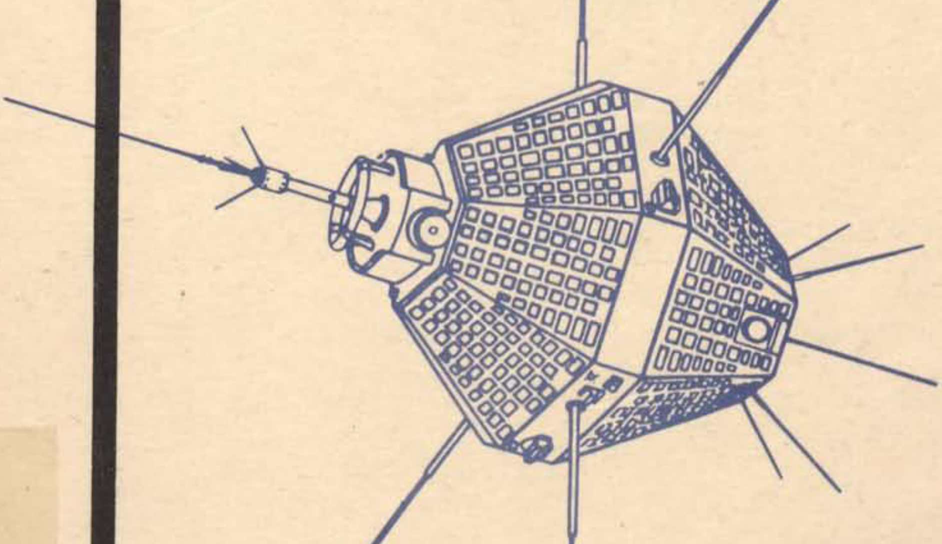
Communications Research Centre

ISIS-II SPACECRAFT



by

F. Daniels

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F. Daniels

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ABSTRACT

The ISIS-II spacecraft is the most complex of a series of four satellites designed and built in Canada for the study of the earth's ionosphere. It contains all of the experiments of each of its predecessors, Alouette I, Alouette II, and ISIS-I, plus two new experiments. This report describes the ISIS-II spacecraft systems which support the experiments, and provides a general description of each experiment.

1. INTRODUCTION

Under a joint programme arranged originally between the USA's National Aeronautics and Space Administration (NASA) and Canada's Defence Research Board (DRB), Canada agreed to design and construct a number of spacecraft for scientific studies of the earth's ionosphere. The programme developed out of the successful operation of Canada's first satellite, Alouette I, and was based upon, but not limited to, an exploitation of the topside sounder technique developed for Alouette I. With the formation of the Department of Communications in 1969, the agreement was transferred, along with the Communications Research Centre[1] (CRC) to the new Department.

The Alouette I satellite was launched by NASA in 1962 and continues to transmit useful data after eight years in orbit. Alouette II was launched in November 1965, followed by ISIS-I in January 1969. In each case, the spacecraft was launched by NASA from the Western Test Range, California; Thor Agena vehicles were used for Alouettes I and II, and a Thor Delta for ISIS-I. It is expected that ISIS-II[2] will be launched early in 1971 from the California range, using a Thor Delta vehicle.

The mission objectives for each of the spacecraft in this programme include a requirement for a minimum operational lifetime of one year.

As each spacecraft is more complex than its predecessor, an increasing level of engineering effort was required to carry out the programme. This was obtained through increased participation in the programme by Canadian industry. In fact, ISIS-I and ISIS-II were built almost entirely by industry. The electronic systems and spacecraft ground support equipment for these satellites were assembled, under contract, by RCA Victor Ltd., Montreal; SPAR Aerospace Ltd., Toronto, provided the mechanical structure and the extendible sounder antennas. The Communications Research Centre retained responsibilities as the design authority and for the programme management.

1 Until 1 July 1969, the Defence Research Telecommunications Establishment (DRTE), of DRB.

2 Before launch the ISIS-II spacecraft was known as ISIS-B.

The five major systems described in the report are:

- mechanical,
- power,
- command,
- telemetry,
- attitude sensing and control.

A description is also given of each of the twelve experiments.

2. SUMMARY OF ISIS-II SPACECRAFT CHARACTERISTICS

2.1 DESCRIPTION OF SPACECRAFT

SPACECRAFT SIZE

Shape	approximates an oblate spheroid (Fig. 1)
Height	47 inches
Diameter	50 inches
Weight	575 lbs.

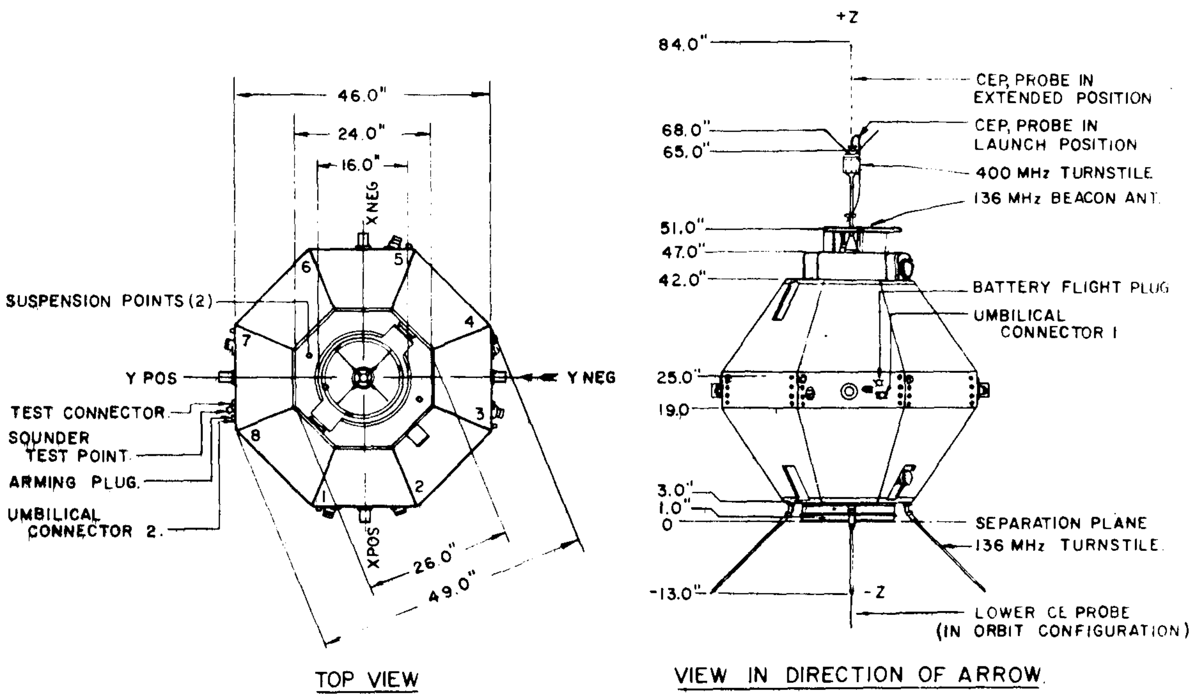


Fig. 1. ISIS-II Spacecraft Outline.

ORBIT

1400 km circular
Inclination 88.7° prograde

STABILIZATION

Spin stabilized

ATTITUDE SENSING

Six-probe flux-gate magnetometer	Four probes, range -600 to +600 millioersteds, an x-y-z orthogonal set, and a fourth probe the S probe along the spacecraft x direction. Two probes, range -200 to +200 millioersteds along spacecraft x and z directions. (Fig. 8)
Digital solar aspect sensor	Two sensors, each with 180° fan field of view; electronic storage register.

SPIN AND ATTITUDE CONTROL SYSTEM

The system capability is designed to be as follows:

(1) Spin axis in the orbit plane:

- Spin change capability of 0.10 to 0.12 rpm/orbit.
- Attitude control (precession) capability of 2.0° to 2.5° per orbit at a spin rate of 3 rpm.

(2) Spin axis in cartwheel configuration:

- Spin change capability of 0.15 rpm per orbit averaged over one day of operation.
- Precession capability of 0.5° per orbit at a spin rate of 3 rpm averaged over one day of operation.

POWER SYSTEM

Solar cells	11,008 n-on-p 10 1/4 per cent calculated for air mass zero (A.M.O.) efficiency
Batteries	3 Ni-Cd
Converters	Five main system dc to dc
Operational time after 1 year	Minimum of 4 hours per day in 70 per cent sun condition
Continuous operation	Two consecutive pole-to-pole passes

COMMAND SYSTEM

Command

Multiple tone-digital AM system

Command receivers	Two, operating at 148 MHz, and connected for redundancy
Decoder capability	216 commands

Programmer and Clock

Remote turn-ON	by means of stored commands
Capacity	5 remote turn-ON from 10 commands
Loading time	5 minutes
Programmer monitoring facility	readout time 3 secs.
Clock output	serial time code BCD format, 60 bps, once per second
Stability and accuracy	1 sec per week, adjustment from the ground provided by command.

Automatic Turn-OFF

Normal turn-OFF	after 16 mins.
Special turn-OFF	after 8 or 24 mins.
Programmed turn-OFF	after 16 mins.
Backup	after 30 mins, unconditionally (subject to revision)
Spin and attitude control	3^{+1}_{-0} and 11^{+1}_{-0} hours, selectable by command.

Tape Recorder

Record time	64 mins.
Playback	4 times record speed
Data channels	4

TELEMETRY SYSTEM

Transmitter No. 1

Frequency	136.080 MHz, bandwidth 100 kHz
Power	4 watts
Modulation FM	Sounder VLF
FM/PAM/PDM	Essential housekeeping time multiplexed with spacecraft time code on 30 kHz SCO
FM/PCM	Auroral scanning photometer data on 30 kHz SCO

Transmitter No. 2

Frequency	136.59 MHz, bandwidth 50 kHz
Power	2 watts
Modulation PCM/PM	Experimental data and housekeeping

Transmitter No. 3

Frequency	401.75 MHz: bandwidth 500 kHz on tape recorder replay 300 kHz real time
Power	4 watts
Modulation (direct modes)	
FM	VLF (M1 mode) or Sounder/VLF (M2 mode)
FM/FM	CEP on 30 kHz SCO
PCM/FM/FM	PCM on 93 kHz SCO
Modulation (recorder replay modes)	
FM	Sounder or VLF
AM/PM	Spacecraft time code 240 bps/46.08 kHz clock
FM/PM	PCM data or VLF on 93 kHz SCO

Tracking Beacon

Frequency	136.410 MHz
Power	100 mW
Unmodulated	

Biphenyl Devices

The release of the upper CEP probe and the four shutters of the optical experiments is controlled by means of biphenyl devices, a material which sublimates in vacuum. The shutters open after release in the manner indicated in Figure 3.

Antennas Bias

A dc bias can be applied to the sounder antennas by command.

EQUIPMENT LIST

The unit codes and equipment lists are shown on page 7. A simplified block diagram of the spacecraft is shown in Figure 2.

2.2 EXPERIMENTS

Swept Frequency Sounder (L.E. Petrie and G.E.K. Lockwood)

Power Output	400 W at PRF 45 pps.
Antennas – two crossed dipoles	240′ and 61.5′ tip-to-tip (when fully extended)
*Flyback duration	3.3 secs

(a) Frequency Range (Swept)

Normal Sweep 0.1 to 10 MHz.

Frequency Range	Sweep Rate
0.1 to 2.0 MHz	0.375 MHz/s
2.0 to 5.0 MHz	1.125 MHz/s
5.0 to 10.0 MHz	1.500 MHz/s

Total Sweep Duration – 10.0 seconds (nominal)

Extended Sweep 0.1 to 20 MHz.

Frequency Range	Sweep Rate
0.1 to 2.0 MHz	0.375 MHz/s
2.0 to 5.0 MHz	1.125 MHz/s
5.0 to 20.0 MHz	1.500 MHz/s

Total Sweep Duration – 20.0 seconds (nominal)

(b) Frequency Markers

0.1, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0 MHz.

Frequency resolution between markers is $\pm$8kHz.

* The one fixed frequency period at initial turn-ON will be 7 seconds (nominal) if in the NORMAL sounder sweep mode.

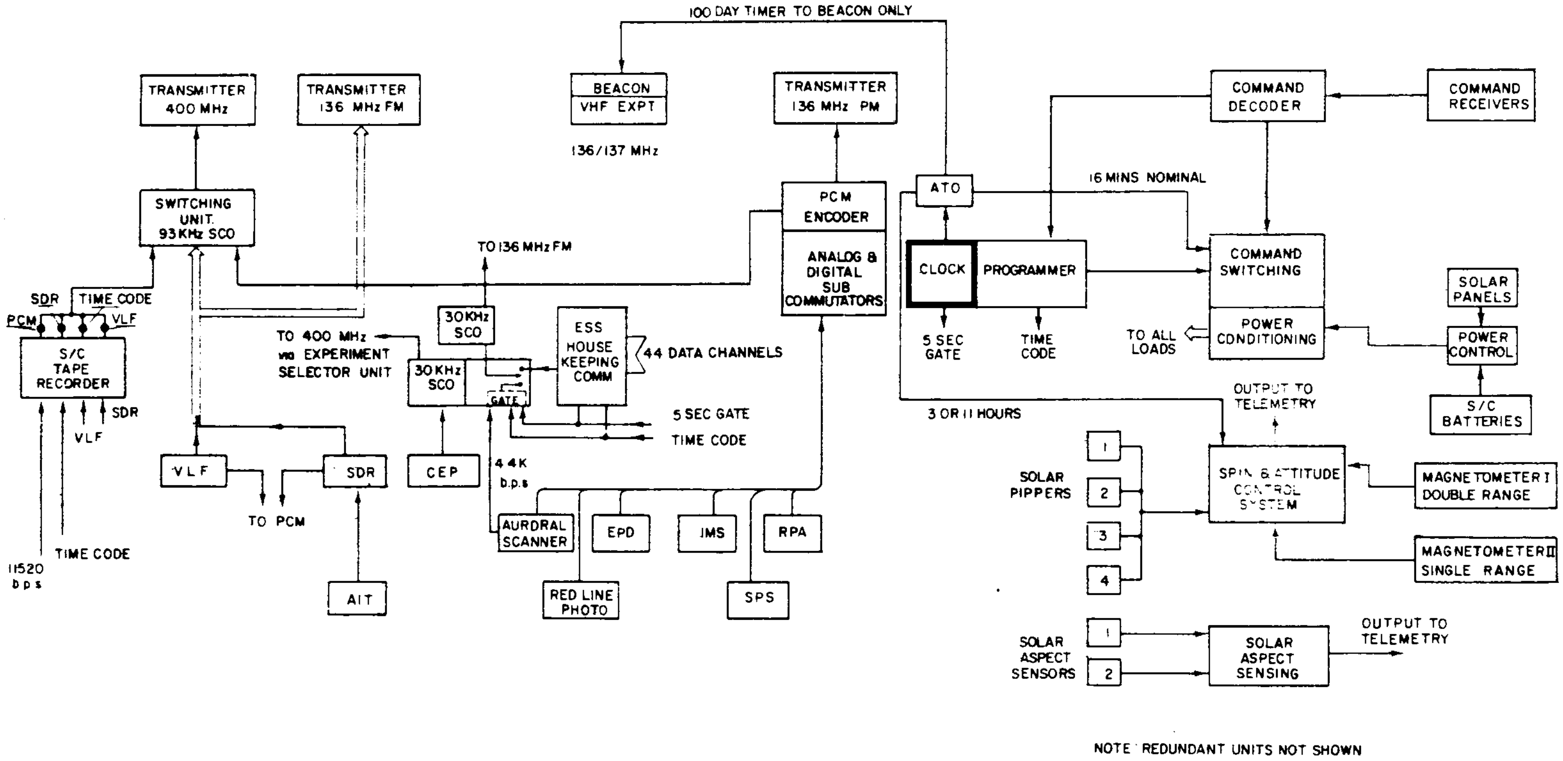


Fig. 2. Simplified Spacecraft Block Diagram.

