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GSFC MAGNETIC FIELD EXPERIMENT
EXPLORER 43

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GSFC —— GODDARD SPACE FLIGHT CENTER ——
GREENBELT, MARYLAND

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ABSTRACT

This paper describes the GSFC Magnetic Field Experiment flown on Explorer 43. The detecting instrument is a triaxial fluxgate magnetometer which is mounted on a boom with a flipping mechanism for reorienting the sensor in flight. An on-board data processor takes successive magnetometer samples and transmits differences to the telemetry system. By examining these differences in conjunction with an untruncated sample transmitted periodically, the original data may be uniquely reconstructed on the ground.

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EXPLORER 43

INTRODUCTION

Explorer 43 (IMP-I, IMP-6) was launched into an elliptical orbit inclined 28.5° to the equator from the Eastern Test Range on March 13, 1971. There are a total of twelve scientific experiments on board measuring magnetic fields, electric fields, energetic particles, plasma, and radio emission. This paper treats the GSFC magnetic field experiment and its interface with the spacecraft.

The sensing device employed is a three-orthogonal-component flux-gate magnetometer with four ranges: ±16, ±48, ±144, and ±432 gammas. During normal operation, the proper range is selected automatically by on-board monitoring circuitry, but this function can be overridden by ground command.

Because it is virtually impossible to achieve a perfectly clean spacecraft magnetically, it is necessary to mount the detecting device as far as possible from any contaminating source. On Explorer 43 the sensor package was located at the end of a 11.5 foot boom, placing it 13.8 feet from the spacecraft center of gravity. Attached to the triaxial sensor is a flipping mechanism which rotates two of the axes 90° about the third axis. This reorientation, coupled with the spinning spacecraft, is used for calibrating the magnetometer effective zero levels in flight.

A special on-board data processor produces the necessary synchronizing signals for the experiment, provides analogue to digital conversion, and, by calculating and transmitting differences between successive magnetometer samples, permits vector sampling at a rate of 12.5 samples per second when the spacecraft is in the 1600 bit-per-second transmitting mode.

Table 1 lists the weight and power of the units comprising the experiment and Figure 1 is a picture of the sensor and electronics packages.

The experiment continues to operate perfectly after more than 34 months as of this printing (January 1974).

FUNCTIONAL DESCRIPTION

Figure 2 is a functional block diagram of the magnetic field experiment. The magnetometer, consisting of a three-axis sensor and electronics, presents its 0 to 5 volt output signal to the analogue-to-digital converter of the processor.

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Table 1

List of Weights and Power

	Weight		Power
	(Lbs)	(Kgm)	(Watts)
Sensors and Flipper	1.2	0.54	6.3 (During Flip)
Mag. Electronics	2.77	1.26	0.9
Processor	3.9	1.77	1.24
Total	7.87	3.57	
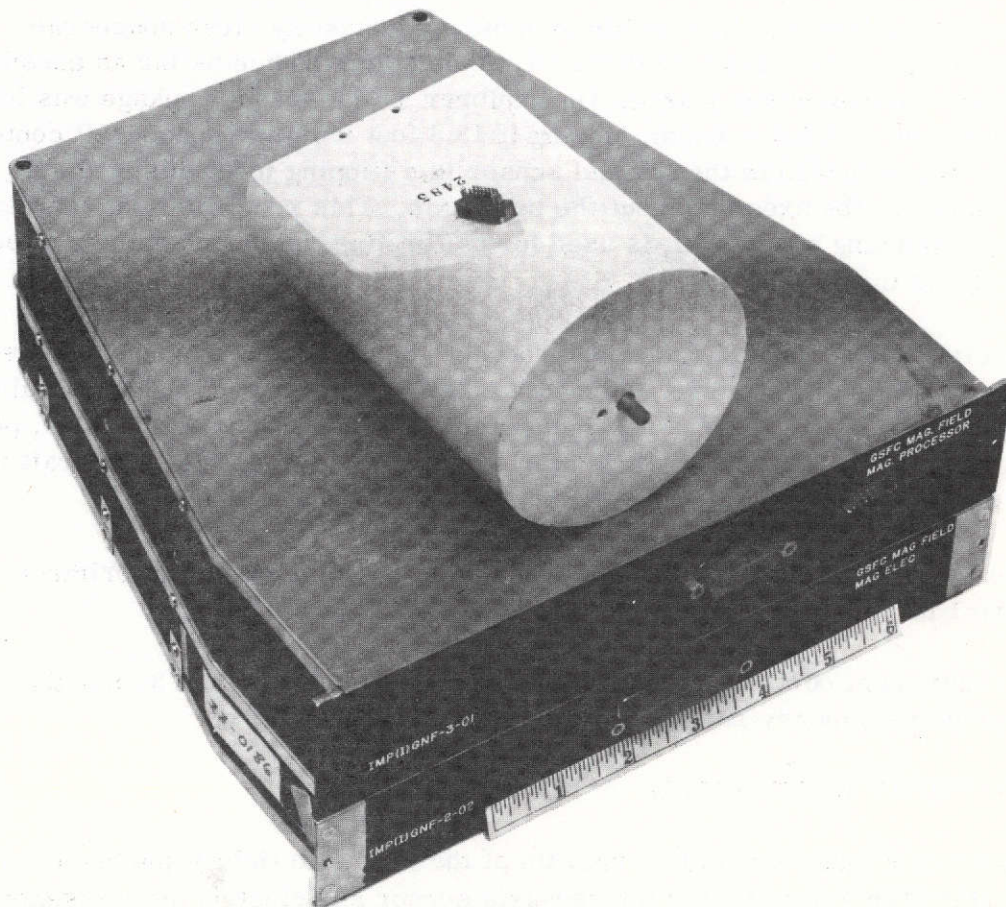
Figure 1. Magnetic Field Experiment
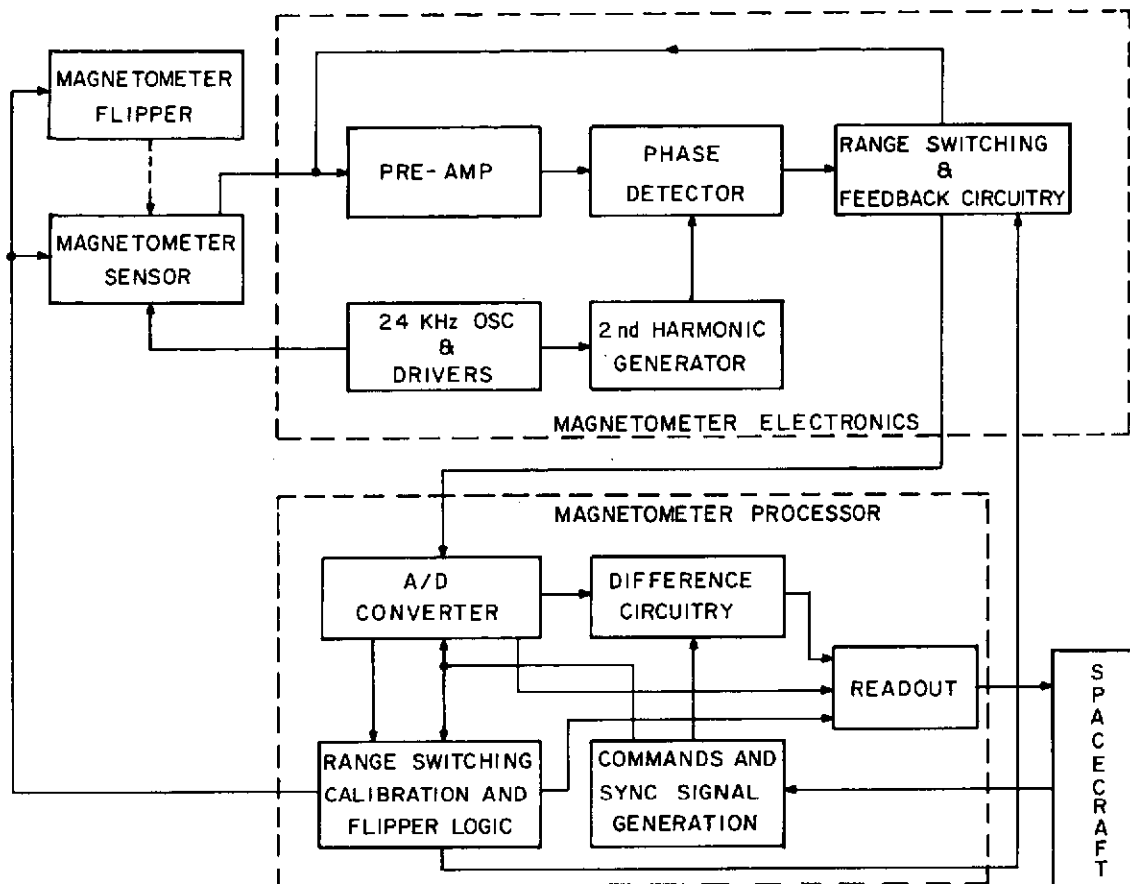
Figure 2. IMP-I Magnetic Field Experiment Block Diagram

At this point, the analogue signal is digitized to a precision of 8 bits and prepared for transfer to the spacecraft encoder. Along with this "full-word" data point, the processor computes differences between successive magnetometer samples, which are also subsequently transferred to the encoder. The encoder then reads out this data in its proper position in the telemetry format.

Triaxial Fluxgate Magnetometer

The magnetometer electronics portion of the block diagram shows only a single axis system. A triaxial arrangement is identical except that a single oscillator. and driver supports the three-axis sensor and the associated circuitry.

Each sensor is essentially a saturable magnetic reactor which is driven at a 24 KHz rate from positive to negative saturation. The presence of an external magnetic field on the reactor core creates an imbalance in the core flux and

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generates even harmonics of the drive frequency detectable in a secondary winding on the solenoid. Through proper tuning of the sensor with its associated electronics only the second harmonic is allowed to pass to the electronics' preamplifier. The reference by Schonstedt (1961) gives a detailed description of this principle.

The second harmonic signal of the sensor is amplified in a tuned preamplifier and presented to one leg of a phase detector. The reference signal to the phase detector is provided by the same oscillator which drives the sensors, but it is first doubled in frequency to match the second harmonic input signal. The phase detector is DC biased so that a zero magnetic field gives an output of 2.5 volts. The frequency response of the system is determined by low pass filtering elements at the output circuit. The voltage output (0 to 5 VDC) is calibrated to yield the magnetic field component parallel to the axis of the sensor core. The magnetic field strength determines the amplitude of the second harmonic voltage, and the field direction through the core dictates whether the signal is in phase with the phase detector reference or 180° out of phase.

