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ATS-E MAGNETIC FIELD MONITOR INSTRUMENTATION

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GSFC
GODDARD SPACE FLIGHT CENTER
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I. INTRODUCTION

The overall objective of the Applications Technology Satellite (ATS) program is to advance technology in areas which may have application to future spacecraft. The ATS-E mission was to have been a gravity-gradient stabilized spacecraft, placed in a synchronous equatorial orbit over the Pacific Ocean at approximately 108° west longitude.

In late 1967 it was decided to add a magnetometer to the ATS-E spacecraft for the following reasons:

a. to use the magnetometer output for determining the current settings in a three-axes magnetic torquing system. This system was to be used to back up the gravity-gradient stablization experiment. Two current-controlled, iron-core, wire-wound coils were located in each of the three orthogonal axes of the spacecraft. After the magnetometer data were reduced, the coil strength was to be determined and applied by ground command in order to torque the spacecraft against the earth's field about its own center of gravity in space.

b. to use the magnetometer data for scientific studies of the processes taking place on the auroral magnetic shells where there is maximum energy exchange within the magnetosphere.

c. to use the magnetic field data for correlation studies with other scientific experiments aboard ATS-E Environmental Measuring Experiment (EME).

d. to compare field data at the satellite with ground station magnetic field data. This would be accomplished through a cooperative program with the Canadian Dominion Observatory.

The following information is to describe the Magnetic Field Monitor (MFM) instrumentation, tests, and data outputs. Analysis of the data will be covered at a later date.

II. INSTRUMENTATION

The Magnetic Field Monitor (MFM) consists of two (2) assemblies: the sensor mounted on a short boom and the electronics package mounted on the forward bulkhead of the spacecraft. Figure 1 is a photograph of the unmounted assemblies and Figure 2 is a sketch of the relative position of the assemblies mounted on the spacecraft. The sensors contain three (3) sensing elements (permalloy transformers) which are aligned along mutually perpendicular axes. Each sensing element is surrounded by primary, secondary, compensating field, and calibration windings. A thermistor is mounted near the center of the sensor package for monitoring its temperature. The electronics package contains the following subassemblies:

A. Fluxgate Electronics

B. Current Source

C. Signal Condition Unit

D. Power Converter

(Figure 3 is a functional block diagram of the MFM and includes both sensors and electronics.)

A. The fluxgate magnetometer was manufactured by Schonstedt Instrument Company (Reston, Va.) and is similar to the magnetometer flown on the Orbiting Geophysical Observatory (OGO-5) in March, 1968. The oscillator driver drives the primary winding of each sensor at a frequency of approximately 12,000 cps (f_0). The signal picked up in the secondary winding is filtered and amplified in order to measure the second harmonic content ($2f_0$) in this driver B-H loop. The oscillator-driver frequency is also doubled by a frequency doubler (Ref. $2f_0$) and fed into a phase detector for comparison with the secondary pick-up. The <u>direction</u> of the magnetic field being measured will control whether the output of the secondary ($2f_0$) is in phase or 180° out of phase with respect to the reference signal (Ref. $2f_0$). The <u>magnitude</u> of the magnetic field being measured is determined directly from the amplitude of the second harmonic content ($2f_0$). The output of the phase detector provides a d.c. voltage from zero to five volts. Zero field components along the sensor axes correspond to a 2.5 volt output and is set at this value by the bias circuit. The output of the phase detector is fed into the current source and a signal conditioning unit. An example of a "fine" calibration curve is shown in Figure 4. A table of octal numbers converted to magnetometer voltage output is shown in Appendix A, Table 1. This conversion table applies to both the PCM and PFM "fine" outputs as designated at the left edge of the table.

B. The current source is a modification of a design developed for an OGO-5 experiment and subsequently improved so that it has an accuracy of ±0.04% over the temperature range of -5°C to +45°C (Ledley, 1969). Each

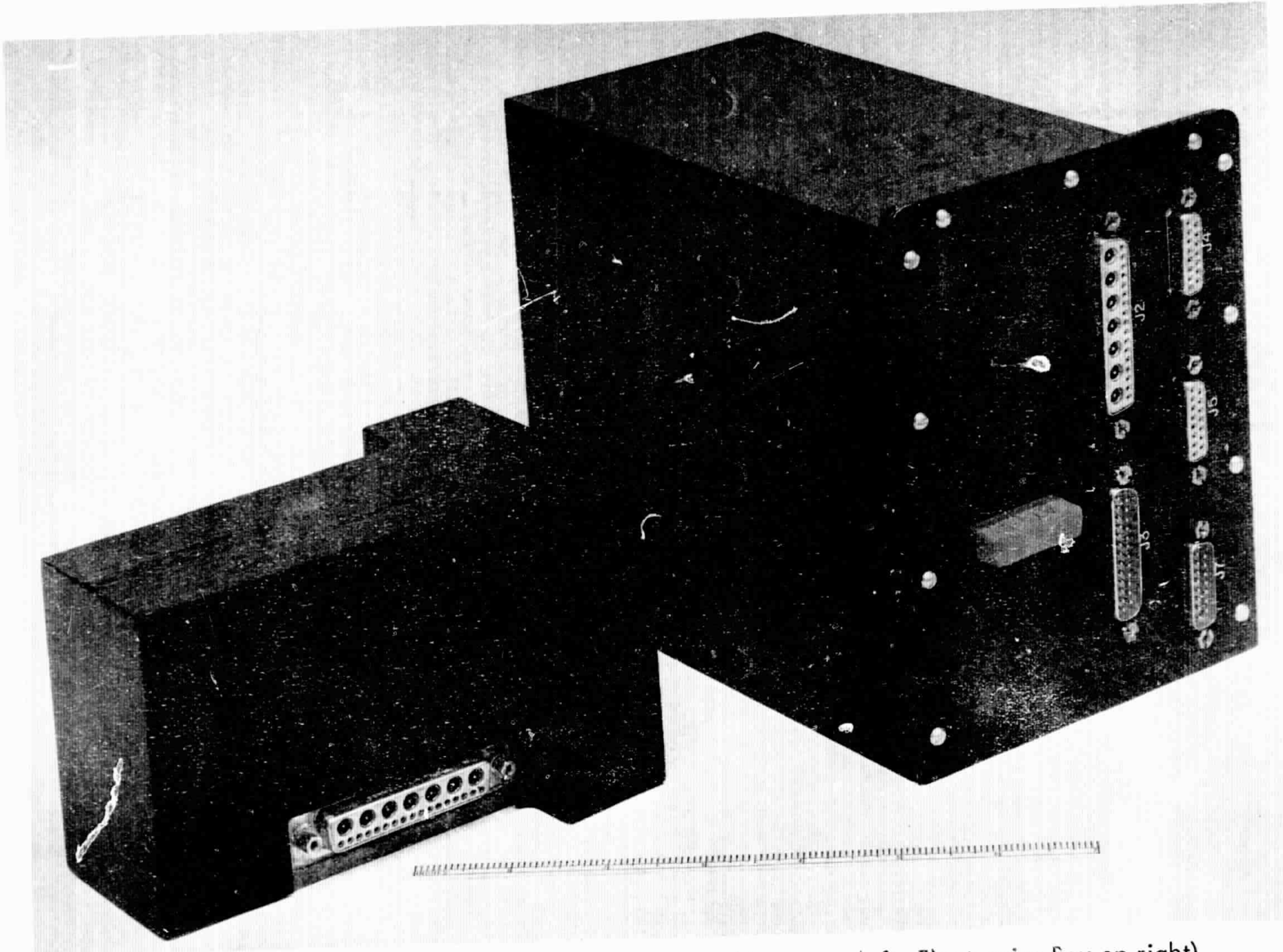


Figure 1. Unmounted ATS-E Magnetic Field Monitor (Sensor on left; Electronics Box on right)

