identification	Format
20	Orbit Tape Date of Generation Day	I
21	Average Spin Period in Milliseconds	I
22	Year of Start Time	I
23	Year of Stop Time	I
24	Experimenter Tape Number	A4
25	Analysis Date	A4
26	Year of Frame 0, Channel 0	I
27	Day of Frame 0, Channel 0 (Decimal Day)	I
28	Milliseconds of Day	I
29	Time Quality Flag	I
30	Data Quality Flag for this Sequence	I
31	Experimenter On/Off Flags (Frame 4, Channel 2)	I
32	Orbit Data Flag	I
33	Analog Calibration Flag (Channel 1, Frame 4)	I
34	Pseudo-Sequence Count Quality Flag	I
35	Pseudo-Sequence Count	I
36	Sequence I. D. Quality Flag	I
37	Sequence I. D.	I
38	Satellite Clock	I
39	Average Frame Time in Milliseconds	I
40	PP21 (Bellows Temperature)	I

Item No.	Identification	Format
41	PP7 (+11.7 Volt Line)	I
42	Frame Number (1)	I
43	X Apparent	F
44	Y Apparent	F
45	Z Apparent	F
46	Frame Number (3)	I
47	X Apparent	F
48	Y Apparent	F
49	Z Apparent	F
50	Frame Number (5)	I
51	X Apparent	F
52	Y Apparent	F
53	Z Apparent	F
54	Frame Number (7)	I
55	X Apparent	F
56	Y Apparent	F
57	Z Apparent	F
58	Frame Number (9)	I
59	X Apparent	F
60	Y Apparent	F
61	Z Apparent	F

Item No.	Identification					Format
62	Frame Number (11)					I
63	X Apparent					F
64	Y Apparent					F
65	Z Apparent					F
66	Frame Number (13)					I
67	X Apparent					F
68	Y Apparent					F
69	Z Apparent					F
70	Frame Number (15)					I
71	X Apparent					F
72	Y Apparent					F
73	Z Apparent					F

(Items 74-78 are autocorrelation data, and are identified by item 79, JAUTO.)

	JAUTO	3	4	5	6	
74		$AV_{\parallel}$	$AV_{\perp}$	$L4_{\parallel}$	$L4_{\perp}$	I
75		$L8_{\parallel}$	$L8_{\perp}$	$L3_{\parallel}$	$L3_{\perp}$	I
76		$L7_{\parallel}$	$L7_{\perp}$	$L2_{\parallel}$	$L2_{\perp}$	I
77		$L6_{\parallel}$	$L6_{\perp}$	$L1_{\parallel}$	$L1_{\perp}$	I
78		$L5_{\parallel}$	$L5_{\perp}$	$L0_{\parallel}$	$L0_{\perp}$	I
79	JAUTO					I
80	OA SCAN (Spin-Axis-Sun-Angle)					F
81	OA1 (Sun Time)					F
82	OA2 (Spin Period)					F
83	OA3 (Earth Time)					F

Item No.	Identification		Format
84	OA4 (Earth Width)		F
85	Day of Orbit Data		I
86	Milliseconds of Day of Orbit Data		I
87-129	Items 231-273 (Trajectory Data) from IMP E Experimenter Tape Format		F
130	X Payload	For Frame 1. Repeat 7 more times for Frames 3,5,7,9, 11,13,15, Items 136-177.	F
131	Y Payload		F
132	Z Payload		F
133	ALPHA Payload		F
134	PSI Payload		F
135	Total Field Payload		F
178	X Average Payload		F
179	Y Average Payload		F
180	Z Average Payload		F
181	TOTAL FIELD AVERAGE 1 Payload		F
182	TOTAL FIELD AVERAGE 2 Payload		F
183	ALPHA Average Payload		F
184	PSI Average Payload		F
185	Standard Deviation of X Payload	SDXS(1)	F
186	Standard Deviation of Y Payload	SDYS(1)	F
187	Standard Deviation of Z Payload	SDZS(1)	F
188	Normalized Covariance, X,Y, Payload	SDXY(1)	F
189	Normalized Covariance, Y,Z, Payload	SDYZ(1)	F
190	Normalized Covariance, Z,X, Payload	SDZX(1)	F
191	Standard Deviation of Total Field 1 Paylaod		F
192	Standard Deviation of Total Field 2 Payload		F
193	Component Ratio Payload		F

Item No.	Identification			Format
194	Total Field Ratio Payload			F
195	X Solar Ecliptic			F
196	Y Solar Ecliptic			F
197	Z Solar Ecliptic	Frame 1. Repeated 7 times for Frames 3,5,7,9,11,13, 15, Items 200-234.		F
198	THETA Solar Ecliptic			F
199	PHI Solar Ecliptic			F
235	X Average Solar Ecliptic			F
236	Y Average Solar Ecliptic			F
237	Z Average Solar Ecliptic			F
238	THETA Average Solar Ecliptic			F
239	PHI Average Solar Ecliptic			F
240	Standard Deviation of X Solar Ecliptic		SDXS(2)	F
241	Standard Deviation of Y Solar Ecliptic		SDYS(2)	F
242	Standard Deviation of Z Solar Ecliptic		SDZS(2)	F
243	Normalized Covariance, X,Y, Solar Ecliptic		SDXY(2)	F
244	Normalized Covariance, Y,Z, Solar Ecliptic		SDYZ(2)	F
245	Normalized Covariance, Z,X, Solar Ecliptic		SDZX(2)	F
246	Component Ratio Solar Ecliptic		CRTIOS(2)	F
247	Total Field Ratio Solar Ecliptic			F
248	X Solar Magnetospheric			F
249	Y Solar Magnetospheric			F
250	Z Solar Magnetospheric	For Frame 1. Repeated 7 times for Frames 3,5,7, 9,11,13,15, Items 253-287.		F
251	THETA Solar Magnetospheric			F
252	PHI Solar Magnetospheric			F
288	X Average Solar Magnetospheric			F
289	Y Average Solar Magnetospheric			F