In order to extend the capability of the experiment, the magnetometer is operated in four ranges: ±16, ±48, ±144, and ±432 gammas. The magnetometer processor's eight-bit analogue-to-digital converter processes the output of the magnetometer and yields overall sensitivities of ±0.06, ±0.19, ±0.56, and ±1.69 gammas for the above ranges respectively. Proper range is selected automatically by the processor by monitoring the magnetometer's three axes. A system of magnetic latching relays energized by circuitry in the processor switches resistors in and out of a feedback circuit and thus changes the range or sensitivity of the instrument. Points at which the system switches to the next highest range are: ±14, ±42, and ±126 gammas. Down range switching points are: ±108, ±36, and ±12 gammas.

A special winding is placed on each sensor to which an accurately known current is periodically applied. This provides a bias field for in-flight calibration of the instrument sensitivity. For the 16γ and 48γ ranges this bias field is 5γ. For the 144γ and 432γ ranges it is 50γ.

Magnetometer Processor

The magnetometer processor contains an analogue-to-digital converter and circuitry for computing differences between successive samples. It also provides the logic for determining proper magnetometer range, produces the necessary gates for magnetometer calibration and flipper actuation, generates the house-keeping data for engineering information, and buffers all of this data in a readout register for proper presentation to the spacecraft telemetry system. All of the commands and sync signals internal to the experiment are generated by the

processor. It also includes a DC to DC power converter which provides the various voltages for the system (±12VDC ±1%, ±7VDC ±2%, 5VDC ± .05%

Referring again to the block diagram, one may trace the signal flow through the processor. The analogue output signal from the magnetometer electronics is digitized in the 8-bit A/D converter. This digitized signal is then transferred to a sample storage buffer as well as to a counter in the differencing network. Here the difference between the current sample and the previous sample is computed. These differences, as well as the whole sample, are transferred to shift registers in the readout portion of the processor where the data stream is shifted to the spacecraft encoder. There are also eight bits of engineering data generated in the processor which are shifted out along with the full word magnetometer sample. These describe the status of the experiment and indicate magnetometer range, calibration, flipper actuation, and sensor position.

An important function of the processor is determining the proper range for the experiment. It is desirable to operate in the most sensitive range whenever possible. The processor uses the following criteria for shifting up-range or down-range:

1. A command is given to shift up whenever the digital word is >240 counts or <16 counts, or the differences are greater than 15 counts.

2. A down-range command is given when all words are between 96 and 160 counts and all differences are less than 4 counts.

The 8-bit A/D converter's output is 0 to 255 counts, limits which correspond to saturation points for the magnetometer. Thus the up- and down-range switching points were chosen to assure operation on a linear portion of the magnetometer calibration curve and provide a guard band in the probable event of zero drift of the magnetometer. Range switching criteria are tested continuously and a range change command, if required, is sent near the beginning of each telemetry sequence.

The processor receives various timing signals from the spacecraft encoder and uses these to generate the required sync signals for the experiment. These include the shift pulses for transferring the differences and whole sample and engineering data to the encoder, as well as the gates for flipper actuation and magnetometer calibration.

Flipping Mechanism

The magnetic field measurement using a fluxgate magnetometer is relative because of unknown effects on the measurement of the permanent magnetic

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moment of the core. However, by physically reversing the sensing element in the ambient magnetic field, a determination of the amount of permanent mganetic moment and electronic circuit drift can be made so that data collected is placed on a more accurate scale.

Since two of the fluxgate elements are oriented perpendicular to the spin axis of the spacecraft as well as perpendicular to each other, they are reversed by the spinning motion of the satellite. The net result of this motion is to allow an accurate measurement of the field component perpendicular to the spin axis regardless of any offset of the sensor, its electronics, or spacecraft fields.

For the fluxgate element parallel to the spin axis such a reversal does not naturally occur as a result of the spinning motion of the spacecraft. An in-flight physical reversal must be accomplished if the component of the field parallel to the spin axis is to be placed on an absolute scale. An inherent part of this experiment is the employment of a special flipper mechanism which provides for periodic reversal of the spin axis sensor. This is done by reorienting the sensor package 90 degrees, thus allowing the sensor axis parallel to the spin axis to periodically exchange position with one perpendicular to the spin axis. The spinning spacecraft then provides a 180 degree rotation for this previously parallel sensor, which permits a zero level calibration each spin.

One distinguishing feature of the field-parallel component is that although the reversal removes the effects due to offsets in the sensor and electronics, it does not remove that due to spacecraft fields. This is the reason for mounting the sensor package on a support structure as far from the satellite as possible. However, Explorer 43 is a magnetically clean spacecraft. Magnetic mapping prior to launch indicates that the remanent field at the sensor flight position is < 0.1 gamma. (Harris, 1972)

TECHNICAL DESCRIPTION

This section of the paper treats in detail the circuitry of the Fluxgate Magneto-meter and the Magnetometer Processor as well as some of the mechanical details of the Flipper Mechanism. But first the various interfaces with the spacecraft, sync signals, and other spacecraft requirements by the experiment will be described.

Interfaces and Spacecraft Requirements

Figure 3 is a wiring diagram of the overall experiment and shows the power and signal flow. 28VDC spacecraft power is supplied the experiment through the spacecraft Programmer. This power on-power off function is commandable

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Figure 3. IMP-I Magnetometer Experiment Wiring Diagram

from the ground. Other ground commands, which the experiment receives via the spacecraft Tone Decoder, are commands to place the magnetometer range control in either the automatic or fixed mode and commands for calibration and flipping. These all override the normally automatic functions inherent in the experiment design.

The experiment's major spacecraft interface is with the Encoder. The Encoder provides sync signals from which the Magnetometer Processor generates the necessary timing functions for the experiment, and it also receives the output data from the experiment for presentation in the proper place in the telemetry format.

The sync pulses labeled "MAG. A SYNC", "MAG. E SYNC" and "MAG. S SYNC" refer to sequence, frame, and channel rates respectively, which are time segments of the telemetry format to be described subsequently. "MAG. C4 SYNC" is a series of clock pulses at 12.8 KHz. "MAG. C33 SYNC", which is a square wave with a period of 11.7 hours, is used for timing the experiment in-flight calibration. "MAG. C28 SYNC" and "MAG. C35 SYNC" together are used to gate the command for the flipping function. C35 occurs every 46.6 hours and C28 every 21.8 minutes. By using only one half the period of C28, the Processor gates the power on to the flipper for approximately 11 minutes every 46.6 hours.

The remaining experiment-Encoder signals shown on Figure 3 concern the data output. "THERM. ANALOG PP#43" is a performance parameter in the telemetry output which indicates the flipper temperature. This particular line is connected to a thermistor mounted on the flipper, which is in parallel with a resistor network in the Encoder. The resistance variation of this network is calibrated over the temperature range of -40°C to +80°C. "MAG. OUTPUT 1 (IN-1)" and "MAG. SHIFT PULSE 1 (SP-1)" govern the transfer of the sample differences to the Encoder. "MAG. OUTPUT 2 (IN-2)" and "MAG. SHIFT PULSE 2 (SP-2)" control the transfer of the whole samples and the engineering (housekeeping) data to the Encoder. The Encoder maintains two different and redundant storage registers for these two types of data output.

Figure 4 shows the spacecraft telemetry format. The format shown in the figure is called a "page." Each page consists of 4 "snap shots" and each snap shot can be broken down into 4 "sequences." A sequence is considered the primary reference when discussing the telemetry format. It consists of a 16 by 16 matrix with channels 0 through 15 in columns and frames 0 through 15 in rows. Each element of the matrix represents 8 bits of telemetry information data. The Encoder has the capability of operating in either of two bit rates: 1600 bits per second or 400 bits per second. In the 1600 BPS mode the sequence

period is 1.28 seconds. At this rate, the "MAG. A," "MAG. E" and "MAG. S" sync pulses referred to previously will occur every 1.28 secs., .08 secs., and .005 secs. respectively. From Figure 4 one can see that the magnetometer sample differences are read out during the first half of frames 1, 5, 9, and 13, and the full vector sample and housekeeping data occur during channels 12 through 15 of frame 15 of each telemetry sequence. The flipper temperature (performance parameter #43) is read out during channel 4, frame 8, sequence 2 of snap shot 3.

For more details on the Encoder design and operation the reader may refer to White (1970).

Fluxgate Magnetometer

Figure 5 is a schematic diagram of the Fluxgate Magnetometer. The upper half of the diagram consists of the oscillator and drive circuit, while the lower half covers the signal amplifier, phase detectors, and output circuit. Note that while the oscillator and drive circuits shown supply all three sensor axes, the signal and output circuit for only the X channel is shown. The Y and Z channels are identical.

Q101 and T101 comprise an oscillator tuned by C102 to approximately 24 KHz. Q102 and Q103 amplify this signal and T102 couples it to the excitation winding of each sensor. C106 adjusts the phase of the power amplifier to agree with that of the oscillator. L101, L102, and L103 prevent interaction between the three sensor axes due to a common excitation drive. The 4, 5, 6, winding on T102 serves two purposes. With CR106, CR107, and C112 a rectified - 6VDC is generated which supplies the negative reference for the output circuitry. In addition, this winding together with CR101, 102, 103, 104, and 105 provides a feedback network for stabilizing the oscillator. The 7, 8 winding of T102 provides the supply voltage for the reference amplifiers.