LIST OF EQUIPMENT

SOUNDER SYSTEM

AA1	Power Amp 400W
AA2	Power Amp 400W
AC	Ant. Interface Unit
AD	RCVR Input Unit
AE	Sdr. Rcvr.
AF	R.F. Generator
AG	Freq. Calibrator
AH	Sounder Control Unit
AJ1	Sdr. Antenna (Long pole)
AJ2	Sdr. Antenna (Long pole)
AK1	Sdr. Antenna (Short pole)
AK2	Sdr. Antenna (Short pole)
AM	Amplitude Calibrator
AN	Sdr. Ant. Ion Guard
AP	VLF Exctr. Driver
AQ	A.I.T. Control Unit

TELEMETRY SYSTEM

BA	FM Transmitter (136 MHz)
BB	PM Transmitter (136 MHz)
BC	T/M Diplexer
BD	T/M & Command Antenna
BE	T/M & Command Duplexer
BF	T/M & Command RF Harness
BG	T/M Transmitter (400 MHz)
BJ	TF Harness (400 MHz)
BK	Tracking Beacon Tx.
BM	Beacon Diplexer
BN	Beacon RF Harness
BP1	PCM Encoder
BP2	PCM Encoder
BR	Essen. Kskpg. Commutator
BS1	Analog Sub-commutator
BS2	Analog Sub-commutator
BU1	Digital Sub-commutator
BU2	Digital Sub-commutator
BT1	148 MHz Notch Filter
BT2	148 MHz Notch Filter
BW	Tape Recorder

TELEMETRY SYSTEM (Cont'd)

BZ	400 MHz Antenna
BV1	30 kHz SCO (to 136 MHz)
BV2	30 kHz SCO (to 400 MHz)
BV3	93 kHz SCO (to 400 MHz)
BP	NRZ Converter

COMMAND SYSTEM UNITS

CA1	Command Receiver
CA2	Command Receiver
CB	Command Decoder
CC	Main Clock & Programmer
CF	Back-up Clock & Programmer
CD	A.T.O. Unit
CE	Switching Unit

POWER SYSTEM

DA/DB	Solar Panel Assy Type A & B
DC	Converter No. 1
DD	Converter No. 2
DE	Converter No. 3
DF	Converter No. 4
DJ	Expts. Limiter Assy.
DK	Battery Current Sensor
DL	Battery Assembly
DM	Power Control Unit
DN	Wiring Harness
DP	Tape Recorder Limiter
DQ	Unit Current Sensor
DS	Optical Experiments Limiter

EXPERIMENTS

EA	VLF Receiver
EB	Aurora Scanner
EC	Red-Line Photmtr
ED	Ion Mass Spectrometer
EE	Retarding Potential Analyzer
EG	VHF Beacon
EH	S.P.S. Detector
ET	S.P.S. Electronics

EXPERIMENTS (Cont'd)

EJ	Cyl. E/S Probe & Fltr. (Btm.)
EK	Cyl. E/S Probe & Filtr. (Top)
ER	C.E.P. Electronics
EL	Energetic Particle Detector
EV	E.D.P. Encoder

SPIN & ATTITUDE CONTROL UNITS

JB	Torquing Coils Assembly
JC	Converter No. 6
JD	Spin & Att. Control Unit
JE1	Solar Pippers
JE2	Solar Pippers
JE3	Solar Pippers
JE4	Solar Pippers
JF	Mag. Sensors Single Range
JG	Mag. Sensors Double Range
JH	Magnetometer Electronics
JJ1	Solar Aspect Sensor
JJ2	Solar Aspect Sensor
JK	S/A Sensor Electronics

SPACECRAFT MECHANICAL UNITS

SA	Basic Structural Assy.
SB	Equatorial Zone Hardware
SC	Thermal Insulation
SD	Segment Brackets & Deck
SE	Separation Plane Panel
SF	Masking Shrouds
SG	Shock Mounts
SH	Heat Shields
SJ	RFI Shields
SK	Mag. Deck & Rd Line Photmtr. Inst.
SM	Aurora Scanner Deck
SN	Indicator Post Set

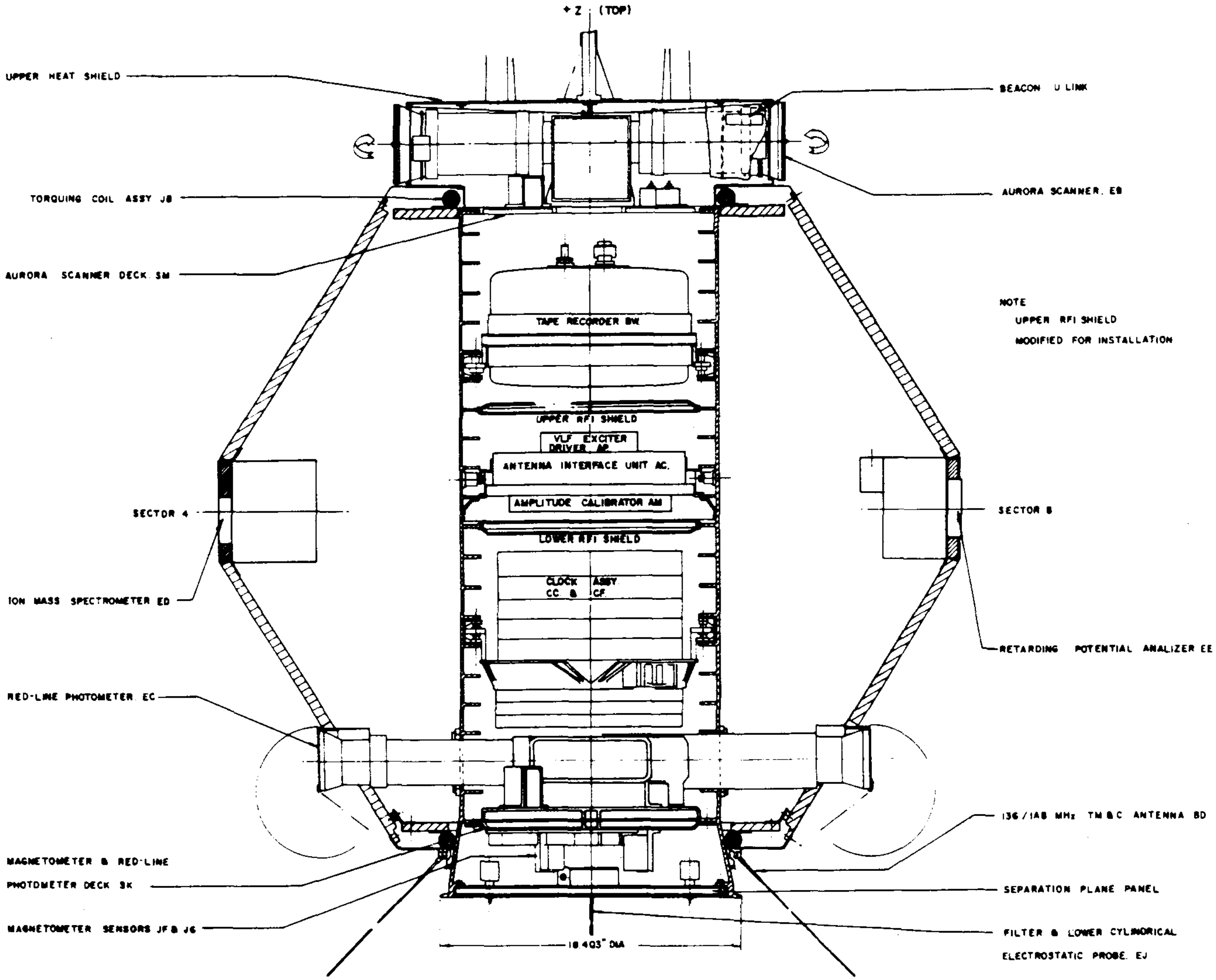


Fig. 3. ISIS-II Spacecraft Thrust Tube and Optics.

(c) Range Marker

11.11 msec after zero range mark.

Fixed Frequency Sounder (L.E. Petrie and G.E.K. Lockwood)

The fixed frequencies, which are available for selection by command, are: 0.12, 0.48, 1.0, 1.95, 4.0 and 9.303 MHz. A fixed frequency OFF command is also available.

Fixed frequency sounding occurs during the flyback period of the Sounder Sweep (Fig. 27), or ON command (Mode G) for a full sounder frame period on alternate frames.

The same receiver and transmitter system are used for both swept and fixed frequency soundings.

Sounder Operating Modes

(i) Swept Frequency Mode – a quasi logarithmic sweep from 0.1 MHz to either 10 (normal) or 20 MHz (extended) followed by a transmission, of 3.3 seconds duration, at any one of the selectable fixed frequencies.

(ii) D Mode – transmitter ON/OFF for alternate frame pairs operating at frequencies as in (i) above.

(iii) G Mode – transmission of alternate frames of swept and fixed frequencies, as selected in (i) above.

(iv) Mixed Mode – transmission of one of the six fixed frequencies during flyback and while the sounder receiver is sweeping.

(v) Alternate VLF/Sounder Mode – the VLF only can be selected to replace the fixed frequency sounding.

(vi) AIT Mode – allows for the automatic operation of the sounder system once every 3 minutes in either swept frequency mode or mixed mode.

NOTE: The significant modifications to the ISIS-I sounder for use in ISIS-II are as follows:

(a) Mixed mode
(b) VLF/Sounder mode
(c) AIT mode
(d) Substitution of 400W PA for 100W PA
(e) Line frequency PRF
(f) Video format (5 calibrate levels)
(g) Gating
(h) Cosmic Noise AGC
(i) Voltage ramp generation
(j) Range marker.

Sounder Receiver Characteristics

Seven bands	(a)	0.1 – 1.0 MHz
	(b)	1.0 – 2.0 MHz
	(c)	2.0 – 3.0 MHz
	(d)	3.0 – 5.0 MHz
	(e)	5.0 – 8.0 MHz
	(f)	8.0 – 13.0 MHz
	(g)	13.0 – 20.0 MHz

Back-up preamp and filter, wideband 0.1 – 20.0 MHz.
Linear-logarithm receiver with an AGC loop having an attack time of 60 mS and decay time of 12 mS (0–90 per cent).

VLF Experiment (R.E. Barrington)

(a)	VLF Receiver (Sounder long dipole or torquing coil antenna).	0.20 – 28 kHz (3dB points)
	Monitored AGC voltage, attack time	at 1 volt 0.5 sec ± 10 per cent at 4 volts 2.5 sec ± 10 per cent
	decay time	at 1 volt 0.125 sec ± 10 per cent at 4 volts 0.320 sec ± 10 per cent
(b)	VLF Swept Frequency Exciter (Sounder short dipole antenna).	Range 15,000 – 50 Hz exponential Sweeps 1 sec duration Output level fixed Dwell 3.5 secs
(c)	VLF Impedance Measurement (sounder short dipole antenna measurement).	Measure phase amplitude and current. Exponential sweep duration 10 secs. Three levels 0–20–40 dB Selectable by command Retrace: 1 sec maximum

Energetic Particle Detectors (I.B. McDiarmid, J.R. Burrows)

Measurement of intensity, angular distributions and energy spectra of electrons and protons.

Soft Particle Spectrometer (W.J. Heikkila)

Electrons 10 – 10,000 eV.

Ion Mass Spectrometer (J. Hoffman)

Direct measurement of positive ion density mass numbers. 1— 64 amu.

Cylindrical Electrostatic Probe (Langmuir Probe) (L. Brace, J. Findlay)

Direct measurement of electron density and electron temperatures using two Langmuir probes at opposite ends of the spacecraft.

Retarding Potential Analyzer (J. Donley, E. Maier)

Direct measurement of electron temperature, ion temperature, ion composition, and charged particle density by retarding potential analyzer.

Beacon (P.A. Forsyth, G.F. Lyon)

136.410 MHz, 137.950 MHz, 100 mW beacons.

Cosmic Noise (T. Hartz)

From AGC of sounder receiver 0.1 to 16 MHz. Monitors background radio noise levels due to galactic, solar, and ionospheric sources.

Atomic Oxygen Red Line Photometer (E. Shepherd)

Designed to map the global distribution in the intensity of the 6300 Å emission from the atomic oxygen 0 (^{1}D).

Auroral Scanner (C. Anger)

Designed to map the distribution of auroral emissions at 5577Å and 3914Å over the portion of the dark earth visible to the spacecraft.

3. MECHANICAL SYSTEM

The mechanical system performs three primary functions:

(a) provides a structure to house the payload,

(b) provides an acceptable thermal environment for the internal payload,

(c) provides the spacecraft dynamics required for the ISIS-II mission.

The basic structure consists of a central thrust tube, eight equatorial panels, and various miscellaneous attachments. (Figures 3 to 8). This structure has been designed so that the stresses will be less than 1/2 the yield strength of the material when the spacecraft is subjected to qualification testing.

The fully assembled structure has a shape that can be generally described as an oblate spheroid with a diameter of 50 inches and a height of 47 inches. The 136 MHz telemetry, 136 MHz beacon and 400 MHz telemetry antennas extend beyond the 47 inch dimension by 21 inches at the top and 13 inches at the bottom making a total launch configuration height of 81 inches. The weight of the structure including the miscellaneous attachments is 104 lbs.

The thermal control is passive, and is designed to maintain the temperature of the internal payload mounting interface within a range of −8° to +40° C. Orbital temperatures of the spacecraft will be monitored by 15 thermistors (Fig. 11) and the data telemetered to the ground.

(a) The spacecraft spins about the longitudinal axis of the thrust tube at a rate of 1 to 3 rpm in the orbital configuration with the sounder antennas extended 240 ft. and 61.5 ft. tip-to-tip, respectively.

(b) The estimated moments of inertia about the centre of gravity for the ISIS-II spacecraft in the launch configuration, i.e., before the sounder antenna extension, are as follows:

Spacecraft Axis	M of I Slug Ft.^{2}
XX	24.08
YY	24.38
ZZ	25.15

(c) The ratio of the moments of inertia about the spin axis (ZZ) to the other axes (XX,YY) is designed to be not less than 1.03 in the orbital configuration and not less than 1.05 in the launch configuration.

Four views of the spacecraft structure are shown in Figures 3 to 6.

The layout of the electronic equipment is shown in Figures 5 and 7. The solar panel geometry is illustrated in Figure 9 and the spacecraft separation plane and magnetometer layout in Figure 8.

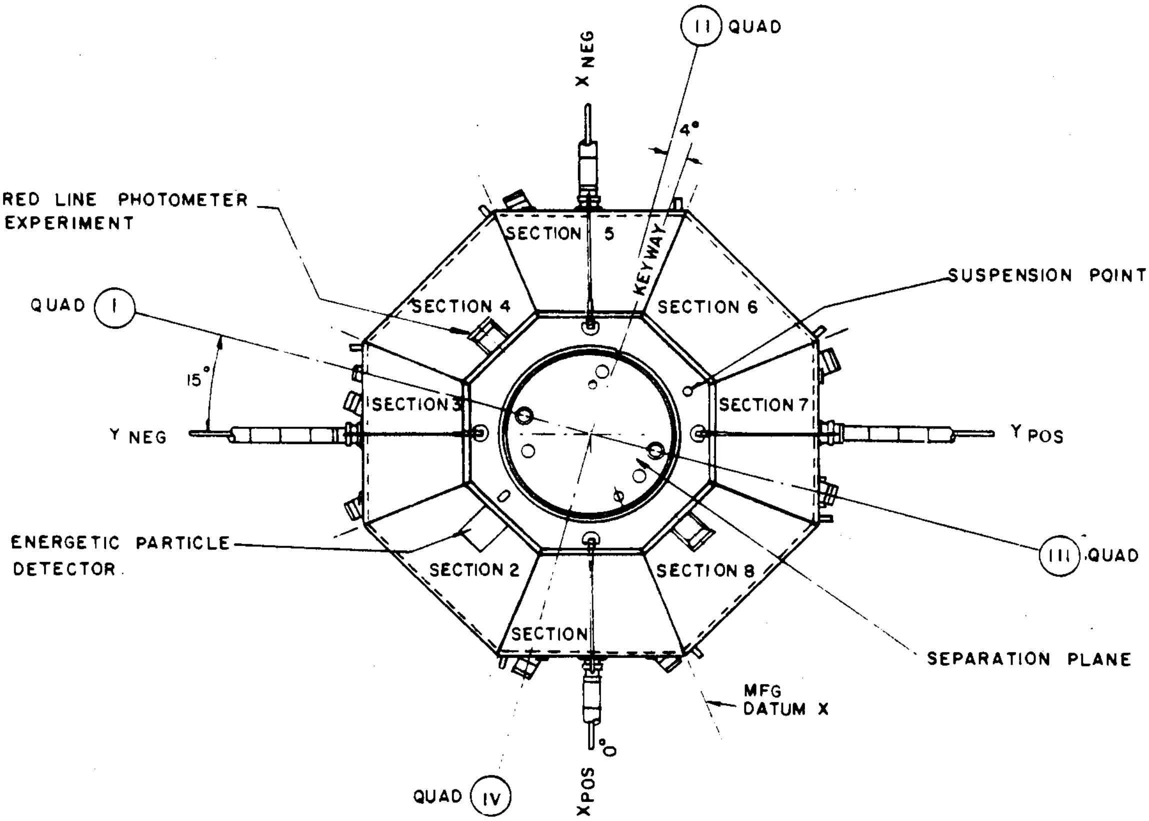


Fig. 4. ISIS-II Spacecraft Bottom View.

The Improved Delta Vehicle, Model No. DSV-3E manufactured by McDonnell Douglas Astronautics Company (MDAC), was approved for the ISIS-II mission. This vehicle, illustrated in Figure 12, is made up of the following stages:

1st Stage; Thrust Augmented Delta (Delta with 3 TX33-52 Motors)

2nd Stage; AJ10-118E

3rd Stage; FW4D.

For further details of the DSV-3E vehicle, refer to the MDAC report number 61687, dated October 1968.

The improved Delta Separation schematic and Preliminary ISIS-II Trajectory Sequence is shown in Figure 10.

The configuration of the spacecraft within the shroud is shown in Figure 13.

ENVIRONMENTAL TESTING

The completed spacecraft was subjected to a number of environmental tests including: vibration, shock, magnetics and thermal vacuum, (+47° C and −20° C at $p \leq 10^{-5}$ Torr). These tests were carried out at the Goddard Space Flight Center, Maryland, over a period of some four months.

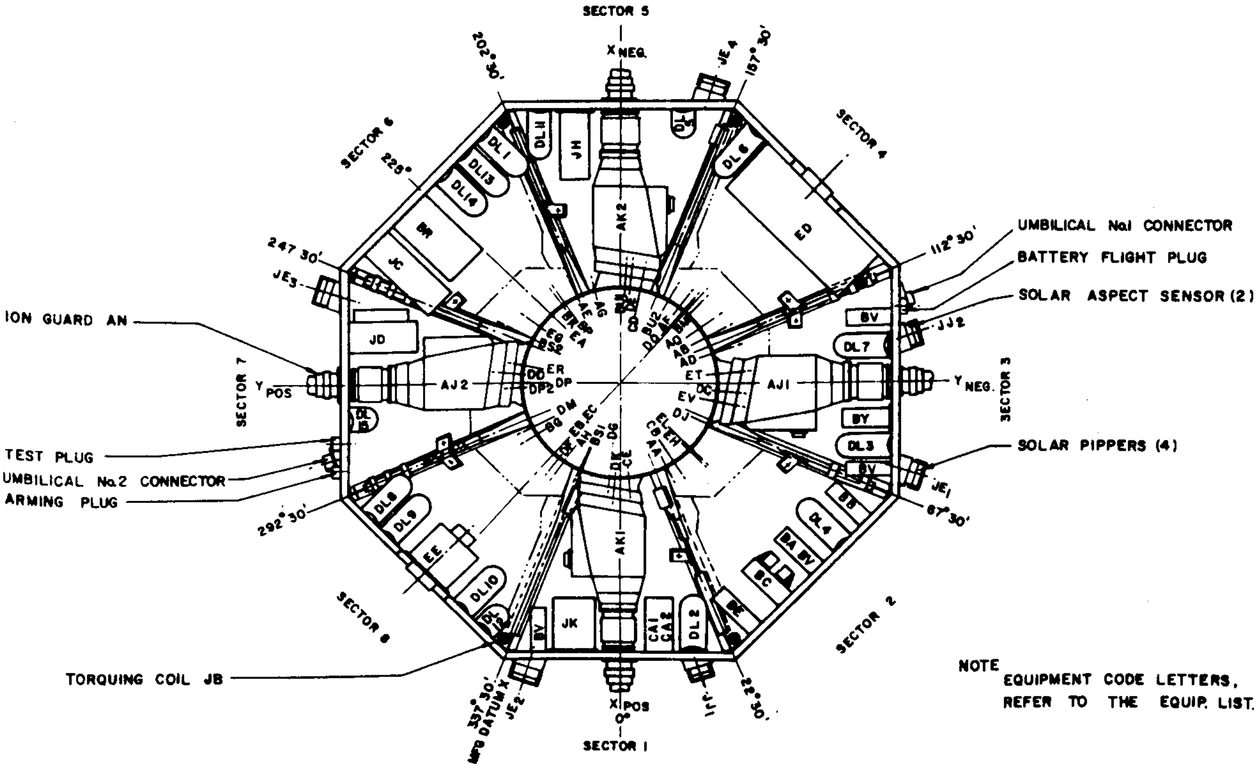


Fig. 5. ISIS-II Spacecraft Interior Equatorial Section.