Item No.	Identification		Format
290	Z Average Solar Magnetospheric		F
291	THETA Average Solar Magnetospheric		F
292	PHI Average Solar Magnetospheric		F
293	Standard Deviation of X Solar Magnetospheric		F
294	Standard Deviation of Y Solar Magnetospheric		F
295	Standard Deviation of Z Solar Magnetospheric		F
296	Normalized Covariance, X,Y, Solar Magnetospheric		F
297	Normalized Covariance, Y,Z, Solar Magnetospheric		F
298	Normalized Covariance, Z,X, Solar Magnetospheric		F
299	Component Ratio Solar Magnetospheric	CRTIOS(3)	F
300	Total Field Ratio Solar Magnetospheric		F
301	Celestial Inertial Orientation of Spin Axis for X		F
302	Celestial Inertial Orientation of Spin Axis for Y		F
303	Celestial Inertial Orientation of Spin Axis for Z		F
304	Number of Points in Payload Average	(AN)	F
305	Number of Points in Solar Ecliptic Average	(AN)	F
306	Number of Points in Solar Magnetosphere Average	(AN)	F

End of tape is indicated by a EOF mark. Files are not separated by any logical type of EOF record. This is a 9 track IBM 360 binary tape (999.0 indicates bad data). All words are single precision (i.e. 4 bytes in length).

APPENDIX D

TRANSFORMATION TO PAYLOAD COORDINATES

A top view of the spacecraft with the three sensors is shown in Figure 1. Note that the $+Z_A$ direction points into the page* and $+X_A$ is tangential to the spin axis. Y_A forms a right hand coordinate system.

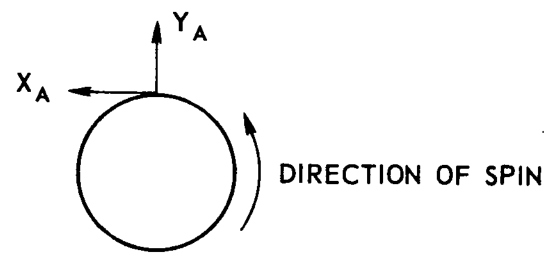

Figure 1.

Figure 2, in perspective, shows the situation when Figure 1 is turned over so that the $+Z$ direction is up.

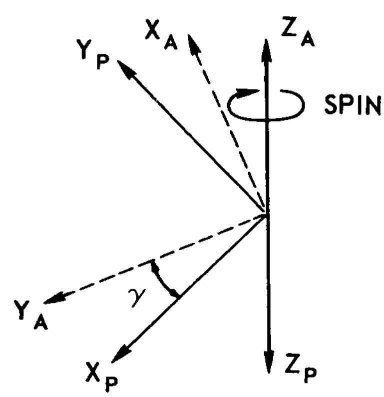

Figure 2.

Let the dotted coordinate system be the apparent coordinate system at a measurement time, t_i. Let the solid line coordinate system represent payload coordinates, (the $+X_P$ axis of which points toward the sun) thus X_P defines $t_{s/s}$, the time the optical aspect sensor saw the sun. Gamma, γ, is the angle swept out from $t_{s/s}$ to t_i by the spinning spacecraft minus 22.5° (Sun sensor-boom separation).

*This is referred to as "down" position.

ıus we get:

$$X_P = Y_A \cos\gamma - X_A \sin\gamma$$

$$Y_P = Y_A \sin\gamma + X_A \cos\gamma$$

$$Z_P = -Z_A$$

or

$$\begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} = \begin{bmatrix} -\sin\gamma & \cos\gamma & 0 \\ \cos\gamma & \sin\gamma & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix}$$

APPENDIX E

TRANSFORMATION TO SOLAR ECLIPTIC COORDINATES

The solar ecliptic coordinates of the unit spin axis are defined as EPX EPY and EPZ. Now compute the following angles (see Figure 1).

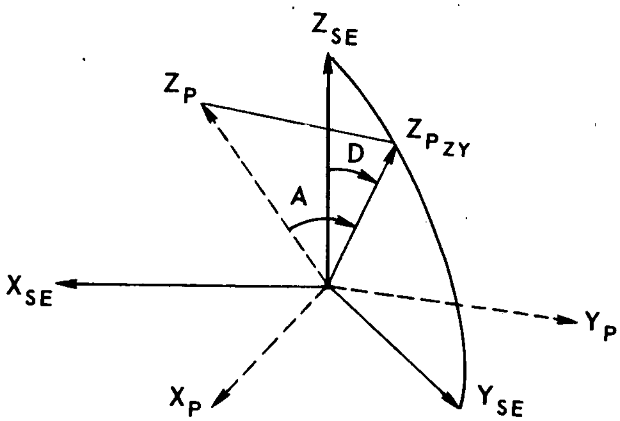

Figure 1.

$$\text{Cos A} = \frac{|\vec{Z}_{P_{ZY}}|}{Z_P} = \frac{\sqrt{(EPY)^2 + (EPZ)^2}}{\sqrt{(EPX)^2 + (EPY)^2 + (EPZ)^2}}$$

or

$$\text{Cos A} = \sqrt{(EPY)^2 + (EPZ)^2}$$

$$\text{Sin A} = \frac{EPX}{\sqrt{(EPX)^2 + (EPY)^2 + (EPZ)^2}} = EPX$$

$$\text{Cos D} = \frac{EPZ}{\sqrt{(EPY)^2 + (EPZ)^2}} \text{ or Cos D} = \frac{EPZ}{\text{Cos A}}$$

$$\text{Sin D} = EPY/\text{Cos A}$$

If we rotate X_P into X_{SE}, Z_P must then be perpendicular to X_{SE} and consequently must lie in the Z_{SE} - Y_{SE} plane: thus rotate through angle A, about Y_P axis (Z_P would then lie along $Z_{P_{ZY}}$). Call the new coordinates after this rotation X', Y', Z'. (See Figure 2.)