The second harmonic signal generated on the sensor's output winding is passed to preamplifier Q201. C201 tunes the input to the second harmonic signal. R203 is used for temperature compensation when needed. C202B is a high frequency trap for the spacecraft transmitter frequency. C206 and C207 tune T201 to the second harmonic signal and they are adjusted for maximum output of the preamplifier stage. Any remnants of the 24 KHz drive frequency and its third harmonic are trapped by C208, C209, L201, and L202. Emitter follower Q202 isolates the high impedance preamplifier output from the phase detector driver Q203. This latter stage, tuned by C214, provides additional amplification of the second harmonic signal. R214, R215, and C213 are used for temperature compensation.
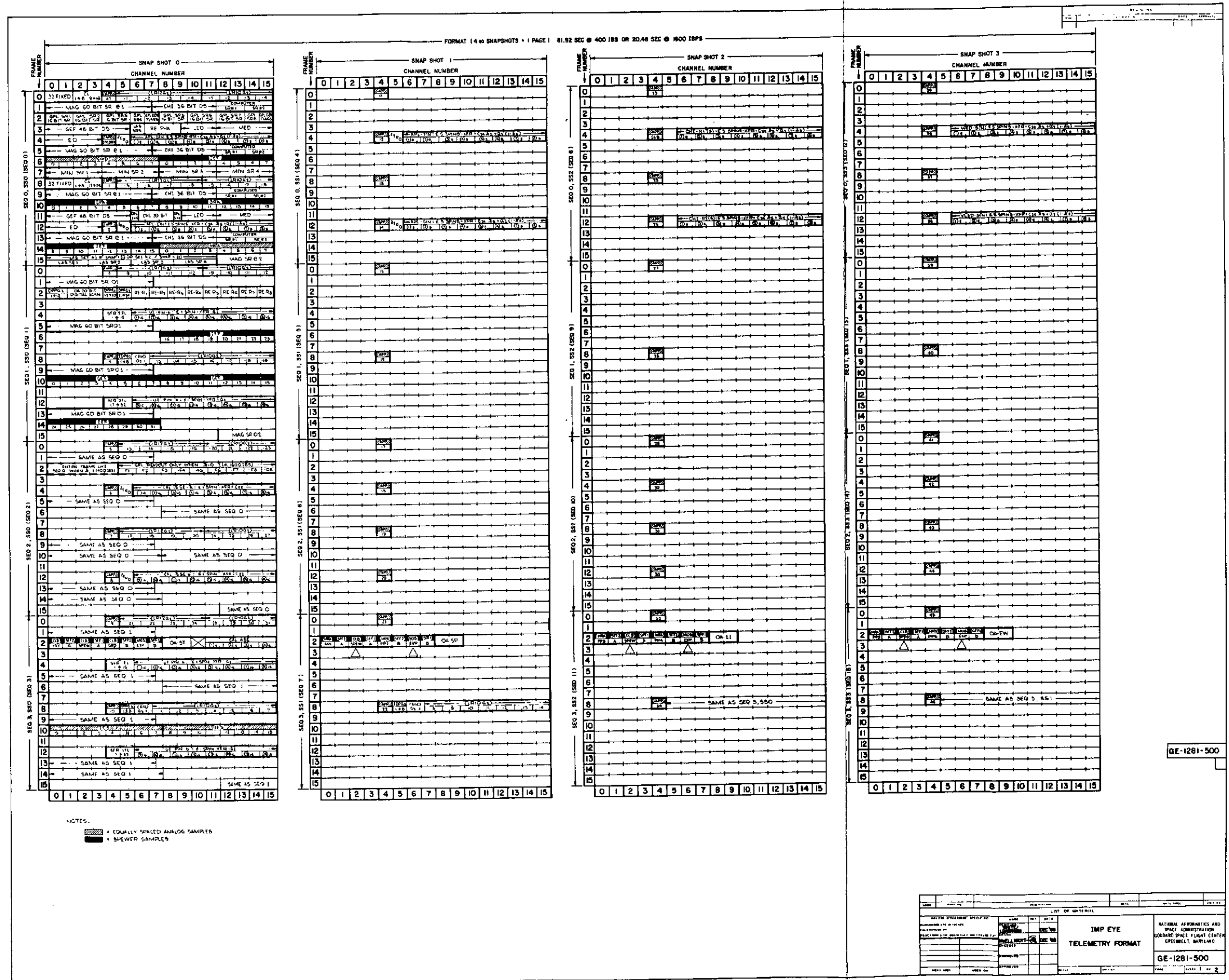
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Figure 4. IMP-I Telemetry Format

Figure 5. IMP-I Fluxgate Magnetometer and Magnetic Field Experiment Schematic Diagram

FOLDOUT FRAME

FOLDOUT FRAME

Q204 is the heart of the phase detector. It is essentially a switch by which the input signal generated by the ambient magnetic field is compared in magnitude and phase with a reference signal. This reference signal is constructed from the same source which drives the excitation winding of the sensors. Note that both polarities of the fundamental frequency are applied to amplifiers Q252 and Q253 such that the output of Q251 contains the frequency doubled. As mentioned previously, the supply voltage for this circuit is generated from T102 and rectified by CR251 and CR252. The double frequency reference signal is now applied to the gate of FET Q204, which conducts the second harmonic input signal to C216 and C217, where it is integrated to form the DC output. The magnitude of this output is directly proportional to the magnetic field strength and its polarity is determined by the field direction through the sensor. CR202 with voltage divider network R216, R217, and R218 set the operating bias of the phase detector at 2.5 VDC.

The detected signal is now applied to the output circuit consisting of amplifiers Q1, Q2, and Q3 and their associated components. CR1 provides a constant current to the emitters of Q1 and Q2, which improves the stability of the network. CR2 limits the output to the extremes of approximately -0.5 VDC and 5.5 VDC. C3 adjusts the frequency response of the system, which is shown on Figures 6, 7, and 8.

Before leaving Figure 5 note point "A (FEEDBACK)" at the junction of R3 and R4 and the point at the signal intput channel labeled "TO RELAY CKT." Between these two points are inserted feedback resistors which establish the sensitivities for the various operating ranges. The relay circuit which switches the appropriate resistors in and out of the feedback network is shown on Figure 9. Logic using 2 bits defines the operating modes of the relays necessary to switch between the four ranges. The least significant bit (LSB) and most significant bit (MSB) commands are generated in the Magnetometer Processor Card, whose function was described earlier. Half of K501 and half of K502 are used to indicate whether the LSB and MSB are ones or zeros. This information is transmitted in the telemetry signal for use in the data analysis. The truth table for the 2 bit logic is shown in the figure.

Processor

Operation of the Magnetometer Processor will be discussed with the aid of four logic diagrams: Figures 10, 12, 13 and 14. These divide the Processor into four functional units: the A/D converter, sample storage and encoder transfer, difference control and transfer, and range, calibration and flip control.

The A/D converter (ADC) logic is shown in Figure 10. It is an eight bit successive approximation, weighted resistor network type. The accuracy and linearity
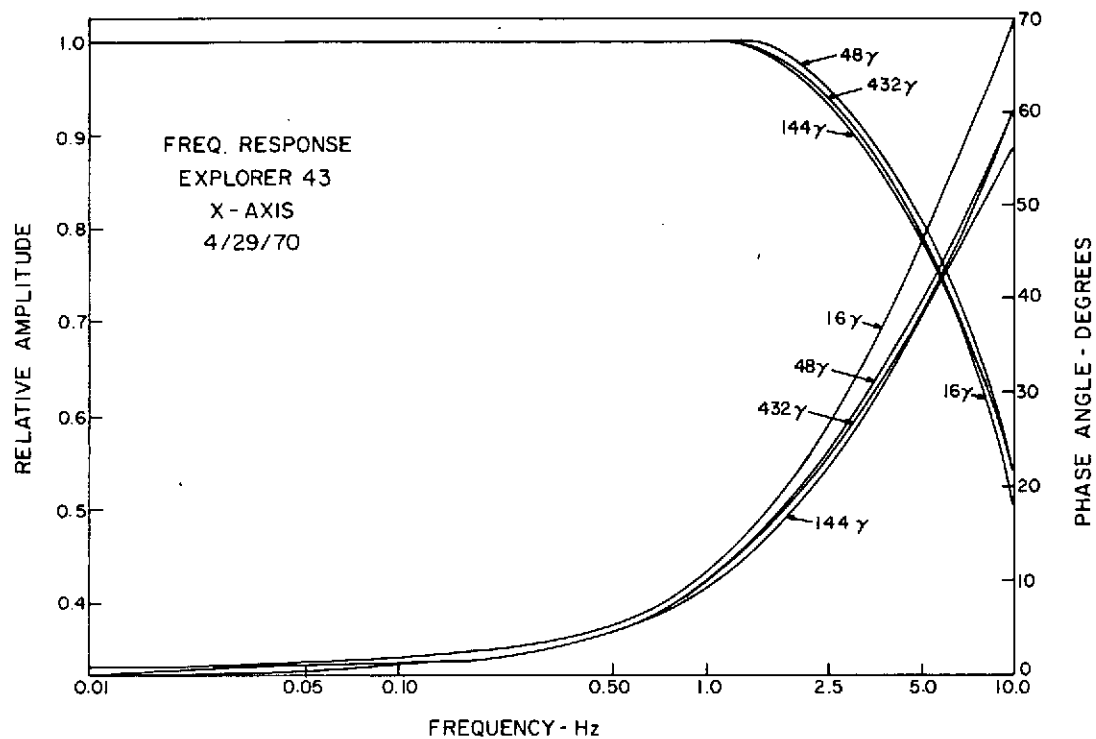
Figure 6. Explorer 43 Frequency Response X-axis, April 29, 1970
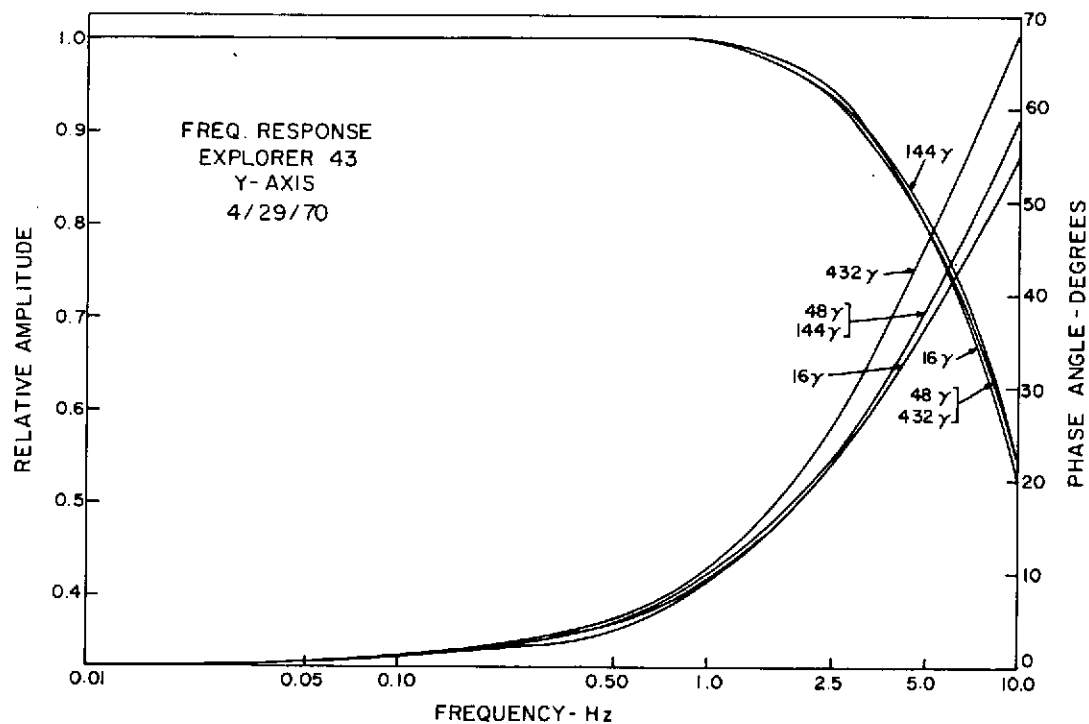
Figure 7. Explorer 43 Frequency Response, Y-axis, April 29, 1970