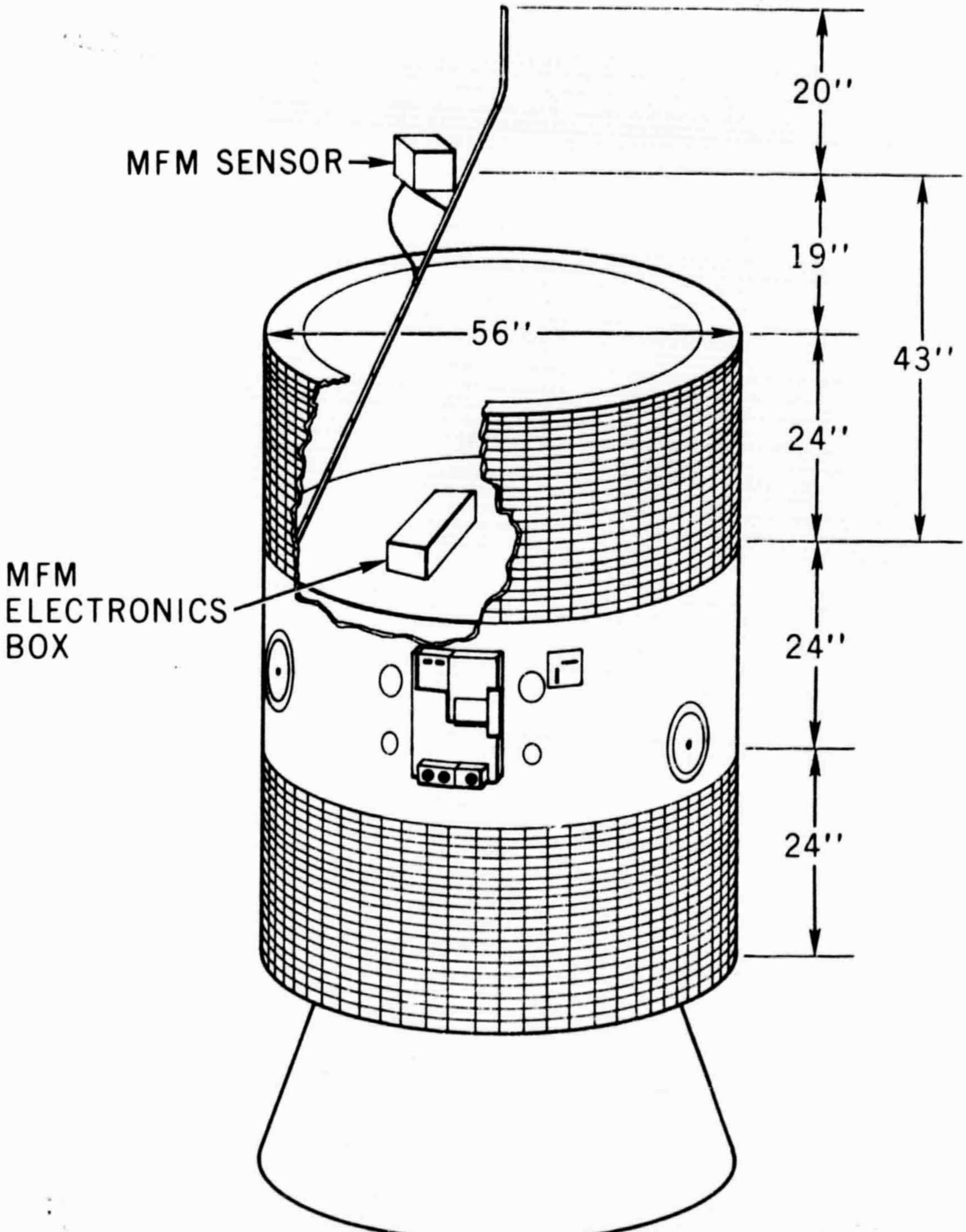
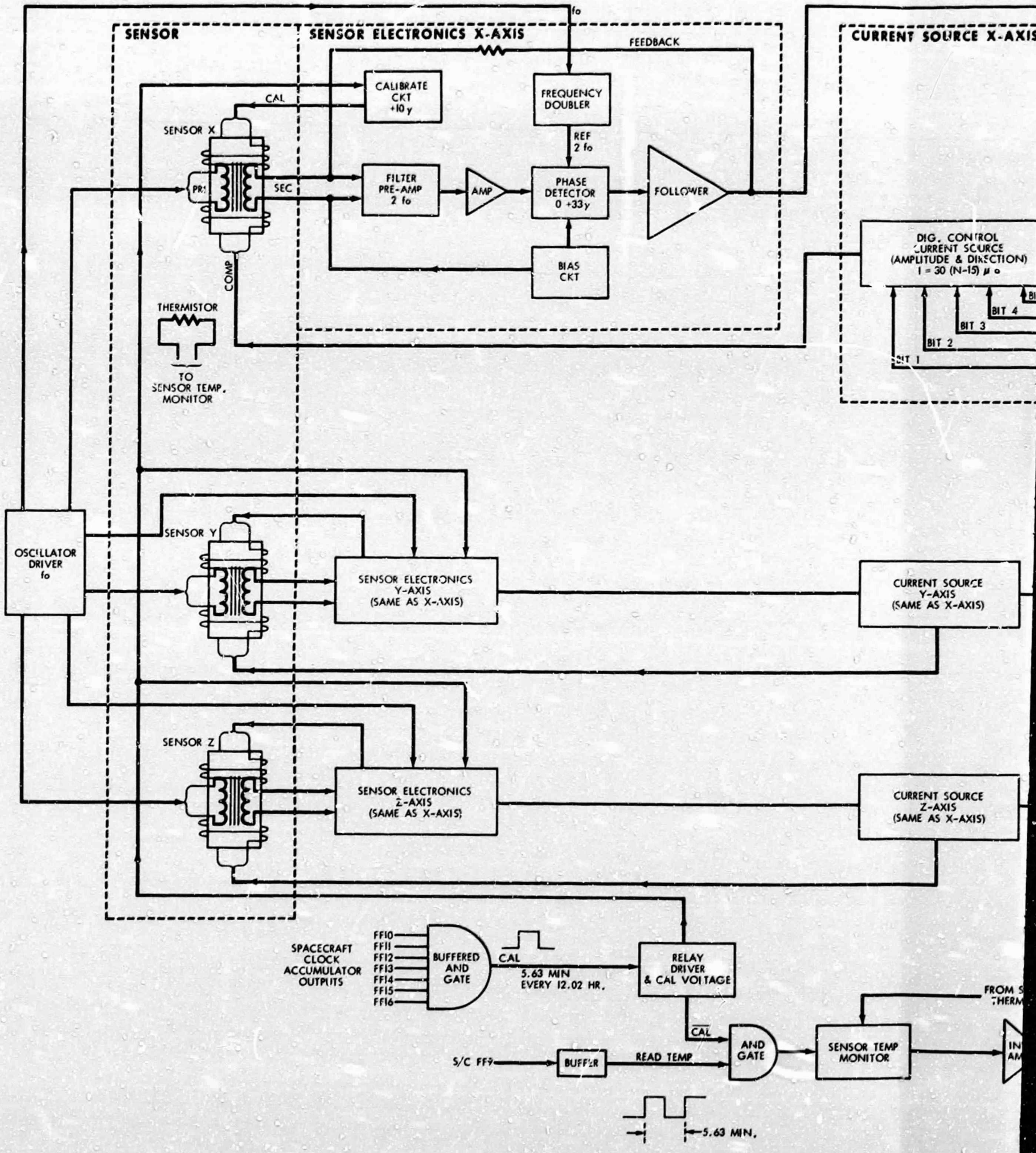


Figure 2. Sketch of the Relative Positions of the MFM Sensor and Electronics on the ATS-E Spacecraft