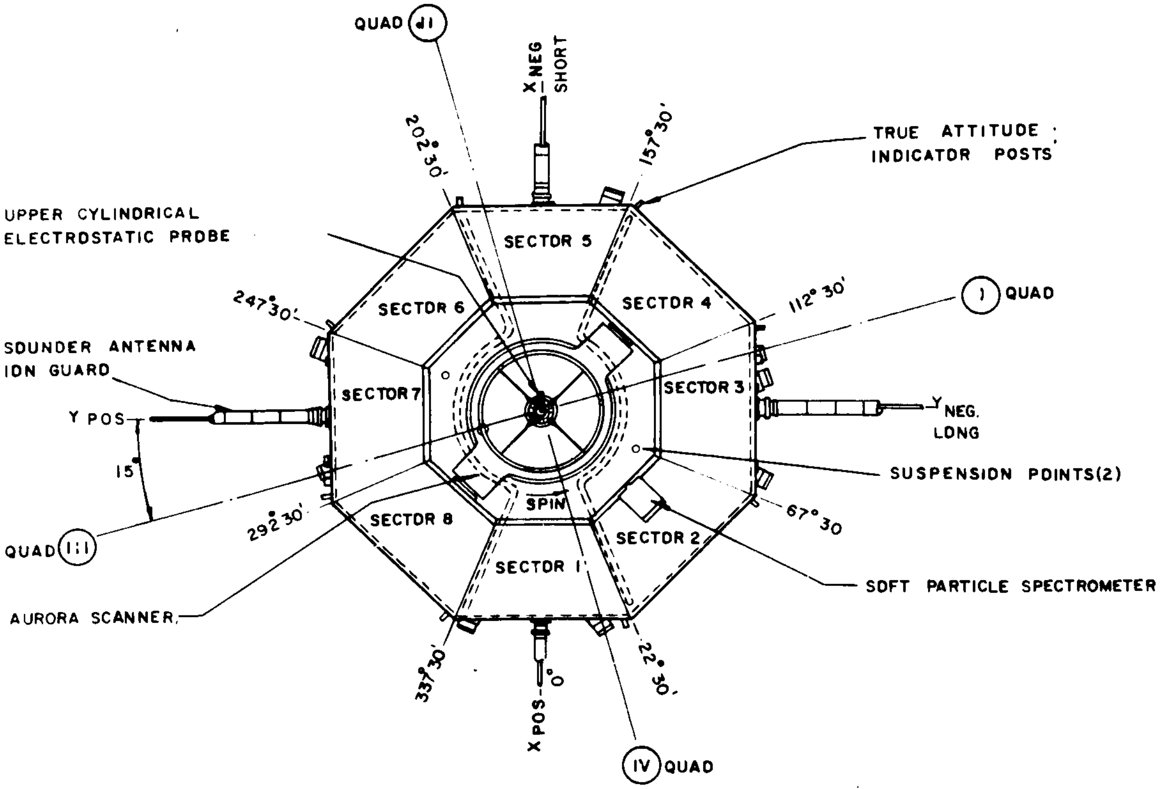


Fig. 6. ISIS-II Spacecraft Top View.

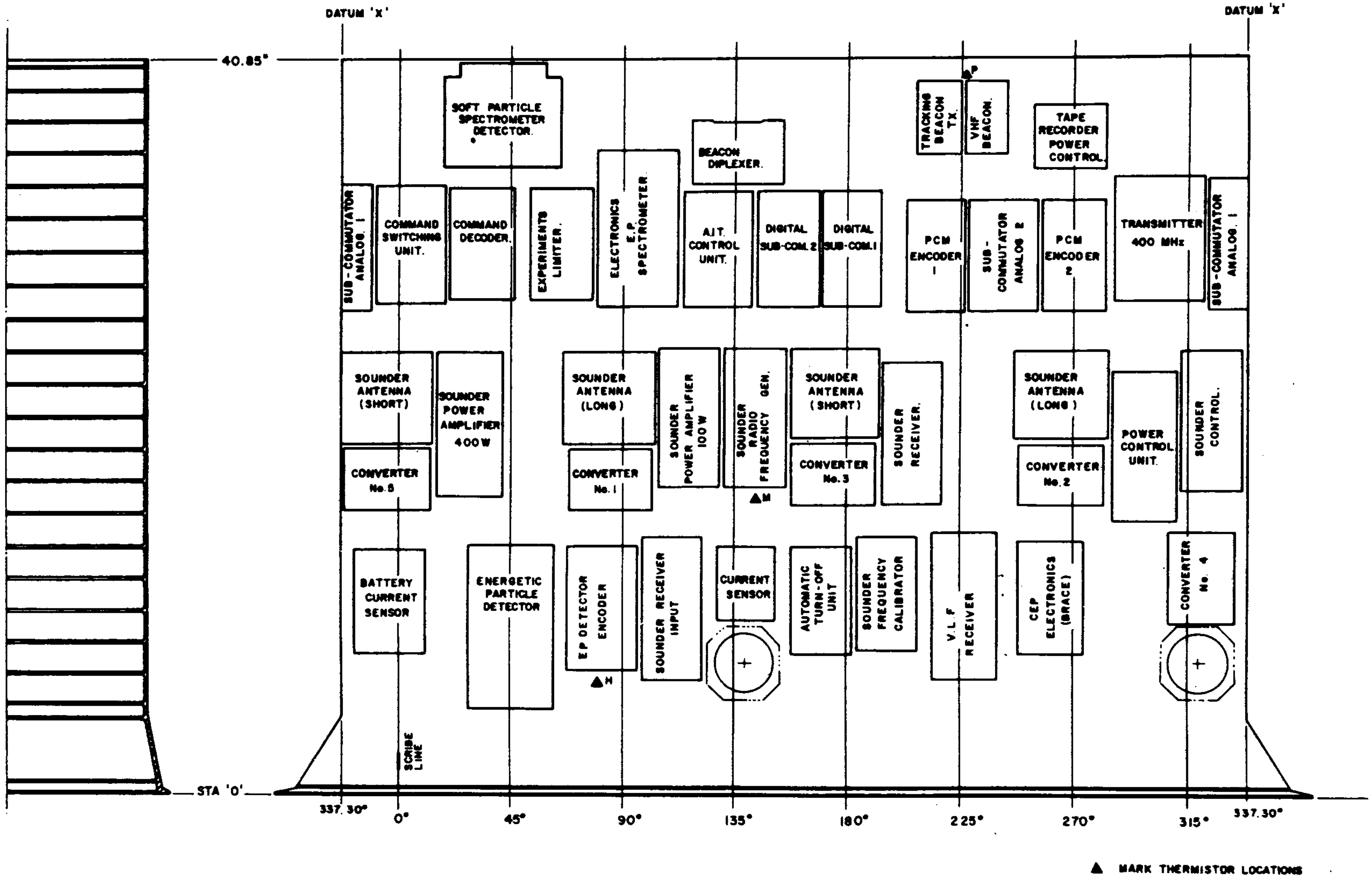


Fig. 7. ISIS-II Spacecraft Thrust Tube Layout.

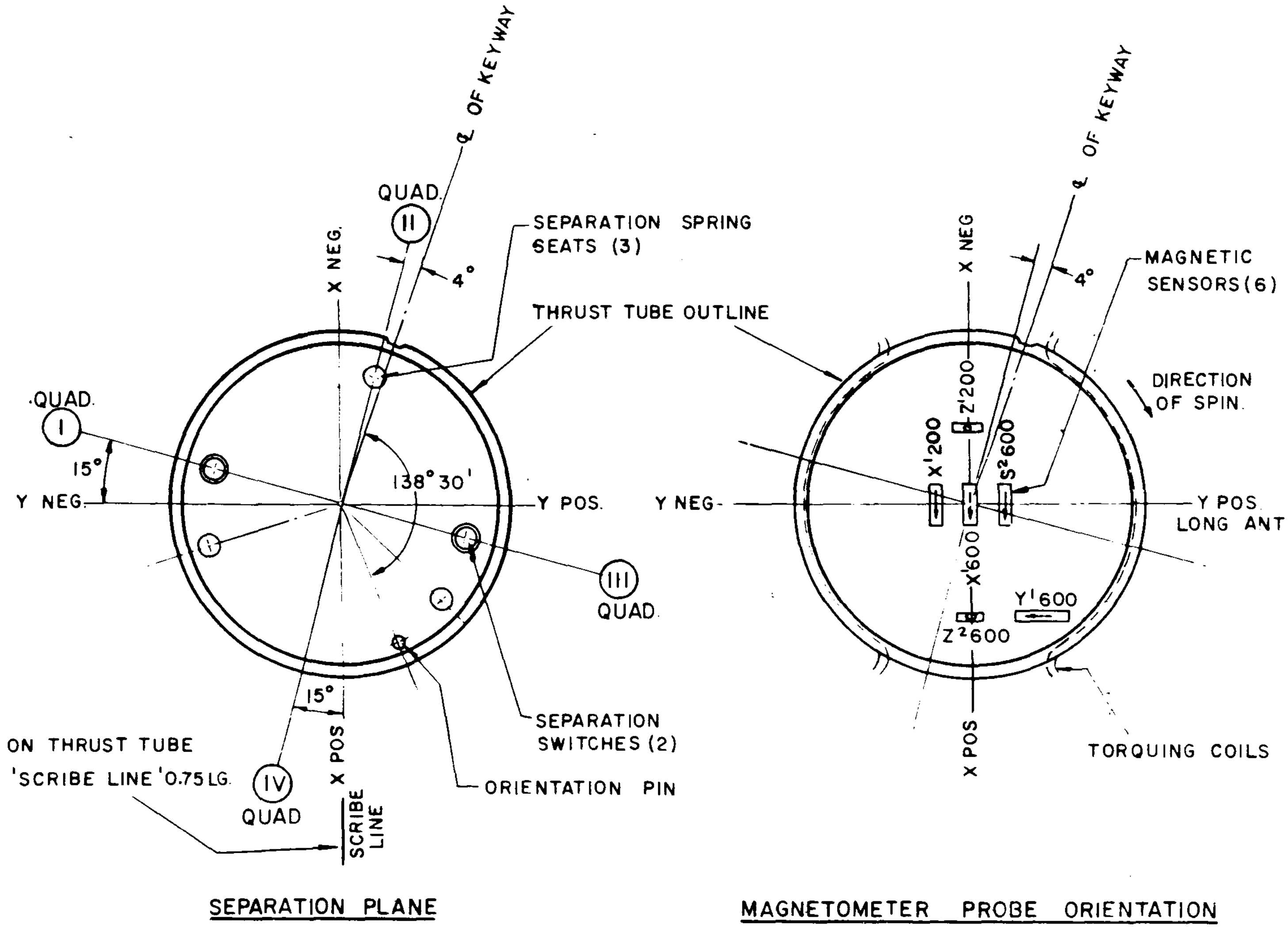


Fig. 8. ISIS-II Spacecraft Magnetometer Layout and Separation Plane (View from Bottom).

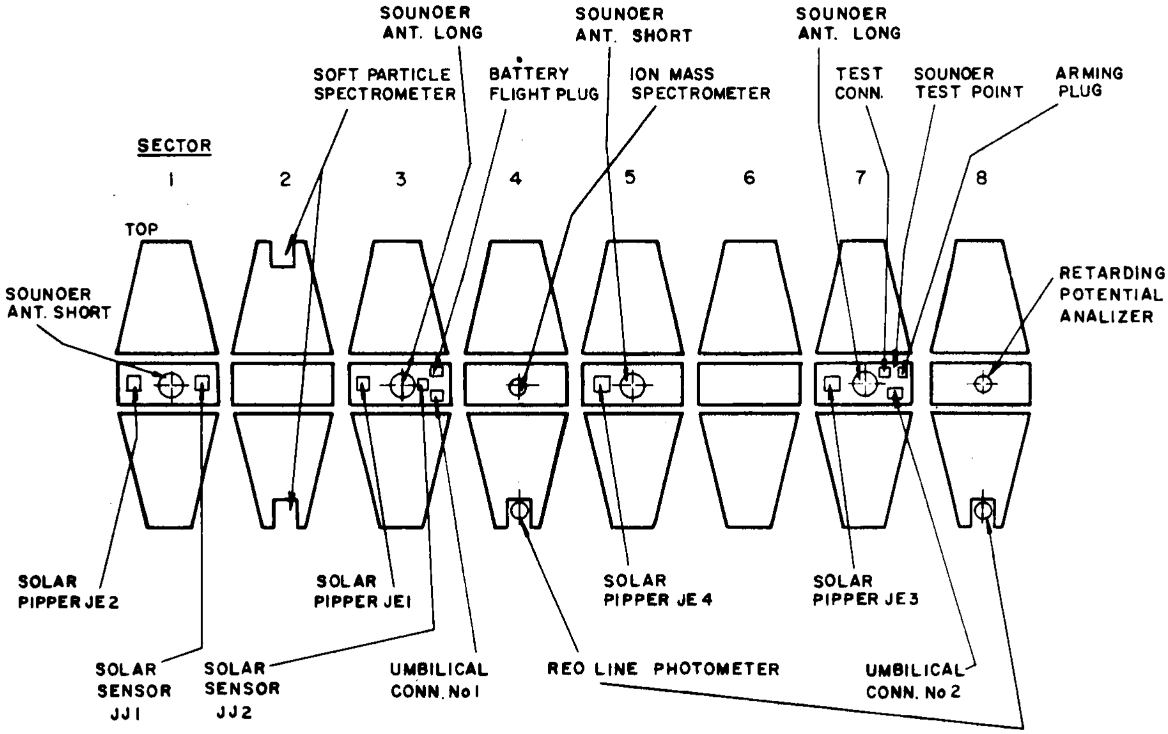


Fig. 9. ISIS-II Spacecraft Solar Cell Panels Geometry.

Each unit was also temperature tested (at atmospheric pressure) over the range of –50° C to +70° C; units with high voltage and/or high frequency functions were examined for corona or breakdown malfunctions during additional vacuum testing.

TABLE 1

Spacecraft Main-Mode Turn-On Commands

MODE	SDR TX.	SDR RX.	PM TX.	PCM ENC. & SUB-COMMS	VLF RX	FM TX. +S.C.O. +E.H.C.	D.M.E. & 137 MHz BEACON	TAPE RECORDER
A1	ON	ON	ON	ON	ON	ON	ON	RECORD
A2	ON	ON	OFF	ON	ON	OFF	ON	RECORD
B1	ON	ON	OFF	OFF	ON	ON	OFF	RECORD
B2	ON	ON	OFF	ON	ON	OFF	OFF	RECORD
C1	OFF	ON	ON	ON	ON	ON*	ON	–
C2	OFF	ON	OFF	ON	ON	OFF	ON	RECORD
D1**	ON/OFF	ON	ON	ON	ON	ON	ON	–
D2**	ON/OFF	ON	OFF	ON	ON	OFF	ON	RECORD
G1	ON***	ON	ON	ON	ON	ON	ON	–
G2	ON***	ON	OFF	ON	ON	OFF	ON	RECORD
AIT ON	ON	ON	OFF	OFF	OFF	ON	OFF	-

TABLE 1

Spacecraft Main-Mode Turn-On Commands

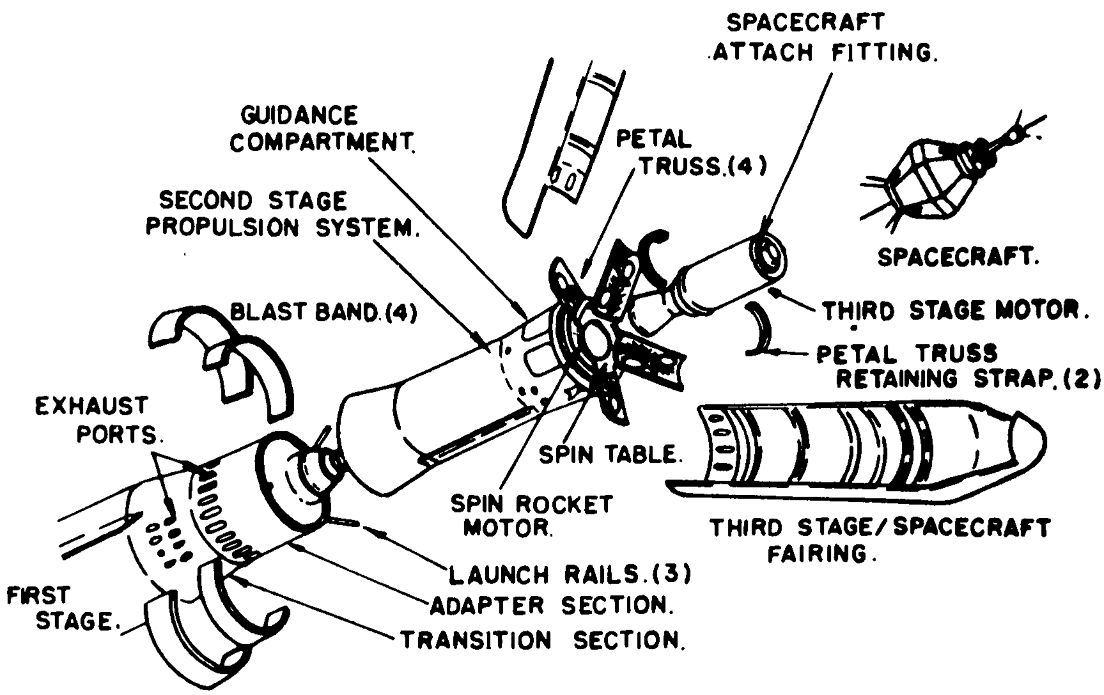
F1	400 MHz TX Transmits replayed VLF & PCM
F2	400 MHz TX Transmits replayed SDR. & VLF
F3	400 MHz TX Transmits replayed SDR. & PCM
F4	400 MHz TX Transmits replayed VLF wideband

NOTE: In cases where a unit or a group of units has sub-modes, the "ON" condition given above simply means that power is supplied to the device which controls the sub-mode, e.g., if the sub-mode of the VLF Receiver is "OFF" then the VLF Receiver will be OFF in all main modes.
main modes.