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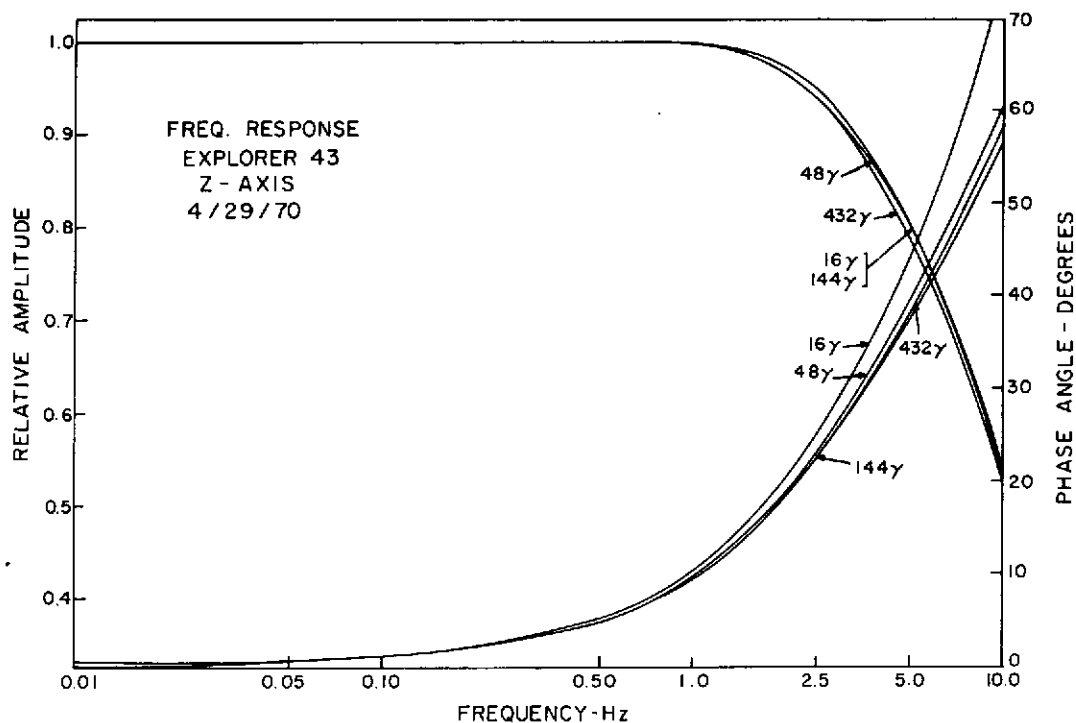
Figure 8. Explorer 43 Frequency Response, Z-axis, April 29, 1970

are better than 1/2 bit over the entire range of operating conditions ($-40°C \leqslant$ $T \leqslant +60°C$).

The resistor network is contained in the block labeled "D/A CONV 8 BIT" and is shown schematically in Figure 11. The precision resistors, two each connected in series, have binary multiple values ranging from 25K to 3.2M ohms. One end of each chain is connected to the +5v precision reference, while the other end is tied to the summing junction of an operational amplifier. The centertap of each chain is tied to ground through transistor switches, and these switches control the current to the summing point. This operational amplifier functions as a current to voltage converter and has an output between 0 and -5 VDC, depending on how many of the eight transistor switches are on.

Three additional operational amplifiers take the output from the summing amplifier and compare it to the input from the Magnetometer. Note that a single ADC is time-shared by the X, Y and Z outputs from the Magnetometer. The control gates following these amplifiers allow the proper amplifier to be used as feedback control of the ADC.

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Operation of the converter begins with the appearance of the S/C MAG E pulse, which occurs at the S/C encoder frame rate. One can see from Figure 10 how the Processor takes this signal and generates the required pulses for A/D operation. (FR, A/D START, A/D RESTART, A/D SHIFT, A/D RESET.) The signal labeled "CLOCK" is generated from the 12.8 KHz S/C MAG C4 input. Initially flip-flops (FF) 10 through 17 are reset to "O" and FF 18 to "1". On the occurrence of the sample gate (Frame) an A/D start pulse is generated, which sets FF2, 3, and 10 and resets FF 18. Now FF2 will not allow any further clock pulses through Gates 1 and 2 until it is reset. FF3 gates the X voltage comparator to control the ADC.

With FF10 set, the most significant 2^7 (128) current level is gated on, comparing the magnetometer with 1/2 scale. The next clock pulse is decoded thru Gate 13 and sets FF11. This gates on the 2^6 (64) current, and, if the magnetometer voltage is less than half scale, resets FF10 thus shutting off the 128 current. If the magnetometer voltage is greater than half scale FF10 remains set. This action continues through the remaining bits for 7 more clock times. The eighth pulse completes the conversion and sets FF18 and FF6.

FF18 disables Gates 13-20. FF6 enables Gate 6 for one pulse which then resets FF6 and sets FF7. FF7 enables Gate 7 allowing the next clock to set FF8 and reset FF7 and FF3. This pulse also shifts data from FF10 through FF17 to the data storage buffer and shifts the "1" from FF3 to FF4, which gates the Y voltage comparator to control the ADC. The next clock pulse resets the ADC through Gate 8 and sets FF9. The following clock pulse restarts the ADC.

This process is repeated until the X, Y, and Z conversions have been completed. After Z is completed no restart is given, but a pulse from Gate 11 signals three conversions are completed. From the start of the X comparison to the completion of the Z conversion a total of 33 clock pulses has occurred. With a clock of 12.8 KHz this means the S/C will have rotated through less than 5 min. of arc at 5 RPM.

Figure 12 shows the logic for controlling the full word sample and engineering data readout. On the occurrence of an A/D start pulse (T1), eight experiment status bits are transferred in parallel into an eight bit serial shifting register. Eight shift pulses then shift the eight status bits to the encoder. When the A/D restart pulse (T2) occurs, the latest sample in the whole-sample storage buffer is loaded into the eight bit register in parallel. Again eight pulses shift this data to the encoder. The combined full word sample and engineering data read out loads four eight bit words (status and X, Y, and Z) into the encoder each telemetry frame. These words are loaded most significant bit (128) first through the termination labeled "MAG IN2." The output labeled "MAG SP2" supplies the controlling shift pulses to the encoder.

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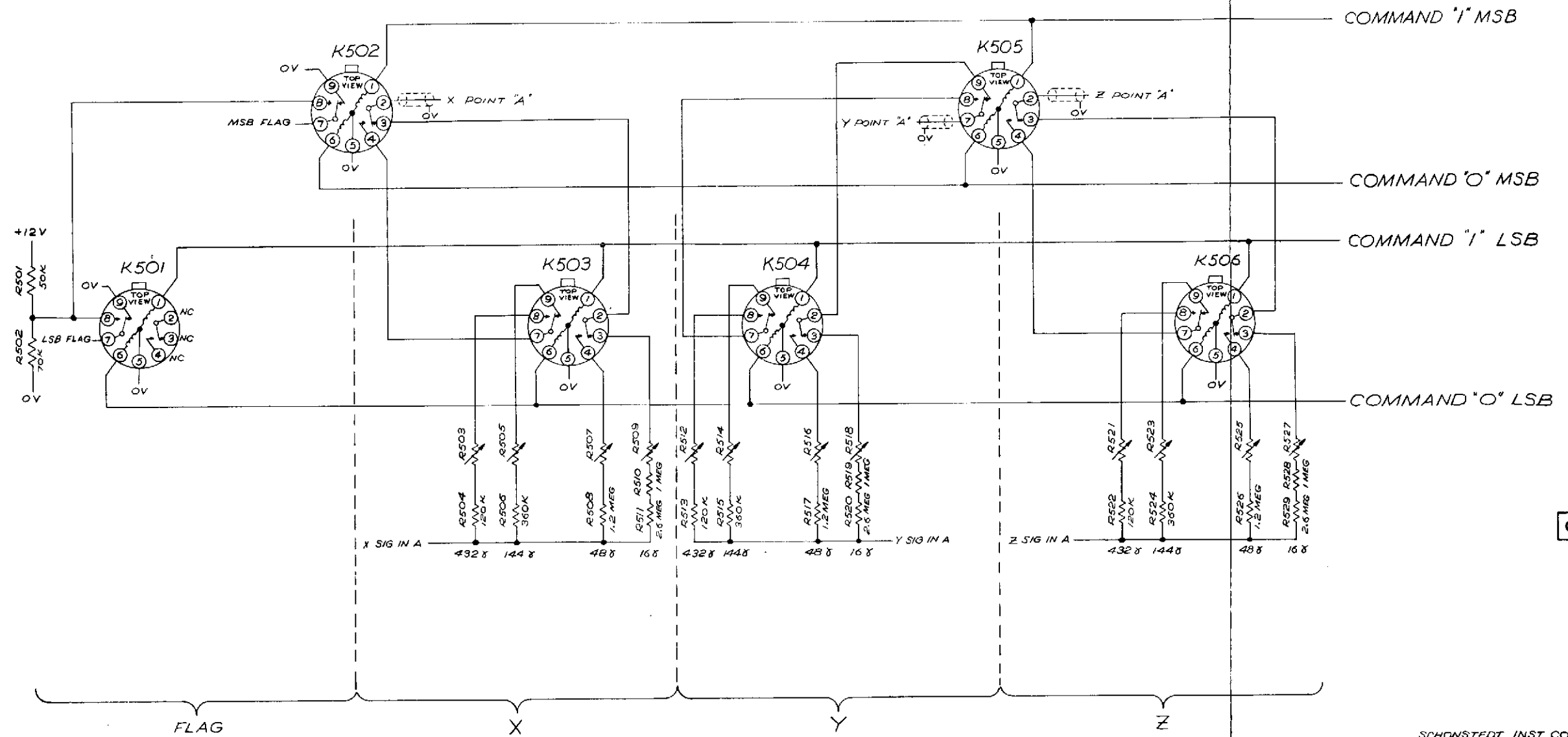
Figure 9. IMP-I Relay Circuit, Fluxgate Magnetometer, Magnetic Field Experiment Schematic Diagram

Figure 10. IMP-I AID Converter Schematic Diagram

Figure 11. Schematic Diagram, IMP-I Digital to Analogue Converter

Figure 12. IMP-I AID Converter, Sample Storage and Encoder Transfer Schematic Diagram

Figure 13. IMP-I Difference, Control and Transfer Schematic Diagram

Figure 14. IMP-I Range, Calibration and Flip Control Schematic Diagram

Note that the full word sample storage buffer is a series of shift registers which stores six full word (eight bits each) samples. The buffer is accessible at three points. When full, there are two samples of each axis from the magnetometer. These two samples are used to compute the differences, whose controlling logic will be discussed next.