FOLDOUT FRAME /

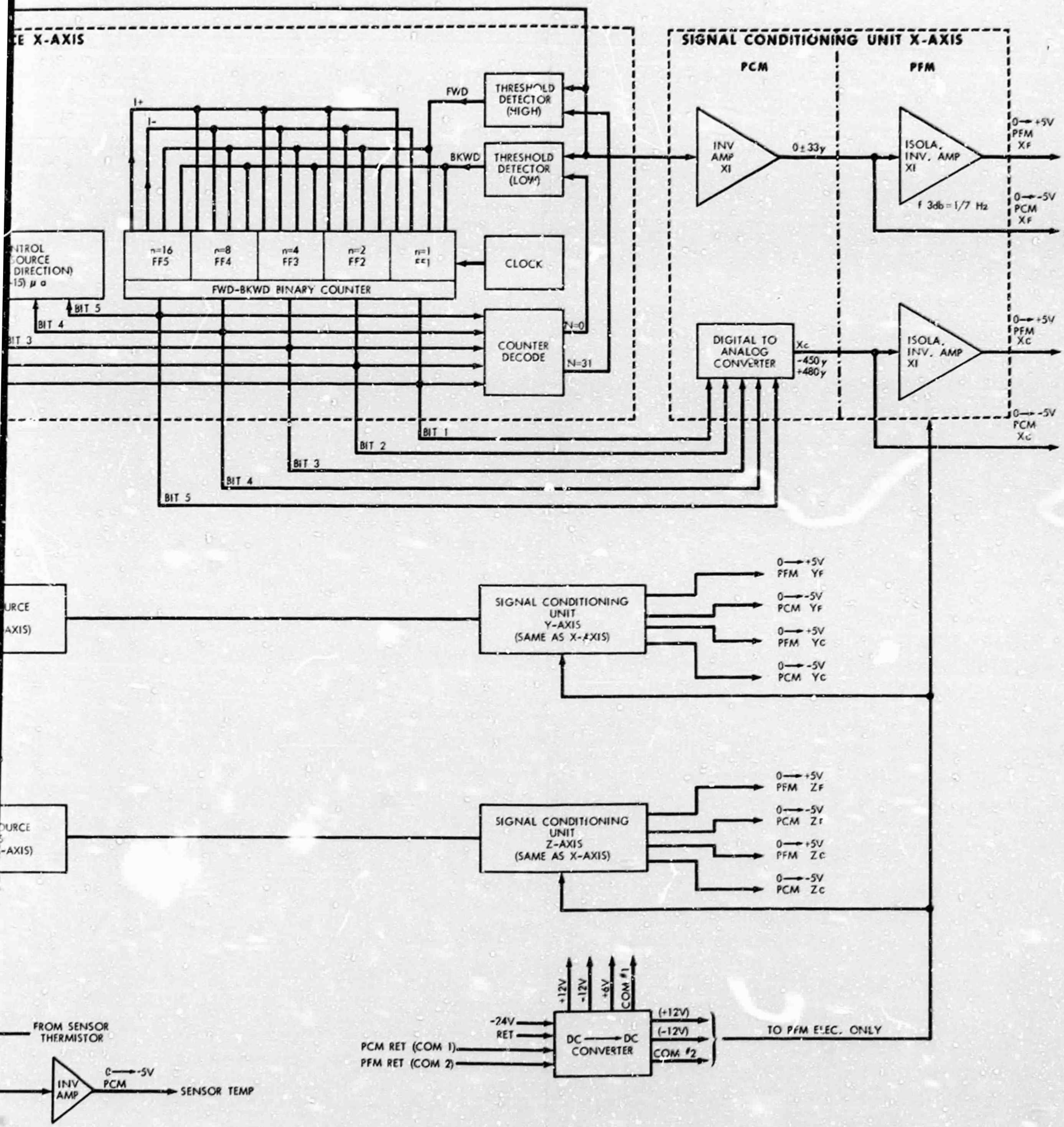


Figure 3. Functional Block Diagram ATS-E Magnetic Field Monitor

FOLDOUT FRAME 2

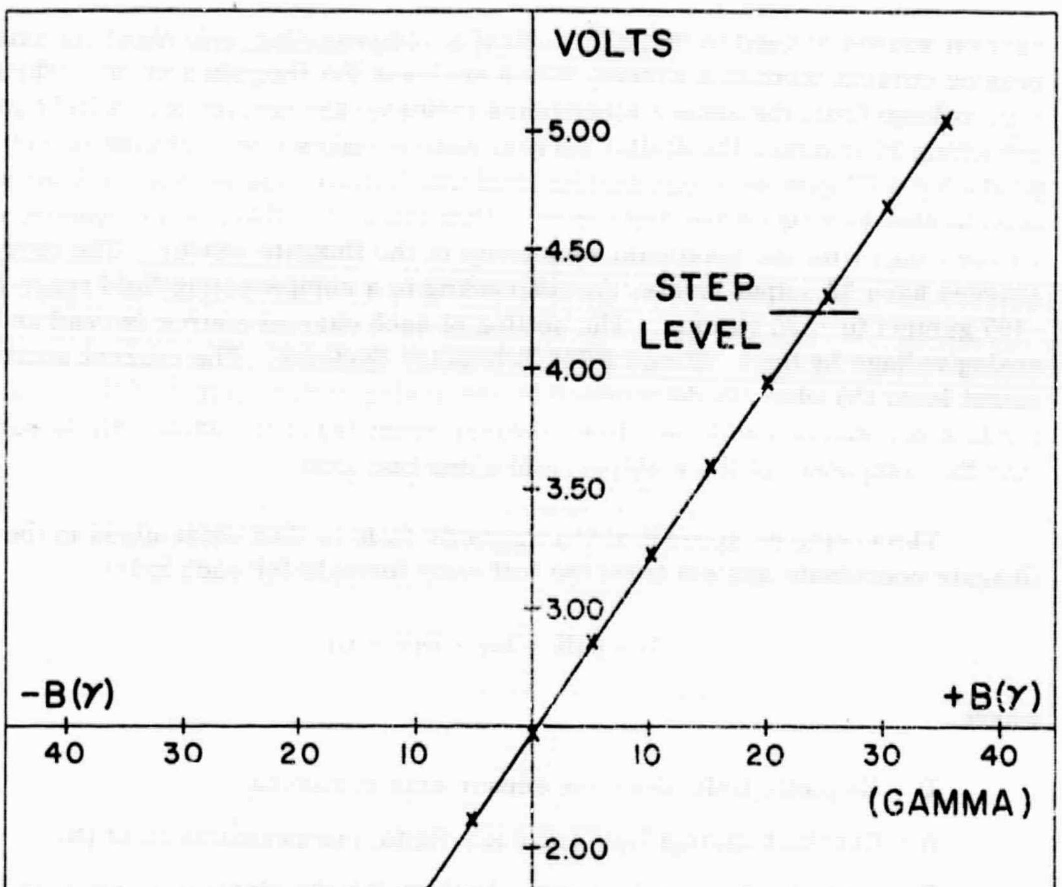


Figure 4. Typical "Fine" (V) Calibration Curve

current source is used to digitally control a compensating field about its axis by passing current through a winding which encloses the fluxgate sensor. When the d.c. voltage from the sensor electronics indicates the sensor is in a field approaching 25 gamma, the digital current source makes a step change in current, producing a 33 gamma compensating field which drives the sensor back through zero to nine gamma on the other side. This allows the fluxgate to measure over a wide range with the maximum sensitivity of the fluxgate sensor. The current sources have 32 output levels, corresponding to a compensating field range of -495 gamma to +525 gamma. The setting of each current source is read as an analog voltage by the PCM and PFM Telemetry Systems. The current source output level (N) which is determined by the analog voltage output of the "coarse" reading is combined with the "fine" measurement (V) of the same axis to compute the component of the ambient field along that axis.

The vector component of the magnetic field is thus determined in the fluxgate coordinate system from the following formula for each axis:

$$B = A(N - 15) + D(V - C)$$

where

B = Magnetic field along the sensor axis in gamma

A = Constant gamma field for each digital compensating field (N)

N = Digital number telemetered back giving the status of current applied to sensor compensating coils

D = Constant number of gamma per volt for fluxgate axis over its linear portion of its response curve

V = Output voltage from the fluxgate (nominally 0.75 to 4.25 volts)

C = Voltage for zero magnetic field along sensor axis

Each of the above constants vary for the sensor and electronics used as part of the magnetometer and must be calibrated prior to flight.