* = FM Transmitter ON only if VLF receiver is "ON"

** = ON/OFF for alternate frame pairs

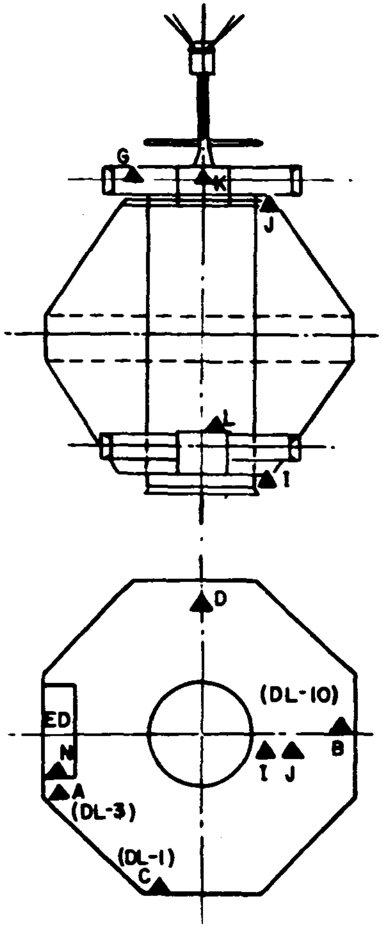
*** = Alternate frames of swept and fixed frequency

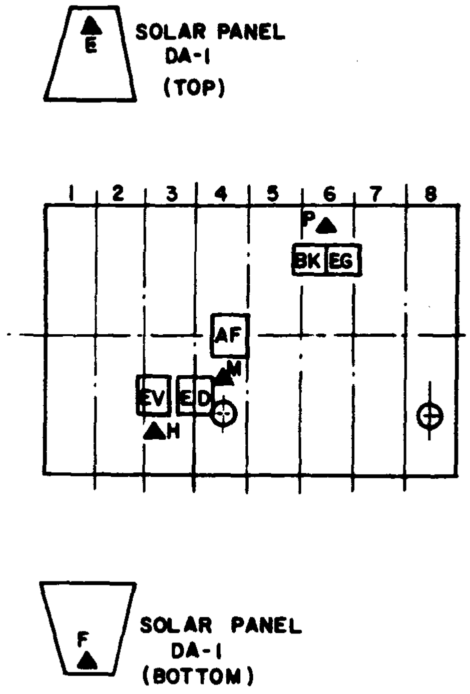


PRELIMINARY ISIS-B TRAJECTORY SEQUENCE

TIME (SECONDS)	EVENT
00	Lift Off
150	1st Stage Cutoff
155	2nd Stage Ignition
165	Jettison Firing
550	2nd Stage Cutoff
1115	3rd Stage Spinup
1130	3rd Stage Ignition
1160	3rd Stage Cutoff
1280	Spacecraft Separation

Fig. 10. Improved Delta Separation.





K - ON AURORA - SCANNER OPTICS.

L - ON RED-LINE - PHOTOMETER OPTICS.

THERM-ISTOR.	LOCATION	RANGE °C	TELEM. CHANNEL
A	BATTERY #2 (DL - 3)	-10 TO +50	ASCI-20
B	BATTERY #3 (DL - 10)	"	EHC-39
C	BATTERY #1 (DL - 1)	"	ASCI-8
D	EQUATORIAL PANEL #2	"	EHC-42
E	SOLAR PANEL #1 (TOP)	-50 TO +70	ASCI-56
F	SOLAR PANEL #1 (BOTTOM)	"	ASC2-8
G	AUXILIARY HEAT SHIELD	"	ASC2-20
H	THRUST TUBE (BELOW 'EV')	"	ASC2-54
I	BOTTOM HEAT SHIELD	"	ASCI-44
J	TOP HEAT SHIELD	"	ASCI-32
K	AURORA SCANNER OPTICS	-10 TO +50	ASC2-44
L	REDLINE PHOTOMETER OPTICS	"	ASC2-56
M	THRUST TUBE MIDDLE (BETWEEN AD & AF)	"	EHC-40
N	EQUATORIAL PANEL (NEAR IMS)	"	ASC2-32
P	THRUST TUBE TOP (NEAR BK & EG)	"	EHC-41

Fig. 11. ISIS-II Spacecraft Thermistor Locations.

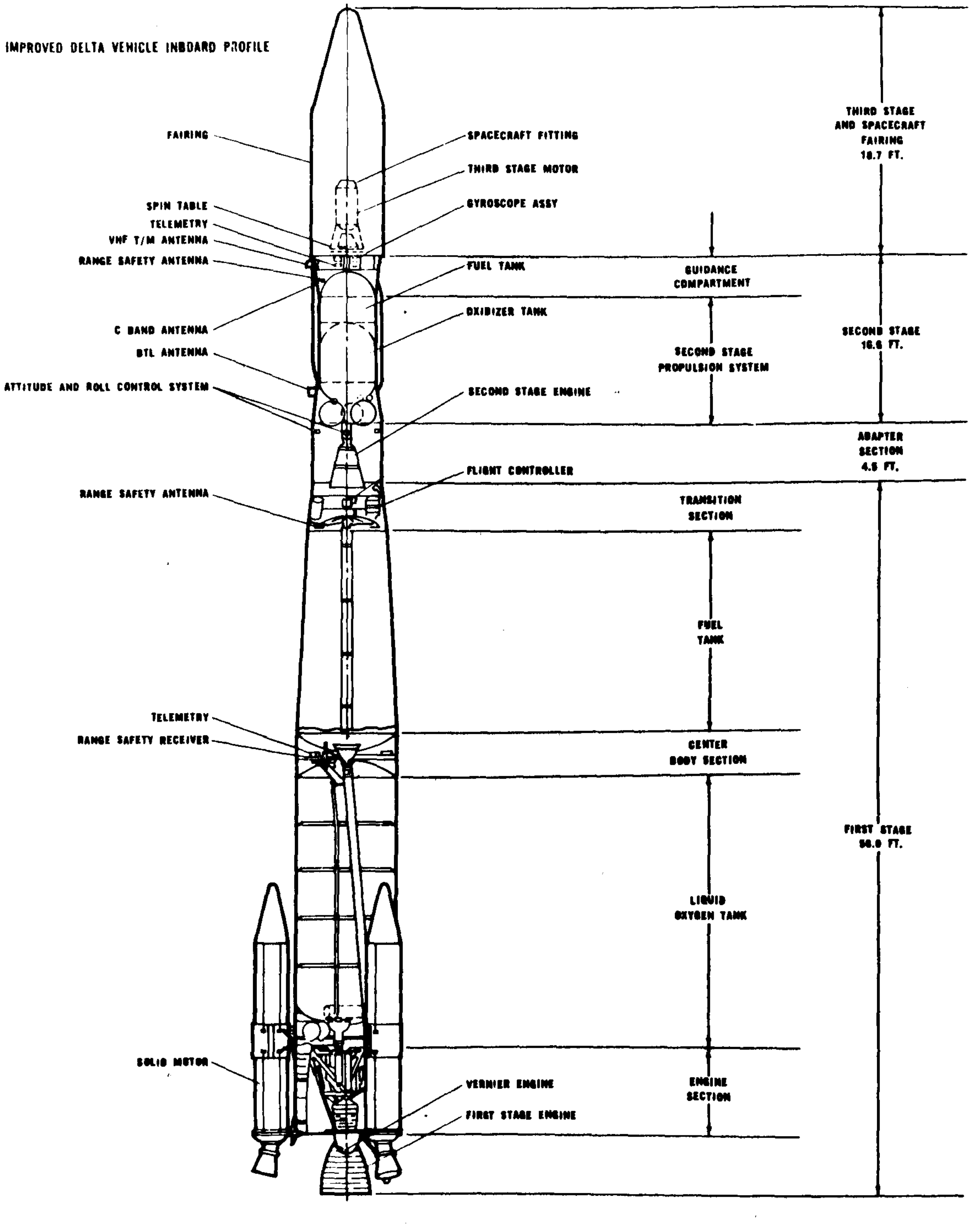


Fig. 12. Improved Delta Profile.

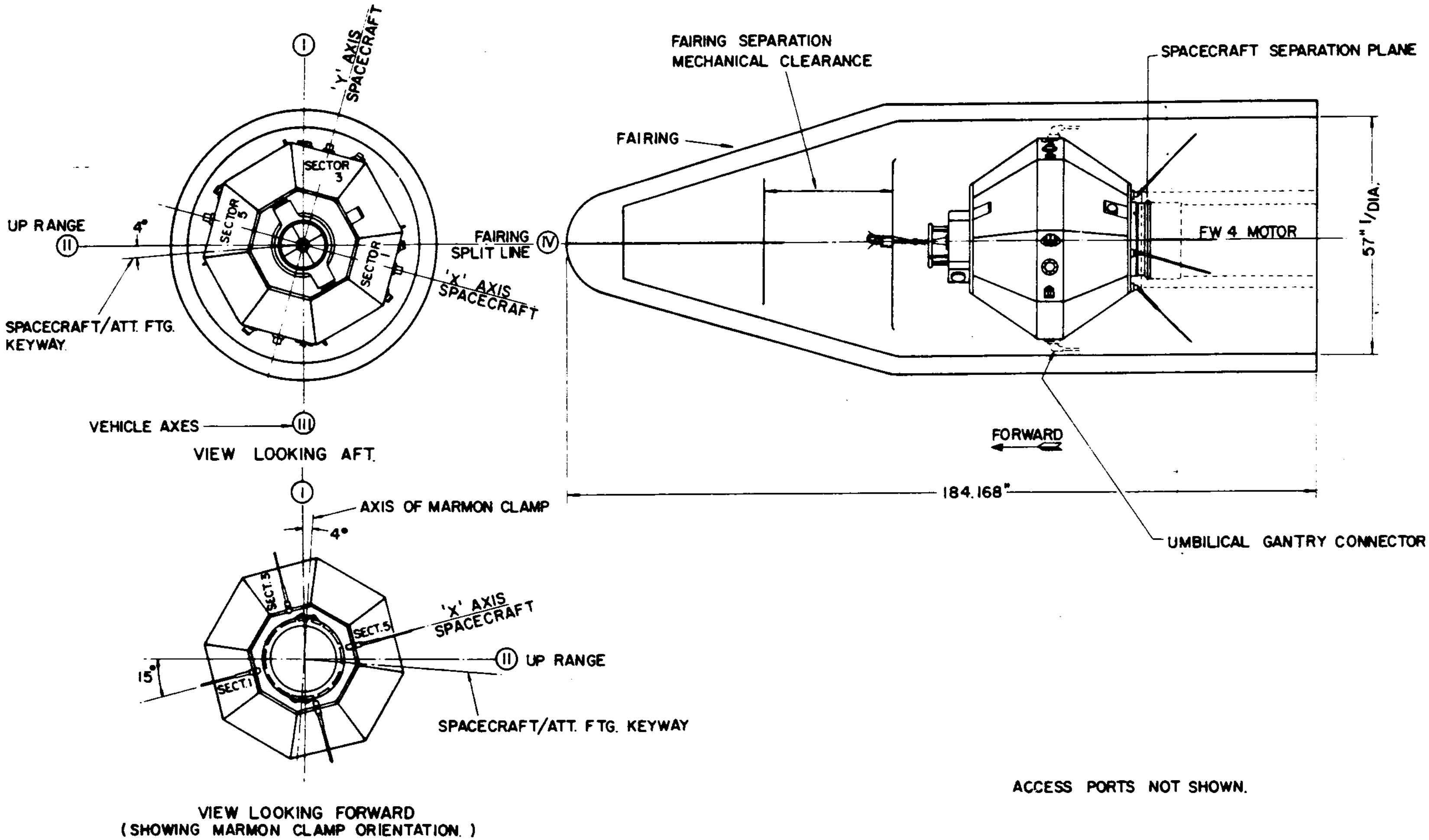


Fig. 13. ISIS-II Spacecraft to Shroud Orientation.

4. COMMAND SYSTEM

The command system (Figs. 14, 15) is designed to execute a total of 216 individual commands and comprises:

(a) two command receivers
(b) one command decoder
(c) command switching unit
(d) programmer and clock
(e) back-up programmer and clock
(f) automatic turn-off unit

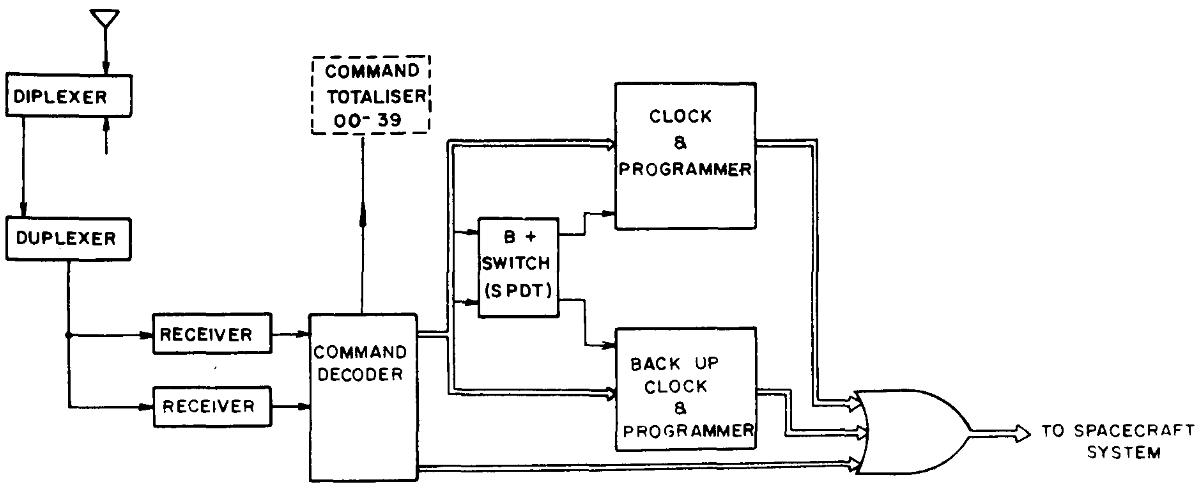


Fig. 14. Block Diagram of Command System.

The RF signal input to the command receivers comes from the 136/148 MHz duplexer (Fig. 20a, page 29), the 148 MHz notch filters shown are designed to prevent desensitization of the command receivers due to spurious outputs from the two telemetry transmitters. The command decoder configuration allows for 108 command outputs with an additional 108 redundant commands; with this arrangement the commands are so grouped that single failure does not preclude the use of any command.

On receipt of the appropriate command from a ground station, the command system sets the spacecraft into a selected mode of operation. The command modes available may be grouped as follows:

(1) Main modes (see Table 1).
(2) Spacecraft sub-modes.
(3) Spacecraft turn-off.
(4) Experimental and equipment sub-modes.

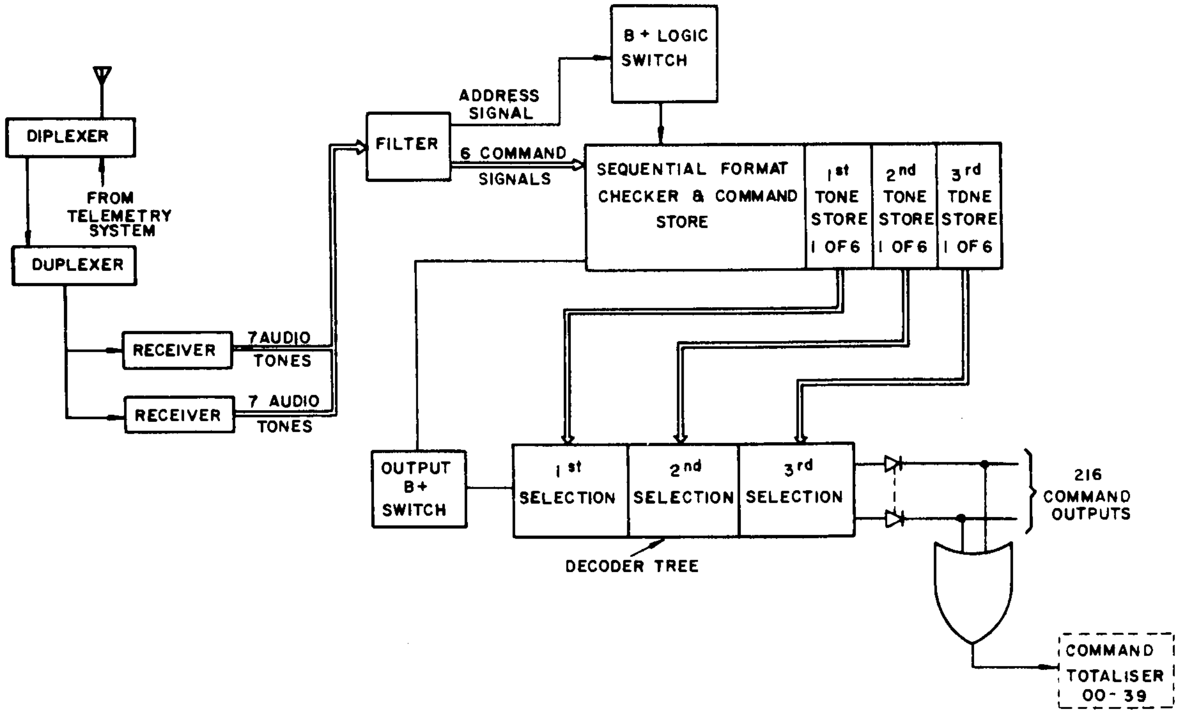


Fig. 15. Block Diagram of Command Decoder.