The "C" and "P" outputs of the whole sample storage buffer in Figure 12 are connected through gates to two 8 bit counters shown on the difference control logic diagram Figure 13. The most recent sample is used to preset the "C" counter (FF 1 through 8) and the previous sample presets the "P" counter (FF 9 through 16). Unless the number is 255, the "C FULL" or "P FULL" gate is negative. These gates enable a gate on the input of each counter to pass the clock to the counter till the "C" or "P FULL" gate goes positive. By feeding the "C FULL" and "P NOT FULL" outputs and "CLOCK" to gate 39, and "P FULL" and "C NOT FULL" outputs and "CLOCK" to gate 40, and ORING the two outputs, the difference appears as clock pulses which are counted by 4-bit counter FF 32 through 35. If this counter should reach 15, it disables the input. If the difference is greater than 15, the counter remains at 15.

By feeding the clock pulse output of gate 39 to the J of sign FF36 when "C" is full before "P" and the output of gate 40 to the K of FF36 when "P" is full before "C", this difference is signed negative and positive respectively.

As soon as both 8 bit counters are full, the next clock pulse transfers the sign and four bit counter contents to 5-bit serial shift register FF27 through 31. The next five clock pulses shift the difference to the spacecraft encoder through the termination labeled "MAG IN 1." The last pulse initiates the "TRANSFER" pulse which starts the operation again until three differences are computed. The output labeled "MAG SP1" provides the controlling shift pulses to the encoder.

The remaining portion of the Magnetometer Processor contains the range, inflight calibration and flipper control. The logic for these functions is shown on Figure 14. As was pointed out in the Functional Description, an up-range command is required whenever the magnetometer's converted digital count is greater than 240 or less than 16, or when the differences exceed 15 counts. If either of these criteria, which are tested continuously, occurs, FF7 is set and at channel 8, frame 0 of the next telemetry sequence a range command is generated to change the range to the next less sensitive range. Conversely a down-range command is generated whenever the digital word is between 96 and 160 counts and the differences are less than 4 counts. FF8 controls this function. Note that the difference-limit inputs HK and LK are generated in circuitry shown on Figure 13.

Upon receiving a ground command to the Fixed Range the Auto Range control is disabled. The magnetometer is then locked in its present range until it receives

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another Fixed Range command. Each following Fixed Range command will change the magnetometer to the next sensitivity.

The in-flight calibration of the magnetometer may be either automatic or by ground command. The "MAG C33" signal from the spacecraft encoder goes negative approximately every twelve hours and a calibrate gate is generated for four sequences. Due to the wide range of the magnetometer, two fixed currents are applied to the sensor calibrate windings. If the range status bits indicate the magnetometer is in either the 16 γ range or 48γ range, the current will change the magnetometer output about 5 γ. Should the magnetometer be in either the 144γ or 432γ range, the current applied will change the magnetometer output approximately 50 γ.

Every 46.6 hours the "MAG C35" signal from the encoder goes negative, and on the next positive edge of "MAG C28", 28 VDC is applied to the flipper thermal actuator. This 28 V is applied till either "MAG C28" goes negative (about 10 minutes) or the microswitch on the thermal actuator opens. Flipper heater power may also be applied by ground command. After receiving the flip power command the Processor will apply the 28 VDC to the actuator at the next positive edge of "MAG C28." Again power will be removed after 10 minutes or flip completion, whichever occurs first.

Figure 15 shows a schematic diagram of a typical logic block used in the Magnetometer Processor.

Flipper

A picture of the flipper mechanism, as it is attached to the sensor package is shown in Figure 16. A detailed description of the flipper mechanism, entitled "Nonmagnetic, Lightweight Oscillating Actuator," is given in the reference by McCarthy (1970). Only a functional description of the mechanism will be given here.

The basic flipper assembly appears in Figure 17. The heart of the system is a thermal actuator, which consists of a piston encased in a rubber boot that is embedded in an expansion material of epolene and paraffin wax and housed in a brass case. Around this case is bonded a heating element of vapor-deposited gold. When current is applied, the epolene and wax mixture melts and expands forcing the piston out of the case and against a rocking beam. As the piston continues its travel, the shaft to which the rocking beam is attached begins to revolve. When this movement has progressed to approximately midway of its total travel, an over-center spring, to which the rocking beam is also attached, takes over and immediately completes the shaft rotation. This shaft is, of

SYM	DESCRIPTION	DATE	APPROVAL

GC

Rμ

D1
DHD899

R1
47K

+V

Q1
160P2

Q3
160P2

R3
390K

R6
390 K

C1
33pF

R9
30K

R10
30K

C3
33pF

R4
3.3K

D5
DHD899

D6
DHD899

R7
3.3K

"0"

"1"

C2
33pF

C5
150pF

C6
150pF

C4
33pF

R5
390K

R8
390K

Q2
160N2

Q4
160N2

GND.

J

K
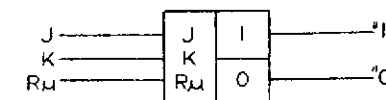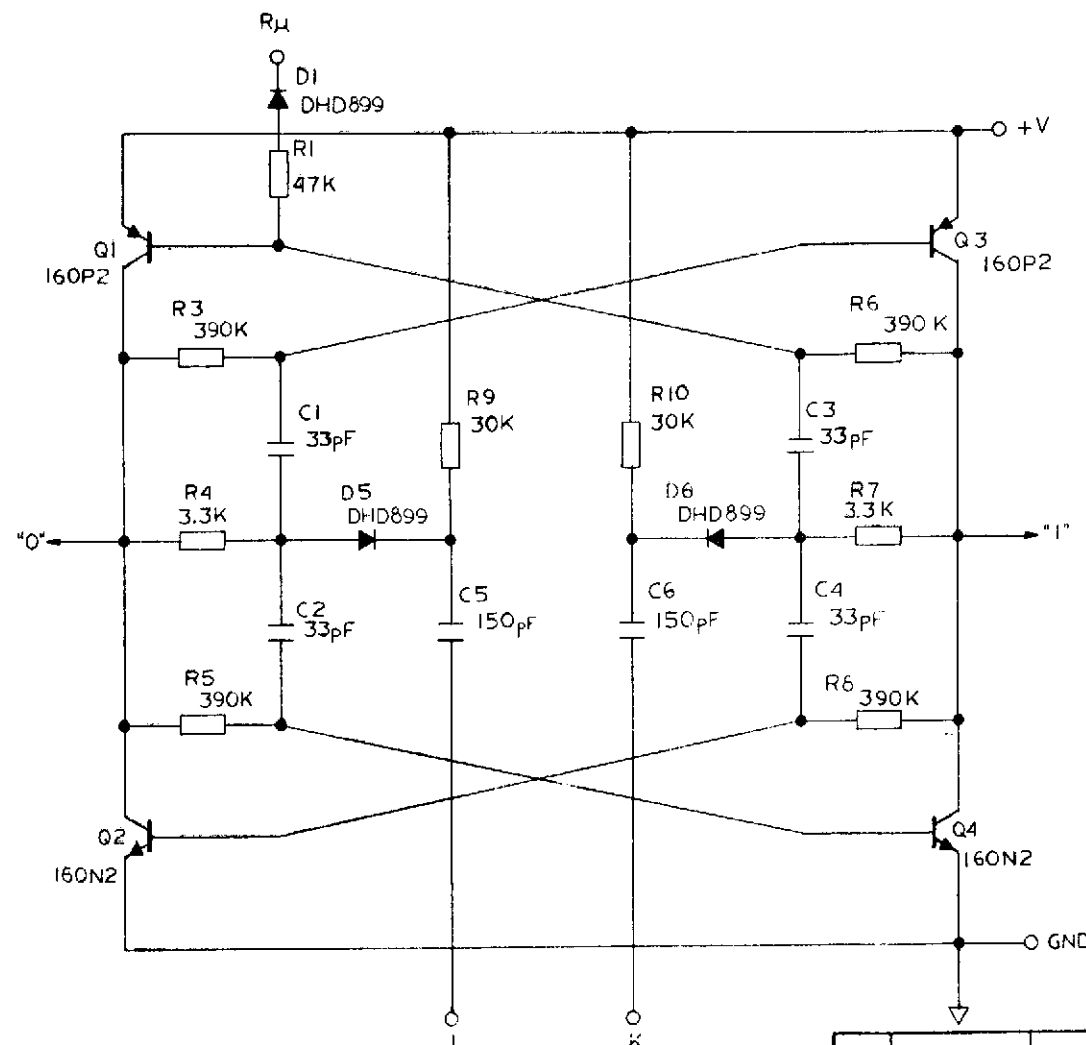
MOD. NO. – 09 –130

LOGIC SYMBOL

J		J	I		"I"
K		K			
Rμ		Rμ	0		"0"

REQD	PART NO.		DESCRIPTION		MATL	MATL SPEC	UNIT WT.