C. The signal conditioning unit serves a number of purposes:

1. The analog voltage from the sensor electronics is 0 to +5.1 volts. This voltage is inverted to the required 0 to -5.1 volts for the PCM Telemetry. The inverted output is then fed into another x1 (times one) inversion amplifier to obtain the required isolation between the grounds of the two telemetry systems and to produce the PFM telemetry output of 0 to +5.1 volts. The output of the magnetometer "fine"

measurement is filtered prior to transmission on PFM by using a single pole RC filter. The 3 db point of this filter is at one cycle per eight seconds.

2. The digital numbers from the current sources are passed through a digital to analog converter for transmission to the ground. The voltage level identifying the 32 values of N are listed in Appendix A, Tables 2 and 3 for PCM and PFM respectively.

3. A calibration field of +10 gamma per axis is internally generated once every 12.02 hours for a duration of 5.63 minutes as a means for checking the sensitivity of the magnetometer.

4. The temperature of the sensor is monitored every 5.63 minutes for a duration of 2.81 minutes and is calibrated over a temperature range of +50°C to -65°C. Table 4 in Appendix A is the temperature calibration for the sensor flown on ATS-E.

D. The power converter is a GSFC design for this instrument and it uses the spacecraft input of -24 volts ±0.5 volts to produce five (5) regulated output voltage (two +12 volts, two -12 volts, and one +6 volts). The converter is simple in design and small in volume (7 cubic inches). The efficiency is 66% while delivering 1.2 watts with the regulation of +0.2% for all 12-volt outputs over the temperature range of -20°C to +65°C. Regulation of the +6 volt output is 1% over the same temperature range.

E. The following is a list of miscellaneous information about the MFM:

Sensor

(a) Weight: 1.03 pounds

(b) Alignment: manufacture tolerances and probably good to only ±1.5°

(c) Thermal: passively controlled with 10 layers of 0.25 mil aluminized mylar. Outside layer 3 mil aluminized mylar with mylar out. Inflight temperature expected +20°C to -50°C.

(d) Volume: 50 cubic inches

Electronics

(a) Weight: 5.89 pounds

(b) Volume: 200 cubic inches

(c) Power: 1.2 watts

(d) Temp. Range (operating) -5°C to 45°C

Magnetometer (Combined Sensor and Electronics)

(a) Frequency Response of Fine (V) Output:

PCM (3 db down at ~ 70 cps)
(3 db down at ~ 130 cps)

PFM (3 db down at ~ 115 cps)

(b) Slew Rate: If the field is instantaneously changed by 30 gamma, it takes 2 millisedonds for the sensor to indicate 25 gammas of the change and an additional 50 milli-seconds to indicate the remaining 5 gammas.

(c) Calibration Pulse: A calibration pulse of $9.8 \pm 0.1\gamma$ is applied to all three axes simultaneously by passing current through an auxiliary winding wrapped about each sensor element.

(d) Maximum Compensating Fields for ATS-E:

X axis $+525\gamma$ to -492γ
Y axis $+528\gamma$ to -495γ
Z axis $+525\gamma$ to -493γ

(e) Noise: Fluxgate Sensor Noise $+0.12\gamma$

(f) Electronic Package Temperature: Temperature of the electronics package is measured by a spacecraft furnished standard thermistor and is read out on spacecraft encoder #2 once every 190 seconds on the PCM Subcom Word 62, Channel 0. (See Appendix A, Table 5.)

III. TESTING AND CALIBRATION

The ATS-E spacecraft was brought to the 40' Coil Test Facility at GSFC in July 1969 for three (3) days of tests and calibration prior to shipment to Cape Kennedy for launch (Boyle, 1969).

a. Tests made to check the boom on which the sensor was mounted for magnetic inclusions produced the following results:

Initial Condition	30γ	maximum at sensor
25 Gauss Perm	1000γ	maximum at sensor
Deperm	$\sim 10\gamma$	maximum at sensor
15 Gauss Perm	200γ	maximum at sensor
Deperm	$<10\gamma$	maximum at sensor
5 Gauss Perm	10γ	maximum at sensor
Final Deperm	4 to 6γ	on all three axis

The boom was again checked after shipment to Cape Kennedy just prior to being attached to the spacecraft to see that the final deperm condition had not changed at that time.

b. The initial perm field of the spacecraft was measured at the position of the MFM and was found to be:

$$X = +119.7\gamma$$

$$Y = -80.8\gamma$$

$$Z = -164.0\gamma$$

c. After a series of perming and deperming sequences, the spacecraft was compensated using six (6) magnets and this reduced the field at the magnetometer sensor to:

$X = +21\gamma$ (These corrections are for the space-
$Y = +31\gamma$ craft permanent magnetic field while
$Z = +109\gamma$ being powered from solar arrays.)

The field corrections were left at these values to insure the magnetometer of being near zero field when offset by the in-flight ambient field thereby insuring use of the maximum range of the instrument.

d. The MFM was calibrated and found to be the same constants as determined by earlier tests. Table 6 in Appendix A includes data taken during operation of the torquing coils. Magnetic field readings should not be used when the torquing coils are "on."

e. Measurements of stray fields, obtained with the spacecraft operating on an auxiliary power supply, and also on solar arrays to the extent possible, are included in Table 7 in Appendix A.

f. The effects of the sun shining on various portions of the solar arrays were tested by rotating the spacecraft while a bank of xenon lamps illuminated one side of the spacecraft. Table 8 of Appendix A lists these effects.

g. Table 9 in Appendix A is a history of the magnetic moment of the complete spacecraft. For final values and a complete report of all the magnetic tests conducted in the GSFC 40' Coil Facility, see GSFC Document X-325-69-536, ATS-E Spacecraft Magnetic Tests.

The corrections listed in Tables 7 and 8, and the permanent spacecraft field are corrections and should be applied directly to the observed fields (X, Y, Z) as indicated by the magnetometer outputs.

IV. TELEMETRY

A. PFM Telemetry

The magnetometer analog outputs are fed into the Environmental Measurements Experiment (EME) encoder where the data is presented in the proper sequence to subcarrier oscillators which in turn, present a series of data pulses to the transmitter. The multiplexing technique is time division, and commutation occurs at the output of the oscillators. Each analog oscillator input is subcommutated. This type of encoding system, where signal information is carried in the form of the frequency of a subcarrier oscillator, is called pulse frequency modulated (PFM). Analog voltages from the MFM vary between 0 and +5 volts d.c. Several subcarrier oscillators are used to convert these analog voltages to their corresponding frequencies. The output frequency of each oscillator is inversely proportional to the input voltage.

The PFM Telemetry format is composed of a 256 position matrix of 16 frames and 16 channels. The horizontal positions are designated as frames 0 to 15 and the vertical positions as channels 0 to 15. The complete matrix is referred to as a sequence (e.g., F2C7 means Channel 7 of Frame 2). Each channel (except channel zero of all frames) consists of a 10 millisecond reference data pulse and a 10 millisecond burst data pulse. It can be seen that one may have a reference data format and a burst format due to the nature of the breakup of a channel into two parts. Each channel is 20 milliseconds long and the sample rate is 50 hertz per second. The frame is 320 milliseconds long and one complete telemetry sequence is 5.12 seconds. The magnetometer data appears on the Burst Format only and the position of the "fine" and "coarse" readings are shown in Figure 5.

B. PCM Telemetry

The magnetometer analog outputs are telemetered via redundant spacecraft PCM (Pulse Coded Modulation) telemetry subsystems. Analog information is first converted to a 9-bit digital word and then transmitted. The telemetered data is commutated at a rate of once every 2.97 seconds and/or subcommutated at a rate of once every 95.04 (mainframe word 63) or 190.09 seconds (main frame word 62). The telemetry subsystem upon command can be placed in a dwell mode of operation in which one of the non-subcommutated inputs is sampled 64 times faster than in a non-dwell mode. Figure 6 is a tabular list of PCM telemetry words used by the MFM. The PCM telemetry format is 64 main frame words numbered 0 to 63.