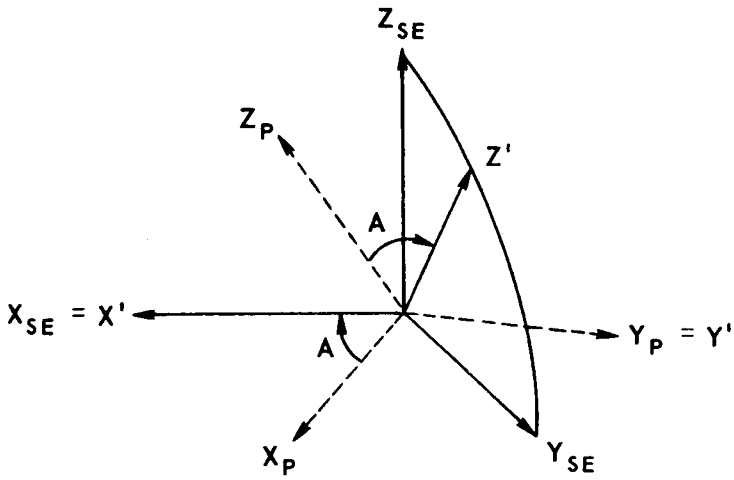

Figure 2.

$$X' = X_p \operatorname{Cos} A + Z_p \operatorname{Sin} A$$

$$Y' = Y_p$$

$$Z' = - Xp \operatorname{Sin} A + Zp \operatorname{Cos} A$$

or

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} \operatorname{Cos} A & 0 & \operatorname{Sin} A \\ 0 & 1 & 0 \\ -\operatorname{Sin} A & 0 & \operatorname{Cos} A \end{bmatrix} \begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix}$$

Then rotate about X' = X_{SE} axis to get Y' into Y_{SE} and Z' into Z_{SE}. (See Figure 3.)

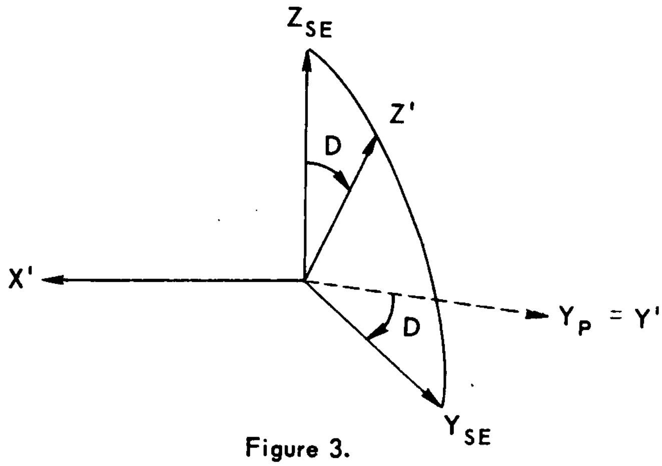

Figure 3.

$$X_{SE} = X'$$

$$Y_{SE} = Y' \cos D + Z' \sin D$$

$$Z_{SE} = -Y' \sin D + Z' \cos D$$

$$\begin{bmatrix} X_{SE} \\ Y_{SE} \\ Z_{SE} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos D & \sin D \\ 0 & -\sin D & \cos D \end{bmatrix} \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

Hence

$$\begin{bmatrix} X_{SE} \\ Y_{SE} \\ Z_{SE} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos D & \sin D \\ 0 & -\sin D & \cos D \end{bmatrix} \begin{bmatrix} \cos A & 0 & \sin A \\ 0 & 1 & 0 \\ -\sin A & 0 & \cos A \end{bmatrix} \begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix}$$

or

$$\begin{bmatrix} X_{SE} \\ Y_{SE} \\ Z_{SE} \end{bmatrix} = \begin{bmatrix} \text{Cos } A & 0 & \text{Sin } A \\ -\text{Sin } A \text{ Sin } D & \text{Cos } D & \text{Cos } A \text{ Sin } D \\ -\text{Sin } A \text{ Cos } D & -\text{Sin } D & \text{Cos } A \text{ Cos } D \end{bmatrix} \begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix}$$

APPENDIX F

DESCRIPTION OF SC 4020 SEQUENCE STATISTICS

PLOTS

The sequence statistics plotting routine plots the following parameters as a function of time for the Payload, SE and SM coordinate systems.

1. Total field
   a. Actual (TF1)
   b. Theoretical
2. ϕ (0 - 360°)
   a. Actual
   b. Theoretical
3. θ (±90°)
   a. Actual
   b. Theoretical
4. Standard deviation Z computed by the autocorrelation computer.
5. Standard deviation of the actual field, $\frac{1}{3}(\hat{\sigma}_x + \hat{\sigma}_y + \hat{\sigma}_z)$.