4.1 MAIN MODE COMMANDS

Table 1 shows the equipment and experiments which will be powered in these modes, the execution of one of these commands will be sufficient to set the spacecraft into a mode of operation in which experimental data will be collected if the appropriate submodes have been executed. In normal operation, to change from one main mode to another requires first an automatic turn-OFF or a direct spacecraft OFF command.

4.1.1 Spacecraft Sub-modes

Sub-mode commands are normally used in conjunction with the main mode turn-ON commands to provide major modifications to the selected spacecraft main mode of operation. At the conclusion of each operating period, the modifying commands are reset to a normal mode state by an ATO pulse.

4.1.2 Experimental and Equipment Sub-modes

Experimental sub-modes are used to select among the several states in which the experiments can operate. Similarly the equipment sub-modes select among the several equipments that are available. For example, either of the two PCM encoders may be selected on command of the appropriate equipment sub-mode. These sub-modes are not reset by an ATO pulse and remain in effect until specifically changed by command.

4.2 SPACECRAFT TURN-OFF

This command resets all of the ON commands that are subject to ATO action, with the exception of the spacecraft spin and attitude control system.

4.3 COMMAND TOTALISER

An output from the command decoder is used to indicate the number of commands sent, up to a maximum of 39. A bistable flag is also provided on channel 45 of the essential housekeeping commutator.

4.4 CLOCK AND PROGRAMMER SUB-SYSTEM (Fig. 16)

The clock and programmer:

(a) generates time information for transmission to ground stations.

(b) generates spacecraft time code information for the on-board tape recorder. The main clock time can be reset by command.

(c) accepts and stores a programme of commands transmitted from a ground station. This programme results in delayed execution of the main mode commands, A_1, A_2, B_1, B_2, C_1, C_2, D_1, D_2 and G_1, G_2.

(d) provides accurate synchronization and timing pulses of stable frequency to other equipment in the spacecraft.

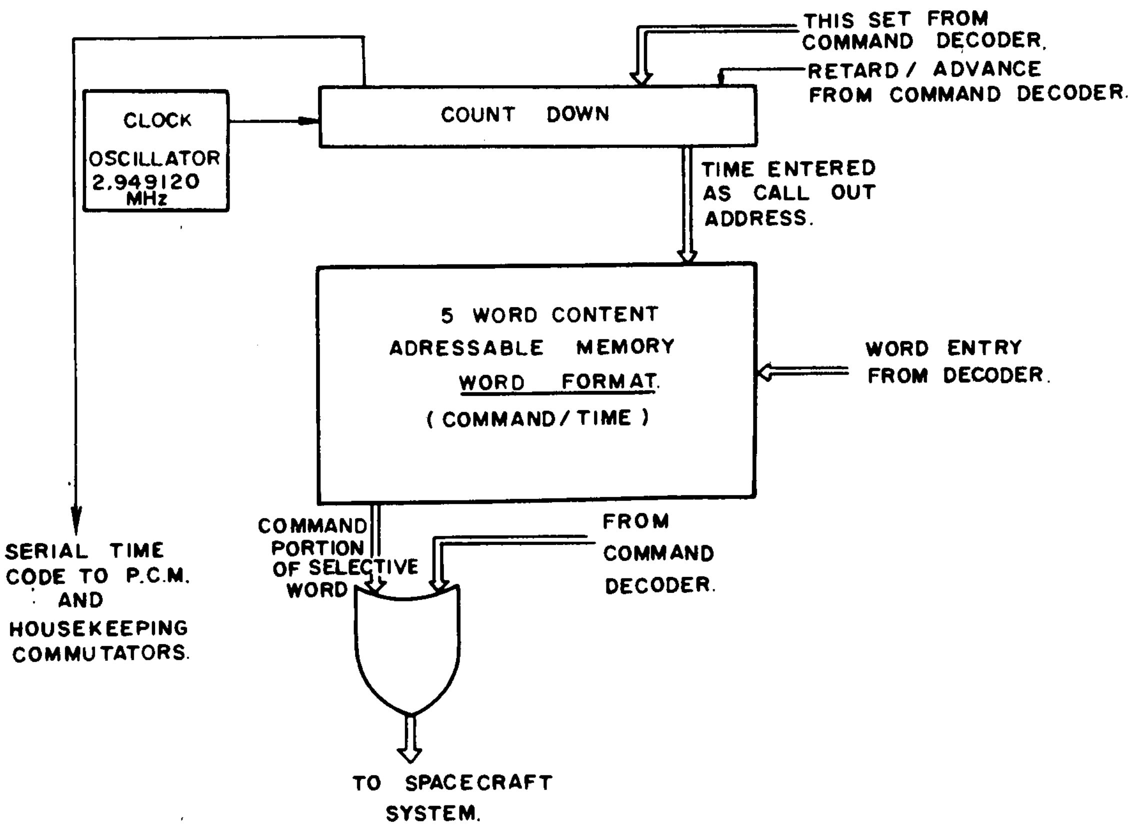


Fig. 16. Block Diagram of Clock and Programmer.

The back-up clock and programmer is a simplified version of the main unit, and is provided for redundancy. The main unit can execute up to five successive delayed-turn-ON's before reprogramming, the back-up unit, however, is limited to one.

Command execution times can be programmed with reference to the spacecraft clock, (to within $\pm$ 30 seconds) and delay durations of up to 24 hours from the time of programming are possible. Programme loading time is approximately 5 minutes. When delayed turn ON is used, the experiment and equipment sub-modes will remain as those last selected by direct ground station control.

The outputs from the clock and programmer are shown in Figure 16 and 18 and include time code, synchronization and command. Time is presented once per second in a non-standard 60 pps serial binary-coded decimal format, as illustrated in Figure 17.

Access to any main store, for loading and monitoring, is available without altering the state of any other store. The store contents are monitored by substituting them in place of the spacecraft time code information. Thus programmer information is carried by the time codes fed to the tape recorder and also to the essential housekeeping commutator, which can be commanded to accept time code data continuously.

4.4.1 Clock Synchronization Outputs

(a) 1 pulse per minute

(b) 1 pulse per hour

(c) 1 pulse per 10 days

(d) an inhibit pulse to the ATO during clock correction.

(e) Synchronizing outputs as required to the PCM encoder (23,040 pps and 1 pps), and for use by the counter system at 46,080 pps.

4.4.2 Time Code Outputs

Spacecraft time code is supplied to PCM encoders I and II, the spacecraft tape recorder and the essential housekeeping commutator. A gated output to the essential housekeeping presents the time code for five seconds of each minute; continuous time code can be selected by command.

4.5 AUTOMATIC IONOGRAM TRANSMISSION (AIT)

When the AIT mode is commanded the sounder system operates for one full frame once every 3 minutes in either the swept frequency mode or mixed mode.

4.6 AUTOMATIC TURN-OFF (ATO)

Two methods of turn-OFF are available; by command from a ground control station or alternatively, by means of an on-board automatic turn-OFF unit (ATO).

If the turn-OFF from the ground control is not used, the ATO operates to turn OFF all power except that supplied by the common diode rail. The turn-OFF operation occurs after an elapsed time of 16 minutes (normal period), 8 or 24 minutes, as selected by command. The time is measured after receipt of the last mode turn-ON or spacecraft sub-mode command.

4.6.1 Turn-off after Turn-on by the Programmer

When turn-ON is initiated by the programmer the ATO will occur after

(i) 16 minutes in the tape recording mode

(ii) 16 minutes in the direct modes.

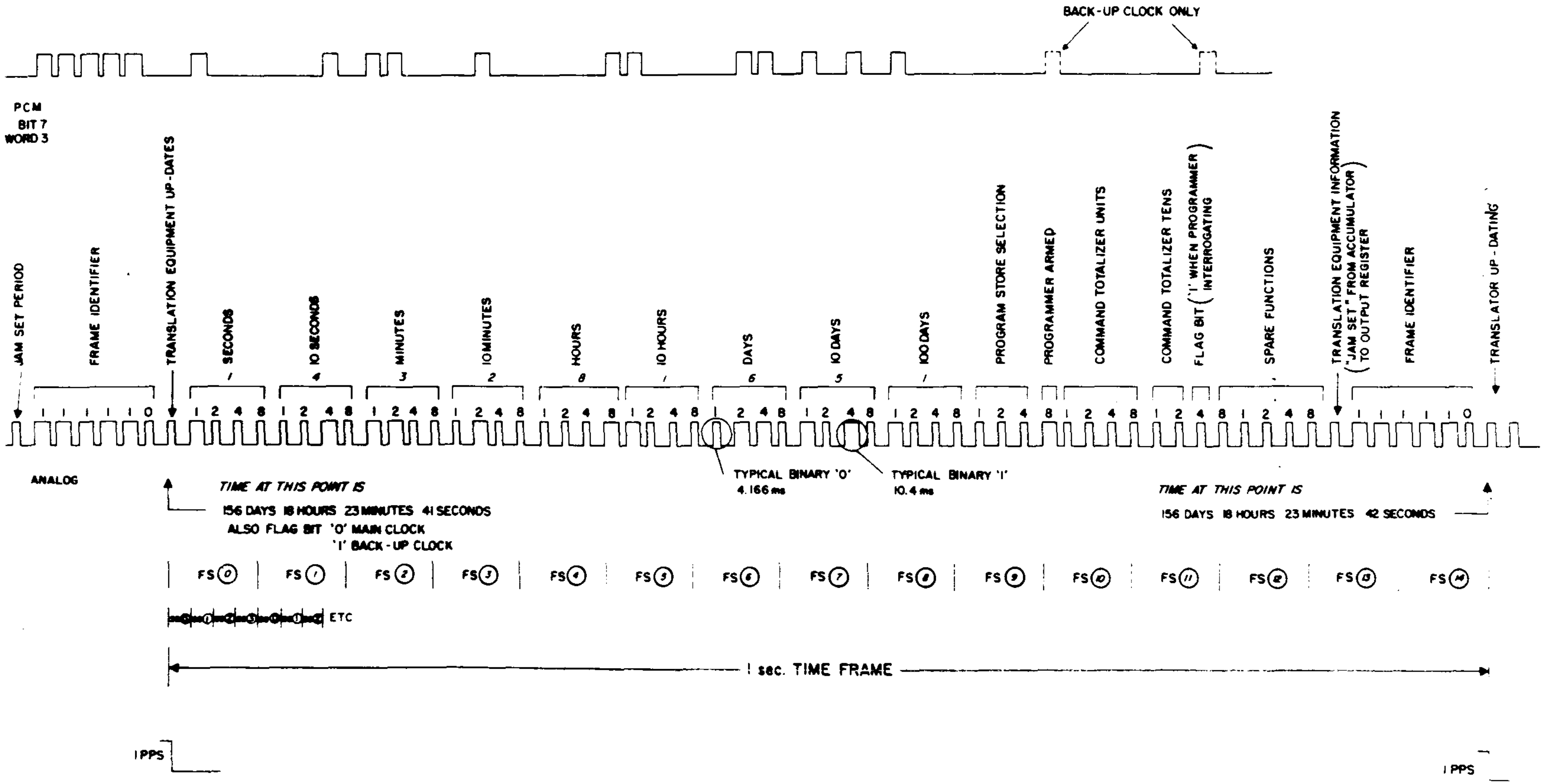
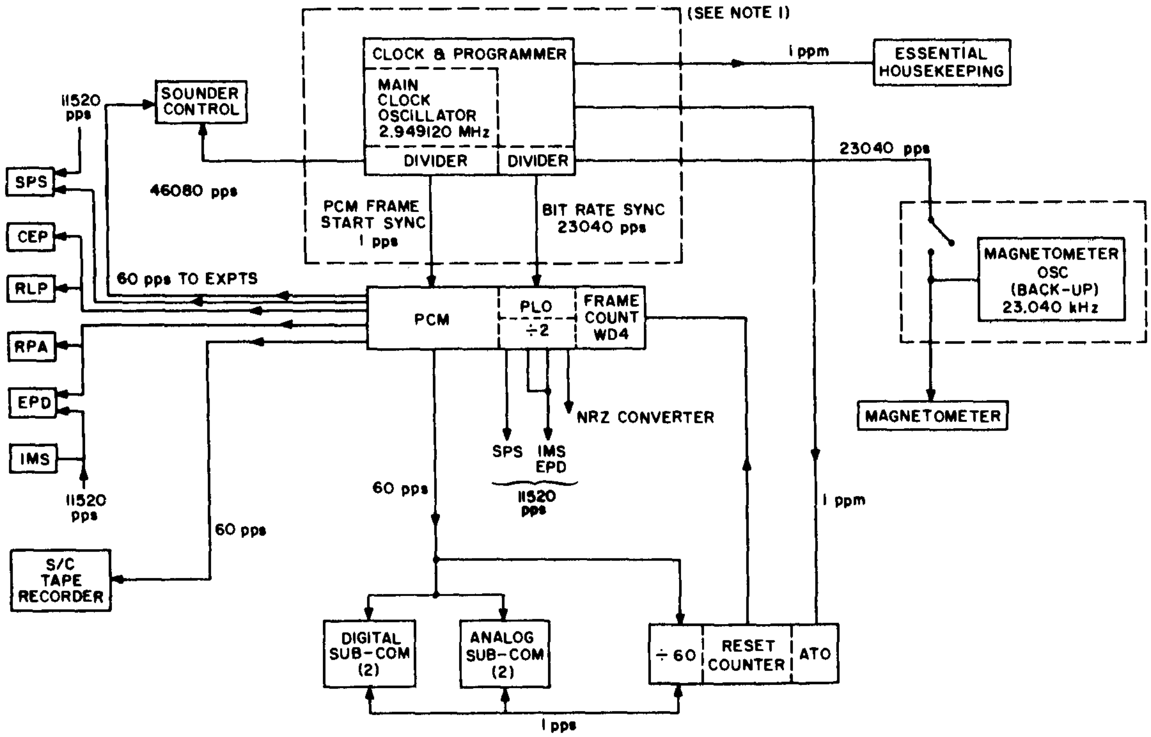


Fig. 17. Spacecraft Time Code Format.



NOTE 1. In the event of a main clock failure in either of the clock and programmers partial redundancy is provided from the free running oscillator in the PCM encoder. A separate back-up magnetometer oscillator is provided.

Fig. 18. Timing Diagram.

4.6.2 Back-up Turn-off

In the event of a failure of both the spacecraft and back-up clocks, an automatic turn-OFF will occur after 16 or 30 minutes , as selected by command.

4.7 SPIN AND ATTITUDE CONTROL TURN-OFF

The spin and attitude control system can be turned off automatically after 3 (+1, −0) hours or after 11(+1, −0) hours.

4.8 TRACKING BEACON TIMER

A 90 day (+10 −0) turn-OFF is provided to disconnect the tracking beacon from the common diode rail, this ATO unit can be commanded to reset for additional 90 day periods.

When disconnected from the common diode rail, the tracking beacon is so connected that it can be switched ON and OFF, by command, in conjunction with the experimental beacon and subject to the 8, 16 or 24 minute ATO control.

5. TELEMETRY SYSTEM

The telemetry system (Figure 19) comprises the following:

(i) telemetry transmitters 136 FM, 136 PM and 400 MHz

(ii) telemetry data processing

(iii) spacecraft tape recorder

(iv) antennas and feed systems (Figures 20a, b, c)

(v) VHF beacon transmitters.

The 400 MHz link, with its increased data transmission capability, is used for playback of the onboard tape recorded data or alternatively for real time transmission of sounder/VLF/CEP data.

5.1 FM SUBSYSTEM (136.080 MHz)

The sounder data is a composite waveform with a spectrum from dc to 15 kHz, which contains calibration, synchronization and sounder echo return pulses. An FM analog transmission system, compatible with the receiving facilities in existing NASA and Canadian ground stations is used. VLF data (50 Hz to 30 kHz) can be combined with the sounder data, or selected on command as the main modulation for the FM transmitter.