V. SPACECRAFT COORDINATE SYSTEMS

The fluxgate magnetometer coordinate system is shown in Figure 7. On the lefthand side is a top-and-side sketch showing the relationship of the fluxgate (F.G) to the spacecraft, and on the righthand side is a sketch of the relationship of the fluxgate while in its planned stabilized orbit. At the bottom of the figure the relationship of coordinate systems used by various groups working on the spacecraft is listed:

G.E. = General Electric

HAC = Hughes Aircraft Corporation

S/C = θ angles measured about the equator of the spacecraft cylinder

VI. POST-LAUNCH

ATS-E was launched from Cape Kennedy on August 12, 1969 and was successfully placed in its parked orbit. At this time the spacecraft was spinning about the Z axis at a rate of 92 rpm. Immediately after the apogee motor was

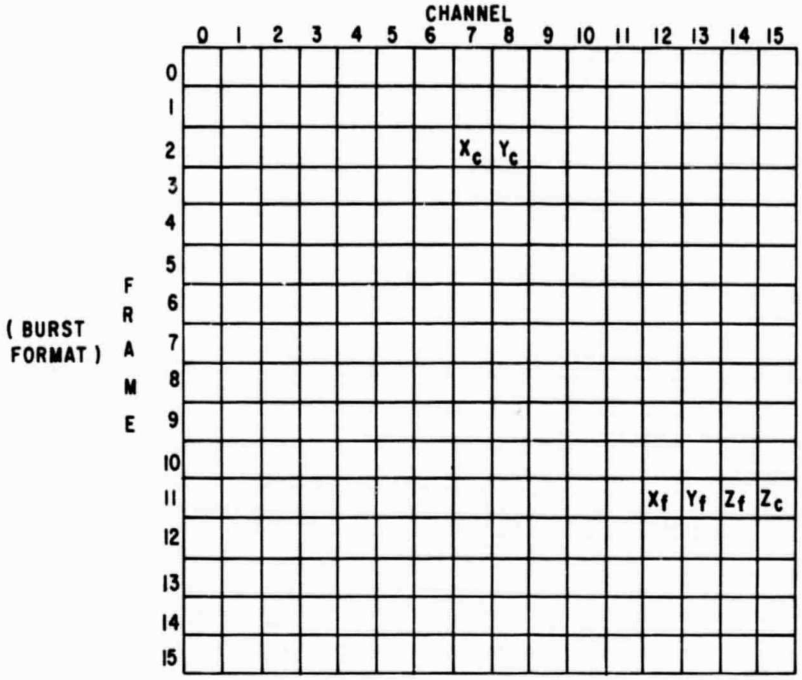
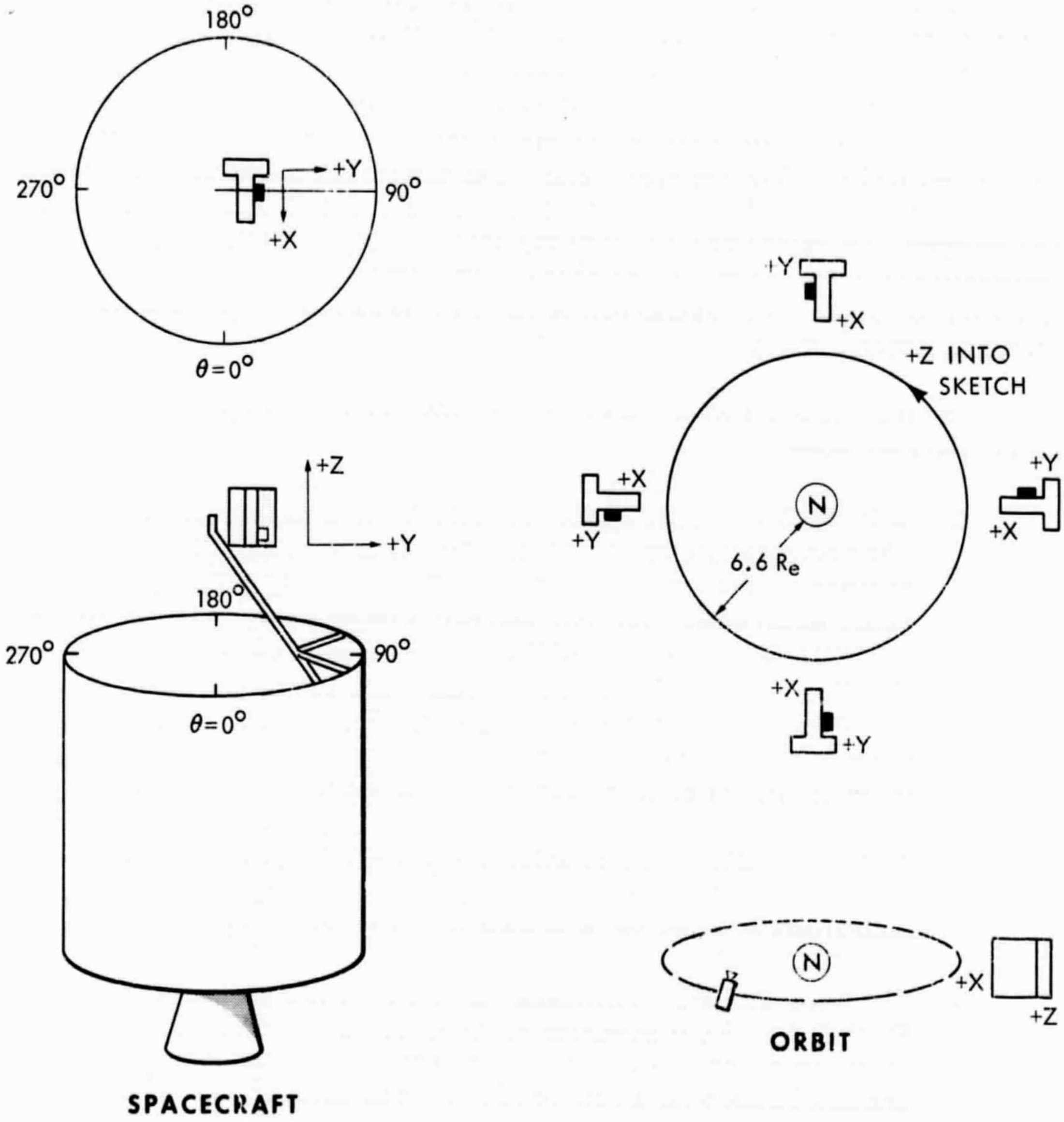


Figure 5. ATS-E PFM Telemetry Assignments for the MFM

ITEM	FUNCTION	RANGE	UNITS	DATA FORM	DATA RATE TIMES/SECOND	DATA LOCATION		
						MAIN WORD	SUBCOM	
						BIT	32 CH	64 CH
N-1	MAGNETOMETER REGULATOR ON-OFF	–	–	D	1/3	8/5	–	–
N-3	X-AXIS (V_x)	±20	GAMMA	A	1/3	49	–	–
N-4	Y-AXIS (V_y)	±20	GAMMA	A	1/3	50	–	–
N-5	Z-AXIS (V_z)	±20	GAMMA	A	1/3	51	–	–
N-6	X-COARSE N_x	0-31	N	A	1/95	63	0	–
N-7	Y-COARSE N_y	0-31	N	A	1/95	63	1	–
N-8	Z-COARSE N_z	0-31	N	A	1/95	63	2	–
N-9	SENSOR TEMPERATURE	+50 to -65	°C	A	1/95	63	30	–
D-20a	ELECTRONICS TEMPERATURE	0-160	°F	A	1/190	62	–	0

Figure 6. ATS-E PCM Telemetry Assignments for the MFM



COORDINATE SYSTEMS

FLUXGATE	GE	HAC	S/C θ
+X	−X	+X	0° (EARTH LOOKING)
+Y	+Y	−Y	90°
+Z	−Z	−Z	−Z (AWAY FROM MOTOR)

Figure 7. ATS-E MFM and Other Spacecraft Coordinate Systems

fired to place the spacecraft in its synchronous orbit, the spacecraft went into a flat spin about 12° off the transverse axis (X) still at the 92 rpm spin rate. On September 5 at 0530 UT, the apogee motor was ejected and the spacecraft fell over into a very solid spin about the Z axis with a rate of 66 rpm. The sense of spin was such that it has been impossible to date to despin the spacecraft, deploy the booms, and stabilize the spacecraft. The spacecraft did achieve a synchronous orbit and it was allowed to drift on to station at 107°W longitude where it was stopped. On September 10, 1969 the spin axis (Z) was rotated until it was perpendicular to the ecliptic plane of the earth. These maneuvers raised the spin rate to 76 rpm. The spacecraft is spinning about the -Z axis and the spin vector is pointing North.