Each frame of the plot displays 6 hours of data beginning at 0, 6, 12, or 18 hours in two 3 hour sweeps across the frame. If trajectory information is on the experimenter tape it is displayed every hour in the proper coordinate system in units of R_E. The following characters are used to indicate folding of scales:

Parameter, P	Range of P	Characters
Total Field (Actual)	$0 \leq P < 25$	•
	$25 \leq P < 50$	A

Parameter, P	Range of P	Characters
	$50 \leq P < 75$	B
	$75 \leq P < 100$	C
	$100 \leq P < 125$	D
	$125 \leq P < 150$	E
	$P \geq 150$	F
Total Field (Theoretical)	$0 \leq P < 25$	U
	$25 \leq P < 50$	V
	$50 \leq P < 75$	W
	$75 \leq P < 100$	X
	$100 \leq P < 125$	Y
	$125 \leq P < 150$	Z
ϕ (Actual)	$0 \leq P < 360$	•
ϕ (Theoretical)	$0 \leq P < 360$	T
θ (Actual)	$-90 \leq P \leq +90$	•
θ (Theoretical)	$-90 \leq P \leq +90$	T
Standard deviations of 2.556 sec. and 0.080 sec. samples computed over a 20.454 sec. sequence	$0 \leq P < 5$	•
	$5 \leq P < 10$	A
	$10 \leq P < 7.2 \times 10^{75}$	B
$\mathrm{Log}_{10} \left(\frac{SD_{0.080}}{SD_{2.556}} \right)$	$-0.60206 \leq P \leq 0.60206$	G
Special Characters	Saturation	S
	Addition of 10γ Calibration Field	K
	Heater On	H

APPENDIX F (Cont.)

SUBROUTINE PLOT

I. INTRODUCTION

This subroutine is used to plot the 20.45 second sequence statistics using the SC 4020 plotter. Specifically the following parameters are plotted:

1. Total field, F (actual sequence average, TF1)

2. Total field, F (theoretical)

3. Azimuthal angle, ϕ (actual sequence average)

4. Azimuthal angle, ϕ (theoretical)

5. Polar angle, θ (actual sequence average)

6. Polar angle, θ (theoretical)

7. Standard deviation of Z component of field for the sequence computed by the autocorrelation computer.

8. Standard deviation of total field (actual for the sequence), $\frac{1}{3}(\hat{\sigma}_x + \hat{\sigma}_y + \hat{\sigma}_z)$.

The Plot Subroutine is designed to plot one file of statistics which have been computed by the Statistics Subroutine (approximately 2 hours of data) each time it is entered such that each frame displays 6 hours of data beginning at 0, 6, 12, or 18 hours in two 3-hour sweeps across the frame.

Each frame is labeled with the following information:

1. Coordinate System (Payload, SE, SM)

2. Orbit Number

3. Decimal Day of Year and 3 Hour Periods Covered

4. Experimenter Tape Number

5. Analysis Date

6. Trajectory Flag

7. Trajectory Data in the Appropriate Coordinate System (if this is production data, i.e., there is no trajectory information included with quick-look data.)

8. Saturation of Sensors When It Occurs

9. Addition of 10γ Calibration Field When It Occurs

10. Heater On When It Occurs

II. DESCRIPTION OF PROCESSING

The Subroutine, using the time array for the file, i.e., times for channel zero frame zero of each sequence, operates on the corresponding data array from each Decimal Day separately.* During each Decimal Day the time array is searched in 3-hour sweeps starting at 0, 3, 6, 9, 12, 15, 18 and 21 hours for time (and thus data) falling in these three hour time intervals. When data is found in a specific interval the indices IB and IE are used to indicate the point in the data array where plotting should begin and end respectively, for this particular 3-hour interval. After IB and IE are defined, but before the data are plotted, the routine determines if the SC 4020 frame should be advanced and a new grid drawn. This will be necessary if the data to be plotted occurs in a three hour interval which starts at 0, 6, 12, or 18 hours, otherwise it is unnecessary to generate a new grid. Frame advance and grid construction are done with the GRD Subroutine. The Plot Subroutine now uses IB and IE to set the limits for the DO LOOP which plots the following data from each sequence during this three hour time interval.

1. Computed first is the value for the abscissa which represents the sequence time normalized to the three hour interval.

2. If there is trajectory data on the tape the theoretical magnetic field values are plotted as a function of time every 50 sequences, i.e., F, ϕ, and θ. In the appropriate coordinate system with the exception that the theoretical field is presented in SE Coordinates on the Payload Coordinate plots.

3. The actual total field sequence average, F, ϕ average, θ average, standard deviation computed by the autocorrelation computer for the

*In a two hour file it is only possible to have data from two different Decimal Days.

sequence and the standard deviation computed from the detail data for the sequence are plotted as a function of time.

In addition:

1. Every hour the appropriate trajectory data for the coordinate system are printed out.

    a) X
    b) Y
    c) Z
    d) Radial distance to satellite from Earth center
    e) Geomagnetic latitude of Sun position
    f) Longitude of satellite position
    g) Latitude of satellite position
    h) Distance of satellite from Earth-Sun line

2. The abscissa is labeled with the three hour period being plotted.

2/2

APPENDIX G

IMP-F MAGNETIC FIELD EXPERIMENT CALIBRATION

Spacecraft: IMP-F Proto-flight Date: 4/27/67 & 4/28/67 Magnetometer Serial Number: 06.