FM Transmitter

RF output power	4 watts minimum
Predetection bandwidth	100 kHz
Frequency	136.080 MHz
Modulation	FM/FM
Sub-carrier oscillator centre frequency	30 kHz

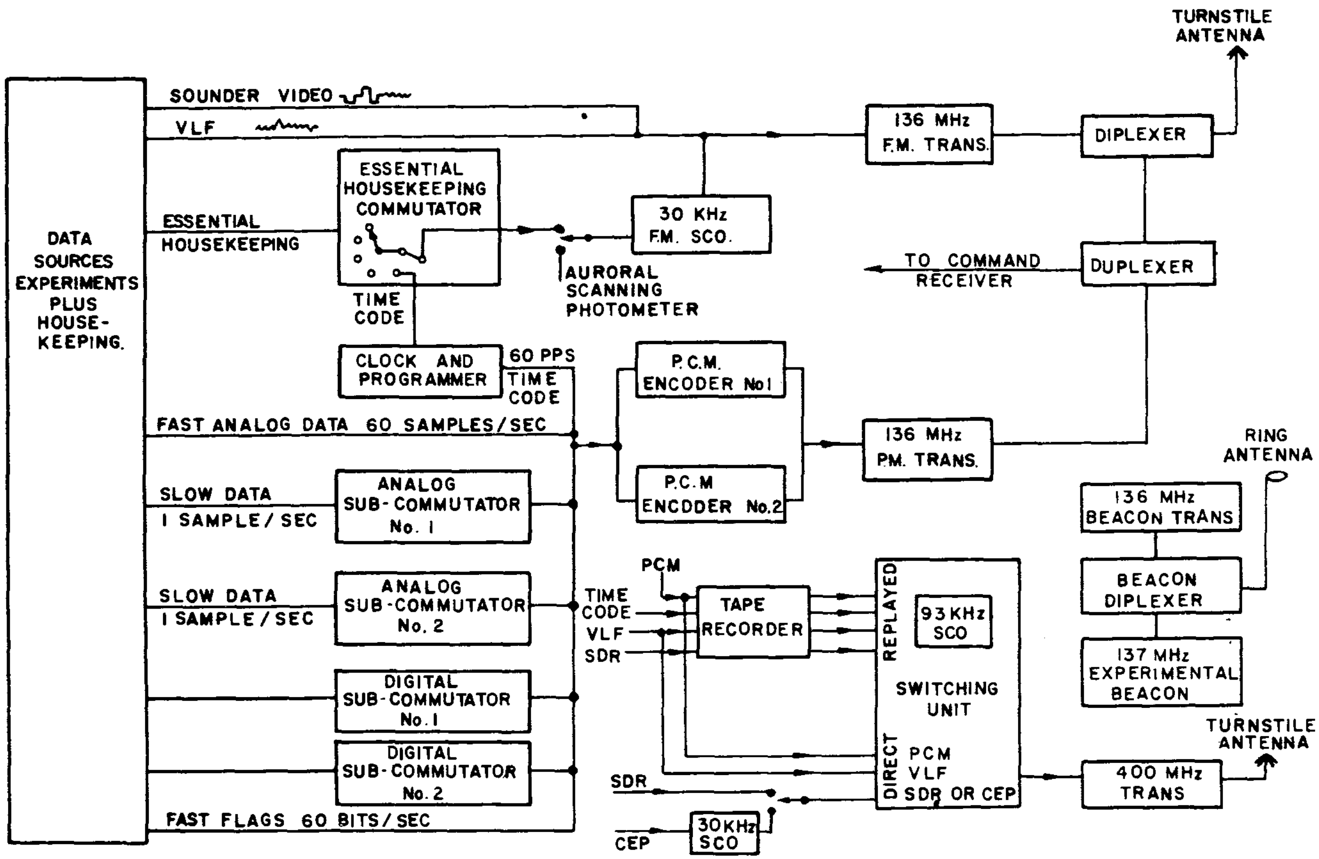


Fig. 19. ISIS-II Telemetry System.

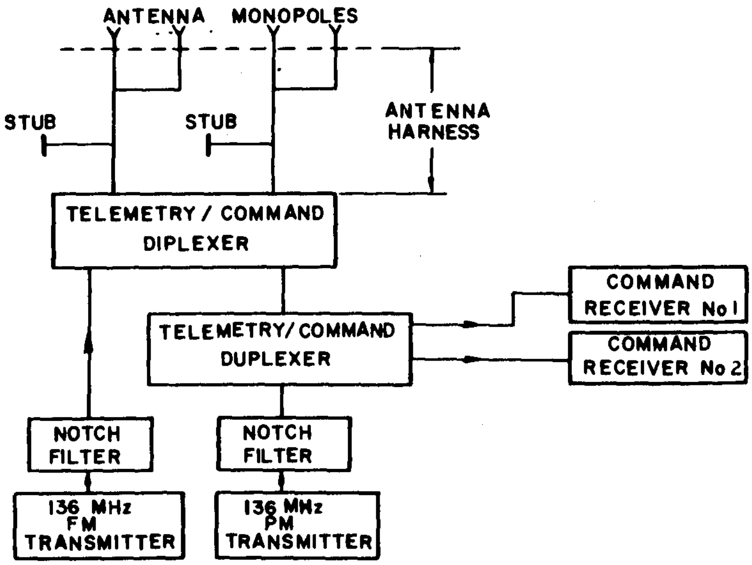


Fig. 20a. VHF. Telemetry/Command System.

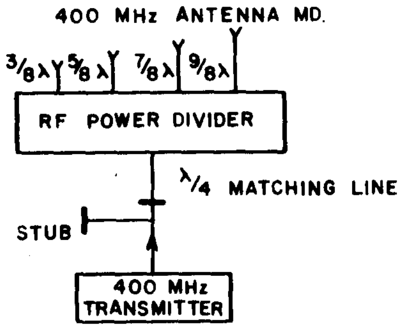


Fig. 20c. 400 MHz Antenna System.

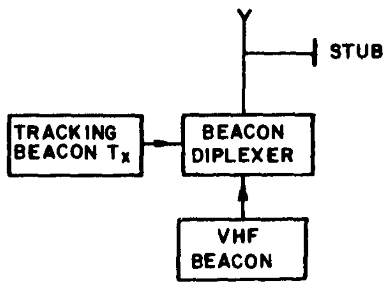


Fig. 20b. Beacon Antenna System.

TABLE 2

136 MHz FM Telemetry Operating Modes

Data Source	Modulating Signal Bandwidth	FM Deviation
(a) Sounder	DC – 15 kHz	± 30 kHz
(b) VLF	.05 – 30 kHz	± 30 kHz
(c) Sounder with (VLF)	DC – 30 kHz	± 30 kHz (13.4 kHz)
30 kHz SCO	± 7 1/2 per cent	± 12 kHz
Always present with a, b and c above		

30 kHz Sub-carrier Modulation

The 30 kHz sub-carrier is frequency modulated by a PAM signal carrying commutated essential housekeeping data multiplexed with spacecraft time code. Normally there will be 5 seconds of time code data at the beginning of each minute followed by 55 seconds of essential housekeeping data. Alternatively, data from the auroral scanning photometer experiment can be substituted, as shown in Figure 19; time code will not be present in this mode of operation. Also by command, the sub-carrier can be made to carry either the spacecraft programmer state of command or continuous spacecraft time code.

5.2 PM TRANSMITTER (136.590 MHz)

Data from all experiments, other than the sounder and VLF, are time multiplexed and encoded using a PCM encoder. The encoding occurs as shown in Figure 21.

The output of the encoder in split-phase format, is used to phase modulate the PM transmitter. PCM word allocations are given on page 34.

RF output power	2 watts
Frequency	136.59 MHz
Predetection bandwidth	50 kHz
Modulation	PCM (Split Phase)/PM, Bit rate 11,520 bits/sec
Deviation	± 1.2 radians

A stable carrier frequency suitable for synchronous detection is provided.

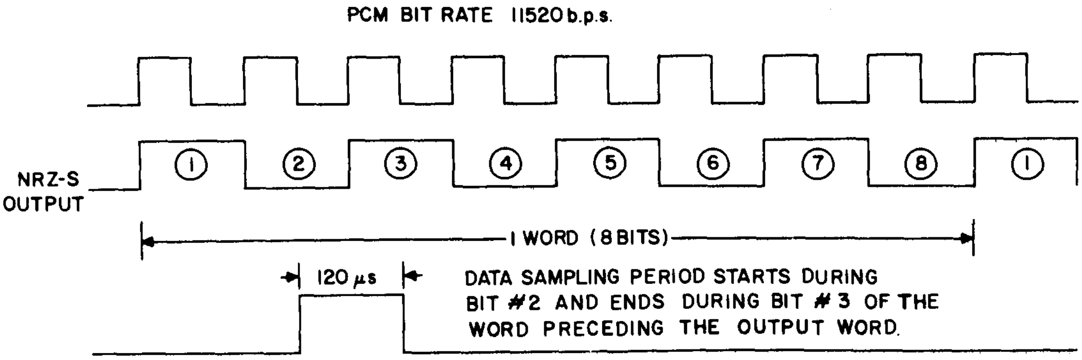


Fig. 21. PCM Encoder Sampling Format.

5.3 400 MHz SUBSYSTEM

The 400 MHz telemetry transmitter has both FM and PM modulation capability. As shown in Figure 19, the tape recorder play-back, or real time data may be selected as inputs to the transmitter.

400 MHz Transmitter

RF output power	4 watts
Frequency	401.750 MHz
Transmission bandwidth	500 kHz maximum 300 kHz during real time transmission
Modulation	FM and PM
Deviation	± 100 kHz FM maximum ± 1.5 radian PM

Sub-Carrier Oscillator

Centre frequency	93 kHz
Deviation of 93 kHz SCO	25 per cent Mode 2 Table 3, replayed VLF Modes 1 & 3 ± 15 per cent
Deviation of transmitter by the 93 kHz SCO	± 1 radian

Low Pass Filter

3 dB bandwidth	38 kHz
20 dB bandwidth	46 kHz

Replay Modes:

In the 400 MHz telemetry subsystem a non-standard 93 kHz sub-carrier oscillator is used to phase modulate the main carrier while other replayed data from the spacecraft tape recorder will directly frequency modulate the main carrier. A low pass filter prevents overlap of these two types of signals. The replayed signals may be combined in various ways as selected by command. (see Table 3). The ratio between record and playback speeds is 1:4.

TABLE 3

Spacecraft Tape Recorder Playback Modes

Replayed Mode	FM Signal	Deviation	Frequency Range (kHz)	Input to 93 kHz SCO	Bandwidth (kHz)
1 (F1)	VLF	± 80 kHz (Specification maximum ± 100 kHz)	0.2 – 40	Replayed PCM (NRZ-S 46,080 bps)	0 – 25
2 (F2)	SDR	± 100 kHz	2.0 Hz – 40	Replayed VLF	0.2 – 20
3 (F3)	SDR	± 100 kHz	2.0 Hz – 40	Replayed PCM (NRZ-S, 46,080 bps)	0 – 25
4 (F4)	VLF	± 100 kHz	0.20 – 100 (LPF not used)	Not used	---

The replayed clock data is transmitted in all four modes and consists of a 46.08 kHz signal, amplitude modulated by a 240 bps time code. The transmitter is phase modulated by this signal.

Deviation during code pulse	$\pm$ 0.5 radians
Ratio of deviation during "inter-pulse gap" to deviation during code pulse.	1:5

Direct Modes

(a) Direct transmission of the VLF data, when the 136 MHz FM transmitter is being used for sounder data transmission.

Signal band 50 Hz to 30 kHz FM; deviation due to signal $\pm$ 50 kHz.

The 93 kHz SCO will be modulated $\pm$ 15 per cent by the output of the active PCM encoder. (Split-phase data at 11,520 bps.)

(b) Direct transmission of the data normally transmitted on the 136 MHz FM system, except for that data carried by the 30 kHz SCO, using a 300 kHz bandwidth.

The transmitter is frequency modulated by the output of the sounder with a deviation of $\pm$ 50 kHz and by the VLF $\pm$ 23 kHz.

By command, high resolution data from the cylindrical electrostatic probe experiment may be transmitted instead of the sounder data. In this case the CEP data will modulate a 30 kHz SCO by $\pm$ 7 1/2 per cent corresponding to a transmitter deviation of $\pm$ 33 kHz. Although not a normal operating mode, the VLF receiver data may also be added on command, to the high resolution CEP data.

The 93 kHz SCO is modulated $\pm$ 15 per cent by the output of the active PCM encoder.

In the direct transmission modes (a) and (b), spacecraft time is available on the PCM.

5.4 TELEMETRY AND COMMAND ANTENNA SYSTEM

The 136 MHz telemetry and 148 MHz command receivers share the same broadband turnstile monopole array. The (136 MHz) PM and (136 MHz) FM transmissions are circularly polarized in opposite directions with respect to each other.

The telemetry/command duplexer Figure 20a, provides for isolation between the transmitters and command receivers. The diplexer provides isolation between FM and PM telemetry transmitters.

The 400 MHz transmitter feeds a turnstile antenna which is mounted on a supporting pillar at the top of the spacecraft, Figures 1 and 20c.

5.5 BEACON TRANSMITTERS (136.410 and 137.950 MHz)

Two 100 mW CW transmitters are provided, one of which (136.410 MHz) is used primarily for satellite tracking. The two transmitters are used together for experimental purposes.

The beacon transmitters are designed to be within ± 4 kHz of nominal frequency over the temperature range - 50° to + 70° C. It is expected the difference frequency between transmitters will be within 1 part in 10^7 over a 10 minute period.

5.5.1 Beacon Antennas

The beacon transmitters are coupled to a ring antenna, Figure 20b, via diplexer which provides isolation between the two transmitters. This antenna design has been changed from the ISIS-I configuration to provide a more uniform radiation pattern.

5.6 TELEMETRY DATA

Spacecraft data will be processed by the following units:

(a) PCM encoder
(b) PCM analog subcommutator No. 1
(c) PCM analog subcommutator No. 2
(d) PCM digital subcommutator
(e) PAM commutator (essential housekeeping).

5.6.1 PCM Format

Bit rate	11,520 bits/sec
Number of words	24 (8 bits per word)
Frames per second	60
Frame sync pattern	(channels 1 and 2)

0 0 0 0 1 0 0 1 1 1 0 1 0 1 1 1

5.6.2 PCM Encoder

The PCM encoder generates 8 bit words at a rate of 11,520 kilobits per second. The output frame consists of 24 words, two of which are occupied by the internally generated frame synchronization pattern. Timing is derived from a phase locked loop oscillator synchronized to the spacecraft clock.

The signals to the encoder comprise sixteen analog data inputs plus four serial digital and two parallel digital inputs. The encoding format is given in Figure 21. The analog data input signals are commutated internally at 1440 words per second, and fed sequentially to a sample-and-hold circuit and thence to the A/D converter.

The output from the hold circuit is encoded to give $2^8 = 256$ quantization levels (1 quanta - 20 mV) for a maximum output voltage of 5.1 volts.

The analog-to-digital converter feeds 8 bit (parallel) words, the most significant digit first, to the output shift register which is read out serially at 11,520 kilobits per second via the gating and coding circuits to the telemetry transmitter.

PCM outputs from the encoder, in the IRIG standard NRZ-S and split phase code formats, are provided simultaneously; NRZ-S to the spacecraft tape recorder, and split phase to the 136 MHz PM and 400 MHz FM transmitters.

PCM WORD ALLOCATIONS

Function or Equipment	Word Number
Frame Sync	1, 2 (Note 1)
Retarding Potential Analyzer, Range 1	3, bit 1
Retarding Potential Analyzer, Range 2	bit 2
Retarding Potential Analyzer, Range 3	bit 3
Retarding Potential Analyzer, Polarity	bit 4
Sounder Receiver Frequency Marker	bit 5
Digital Sub-Comm. No. 1	bit 6
Clock Time Code	bit 7
Solar Aspect Sensor ("Command Eye" bit)	bit 8
Digital Sub-Comm. No. 2	4, bit 1
Clock/Time Code, Programmer Status and Command Totalizer Count	bit 2
Sub-Comm. Frame Count, 2^5 (Note 2)	bit 3
Sub-Comm. Frame Count, 2^4 (Note 2)	bit 4
Sub-Comm. Frame Count, 2^3 (Note 2)	bit 5
Sub-Comm. Frame Count, 2^2 (Note 2)	bit 6
Sub-Comm. Frame Count, 2^1 (Note 2)	bit 7
Sub-Comm. Frame Count, 2^0 (Note 2)	bit 8
Ion Mass Spectrometer, High Mass Peaks	5 (Notes 3, 4)
Cylindrical Electrostatic Probe, Linear Amplifier Output	6 (Note 4)
Cosmic Noise (Sounder Receiver AGC)	7 (Note 4)
Oxygen Red-Line Photometer, Intensity Level	8
Analog Sub-Comm. No. 1	9
Analog Sub-Comm. No. 2	10 (Note 1)
C.E.P. Log Amp	11
R.P.A. Analog Output	12
Energetic Particle Detector Exp't. Output	13, 14
Soft Particle Spectrometer, Data Processor A Output	15
Soft Particle Spectrometer, Data Processor B Output	16
I.M.S. High Mass Peaks	17 (Note 4)
C.E.P. Linear Amp. Output	18 (Notes 1, 4)
Cosmic Noise (Sounder Receiver AGC)	19 (Note 4)
Sounder Antenna Impedance or Aurora Scanner Intensity Level	20
Sounder Antenna VLF Impedance Current Data	21
VLF Receiver AGC Level	22
I.M.S. Low Mass Peaks	23
C.E.P. AC Amplifier Output	24 (Note 1)

NOTES

1: Sounder Transmit Pulse (87 μsec) may occur during bits 2, 3 of PCM words 2, 10, 18.

2: Frame Count range 0 to 59. Counter reads zero at sub-comm. channel 1 and reads 59 at channel 60.

[Frame count + 1 = Sub-Comm. Channel Number]

3: The most significant bit (2^7) is presented first in the 8-bit sequence for each of the words carrying encoded analog data, i.e., words 5 to 12 and 17 to 24.

4: Word 5 and word 17 are a super commutated pair.
Word 6 and word 18 are a super commutated pair.
Word 7 and word 19 are a super commutated pair.

5.7 SPACECRAFT TAPE RECORDER

A four-track tape recorder, with a record capacity of 64 minutes, provides the means for temporarily storing data, on receipt of commands from the clock and programmer or from a ground station. Playback via the 400 MHz telemetry is at 20 ips, four times the record speed and is controlled by direct command from a ground station.

The tape recorder channels are

1. Sounder Video	0 – 7 kHz
2. VLF receiver	0.05 – 20 kHz
3. Digitized data	PCM 11.520 kilobits per second
4. Time Code and Reference Frequency (PCM bit rate 11.520 kilobits per second)	The time code, a 60 pps spacecraft clock output is used to modulate a reference frequency derived from the PCM encoder.