Having a fast spinning spacecraft has affected the operation of the MFM in the following ways:

1. Only the Z axis information from the PFM outputs is of any real use. The fast spin rate (76 rpm), the slow sample rate of once each five seconds for both "fine" and "coarse" outputs, the aliasing due to the relationship of the spin rate and data sample rate, and the filter on the PFM "fine" outputs, all degrade the data in the spin plane (X and Y). The fact that the "coarse" outputs are switched before the filtering of the "fine" outputs means that there is no way of knowing the value of the fine sample. The fine could be sampled anywhere between its limits of $\pm 24\gamma$ and this value applied to the coarse reading at that time would give an error range of that amount (i.e., $\pm 24\gamma$). A $\pm 5\ \gamma$ modulation due to solar array stray fields is seen on the Z axis and must be taken into account when using the data. Preliminary indications are that the spin axis is 2° ±1° off the spacecraft Z axis.

2. The same problems mentioned above for PFM also hold true for the PCM data with the exception of the filter on the "fine" outputs. The PCM "fine" can follow changes of $\pm 10\gamma$ at a rate of 120 cps and changes of $\pm 20\gamma$ at a rate of 60 cps. The sample rate of the PCM data is once each 2.97 seconds for the "fine" outputs, and once each 95 seconds for the "coarse" readings.

   Due to the fact that the PCM data is unfiltered and has solar aspect data available, it is possible to determine magnetic attitude and to eventually obtain magnetic components in various coordinate systems.

3. Preliminary findings on possible changes of the magnetometer permanent field corrections after launch show that the X and Z axes have not changed but that the correction for the Y axis should be -37 gamma. This will be verified at a later date. Even if this correction is found

not to agree with pre-flight measurements, the new value will not be used as a large amount of the data has already been processed. Both X and Y measure the same field value in the spacecraft spin plane.

4. The spin rate of the spacecraft, since the apogee motor was ejected, is increasing with time. All attitude control gas jets are so biased that with the present sense of spin, any activation of the jets tend to speed up the spin rate. During eclipses the spin rate increases very rapidly. In the matter of a couple of hours the spin rate for example would change from 76.140 rpm to 76.170 rpm. In addition to these short-term changes there is a long-term spin rate increase. Since the last known spacecraft maneuver on day 255 when the spin rate was 76.130 ±0.007, the spin has increased to 76.270 on day 348. This information is from preliminary studies by Frank Krause of G.E. using the solar aspect sensor measurements.

5. The constants to be used for the flight magnetometer, in the equation given in II B, are listed below:

$A_x = 32.804\ \gamma/$	$D_x = 13.49\ \gamma/\text{volt}$	$C_x = 2.49$
$A_y = 32.942\ \gamma/$	$D_y = 13.85\ \gamma/\text{volt}$	$C_y = 2.52$
$A_z = 32.775\ \gamma/$	$D_z = 13.63\ \gamma/\text{volt}$	$C_z = 2.55$

VII. GROUND STATIONS

Arrangements made with Dr. Paul H. Serson of the Canadian Department of Energy, Mines, and Resources have resulted in the locating of four (4) ground stations in the province of Manitoba. These station record components of the magnetic field on film over a range of ±2000 gamma at Thompson, Lynn Lake, the Pas, and Winnipeg. These stations are at the foot of field lines passing through the ATS-E satellite. Two digital data recording systems have been furnished by GSFC and are installed at Thompson and Lynn Lake. Samples are taken each second of the three (3) magnetic field components and a fourth-channel is available for other experiments. Copies of all ground station magnetograms are furnished to all scientific experimenters aboard ATS-E, and the information recorded on digital tape is available for comparison studies.

ACKNOWLEDGMENTS

Instrumentation

Design

Fluxgate Magnetometer	Schonstedt Instrument Company
Power Converter	GSFC (S. Billingsley)
Current Source	GSFC (W. Folz and E. Bielecki)
Signal Conditioner	GSFC (E. Bielecki)
Digital Data Logger (Ground Magnetometer Data)	GSFC (S. Billingsley)

Fabrication

Fluxgate Magnetometer	Schonstedt Instrument Company
Power Converter	Washington Technilogical Associates, Inc.
Current Source	Washington Technilogical Associates, Inc.
Signal Conditioner	Washington Technilogical Associates, Inc.

Testing and Calibration

Bench Tests	GSFC (E. Bielecki, S. Billingsley, and G. Miller)
Environmental Tests	GSFC (Test and Evaluation Division)
Magnetic Tests	GSFC (Test and Evaluation Division)
Integration and Spacecraft Testing	Hughes Aircraft Corporation

Pre-Flight Data Tests

Telemetry Data Processing	GSFC (Paul McKowan)
Experiment Data Programming and Tests	GSFC (H. Gillis)

I would like to express my appreciation to the GSFC ATS Project Office, and to J. P. Heppner and members of the GSFC Magnetic and Electric Fields Branch, especially B. Ledley, E. Bielecki, and H. Gillis for their advice, help, and support on this experiment.

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Ledley, B. G., Magnetometers for Space Measurements Over a Wide Range of Field Intensities, GSFC Document X-612-69-156, May 1969.

APPENDIX A

Table 1
ATS-E Magnetic Field Monitor
(Octal to Voltage Conversion)

Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts
0	0	46	0.38	114	0.76	162	1.14	230	1.52
1	0.01	47	0.39	115	0.77	163	1.15	231	1.53
2	0.02	50	0.40	116	0.78	164	1.16	232	1.54
3	0.03	51	0.41	117	0.79	165	1.17	233	1.55
4	0.04	52	0.42	120	0.80	166	1.18	234	1.56
5	0.05	53	0.43	121	0.81	167	1.19	235	1.57
6	0.06	54	0.44	122	0.82	170	1.20	236	1.58
7	0.07	55	0.45	123	0.83	171	1.21	237	1.59
10	0.08	56	0.46	124	0.84	172	1.22	240	1.60
11	0.09	57	0.47	125	0.85	173	1.23	241	1.61
12	0.10	60	0.48	126	0.86	174	1.24	242	1.62
13	0.11	61	0.49	127	0.87	175	1.25	243	1.63
14	0.12	62	0.50	130	0.88	176	1.26	244	1.64
15	0.13	63	0.51	131	0.89	177	1.27	245	1.65
16	0.14	64	0.52	132	0.90	200	1.28	246	1.66
17	0.15	65	0.53	133	0.91	201	1.29	247	1.67
20	0.16	66	0.54	134	0.92	202	1.30	250	1.68
21	0.17	67	0.55	135	0.93	203	1.31	251	1.69
22	0.18	70	0.56	136	0.94	204	1.32	252	1.70
23	0.19	71	0.57	137	0.95	205	1.33	253	1.71
24	0.20	72	0.58	140	0.96	206	1.34	254	1.72
25	0.21	73	0.59	141	0.97	207	1.35	255	1.73
26	0.22	74	0.60	142	0.98	210	1.36	256	1.74
27	0.23	75	0.61	143	0.99	211	1.37	257	1.75
30	0.24	76	0.62	144	1.00	212	1.38	260	1.76
31	0.25	77	0.63	145	1.01	213	1.39	261	1.77
32	0.26	100	0.64	146	1.02	214	1.40	262	1.78
33	0.27	101	0.65	147	1.03	215	1.41	263	1.79
34	0.28	102	0.66	150	1.04	216	1.42	264	1.80
35	0.29	103	0.67	151	1.05	217	1.43	265	1.81
36	0.30	104	0.68	152	1.06	220	1.44	266	1.82
37	0.31	105	0.69	153	1.07	221	1.45	267	1.83
40	0.32	106	0.70	154	1.08	222	1.46	270	1.84
41	0.33	107	0.71	155	1.09	223	1.47	271	1.85
42	0.34	110	0.72	156	1.10	224	1.48	272	1.86
43	0.35	111	0.73	157	1.11	225	1.49	273	1.87
44	0.36	112	0.74	160	1.12	226	1.50	274	1.88
45	0.37	113	0.75	161	1.13	227	1.51	275	1.89