Linearity Calibration

Low Range				High Range			
Field	Counts (118.0)			Field	Counts (120.6)		
γ	X (2.52)	Y (2.28)	Z (2.53)	γ	X (2.49)	Y (2.47)	Z (2.49)
0	117.7	129.8	118.3	0	120.8	122.0	121.0
5	102.3	115.1	102.2	20	104.8	106.0	104.6
10	086.1	100.7	086.8	40	088.1	090.0	088.8
15	070.8	086.1	070.2	60	072.1	074.0	072.3
20	055.6	072.0	055.0	80	056.0	058.2	055.6
25	039.8	057.8	039.1	100	040.0	042.8	039.2
30	024.1	043.8	023.5	120	023.7	027.1	021.7
35	018.0	030.0	018.0	140	018.0	018.0	018.0
0	118.1	129.8	118.2	0	121.0	121.8	121.0
-5	133.7	144.1	133.8	-20	137.0	137.1	137.0
-10	149.0	158.1	149.8	-40	152.8	152.8	153.0
-15	164.1	171.6	165.0	-60	168.0	168.0	169.0
-20	179.2	185.6	180.3	-80	184.0	183.1	184.8
-25	194.1	198.1	195.2	-100	199.3	198.1	200.7
-30	209.0	211.0	210.1	-120	215.0	213.0	216.0
-35	223.0	223.1	223.7	-140	230.0	227.1	231.0

After Deperm:

$$\left.\begin{array}{l} X_o = 2.57(116.6) \\ Y_o = 2.46(123.3) \end{array}\right\} \text{final zeros}$$

After Deperm:

$$\left.\begin{array}{l} X_o = 2.50(120.0) \\ Y_o = 2.52(119.0) \end{array}\right\} \text{final zeros}$$

IMP-F MAGNETIC FIELD EXPERIMENT CALIBRATION

Spacecraft: IMP-F Proto-flight Post Thermal-vacuum Date: 3/21/67 & 3/22/67
Magnetometer Serial Number: 06

New Booms
Linearity Calibration

Low Range				High Range			
Field	Counts			Field	Counts		
γ	X (2.44)	Y (2.56)	Z (2.57)	γ	Y (2.46)	Y (2.55)	Z (2.49)
0	120.7	119.0	114.8	0	121.0	118.2	120.7
5	106.3	104.8	099.7	20	105.0	103.0	104.2
10	091.8	090.3	084.1	40	089.0	087.0	088.0
15	075.7	076.0	069.0	60	073.0	071.7	072.0
20	060.0	062.6	053.1	80	057.0	056.0	055.7
25	045.7	049.0	038.1	100	041.0	040.2	039.0
30	030.8	036.0	022.7	120	025.0	025.0	023.0
35	017.8	023.1	017.5	140	018.0	017.7	017.8
0	120.8	118.8	115.1	0	121.6	118.8	120.7
-5	136.5	133.0	130.8	-20	137.0	134.1	136.8
-10	152.1	147.0	146.0	-40	153.0	149.7	152.6
-15	165.7	160.7	161.1	-60	168.2	165.0	168.2
-20	180.3	174.0	176.0	-80	184.1	180.0	184.0
-25	194.7	186.8	190.6	-100	199.0	194.8	199.7
-30	209.5	199.0	204.8	-120	214.2	209.0	214.8
-35	223.6	211.0	218.8	-140	229.1	223.0	229.3

EXPERIMENTER FLAGS

Bit	Function	Definition
2^5	Heater	On ≡ 1
2^4	Power	On ≡ 1
2^3	Calibrate	On ≡ 1
2^2	Mag. Down	Down ≡ 0
2^1	Mag. Up	Up ≡ 0
2^0	Range	Low ≡ 1; High ≡ 0

The Experimenter Flags appear in word 10 on the Magnetic Field Experimenter Tape as the six low order bits of this 32 bit word.

APPENDIX H

CHARACTERISTICS OF THE IMP F SPACECRAFT AND MAGNETIC FIELD EXPERIMENT THAT SHOULD BE CONSIDERED IN SUBSEQUENT ANALYSIS

I. Telemetry Rates

Parameter	Value
A. Sequence Period	20.454 sec.
B. Frame Period	1.278 sec.
C. Channel Period	.080 sec.

II. Spacecraft

A. Spin Period	2.580 - 2.612* sec.
B. Spin Axis Orientation	(See Figure 1)

III. Characteristics of the Detail Vector Measurements Transmitted in the Odd Numbered Frames

A. Quantization

1. Low Range $64\gamma/200$ counts $= 0.32\,\gamma$/count

2. High Range $256\gamma/200$ counts $= 1.28\,\gamma$/count

B. Folding Frequency for Spectrum Analysis

1. Sampling rate is one vector measurement every two frames of telemetry, or 1 sample/2.556 sec. which gives rise to a folding frequency of approximately 0.2 cycles/sec.

*Change observed from Orbit 1 through Orbit 17. Spin period will always be a function of time and larger variations than this can be expected.