The sounder video modulates the period of an oscillator in the recorder; the oscillator output gives saturation recording on one track. The VLF is recorded on a normal ac biased track. The PCM signals are converted for recording from NRZ-S to split phase and are reconverted by the spacecraft tape recorder electronics to NRZ-S for playback. The four data channels listed are recorded as selected by command and on playback will be reproduced in reverse order for transmission via the 400 MHz telemetry. A 60 pps time code amplitude modulates a reference PCM bit rate signal and is recorded on the fourth track.

ESSENTIAL HOUSEKEEPING COMMUTATOR CHANNELS

1. Zero Cal.
2. F.S. Cal.
3. Battery 1 Voltage
4. Battery 2 Voltage
5. Battery 3 Voltage
6. Battery 1 Discharge Current
7. Battery 2 Discharge Current
8. Battery 3 Discharge Current
9. Battery 1 Charge Current
10. Battery 2 Charge Current
11. Battery 3 Charge Current
12. Com. Diode Rail Current

25. Antenna 1 (Sector 3) Length
26. Antenna 2 (Sector 7) Length
27. Antenna 3 (Sector 1) Length
28. Antenna 4 (Sector 5) Length
29. VLF Receiver AGC
30. Fixed Freq. Sounder, Bit 1 Flag L.S.
31. Fixed Freq. Sounder, Bit 2 Flag
32. Fixed Freq. Sounder, Bit 3 Flag M.S.
33. Cosmic Noise (Sdr. Rx AGC).
34. Batt # 2 Load Current
35. PCM Word 20 Aur. Scan. or VLF Z
36. Antenna Bias Current

(Essential Housekeeping Commutator Channels cont'd)

13. Solar Aspect Sensor (Analog EA4)
14. Solar Aspect Sensor (Analog EA3)
15. Solar Aspect Sensor (Analog EA2)
16. Solar Aspect Sensor (Analog EA1)
17. Mag. 1 X600 or Mag. II S600
18. Mag. 1 Z200 or Mag. II Z600
19. Attitude Sensing & Control System ON/OFF Flag
20. A.S.C. ATO 11 Hrs. or 3 Hrs. Flag
21. A.S.C. System Spin/Att Flag
22. A.S.C. System Torquing Coil Switching (Note 2)
23. 400 W (Prim) PA RF Voltage Monitor
24. 400 W (Sec) PA RF Voltage Monitor
37. Command Rcvr. No. 1 AGC
38. Command Rcvr. No. 2 AGC
39. Temp. Sensor B (Battery 3)
40. Temp. Sensor M (Thrust Tube Middle)
41. Temp. Sensor P (Thrust Tube Top)
42. Temp. Sensor D (Eq. Panel 2)
43. Tape Motion Indicator
44. Batt # 3 Load Current
45. Command Received Flag (Note 1)
46. Spacecraft Separation Indicator
47. Sync.
48. Sync.

NOTES:

1. This flag will change state whenever the command decoder unit issues a command pulse.

2. F.S. = Coil # 2
   1/2 S = Coil # 1
   0 = Coils off

DIGITAL SUB-COMMUTATOR NO. 1 CHANNELS

1. VHF Beacon Exp't. ON/OFF
2. E.P.D. Exp't. ON/OFF
3. Aur. Scan. Exp't. ON/OFF
4. Red. Phot. Exp't. ON/OFF
5. Sounder Receiver ON/OFF
6. R.P.A. Exp't. ON/OFF
7. C.E.P. Exp't. ON/OFF
8. C.E.P. Expt. Probe/Switch Enable/Inhibit.
9. C.E.P. Exp't. Fixed Bias Mode/Automatic Bias Mode
10. C.E.P. Exp't. Probe No. 1 In Use (the upper probe is probe 1)
11. I.M.S. Exp't. ON/OFF
12. VLF Rcvr. ON/OFF
13. S.P.S. Exp't. ON/OFF
14. S.P.S. Exp't. Top Beam Mode
15. S.P.S. Top Beam Step Counter, Stage 1
16. S.P.S. Top Beam Step Counter, Stage 2
17. S.P.S. Top Beam Step Counter, Stage 3
18. S.P.S. Top Beam Step Counter, Stage 4
19. S.P.S. Exp't. Data Processor
20. S.P.S. Exp't. Electron Data
21. 400 W (Prim) PA ON/OFF
22. 400 W (Sec) PA ON/OFF
23. Mode D ON/OFF
24. Mode G ON/OFF
25. Fixed Freq. Sounder Bit 1 (2^0)
26. Fixed Freq. Sounder Bit 2 (2^1)
31. Pre-Amp Band Bit 3(2^0)
32. VLF Exciter ON/OFF
33. VLF Receiver FM Output IN/OUT
34. VLF Impedance Exp't. ON/OF
35. VLF Exciter Level Flag #1 (1=Hi/Lo, 0=M)
36. VLF Exciter Level Flag #2 (1=Hi/M,0=Lo)
37. Sounder AIT ON/OFF
38. Aur. Scan. Overload Protection Disabled
39. Aur. Scan. FET Protection Disabled
40. Aurora Scanner Scan Disabled
41. OCL 1 OUT/IN
42. OCL 2 OUT/IN
43. OCL 3 OUT/IN
44. ASC System ON/OFF
45. ASC Conv. 6 ON/OFF
46. ASC Extended Use ON/OFF
47. ASC A.T.O. 3 Hr. or 11 Hr.
48. ASC Spin or Attitude
49. ASC Spin-up or De-spin
50. ASC Mode (2 or 4) or (1 or 3)
51. ASC Mode (3 or 4) or (1 or 2)
52. ASC Mag. Threshold High or Low
53. ASC Solar Aspect Sensor ED 8
54. ASC Solar Aspect Sensor ED 7
55. ASC Solar Aspect Sensor ED 6
56. ASC Solar Aspect Sensor ED 5

(Digital Sub-Commutator No. 1 Channels cont'd)

27. Fixed Freq. Sounder Bit 3 (2^2)
28. Pre-Amp. Selection Wideband/Switched Band
29. Pre-Amp. Band Bit 1 (2^2)
30. Pre-Amp. Band Bit 2 (2^1)
57. ASC Solar Aspect Sensor ED 4
58. ASC Solar Aspect Sensor ED 3
59. ASC Solar Aspect Sensor ED 2
60. ASC Solar Aspect Sensor ED 1

NOTE:

The mode indication immediately following the channel name is produced by a logical one at the sub-commutator input.

Logical One = +5 volts $^{+0}_{-2.5}$ Logic Zero = 0 volts ± 0.5

DIGITAL SUB-COMMUTATOR NO. 2 CHANNELS

1. PCM Encoder 1 ON/OFF
2. Command Receiver Flag (Note 1)
3. SPARE
4. SPARE
5. SPARE Tape Recorder, Record or Replay
6. SPARE
7. C.E.P. Exp't. Fixed Comp Mode
8. C.E.P. Exp't. Amp. Seq. Mode
9. C.E.P. Exp't. Fixed Bias Mode
10. C.E.P. Exp't. Probe 1 In Use
11. I.M.S. Exp't. ON/OFF
12. SPARE
13. S.P.S. Top Beam Shutter
14. S.P.S. Bottom Beam Shutter
15. S.P.S. Bottom Beam Step Counter, Stage 1
16. S.P.S. Bottom Beam Step Counter, Stage 2
17. S.P.S. Bottom Beam Step Counter, Stage 3
18. S.P.S. Bottom Beam Step Counter, Stage 4
19. S.P.S. Bottom Beam Mode
20. S.P.S. Exp't. Proton Data
21. PCM Encoder 2 ON/OFF
22. UHF Transmitter Mode Bit 1 (F1 or F3 or M2)
23. UHF Transmitter Mode Bit 2 (F1 or M1)
24. UHF Transmitter Mode Bit 3 (F3 or F4)
25. Tape Recdr. Replay or Record
26. R.P.A. Exp't. Flag 1 ('T' Comm)
27. R.P.A. Exp't. Flag 2 ('U' Comm)
28. R.P.A. Exp't. Flag 3 (Ion/Electron Mode)
29. R.P.A. Exp't. Flag 4 (Sat. Ion cycle)
30. I.M.S. Exp't. Calibrate or Data
31. I.M.S. Exp't. Zero/-6V
32. SPARE
33. PCM Word 20 Aur. Scan or VLF-Z
34. VLF Rcvr. Input: Torq. Coil or Sdr. Ant.
35. Red-Line Phot. Overload Prot. Disabled
36. Red-Line Phot. Protection ON/OFF
37. Red-Line Phot. FET Protection Disabled
38. Aur. Scan. Protection ON/OFF
39. SPARE
40. SPARE
41. Under Voltage Cut Out OUT/IN
42. UHF Trans Mode M2; CEP or SDR/VLF
43. VHF Trans SCO: Aur. Scanner or EHC
44. ASCS Input, Mag. I/II
45. ASC Conv. 6 ON/OFF
46. ASC Extended Use ON/OFF
47. SPARE
48. SPARE
49. ASC Spin-up or De-Spin
50. ASC Mode (2 or 4) or (1 or 3)
51. ASC Mode (3 or 4) or (1 or 2)
52. ASC Mag. Threshold High or Low
53. Mag. Drive Normal/Back Up Osc.
54. }
55. }
56. } SPARE
57. }
58. }
59. Sounder Mixed Mode ON/OFF
60. Extended/Normal Sweep

NOTE 1: This flag will change state whenever the command decoder unit issues a command pulse.

ANALOG SUB-COMMUTATOR NO. 1 CHANNELS

1. Hi-Level Zero Cal.
2. Hi-Level F.S. Cal.
3. Comm. Rcvr. 1 AGC
4. Sync Blink
5. C.E.P. Va
*6. Lo-Level Low Cal. (10.2 mV)
*7. Lo-Level High Cal. (80.2 mV)
*8. Temp. Sensor C (Battery 1)
9. C.E.P. T_e (also ASC-2-39)
10. C.E.P. V_s (also ASC-2-40)
11. E.P.D. 3V
12. E.P.D. 6V
13. Batt. 1 Voltage
14. Batt. 1 Charge Current
15. C.E.P. N_e Significant Figure
16. C.E.P. N_e Exponent
17. Converter 3 Voltage (10V)
*18. Converter 1 and/or Ant. Motor 1 Current
*19. Red-Line Photometer Current
*20. Temp. Sensor A (Battery 2)
21. Primary PA RF Voltage Monitor (also ASC-2-51)
22. Mag. I X200
23. Mag. II S600
24. Mag. I Z200
25. Battery 2 Voltage
26. Battery 2 Charge Current
27. I.M.S. Sweep
28. I.M.S. +12V Monitor
29. Converter 5 Voltage (18V)
*30. Converter 2 Current
*31. E.P.D. HV Reg. Current
*32. Temp. Sensor J (Top Head Shield)
33. Antenna 1 (Sector 3) Length
34. Antenna 2 (Sector 7) Length
35. Antenna 3 (Sector 1) Length
36. Antenna 4 (Sector 5) Length
37. Battery 3 Voltage
38. Battery 3 Charge Current
39. S.P.S. Bottom Beam Calibrate
40. IMS Exp't. Current
41. Clock Converter Voltage
*42 Converter 4 Current
*43. R.P.A. Exp't. Current
*44. Temp. Sensor I (Bottom Heat Shield)
45. Secondary PA RF Voltage Monitor (also ASC-2-15)
46. Red-Line Photometer High Voltage
47. R.L.P. Calibration Lamp Current
48. Batt #2 Load Current
49. C.D.R. Voltage
50. Undervoltage Cutout Voltage
51. Sounder SFO Ramp (also ASC-2-21)
52. Aurora Scanner Calibration Lamp Current
53. Tape Movement Sensor
*54. Converter 6 and/or Ant. Motor 2 Current
*55. E.P.D. Exp't. Current
*56. Temp. Sensor E (Solar Panel 1, Top)
57. Tape Recorder Pressure
58. Tape Recorder Temperature
59. C.E.P. Va (also ASC-2-11)
60. Batt #3 Load Current

* Indicates 100 mV Full Scale Channel.

ANALOG SUB-COMMUTATOR NO. 2 CHANNELS

1. Hi-level Zero Cal.
2. Hi-level F.S. Cal.
3. Sync Blink
4. Comm. Rcvr. 2 AGC
5. R.P.A. Program Monitor
*6. Lo-level Low Cal. (10.2 mV)
*7. Lo-level high Cal. (80.2 mV)
*8. Temp. Sensor F (Sol. Cell Panel 1 Bottom)
9. S.P.S. Top Beam Calibrate
10. VLF Exciter Output
11. C.E.P. Va (also ASC-1-59)
12. Antenna Bias Current
13. Battery 1 Discharge Current
14. OCL 1 Voltage
15. Secondary PA RF Voltage Monitor (also ASC-1-45)
16. Converter 1 Voltage (400 W Sec) +20V
*31. S.P.S. Exp't. Current
*32. Temp. Sensor N (Equat. Panel 4, IMS)
33. Aurora Scanner Scan Monitor
34. Aurora Scanner H.V. Monitor
35. C.E.P. Va
36. IMS Multiplier Gain
37. Battery 3 Discharge Current
38. OCL 3 Voltage
39. C.E.P. T_e (also ASC-1-9)
40. C.E.P. V_s (also ASC-1-10)
41. Converter 4 Voltage (18V)
*42. Torquing Coil and/or Ant. Motor 4 Current
*43. C.E.P. Exp't. Current
*44. Temp. Sensor K (Aurora Scan Optics)
45. C.E.P. Ion Slope
46. C.E.P. Amplifier Range

(Analog Sub-Commutator No. 2 Channels cont'd)

17. Converter 1 Voltage (400W Prim) +20V
*18. Converter 3 and/or Ant. Motor 3 Current
*19. Aurora Scanner Exp't. Current
*20 Temp. Sensor G (Auxiliary Heat Shield)
21. Sounder S.F.O. Ramp (also ASC-1-51)
22. Mag. I X600
23. Mag. I Y600
24. Mag. II Z600
25. Battery 2 Discharge Current
26. OCL 2 Voltage
27. IMS +5V Monitor
28. IMS Multiplier Monitor
29. Converter 2 Voltage (28V)
*30. Converter 5 Current
47. S.P.S. +3V
48. S.P.S. +21V
49. C.D.R. Current
50. Spacecraft Separation Indicator
51. Primary P.A. RF Voltage monitor (also ASC-1-21)
52. SDR Amp. Cal. Level
53. Converter 6 Voltage (+18V)
*54. Temperature Sensor H (Thrust Tube Below EV)
*55. Solar Aspect Sensor Monitor
*56. Temperature Sensor L (Redline Phot. Optics)
57. S.P.S. Prog. Power Supply, Top Beam
58. S.P.S. Prog. Power Supply, Bottom Beam
59. S.P.S. +4KV-E
60. S.P.S. -4KV-P

* Indicates 100 mV Full Scale Channel.

6. ATTITUDE SENSING AND CONTROL SYSTEM

6.1 GENERAL

The attitude sensing, and the spin and attitude control are independent subsystems sharing a common magnetometer, (Fig. 22). The magnetometer is connected in such a way that it operates for the ON command of the spin and attitude control system or the PCM encoders. Command control of the spin and attitude subsystem is independent of all other spacecraft systems.

6.2 FLUX GATE MAGNETOMETERS

Two magnetometers, shown in Figure 23, are operated simultaneously, one with four probes, the other with two. The designations and ranges of the probes are given in table 4 below. A right-handed orthogonal set shall be composed of X^1_{600}, Y^1_{600}, Z^1_{600}.

TABLE 4

Distribution of Magnetometer Channels

MAGNETOMETER	FULL SCALE RANGE (MILLIOERSTEDS)	PROBE	INDEPENDENT OUTPUT CONNECTED TO
I	±600	X^1_{600}	a) Analog Sub-Commutator II b) Essen. Housekeeping Commutator and/or (in Mag. II Failure Mode) to spin control system
	±200	X^1_{200}	a) Analog Sub-Commutator I
	±600	Y^1_{600}	a) Analog Sub-Commutator II

(Table cont'd on page 41)

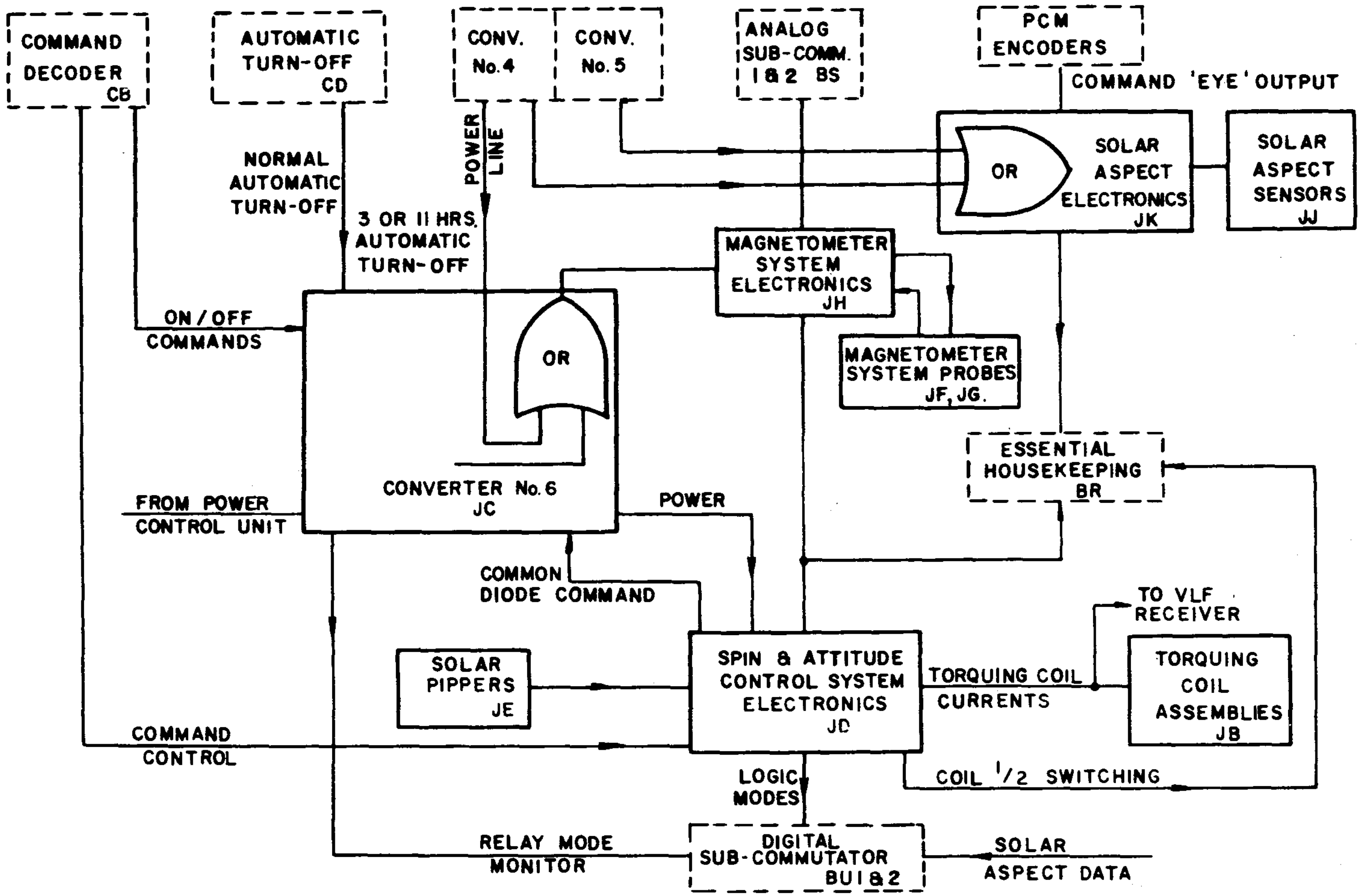


Fig. 22. ISIS-II Attitude Sensing and Control System.