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON:
FRACTIONS ±1/64 DECIMALS ±.005 ANGLES ±½°

	NAME	INIT	DATE
DESIGNER	Scheifele		
DRAWN	J. Hutton		11-17-67
CHECKED	Cunningham		Nov 67
APPROVED	Scearce	cb	11/15/67
APPROVED	C.L. Berger		11-30-67
NEXT ASSY	USED ON		SCALE

IMP EYE
JK-SR FLIP FLOP
SCHEMATIC DIAGRAM

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

GC - 1280 - 008

	CODE	SHEET	OF
UNIT WT			

Figure 15. Schematic Diagram, IMP Eye JK-SR Flip Flop
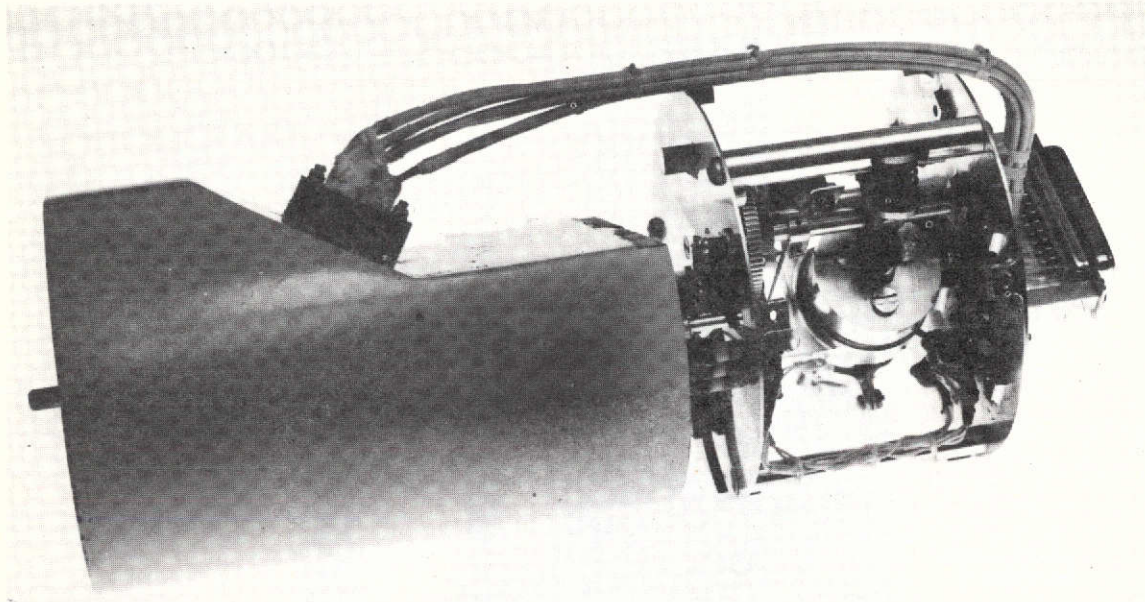
Figure 16. Explorer 43 Flipper and Sensors

course, geared to the output shaft to which the magnetometer sensor package
is attached. When the heater power is removed and the expansion material
cools and contracts, the piston retracts and pulls away from the rocking beam.
This frees the actuator assembly and allows an off-center spring to move the
assembly to its other position so that a new flip cycle can begin in the other
direction.

TELEMETRY OUTPUT

The Magnetic Field Experiment transfers its data to the spacecraft Encoder in
the form of two serial bit streams: one for the full word sample and engineering
(housekeeping) data and the other for the sample differences. These data are
stored by the Encoder in redundant 32 bit and 60 bit shift registers respectively
until time for their read out in the appropriate place of the telemetry format.
This discussion of the data output will treat the matter in terms of Scientific
Data and Engineering Data.

Scientific Data

As noted earlier, the scientific data consists of magnetometer X, Y, and Z axes'
full word sample data and X, Y, and Z sample differences. The reader may refer
to Figure 18 while following this discussion. The figure shows the sample and
read out timing for one telemetry sequence. A complete vector sample (X, Y, Z)

THERMAL ACTUATOR HOUSING

PLUNGER

ROCKING BEAM

OVER-CENTER SPRING

ON-OFF MICRO SWITCHES

OFF-OFF OFF-CENTER SPRING

OUTPUT SHAFT
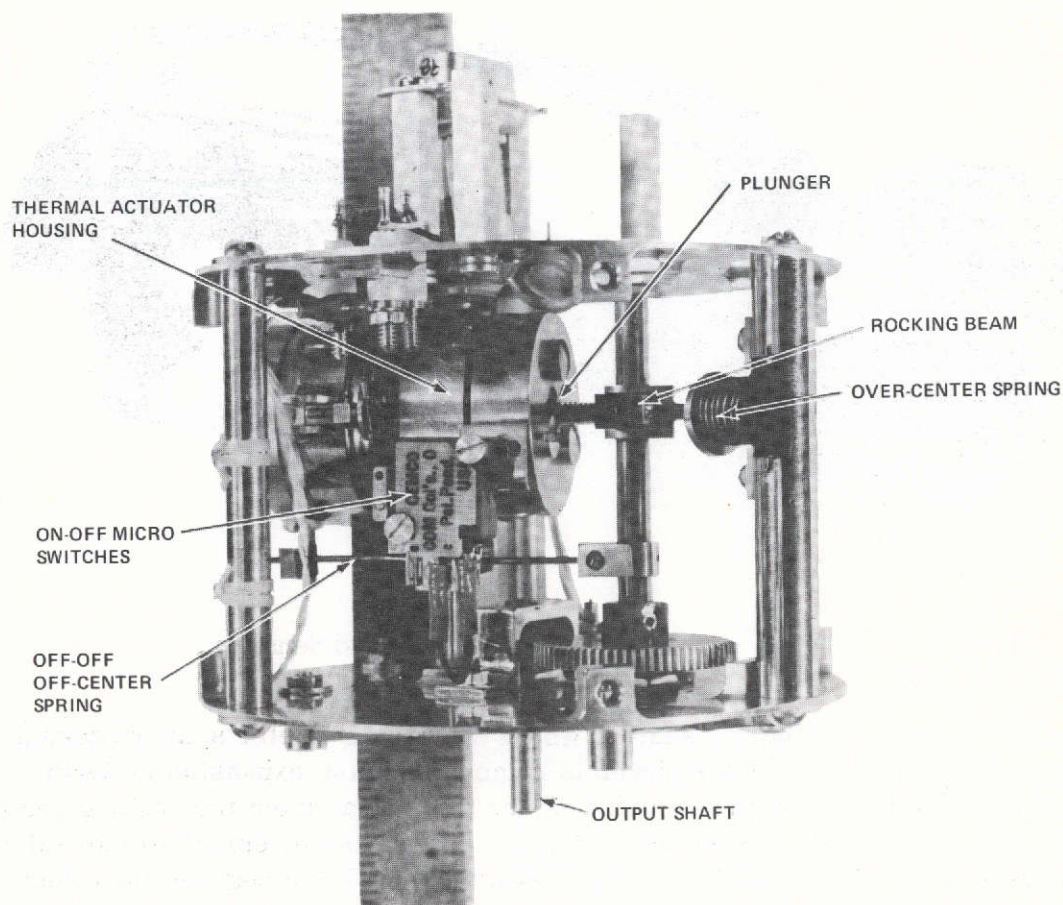
Figure 17. Flipper Mechanism

is made at the beginning of channel 8 of each frame. Only sample 15 is transmitted in the telemetry stream as a full word sample during channels 12, 13, and 14 of frame 15. The other vector samples are not transmitted as 8 bit samples but are used to compute the 5-bit differences for each magnetometer axis. These differences are transmitted in 60-bit blocks during channels 0 through 1/2 of channel 7 for frames 1, 5, 9, and 13. Note that the differences read out in frame 1 are computed from samples made during frame 0 and frames 12 through 15 of the previous telemetry sequence. Those read out in frame 5 are from samples taken during frames 0 through 4. The 60-bit blocks, therefore, are made up from differences between the 5 previous samples. Each vector-component difference is a signed 4-bit integer as illustrated in the figure.

A representative sample of flight data in our "quick-look" format is given on Figure 19. The data was collected on April 22, 1972 during orbit 98. The sheet
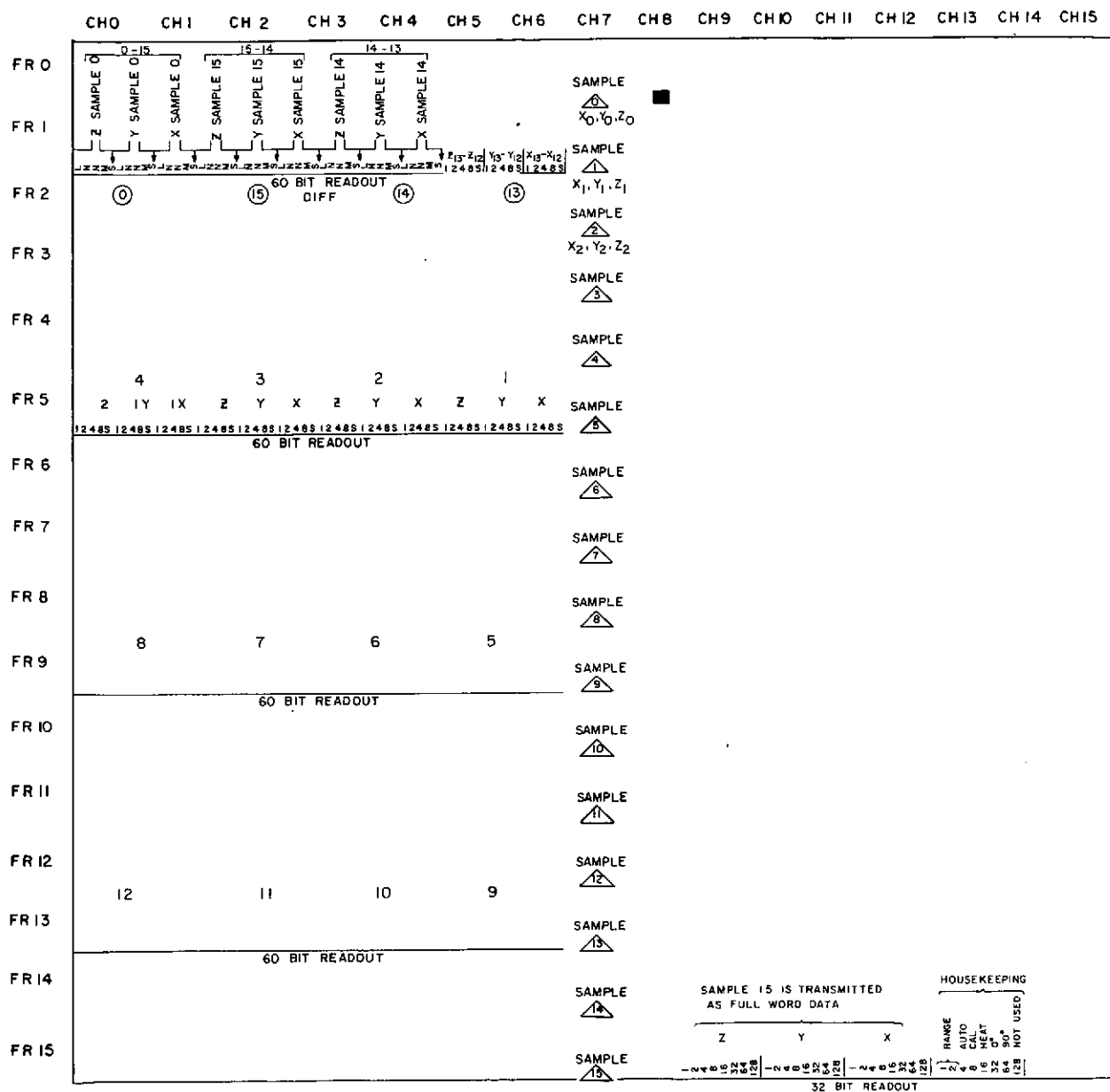
Figure 18. Magnetometer Sampling and Readout Format