SPIN AXIS ORIENTATION
IMP-F

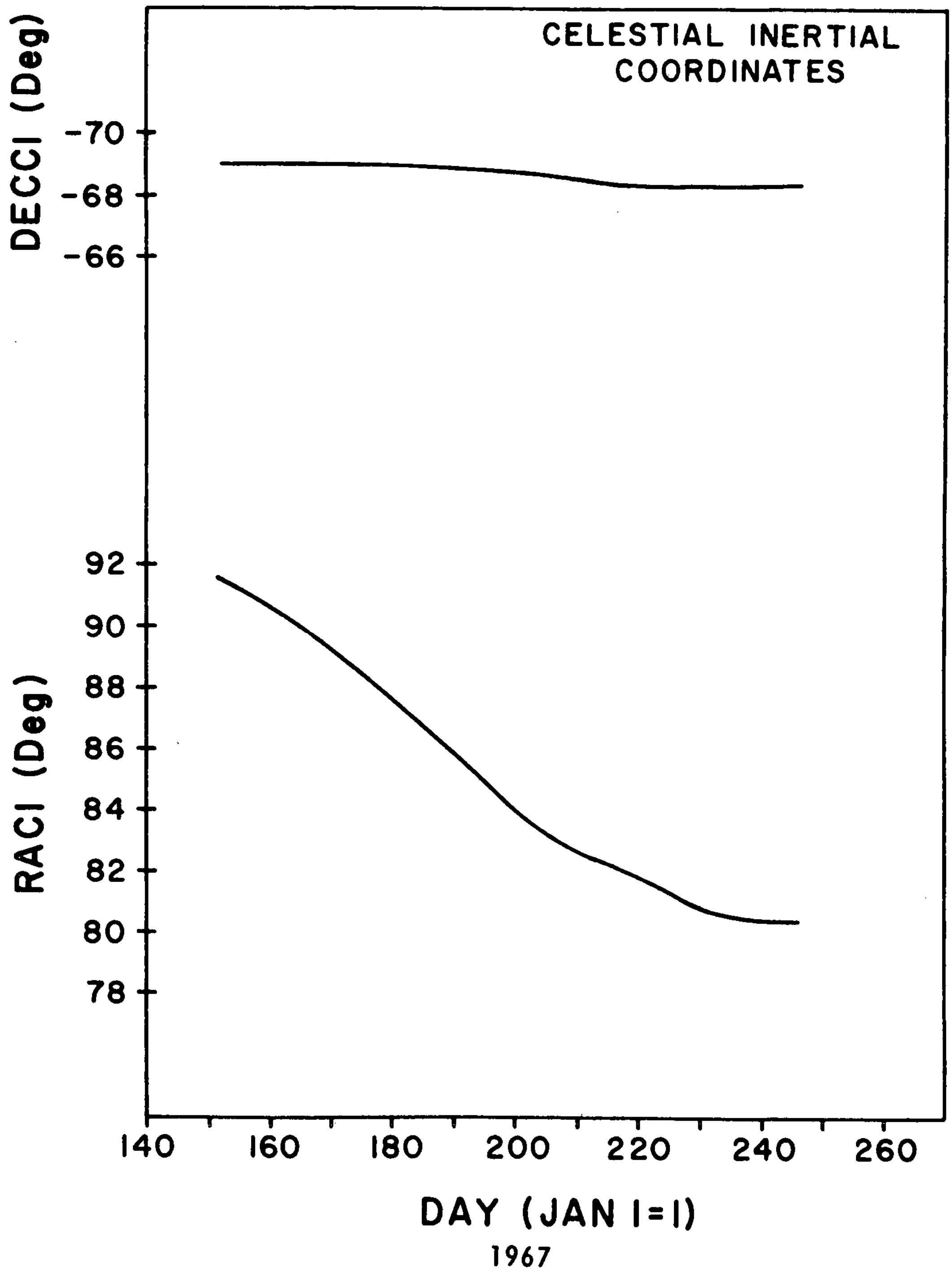

Figure 1

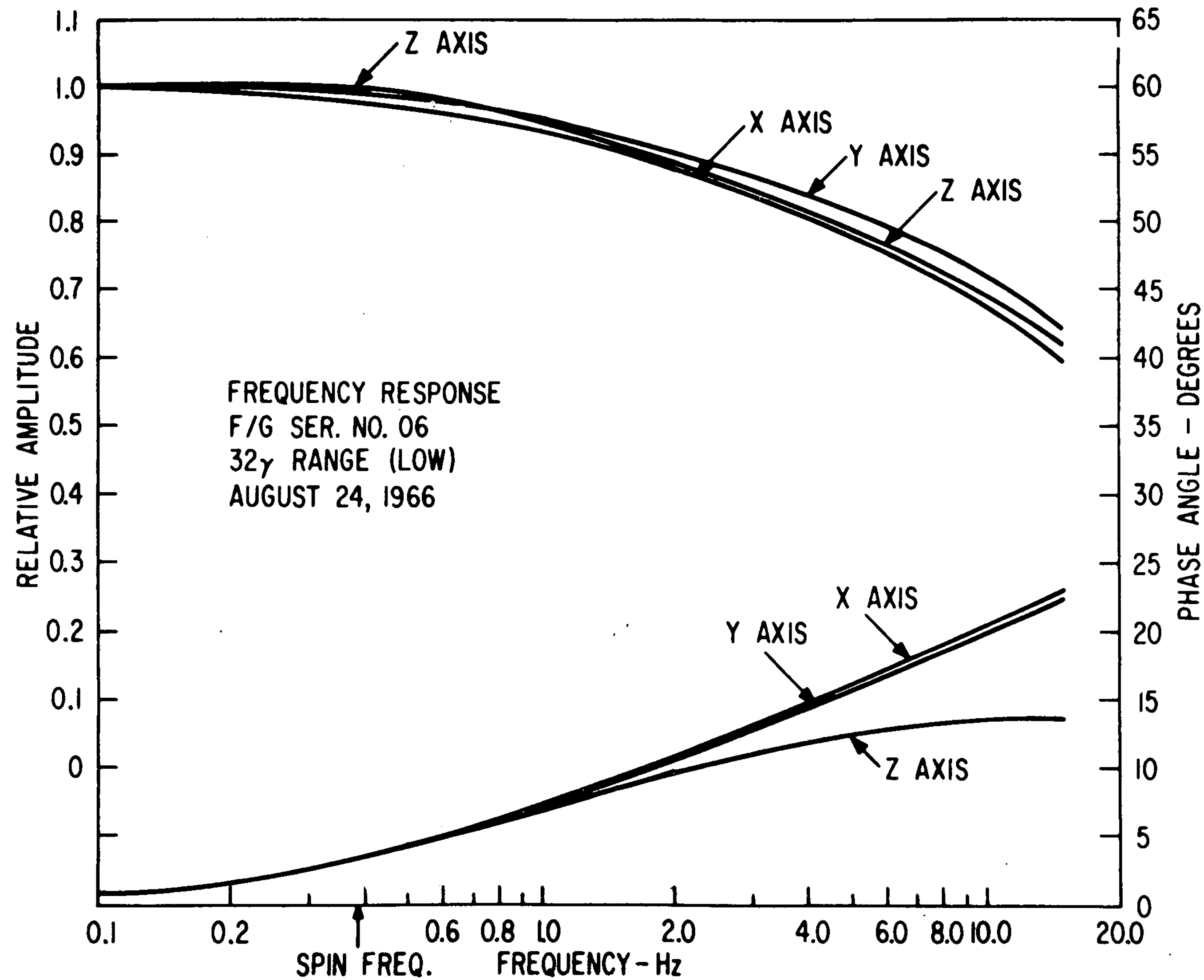
Z AXIS
X AXIS
Y AXIS
Z AXIS
FREQUENCY RESPONSE
F/G SER. NO. 06
32γ RANGE (LOW)
AUGUST 24, 1966
Y AXIS
X AXIS
Z AXIS
RELATIVE AMPLITUDE
PHASE ANGLE - DEGREES
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0.1
0.2
0.6
0.8
1.0
2.0
4.0
6.0
8.0
10.0
20.0
SPIN FREQ.
FREQUENCY - Hz