Table 1. ATS-E Magnetic Field Monitor (Continued)

Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts
276	1.90	345	2.29	414	2.68	463	3.07	532	3.46
277	1.91	346	2.30	415	2.69	464	3.08	533	3.47
300	1.92	347	2.31	416	2.70	465	3.09	534	3.48
301	1.93	350	2.32	417	2.71	466	3.10	535	3.49
302	1.94	351	2.33	420	2.72	467	3.11	536	3.50
303	1.95	352	2.34	421	2.73	470	3.12	537	3.51
304	1.96	353	2.35	422	2.74	471	3.13	540	3.52
305	1.97	354	2.36	423	2.75	472	3.14	541	3.53
306	1.98	355	2.37	424	2.76	473	3.15	542	3.54
307	1.99	356	2.38	425	2.77	474	3.16	543	3.55
310	2.00	357	2.39	426	2.78	475	3.17	544	3.56
311	2.01	360	2.40	427	2.79	476	3.18	545	3.57
312	2.02	361	2.41	430	2.80	477	3.19	546	3.58
313	2.03	362	2.42	431	2.81	500	3.20	547	3.59
314	2.04	363	2.43	432	2.82	501	3.21	550	3.60
315	2.05	364	2.44	433	2.83	502	3.22	551	3.61
316	2.06	365	2.45	434	2.84	503	3.23	552	3.62
317	2.07	366	2.46	435	2.85	504	3.24	553	3.63
320	2.08	367	2.47	436	2.86	505	3.25	554	3.64
321	2.09	370	2.48	437	2.87	506	3.26	555	3.65
322	2.10	371	2.49	440	2.88	507	3.27	556	3.66
323	2.11	372	2.50	441	2.89	510	3.28	557	3.67
324	2.12	373	2.51	442	2.90	511	3.29	560	3.68
325	2.13	374	2.52	443	2.91	512	3.30	561	3.69
326	2.14	375	2.53	444	2.92	513	3.31	562	3.70
327	2.15	376	2.54	445	2.93	514	3.32	563	3.71
330	2.16	377	2.55	446	2.94	515	3.33	564	3.72
331	2.17	400	2.56	447	2.95	516	3.34	565	3.73
332	2.18	401	2.57	450	2.96	517	3.35	566	3.74
333	2.19	402	2.58	451	2.97	520	3.36	567	3.75
334	2.20	403	2.59	452	2.98	521	3.37	570	3.76
335	2.21	404	2.60	453	2.99	522	3.38	571	3.77
336	2.22	405	2.61	454	3.00	523	3.39	572	3.78
337	2.23	406	2.62	455	3.01	524	3.40	573	3.79
340	2.24	407	2.63	456	3.02	525	3.41	574	3.80
341	2.25	410	2.64	457	3.03	526	3.42	575	3.81
342	2.26	411	2.65	460	3.04	527	3.43	576	3.82
343	2.27	412	2.66	461	3.05	530	3.44	577	3.83
344	2.28	413	2.67	462	3.06	531	3.45	600	3.84

Table 1. ATS-E Magnetic Field Monitor (Continued)

Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts	Octal	Volts
601	3.85	633	4.11	665	4.37	717	4.63	751	4.89
602	3.86	634	4.12	666	4.38	720	4.64	752	4.90
603	3.87	635	4.13	667	4.39	721	4.65	753	4.91
604	3.88	636	4.14	670	4.40	722	4.66	754	4.92
605	3.89	637	4.15	671	4.41	723	4.67	755	4.93
606	3.90	640	4.16	672	4.42	724	4.68	756	4.94
607	3.91	641	4.17	673	4.43	725	4.69	757	4.95
610	3.92	642	4.18	674	4.44	726	4.70	760	4.96
611	3.93	643	4.19	675	4.45	727	4.71	761	4.97
612	3.94	644	4.20	676	4.46	730	4.72	762	4.98
613	3.95	645	4.21	677	4.47	731	4.73	763	4.99
614	3.96	646	4.22	700	4.48	732	4.74	764	5.00
615	3.97	647	4.23	701	4.49	733	4.75	765	5.01
616	3.98	650	4.24	702	4.50	734	4.76	766	5.02
617	3.99	651	4.25	703	4.51	735	4.77	767	5.03
620	4.00	652	4.26	704	4.52	736	4.78	770	5.04
621	4.01	653	4.27	705	4.53	737	4.79	771	5.05
622	4.02	654	4.28	706	4.54	740	4.80	772	5.06
623	4.03	655	4.29	707	4.55	741	4.81	773	5.07
624	4.04	656	4.30	710	4.56	742	4.82	774	5.08
625	4.05	657	4.31	711	4.57	743	4.83	775	5.09
626	4.06	660	4.32	712	4.58	744	4.84	776	5.10
627	4.07	661	4.33	713	4.59	745	4.85	777	5.11
630	4.08	662	4.34	714	4.60	746	4.86		
631	4.09	663	4.35	715	4.61	747	4.87		
632	4.10	664	4.36	716	4.62	750	4.88		

PCM Words

V_x = 49

V_y = 50

V_z = 51

PFM Words

V_x = F11C12

V_y = F11C13

V_z = F11C14

Table 2
ATS-E Magnetic Field Monitor

Voltage	N	Octal
0.00 to 0.19	0	000 to 023
0.20 0.28	1	024 034
0.29 0.43	2	035 053
0.44 0.58	3	054 072
0.59 0.73	4	073 111
0.74 0.89	5	112 121
0.90 1.04	6	122 150
1.05 1.19	7	151 167
1.20 1.34	8	170 206
1.35 1.49	9	207 225
1.50 1.65	10	226 245
1.66 1.81	11	246 265
1.82 1.96	12	266 304
1.97 2.11	13	305 323
2.12 2.26	14	324 342
2.27 2.42	15	343 362
2.43 2.57	16	363 401
2.58 2.72	17	402 420
2.73 2.87	18	421 437
2.88 3.02	19	440 456
3.03 3.18	20	457 476
3.19 3.33	21	477 515
3.34 3.49	22	516 535
3.50 3.64	23	536 554
3.65 3.79	24	555 573
3.80 3.95	25	574 613
3.96 4.10	26	614 632
4.11 4.25	27	633 651
4.26 4.41	28	652 671
4.42 4.56	29	672 710
4.57 4.71	30	711 727
4.72 5.11	31	730 777

$$\underline{\text{PCM}} \begin{pmatrix} \text{X Coarse} = N_x = 63\text{-}0 \\ \text{Y Coarse} = N_y = 63\text{-}1 \\ \text{Z Coarse} = N_z = 63\text{-}2 \end{pmatrix}$$

<u>March 25, 1969</u>
ATS-E Flight Unit #1
Fluxgate Serial No. 23

Table 3
ATS-E Magnetic Field Monitor

Voltage		N	Octal	
0.00 to	0.17	0	000 to	021
0.18	0.28	1	022	034
0.29	0.43	2	035	053
0.44	0.58	3	054	072
0.59	0.73	4	073	111
0.74	0.89	5	112	121
0.90	1.04	6	122	150
1.05	1.19	7	151	167
1.20	1.34	8	170	206
1.35	1.49	9	207	225
1.50	1.65	10	226	245
1.66	1.81	11	246	265
1.82	1.96	12	266	304
1.97	2.11	13	305	323
2.12	2.26	14	324	342
2.27	2.42	15	343	362
2.43	2.57	16	363	401
2.58	2.72	17	402	420
2.73	2.87	18	421	437
2.88	3.02	19	440	456
3.03	3.18	20	457	476
3.19	3.33	21	477	515
3.34	3.49	22	516	535
3.50	3.64	23	536	554
3.65	3.79	24	555	573
3.80	3.95	25	574	613
3.96	4.10	26	614	632
4.11	4.25	27	633	651
4.26	4.41	28	652	671
4.42	4.56	29	672	710
4.57	4.71	30	711	727
4.72	5.11	31	730	777

$$\underline{\text{PFM}} \begin{pmatrix} \text{X Coarse} = N_x = \text{F2C7} \\ \text{Y Coarse} = N_y = \text{F2C8} \\ \text{Z Coarse} = N_z = \text{F1C15} \end{pmatrix}$$