Time / ID	Axis	13	14	15	0	1	2	3	4	5	6	7	8	9	10	11	12
113/15:10:22.196	X (192)	3	4	3	3	3	4	3	3	3	3	4	3	3	3	3	4
67706601	Y 197	0	0	0	0	-1	-1	0	0	-2	-1	-1	-2	-2	-1	-1	-3
11000100 0.0	Z 129	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0
113 15 10 23 476	X (220)	2	3	3	3	3	2	2	2	3	2	2	1	2	1	1	1
67706605	Y 152	-2	-2	-2	-3	-2	-2	-3	-3	-2	-3	-3	-2	-4	-2	-4	-2
11000100 0.0	Z 128	2	0	1	0	0	1	0	0	0	-1	0	0	0	-1	0	0
113 15 10 24 756	X 213	1	1	1	0	1	0	0	0	0	0	-1	0	-1	0	-1	-1
67706611	Y 99	-4	-3	-3	-3	-3	-4	-4	-3	-3	-4	-4	-4	-3	-3	-4	-2
11000100 0.0	Z 122	0	0	0	0	-1	-1	0	-1	0	-1	0	0	0	-1	0	0
113 15 10 26 036	X 177	-2	-1	-1	-2	-1	-2	-2	-1	-2	-2	-2	-3	-2	-3	-3	-3
67706615	Y 65	-4	-2	-3	-3	-3	-2	-3	-2	-2	-3	-2	-2	-2	-2	-2	-1
11000100 0.0	Z 117	-1	1	-1	0	0	-1	-1	0	0	-2	0	0	-1	0	0	0
113 15 10 27 316	X 125	-2	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-4	-3	-3	-4	-3
67706621	Y 56	-1	-3	-1	-1	-2	-1	-2	-1	-1	0	-1	-1	0	0	0	0
11000100 0.0	Z 120	0	0	0	0	0	1	0	-1	0	0	1	0	0	0	1	0
113 15 10 28 596	X 77	-4	-3	-4	-3	-4	-4	-4	-3	-3	-3	-3	-3	-3	-3	-3	-2
67706625	Y 79	0	1	0	1	1	1	0	1	2	1	1	1	2	2	1	2
11000100 0.0	Z 123	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	-1
113 15 10 29 876	X 56	-2	-3	-2	-2	-2	-2	-2	-2	-2	-1	-2	-1	-1	-1	-1	-1
67706631	Y 124	2	2	3	3	2	2	3	3	2	3	3	3	3	2	4	3
11000100 0.0	Z 120	0	0	1	-1	1	-1	0	0	0	0	-1	0	0	0	0	0
113 15 10 31 156	X 62	-1	0	0	-1	0	-1	0	0	0	0	1	0	1	1	1	0
67706635	Y 171	3	3	3	4	3	3	3	4	3	3	3	2	3	3	3	2
11000100 0.0	Z 118	-1	0	0	0	0	0	0	1	0	0	0	-1	0	0	-1	0
113 15 10 32 436	X 94	2	1	1	1	2	1	2	1	2	2	2	2	2	2	2	3
67706641	Y 206	3	2	3	2	3	2	2	3	2	3	2	3	1	3	2	2
11000100 0.0	Z 120	0	0	-1	0	0	0	0	0	0	1	0	0	0	0	1	0
113 15 10 33 716	X 148	3	2	3	3	3	3	3	3	3	3	4	3	4	4	3	4
67706645	Y 218	2	2	1	2	2	1	2	1	2	0	0	1	0	0	0	0
11000100 0.0	Z 122	0	0	0	1	0	0	0	0	-1	0	0	0	0	0	1	0
113 15 10 34 996	X 199	3	4	4	4	4	4	4	3	4	3	4	2	3	3	3	3
67706651	Y 193	0	0	1	-2	-1	0	-1	-2	-1	-1	-2	-1	-2	-2	-2	-2
11000100 0.0	Z 125	0	1	0	1	1	0	0	1	0	0	0	1	0	-1	1	-1
113 15 10 36 276	X 217	2	3	2	2	2	2	1	2	0	2	1	1	1	1	1	0
67706655	Y 155	-2	-2	-2	-2	-2	-2	-3	-2	-2	-3	-2	-3	-2	-2	-2	-3
11000100 0.0	Z 113	1	-1	0	-1	0	-1	-1	-1	-1	0	-1	-1	0	-1	-1	-1
113 15 10 37 556	X 211	1	0	1	0	1	0	0	0	0	0	-1	0	0	-1	-1	-1
67706661	Y 107	-3	-2	-3	-2	-3	-3	-2	-4	-3	-2	-3	-3	-4	-2	-4	-3
11000100 0.0	Z 109	0	-1	-1	0	-1	0	-1	0	0	0	-1	0	-1	0	0	0
113 15 10 38 836	X 178	-1	-1	-1	-1	-2	-2	-2	-1	-2	-2	-2	-2	-2	-3	-2	-3
67706665	Y 69	-3	-3	-4	-3	-4	-3	-3	-3	-3	-3	-2	-2	-1	-3	-1	-2
11000100 0.0	Z 107	0	0	0	0	1	0	0	0	0	0	-1	-1	0	-1	0	0
113 15 10 40 116	X 134	-2	-3	-2	-2	-3	-2	-2	-3	-2	-3	-2	-3	-3	-3	-3	-3
67706671	Y 61	-1	-2	-2	-1	-2	-2	-1	-1	-1	0	0	0	-1	0	0	1
11000100 15.9	Z 101	0	0	0	0	0	0	-1	0	-1	-1	-1	-1	0	0	0	-1
113 15 10 41 396	X 73	-4	-2	-4	-3	-5	-4	-3	-4	-4	-3	-4	-4	-5	-4	-5	-3
67706675	Y 88	0	0	0	1	0	0	2	1	1	2	2	1	2	2	2	2
11000100 15.9	Z 137	0	0	0	2	1	2	2	1	2	1	2	3	3	3	3	3

38

Figure 19

contains sixteen telemetry sequences of data. The figures to the left of the X, Y, Z column contain time and housekeeping information and will be considered subsequently. The figures to the right are the staggered X, Y, and Z full word samples followed by sixteen columns of differences. Due to the involved sampling and telemetry readout procedure and the inherent complexity of the computer program to read out the data and check accumulated differences with full word samples, this print out example may appear congested. In order to show the reader how the differences relate to two consecutive full word samples the sheet has been marked up in pencil. If the X full word sample value of 192 is incremented by the differences beginning with 3 in frame 0 and concluding with 1 in frame 15 of the following X line, the answer (220) agrees with the subsequent X full word sample. Similarly the other X, Y, and Z full word samples and differences are ordered.

Figures 20 and 21 show the prelaunch calibration data and a plot of zero levels since launch. The figure indicates the zero levels have remained relatively stable and, for the most part, within the ±1 count precision of the telemetry system. This is also true of the in-flight calibration which has been checked periodically throughout the flight.

Engineering Data

Referring again to Figure 19, the reader may follow the discussion on the housekeeping data. The first group of numbers at the far left of the page is the universal time at which the data was taken. For example, the first sequence of data occurred at day 113, 15 hours, 10 minutes and 22.196 seconds. The next group of 8 digits is referred to as a "pseudo-sequence count", which is merely a cumulative record of telemetry sequences generated by the ground data processing system, and is presented in octal. Proceeding further to the right on the next line are 8 binary digits indicating the overall status of the experiment. The left-most bit we call the "Ready for Flip" flag. This bit is triggered by the positive edge of the "MAG C28" sync pulse referred to earlier. This bit position is a "one" for 10.9 minutes and then a "zero" for 10.9 minutes. It is only during the positive half of this pulse that the flipper heater may be on. The next two bits designate the position of the magnetometer sensor: 0° or 90°. In the example shown, the sensor is in the 90° position, which means that the sensor Z axis is parallel to the spin axis of the spacecraft. If this bit were a "zero" and the next bit a "one", the indication would be the other flipper position in which the sensor X axis would be parallel. The following bit position is the flipper heater flag. When this is a "one", the spacecraft 28 volt power is applied to the flipper. The next bit position is the in-flight calibration flag. As was described earlier, when this is a "one" (approximately every twelve hours), a bias field is applied to the magnetometer. The last three bits concern the magnetometer range. The first indicates whether range is being controlled

16 γ RANGE				48 γ RANGE				144 γ RANGE				432 γ RANGE			
Field γ	COUNTS			Field γ	COUNTS			Field γ	COUNTS			Field γ	COUNTS		
	X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z
16	255.0	255.0	255.0	48	255.0	255.0	255.0	144	255.0	255.0	255.0	432	255.0	255.0	255.0
15	255.0	255.0	255.0	45	255.0	255.0	255.0	135	255.0	254.8	255.0	405	255.0	255.0	254.0
12	237.1	240.1	242.1	36	231.8	233.8	233.3	108	230.6	229.8	230.8	324	230.0	230.0	230.0
6	185.9	188.1	190.0	18	181.9	182.8	182.3	54	180.2	180.9	180.1	162	180.0	180.0	180.0
0	136.5	137.3	137.7	0	131.9	132.0	131.7	0	130.3	130.9	130.0	0	130.0	130.0	130.0
- 6	85.1	87.5	85.7	-18	81.1	82.4	81.4	- 54	80.2	80.5	79.7	-162	80.0	80.0	79.0
-12	34.1	35.8	34.3	-36	31.4	32.0	31.2	-108	30.2	30.7	29.0	-324	30.0	30.0	29.0
-15	10.3	10.5	8.3	-45	6.2	6.5	5.7	-135	5.1	6.0	4.0	-405	5.0	5.4	4.0
-16	2.3	2.1	0.2	-48	0.0	0.0	0.0	-144	0.0	0.0	0.0	-432	0.0	0.0	0.0
IFC	41.0	41.5	42.9		14.1	14.2	14.6		44.1	44.4	44.5		15.0	14.7	15.0

Figure 20. Pre-Launch Calibration Data

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automatically or is fixed. In the example the "one" signifies the automatic mode. The final two bits show which of the four ranges the magnetometer is in. The two "zeros" designate the 16γ range. Two "ones" would be the 432γ range. Figure 22 is an example of range change from 48γ to 16γ .