Figure 2

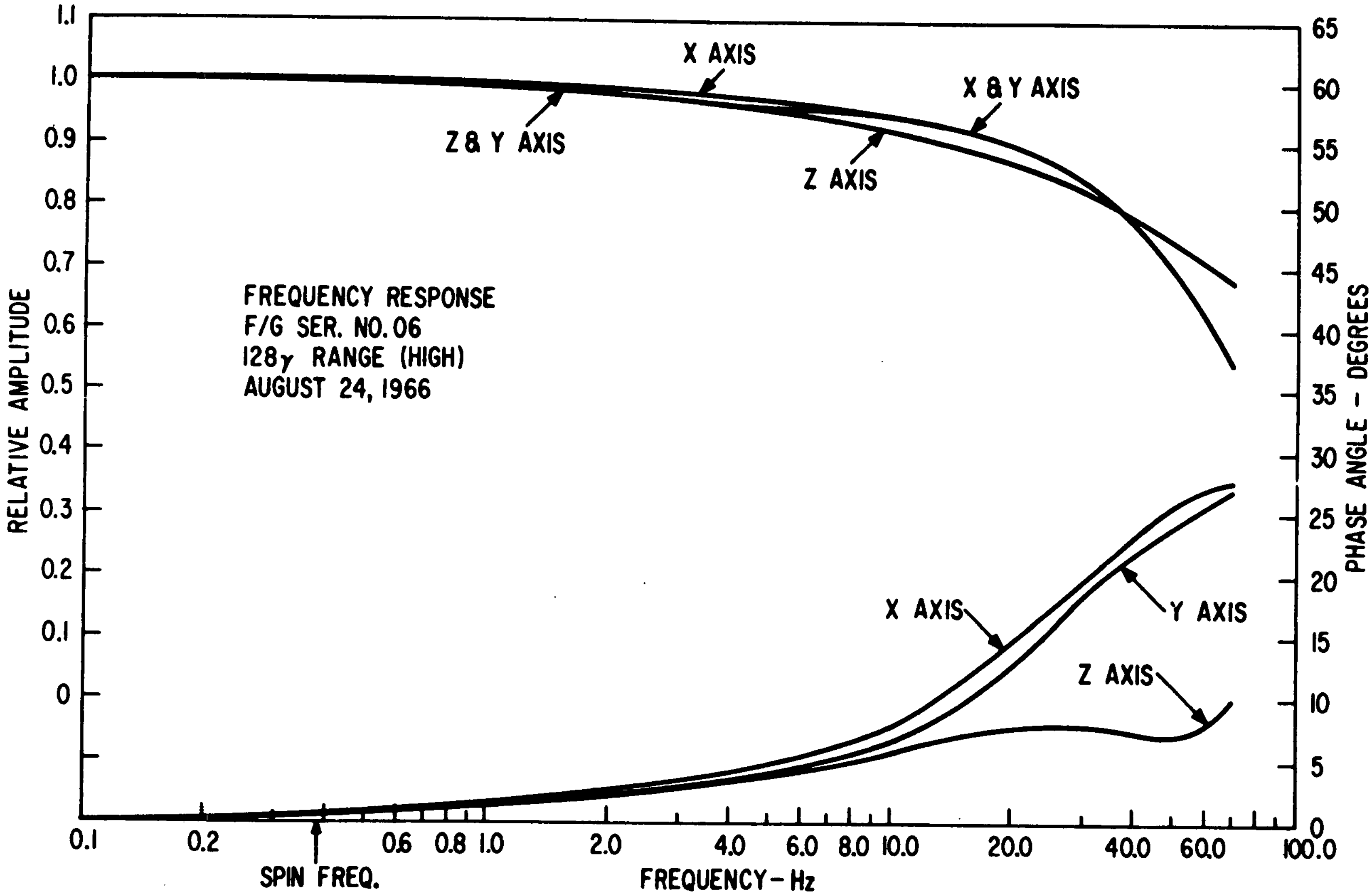
FREQUENCY RESPONSE
F/G SER. NO. 06
128γ RANGE (HIGH)
AUGUST 24, 1966
X AXIS
Z & Y AXIS
X & Y AXIS
Z AXIS
X AXIS
Y AXIS
Z AXIS
RELATIVE AMPLITUDE
PHASE ANGLE - DEGREES
FREQUENCY - Hz
SPIN FREQ.
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0.1
0.2
0.6
0.8
1.0
2.0
4.0
6.0
8.0
10.0
20.0
40.0
60.0
100.0