<u>March 25, 1969</u>
ATS-E Flight Unit #1
Fluxgate Serial No. 23

Table 4

ATS-E Magnetic Field Monitor (Sensor Temperature)

(-) Voltage		Temperature °C	Octal No.	
5.00 to 5.11		50+	764 to 777	
4.98	4.99	45	762	763
4.96	4.97	40	760	761
4.92	4.95	35	754	757
4.86	4.91	30	746	753
4.80	4.85	25	740	745
4.74	4.79	20	732	737
4.64	4.73	15	720	731
4.54	4.63	10	706	717
4.40	4.53	5	670	705
4.24	4.39	0	650	667
4.04	4.23	-5	624	647
3.78	4.03	-10	572	623
3.54	3.77	-15	542	571
3.24	3.53	-20	504	541
2.94	3.23	-25	446	503
2.60	2.93	-30	404	445
2.28	2.59	-35	344	403
1.90	2.27	-40	276	343
1.52	1.89	-45	230	275
1.14	1.51	-50	162	227
0.75	1.13	-55	113	161
0.30	0.74	-60	036	112
0.00	0.29	-65	000	035

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Word 63-30

Table 5
ATS-E Magnetic Field Monitor
(Electronics Temperature)

(-) Voltage	Temperature °F	Octal No.
1.15	160	163
1.33	150	205
1.51	140	227
1.73	130	255
1.96	120	304
2.23	110	337
2.49	100	371
2.78	90	426
3.08	80	464
3.38	70	522
3.67	60	557
3.94	50	612
4.20	40	644
4.43	30	673
4.65	20	721
4.81	10	741
4.97	0	761

Table 6
ATS-E Torquer Coil Calibration - 16 July 69

Command Step	M_x	M_y	M_z
1	+6,040	-6,250	+7,260
2	+12,420	-12,880	+14,750
3	+19,700	-19,200	+23,600
4	+26,450	-26,200	+32,400
5	+33,700	-33,500	+40,900
6	+41,000	-40,750	+49,300
7	+48,200	-47,700	+57,500
8	+55,800	-54,600	+65,500
9	+62,600	-61,600	+72,500
10	+68,900	-68,000	+80,800
11	+78,000	-73,400	+86,500
12	+84,300	-80,200	+95,000
13	+90,500	-86,000	+99,700
14	+96,800	-92,100	+103,800
15	+102,300	-97,600	+108,500
16	+3,270	-3,760	+3,960
17	-4,110	+3,230	-4,540
18	-11,770	+10,280	-13,700
19	-19,170	+17,350	-22,050
20	-26,450	+24,400	-31,200
21	-33,800	+31,600	-40,400
22	-42,300	+39,200	-48,700
23	-49,500	+46,200	-56,700
24	-57,200	+53,700	-64,600
25	-64,200	+60,600	-72,800
26	-71,000	+67,300	-79,300
27	-77,300	+74,800	-86,500
28	-83,500	+81,600	-93,600
29	-89,100	+88,000	-97,800
30	-96,100	+94,200	-102,200
31	-102,200	+100,000	-106,100
32	-3,825	+3,480	-3,200

Moment values are in pole cm.

Table 7

ATS-E Magnetometer Corrections

Preliminary Values Obtained During Test GSFC 40-ft. Coil

	X	Y	Z
1. Perm Field after S/C compensation	+21γ	+31γ	+109γ
2. Auxiliary Power Supply to Battery Power			
Minimum Load (Basic S/C) 002, 127, 375, 212, 075	-1	-5	-3
Low Load (Set #8) 316, 251, 053, 203, 355	0	+1	-1
Medium Load (Set #7) 251, 053, 203, 357, 022, 001	-2	-9	-11
3. Auxiliary Power Supply to Solar Array Power			
Low Load (Set #8) - same as above	+4	-5	-7
Medium Load (Set #7) - same as above plus 355	0	-11	-14
4. Stray Fields - On auxiliary power supply			
Set #1 Minimum load plus 251, 053, 203, 223, 357, 022, 001	+1	-6	-1
#2 Minimum load plus 251, 053, 203, 223, 357, 022, 001, 315	-5	-4	+11
#3 Minimum load plus 251, 053, 203, 223, 357, 002, 001, 315, 301	-5	0	+25
#4 Minimum load plus 251, 053, 203, 223, 270, 164, 232, 126, 116	-15	-12	+41
#5 Minimum load plus 251, 053, 203, 223, 077, 003, 355, 067, 301, 357, 315, 001	-4	+8	+33
#6 Minimum load plus 251, 053, 203, 223, 340, 003, 250, 127, 165	+1	0	-1
#7 Minimum load plus 251, 053, 203, 223, 357, 022, 001, 077, 023	-1	-4	0
#8 Minimum load plus 251, 053, 203, 223, 357, 355, 077, 157, 174	-1	-1	+1
5. Torque Coil - Flag all data			

Table 8
ATS-E Magnetometer Corrections
Additional Correction for S/C Orientation Relative to Sun

Condition	S/C θ Pointing Toward Sun	Local Time	X	Y	Z
Low Load	270°	1800	0	0	0
(Set #8)	300°	2000	+1	+2	-1
	330	2200	+3	+2	-1
TM #1 & 2	0	0000	+3	+4	-3
Encoder #1 & 2	30	0200	+2	+8	-3
Magnetometer	60	0400	0	+8	-1
G. G. Experiment	90	0600	-1	+9	+3
SAS-A	120	0800	-3	+7	+4
SAS-C	150	1000	-4	+6	+5
EME	180	1200	-4	+4	+5
	210	1400	-3	+2	+2
CMDS - 127, 002, 357, 212,	240	1600	-2	+1	0
251, 053, 203, 355, 075	270	1800	0	0	0
Medium Load	270	1800	0	0	0
(Set #7)	300	2000	0	0	-1
TM #1 & 2	330	2200	0	+2	-2
Encoder #1 & 2	0	0000	0	+4	-3
Magnetometer	30	0200	0	+6	-2
G. G. Experiment	60	0400	0	+7	-1
SAS-A & SAS-C	90	0600	-4	+7	+3
IR Sensor	120	0800	-3	+6	+4
Repeater #1	150	1000	-3	+4	+6
	180	1200	-3	+3	+5
CMDS - 002, 127, 375, 212,	210	1400	-3	+1	+3
251, 053, 203, 075, 223, 357,	240	1600	-2	+1	0
022, 001, 355	270	1800	0	0	0

Table 9
ATS-E Magnetic Moment History

Date	State	M_x	M_y	M_z	M_t	Remarks
7-15-69	As Received	+8130	+1827	+1342	8440	
7-15-69	Post Exposure	+13419	+560	+949	13450	15 Gauss at θ = 190°
7-15-69	Post Deperm	+5632	+1585	+838	5910	Rotational from 32 G
7-15-69	Post Init. Comp.	-88	-222	+276	366	
7-16-69	Post Final Comp.	+2656	+828	+763	2884	Magnets 2 & 6 Removed Magnet 3 Reversed
7-17-69	Post Torq. Tests	+2438	+1030	+730	2743	
7-17-69	Max. Stray Field	+2335	+1168	+2140	3720	Load No. 5 Commands 315 & 001
7-17-69	Max. Battery	+2557	+782	+814	2790	Final Load
7-17-69	Max. Solar Sim	+2450	+891	+698	2700	Load No. 8

Moments are given in pole cm.