The number just to the left of the X, Y, Z column in the "quick-look" samples is performance parameter number 43, which represents the flipper temperature and is read out during channel 4, frame 8, sequence 2, snapshot 3 of the telemetry format. In the examples it is at the bottom of the sheet: 15.9°C in Figure 19 and 15.1°C in Figure 22. Figure 23 shows a typical flipper actuation sequence and temperature profile.

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IMP-I HIGH BIT RATE DATA FROM JOBURG   ORBIT: 0127   72/05/27   GMT 148/02:30:23.017 QUAL FLAGS: 00000000000 (1=BAD) COMPUTER SYS 1
MAGNETOMETER-NESS BUS CUR 2.97 AMPS   PAGE 03   ALPHA ANGLE 92.75 DEGS   SATELLITE CLOCK 026:15:13.77 (066702) SYSTEM DATE MAY 24 72

```
148/02:30:23.017              X 154        1    2    3    3  -15    0    1    1    1    1    0    1    1    1    2    1
        33341301            Y    156        0   -1    0   -2  -15   -4   -1    0   -1   -1    0    0   -1    0    0    0
            01000101  0.0 Z        122      2    0   -3    0    8    1    0    0    0    0   -1    0   -1    0    0    0
148 02 30 24 297              X 164        0    2    0    2    1    1    2    0    2    0    0    0   -1    0    0    1
        33341305            Y    147       -1   -1   -1   -1    0   -1   -2   -2   -1   -2   -1    0    0   -1   -1   -1
            01000101  0.0 Z        120      0    0    0    1    0    0    0    1    0    0   -1   -1   -2    1    0    0
148 02 30 25 577              X 161        1    0    1    0    0    0    1    0   -1    0    0    0    0    0   -1    0
        33341311            Y    117       -2   -1    0   -2   -1   -1   -2   -1   -2   -1   -2   -1   -2   -1   -2   -1
            01000101  0.0 Z        123      0    0   -1    0    0    0    0    0    1   -1    1    0    0    0    1   -1
148 02 30 26 857              X 148       -1   -1    0   -1   -1   -1   -1   -1   -2   -1    0   -1    0    0   -1   -1
        33341315            Y    109       -1   -2   -1    0   -1   -1    0   -1    0    0    0   -1    0   -1    0   -2
            01000101  0.0 Z        118      1    0    1    1    0   -1    0   -1    0    0   -1    0   -1   -1    0   -1
148 02 30 28 137              X 132        0   -1   -1   -1   -1    0   -1   -1   -1   -1    0   -2   -1   -1   -2   -1
        33341321            Y    103        0   -1   -1    0   -1   -1   -1    0    0    0   -1    0    0    0    0   -1
            01000101  0.0 Z        115      0    0    0    0    0    0   -1    0    0    0   -1    0    0    0   -1    0
148 02 30 29 417              X 115       -1   -2    0   -2   -1    0   -2   -2   -1   -1   -1   -1   -1   -1    0   -1
        33341325            Y    112        0    0    1    0    1    0    1    1    0    1    1    0    1    1    0    0
            01000101  0.0 Z        122      0    0    0    1    1    0    0    0    1    0    1    0    0    1    0    0
148 02 30 30 697              X 105       -1   -1   -1    0   -1    0   -1    0   -1   -2   -1   -2   -1    0   -1    0
        33341331            Y    126        1    0    0    2    2    1    1    0   -1    0    1    1    0    1    1    1
            01000101  0.0 Z        123     -1    1    2    1    0   -1   -2    0    0    0    1    1    0    0    1    0
148 02 30 31 977              X  98        0   -1    1    0    0    0   -1    0    0    0   -1    0    0   -2   -1    0
        33341335            Y    148        1    1    2    2    1    2    0    1    1    1    1    1    1    3    1    1
            01000101  0.0 Z        119      1    1    0    0    1   -1   -1   -1    0    0    0    0    0    0   -1    0
148 02 30 33 257              X  80       -1   -1    0    0  -15   -3    2    5    3    3    3    4    4    3    3    3
        33341341            Y    226        2    2    2    1   15    7    4    2    3    2    2    2    0    2    1    4
            01000100  0.0 Z         83      1   -1   -1    0  -15   -3    0   -4   -2   -2   -3   -2    0    1    0    2
148 02 30 34 537              X 139        3    3    3    3    5    5    3    3    3    3    3    3    3    4    4    6
        33341345            Y    223        1    2    3    1    1    1    1    2    1    0    0    1    0   -2   -1   -3
            01000100  0.0 Z         83      2    0    0    0   -2   -1   -1   -1   -1   -1   -2   -1   -2    0    0    1
148 02 30 35 817              X 166        5    4    2    3    4    2    2    2    1    2    3    2    1    1    1    1
        33341351            Y    194       -3   -1   -1    1    0   -3   -3   -4   -3   -3   -2   -2   -2   -2   -2    0
            01000100  0.0 Z         96      1    2    3    1    0    0    0    1    2    4    2    1    1    1    1   -1
148 02 30 37 197              X 192        0    1    1    0    2    1    1    2    1    4    2    2    1    2    2    1
        33341355            Y    177       -1   -1   -2   -1   -1   -1   -1    0    0   -2    0   -2   -1   -1   -1   -2
            01000100  0.0 Z        106      0    0    0    0    1    0   -1    1    1    0    1    1    1    1    0    2
148 02 30 38 377              X 209        2    1    2    2    3    2    1    3    1    2    1    1    0    0    0    1
        33341361            Y    129       -1   -2   -1   -2   -3   -2   -3   -5   -2   -3   -4   -3   -4   -2   -3   -4
            01000100  0.0 Z         98      1    0    1    1    1    0    0    0    0    0   -1   -1    0   -1   -1   -1
148 02 30 39 657              X 159        0    0    0   -1    0    2    2    0    1   -1   -3   -3   -2   -3   -3   -2
        33341365            Y     86       -2   -3   -3   -3   -2   -4   -3   -2   -2   -4   -3   -4   -2   -2   -3   -1
            01000100  0.0 Z         99     -1   -2    0    0    0    0   -1   -2   -2    0    1    0    1    0    1    0
148 02 30 40 937              X 112       -3   -2   -2   -3   -3   -3   -3   -3   -5   -6   -3   -4   -4   -4   -5   -5
        33341371            Y     42       -2   -3   -4   -4   -2   -2   -2   -2   -2   -3   -5   -7   -6   -8    1    0
            01000100  15.1 Z       104      2    1    0   -2    0    1    0    1    0   -2   -3   -4   -6    4    6    2
148 02 30 42 217              X  73       -3  -10   -2   -6   -5   -5   -5   -4   -4   -1   -2   -2   -2   -1   -3   -2
        33341375            Y     83        1   -1   -2   -1    0    1    2    4    6    6    4    2    2    4    0    4
            01000100  15.1 Z       112      4   -3    1    0    0   -1    0   -2   -1   -1   -1   -2    0    0    1    2
```
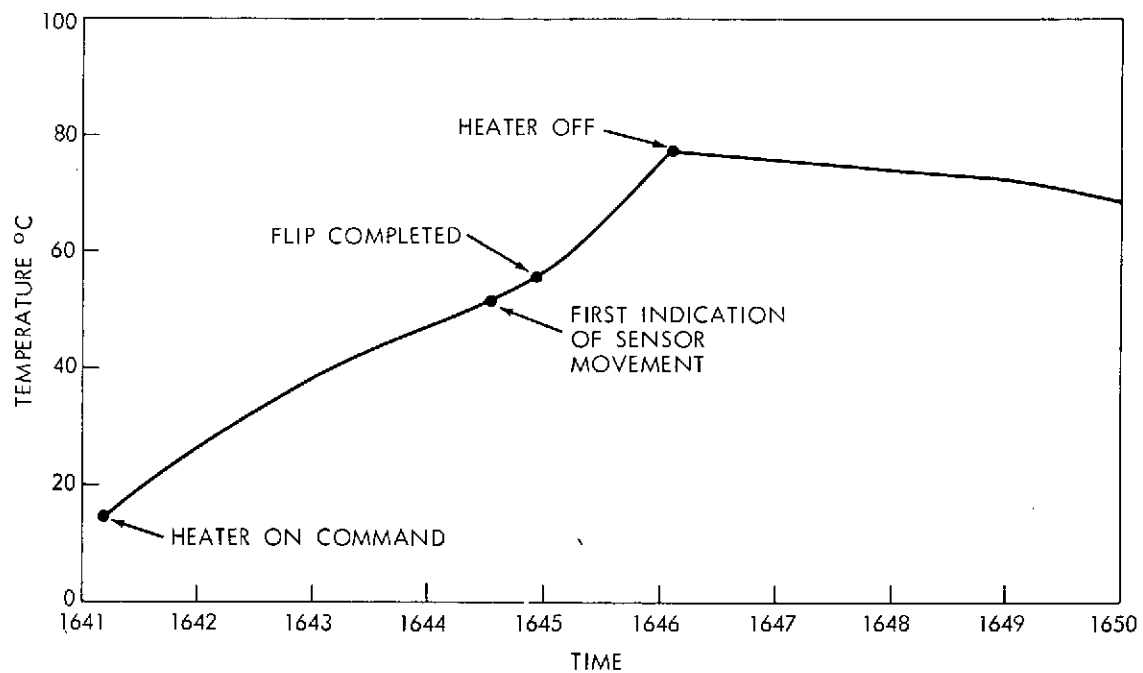
Figure 22

Figure 23. Explorer 43 Flipper Operation, Orbit 199, June 15, 1973

REFERENCES

1. Harris, C. A., IMP-I Spacecraft Final Magnetic Tests, GSFC X-325-72-183, February 1972.

2. McCarthy, D. K., Nonmagnetic, Lightweight Oscillating Actuator, NASA X-723-70-166, April 1970.

3. Schonstedt, E. O., U.S. Patent 2,981,885, Saturable Measurements Device and Core Therefore, April 1961.

4. White, H. D. and Lokerson, D. C., IMP-I (EYE) Encoding System Interface Document, February 1970.