Figure 3

C. Instruments start to roll off at 12.5 cps (See Figures 2 and 3). Frequencies above 12.5 cps are attenuated at the rate of 20 DB per decade.

D. Non-Orthogonal Sampling

The X, Y, Z sensors are not sampled simultaneously but are sampled as shown in Figure 4 0.080 sec. apart.

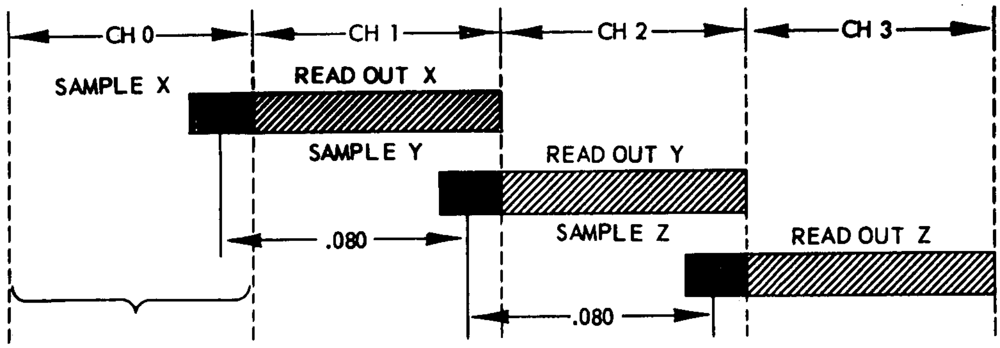

Figure 4

This requires that X be adjusted to the time at which Y is sampled using the following equation:

$$X = (X - Y \sin \Delta)/\cos \Delta$$

where

$$\Delta = (0.080/\text{Refined Spin Period}) * 2\pi$$

IV. Characteristics of the Autocorrelation Computer Output

The input to the autocorrelation computer are the Y or Z (depending on the sequence*) 8 bit component field measurements.

The output from the autocorrelation computer consists of the following items transmitted in frame 8.

*Y is processed in sequences with even sequence ID's.
Z is processed in sequences with odd sequence ID's.

1) Average - 12 bits

2-10) Lag 8 through Lag 0 - 108 bits

These parameters are computed in the spacecraft to a precision of 16 bits (with sign) for the average and 23 bits (with sign) for the lags. These data are accumulated in 23 bit registers in the spacecraft whose bits, for purposes of the following discussion, will be numbered starting from the right from 1 through 23. The MSB (bit 23) is the sign bit. (0 ≡ + ; 1 ≡ -) Before transmission these data are compressed in the following fashion:

A. Compression of the Average

In the case of the average bits 5 through 15 and bit 23 (sign bit) are transmitted (total of 12 bits). On the experimenter tape the average appears as a 32 bit word the 12th bit is the sign, the other 11 bits are magnitude.

B. Compression of the Lags.

The following logarithmic algorithm is used to compress the lags. This generates an 7 bit fraction and 4 bit exponent.

1. If bits 8 through 22 are zero transmit bits 1 through 7 as the fraction and zero as the exponent. Also transmit the sign for a total of 12 bits.

2. If bits 9 through 22 are zero and bit 8 equals 1 transmit bits 1 through 7 as the fraction and 1 as the exponent. Also transmit the sign for a total of 12 bits.

3. If bits 9 through 22 are not equal to zero shift right n times until bits 9 through 22 are equal to zero transmit bits 1 through 7 as the fraction and n + 1 as the exponent. Also transmit the sign for a total of 12 bits.

C. A Lag Appears on the Experimenter Tape as Two 32 Bit Words

1. The fractional portion appears as a separate 32 bit word. Bit 8 is the sign bit. Bits 1-7 are magnitude.

2. The exponent appears as a separate 32 bit word the four low order bits of which are the transmitted exponent, no sign information is necessary.

D. Folding Frequency for Spectrum Analysis

1. Sampling rate for the autocorrelation computer is 1 sample/.080 seconds which gives a folding frequency of 6.25 cps.

V. Optical Aspect

A. Precision of Spin Period

The spacecraft computes spin period to a precision of ±1 count = ±2.5 milliseconds for the 400 cps counter.

The analysis program does not use the spin period as transmitted directly but rather uses the "See Sun Times" which are also quantized to ±2.5 milliseconds and the spin period to compute a refined spin period over approximately 16 spacecraft rotations. This is the actual quantity used in the coordinate rotations unless this result differs by more than 5 milliseconds from the average spin period for the entire file. If the errors in the two "See Sun Times" used to compute the refined spin period add the precision of this quantity would be ±.0050 sec/16 spins = ±.0003 sec/spin which corresponds to ±.043° of spacecraft rotation.

B. See Sun Time - Elapsed time from beginning channel zero, frame zero until the first sun pulse.

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