TABLE 4

Distribution of Magnetometer Channels

MAGNETOMETER	FULL SCALE RANGE (MILLIOERSTEDS)	PROBE	INDEPENDENT OUTPUT CONNECTED TO
I	±200	Z^1_{200}	a) Analog Sub-Commutator 1 b) Essential Housekeeping Commutator and/or (in Mag II failure mode) to Attitude Control System
II	±600	S^2_{600}	a) Analog Sub-Commutator 1 b) Spin Control System and/or (in Mag I failure mode) to Essential Housekeeping Commutator
	±600	Z^2_{600}	a) Analog Sub-Commutator 2 b) Attitude Control System and/or (in Mag. I failure mode) to Essential Housekeeping Commutator

6.3 ATTITUDE SENSING

Two digital solar aspect sensors measure the angle of the sun line with respect to the spacecraft spin axis, (aspect angle). A three-axis flux-gate magnetometer measures the components of the local terrestrial magnetic field with respect to the spacecraft fixed axes. The attitude of the spacecraft is computed from the sensor and magnetometer data.

In sunlight the two solar aspect sensors shown in Figure 5, give an eight bit reading, in Gray code, of the aspect angle, this occurs twice for each 360° of the spacecraft rotation. This reading is sampled once each second by digital sub-commutator 1, see page 36. Redundant information is provided in a four-level staircase format on channels 13 to 16 of the essential housekeeping commutator.

A binary output from each sensor, which changes state at the time of the solar input to the sensors, is used to determine the spin direction. The binary output, "command eye", is on bit 8 of PCM word 3.

6.4 SPIN AND ATTITUDE CONTROL

A magnetic torquing system, in response to ground station commands, changes either the spin rate or the attitude of the spacecraft. Only one of these changes can be performed at a time. A block diagram of the system is shown in Figure 22.

In operation a magnetic moment (approximately 145 x 10^3 pole cm) is generated by controlling the current in a pair of aluminum wire coils which are mounted on the spacecraft frame. The locations of the coils in the spacecraft are shown in Figure 6.

The spacecraft spin or attitude is controlled, as a function of the magnetometer and solar pipper outputs, see Figures 22 and 23, which suitably time the coil-generated magnetic field to interact with the terrestrial magnetic field and produce the required torque.

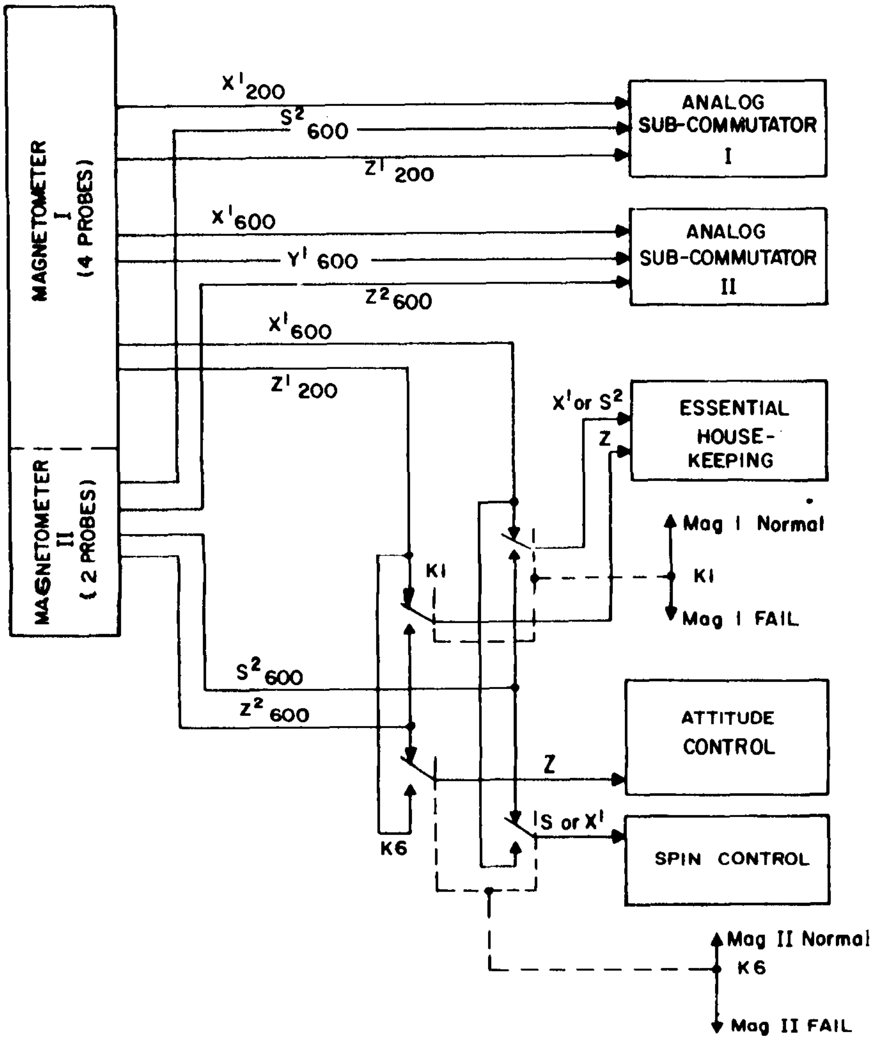


Fig. 23. Distribution of Magnetometer Outputs.

6.4.1 Spin Control

The spin control subsystem is switched by the output of the S^2_{600} magnetometer sensor, see Figure 23. The position of the probe is shown in Figure 8. In orbit the probe output will be sinusoidal with an amplitude and phase dependent upon the location of the spacecraft and the attitude of the spin axis. The coil current is reversed for each 180° of spacecraft rotation to maintain the control torque in the required sense.

6.4.2 Attitude Control

The Z^2_{600} magnetometer probe outputs, see Figure 23, and switching signals from two pairs of solar pippers are used to control the attitude subsystem outputs.

Controlled positive or negative precession of the spin axis is possible in two planes each containing the spacecraft spin axis. The first is a plane which includes the line from the sun through the solar pippers, JE1 and JE3 shown in Figure 5, to the spin axis. The second plane is at 90° to the first and contains a line through JE2 and JE4.

To ensure an unobstructed field of view the solar pippers are mounted at an angle, consequently the plane of precession containing the line through JE1, JE3 and the plane through JE2, JE4 are 17 1/2 per cent offset in relation to the y and x axes respectively.

6.5 MAGNETOMETER THRESHOLD LEVEL DETECTORS

Two "deadbands", in which the system will not provide control are defined by magnetic field (terrestrial) level detectors. The upper and lower edges of each deadband correspond to a positive and a negative field level:

Spin and attitude control using 600 mOe probe	High mode ±90 mOe Low mode ±45 mOe
Attitude control using 200 mOe probe	High mode ±30 mOe Low mode ±15 mOe

The threshold detector output turns OFF the current to the torquing coils when the terrestrial field is too low in magnitude for efficient use of the spin and attitude system.

6.6 DARKNESS INHIBIT

The darkness inhibit circuit turns OFF the attitude control within two minutes after the time the spacecraft passes into darkness. Unless overridden by an OFF command the inhibit is automatically removed when the spacecraft passes into sunlight.

7. POWER SYSTEM

The main purpose of the primary power subsystem (Figure 24) is to provide 125 watts for 4 hours per day with the spacecraft in a minimum sun oribt. The daily operating time of the spacecraft is based on predicted and measured values of charge-to-discharge current balance.

Three independent 8.5 amp hour batteries of 17 sealed nickel cadmium cells are each employed to provide +21.5 volts with respect to spacecraft ground. An array of n-on-p solar cells comprising 16 flat solar cell panels is fitted symmetrically around the spacecraft surface. The array provides three (1 amp maximum) individual charge rails, one for each of the batteries. Overcharge limiting is controlled by coulometers which are switched in or out by command. A power conditioning subsystem controls the distribution of the load between batteries.

Five main dc-dc converters are employed with operating frequencies in the range 33–42 kHz. Voltage and/or current limiter circuits are provided for the command system, ATO clock and programmer, tape recorder, and a number of the experiments.

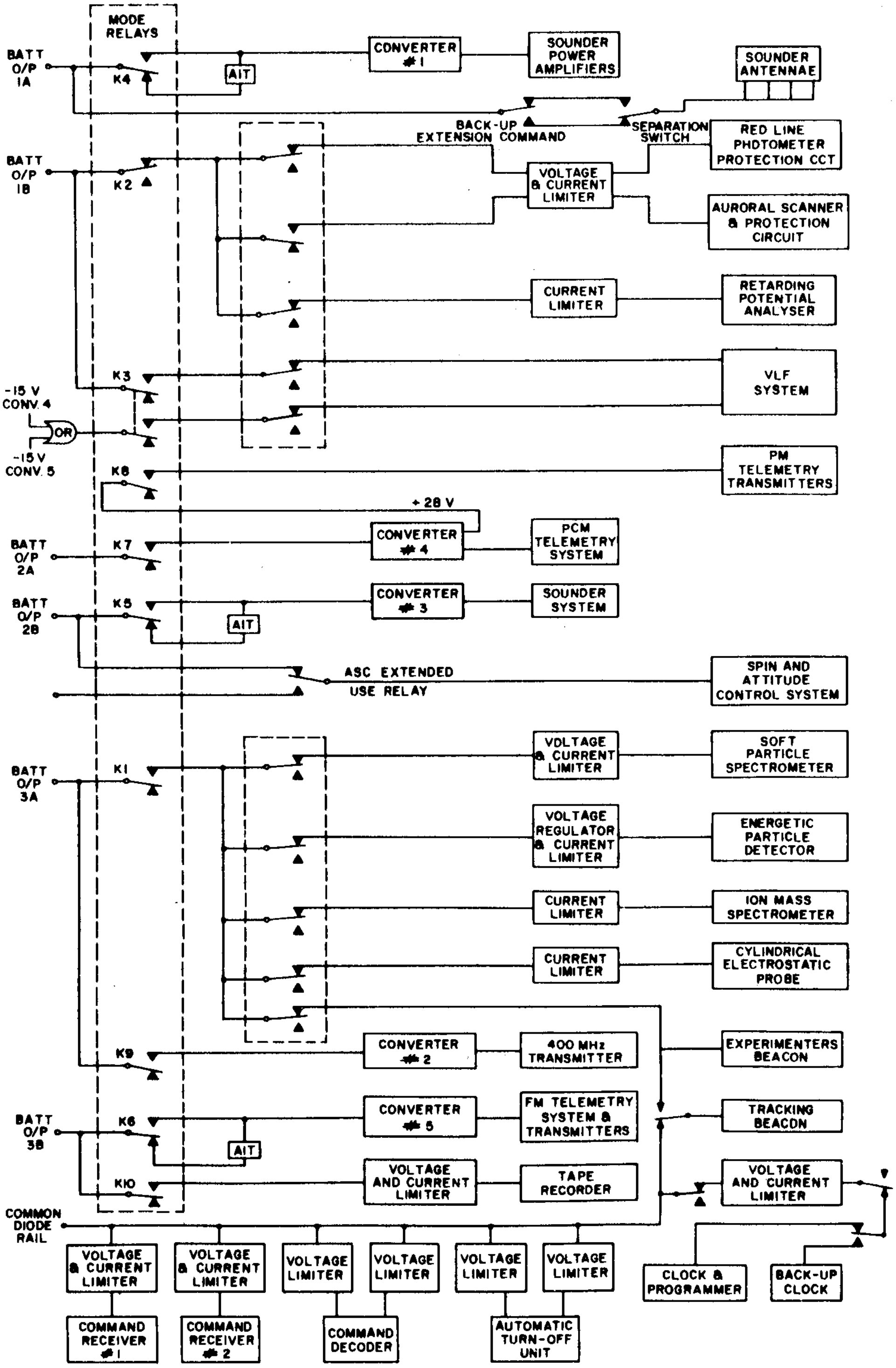


Fig. 24. ISIS-II Power System.

TABLE 5

Spacecraft Battery Load Distribution

	Battery 1	Battery 2	Battery 3	Common Diode Rail (CDR)
	Converter 1	Converter 4	Converter 2	Command Receiver
	Retarding Potential Analyzer	Converter 3	Converter 5	Command Decoder
LOADS	Aurora Scanner	ASC System	Soft Particle Spectrometer	ATO Unit
Unit or	Red Line Photometer		Energetic Particle Detector	Clock and Programmer
Unit Group	VLF Receiver Pos. Line		Ion Mass Spectrometer	UVC Cct (in Power Control Unit)
	Sounder Antenna Motors		Cylindrical Electrostatic Probe	OCL Ccts (in Power Control Unit)
			VHF Beacon Experiment	
			Tracking Beacon	
			Tape Recorder	

TABLE 6

ISIS-II Load Currents

Load	Input current required by loads 21.5V battery voltage at room temp. (mA)	
Unit or Group	Nominal	Limit
Converter 1 – with 400 W P.A.	959	2500
Converter 2	1002	2500
Converter 3 – normal	901	2500
– with Amplitude Calibrator	1167	2500
Converter 4 – with Transmitter ON	1226	2500
– with Transmitter OFF	771	2500
Converter 5	935	2500
VLF Receiver, positive line	55	100
VHF Beacon Experiment	45	100
Soft Particle Spectrometer and Protection Cct.	215	400

(Table cont'd on page 46)

TABLE 6

ISIS-II Load Currents

Load Unit or Group	Input current required by loads 21.5V battery voltage at room temp. (mA) Nominal	 Limit
Cylindrical Electrostatic Probe and Protection Cct.	93	340
Energetic Particle Detector and Protection Cct.	192	390
Ion Mass Spectrometer and Protection Cct.	336	780
Retarding Potential Analyzer and Prot. Cct.	158	340
Aurora Scanner	350	500
Red Line Photometer	150	250
Tape Recorder (Record)	300	1000
Tape Recorder (Replay)	580	1000
ASC System	1102	2530
Sounder Antenna Motors	320	2000
Command System (Standby)	100	– from CDR
UVC Cct. & Voltage Monitors (Standby)	30	– from CDR
Tracking Beacon	40	100 from CDR

TABLE 7

System Performance

Mode	Average Load Current Battery 1 (mA)	 Battery 2 (mA)	 Battery 3 (mA)	Balance Efficiency (per cent)	T1 Hours/Day	T2 Hours/Day
A1	1627	2127	1861	89	9.8	4.8
B1	1014	901	935	94	21.6	10.0
C1	713	2127	1861	74	9.8	4.8
D1	1262	2127	1861	82	9.8	4.8
G1	1672	2127	1861	89	9.8	4.8
A2	1672	1672	1226	91	12.6	6.1
B2	1014	1672	300	60	12.6	6.1
C2	713	1672	1226	72	12.6	6.1
D2	1262	1672	1226	83	12.6	6.1
G2	1672	1672	1226	91	12.6	6.1
AIT	959xK	901xK	935xK	97	24.0	24.0
F1–F4	–	–	1582	–	13.3	6.4

NOTES:

1. K is the mark/space ratio in the AIT mode.

2. T1 is the average operating time per day with the spacecraft operating only in the mode indicated, at launch, in orbital sunlight.

3. T2 is the average operating time per day with the spacecraft operating only in the mode indicated, after one year, in minimum (70 per cent) sunlight.

4. With the spacecraft in orbital sunlight, the typical average charge current is 0.92A at launch and the minimum average charge current (in 70 per cent sunlight) is 0.47A after one year in orbit.

5. The charge efficiency used in these calculations is 90 per cent.

8. IONOSPHERIC SOUNDER

The topside ionospheric sounder is a pulsed system, transmitting in the frequency range 0.1 to 20 MHz. Various operating modes (see pages 5 and 9) are available on command and include both fixed frequency and swept frequency operation (Fig. 25, a system block diagram). The antennas employed for this system are extended from the spacecraft after separation from the third stage of the launch vehicle. A common transmit/receive antenna system is used.

8.1 SOUNDER CONTROL

The spacecraft sounder control unit performs the following functions:

(a)	Sweep Generator	– To generate a voltage ramp for use by the Voltage Controlled Oscillator (VCO), and to generate frame reference pulses.
(b)	Timing Generator	– To generate pulse waveforms occurring at the line frequency.
(c)	Sequencer	– To generate switched dc voltages which are used to select the passband in the receiver preamplifier.
(d)	Mode Control	– To generate or control waveforms in accordance with the various modes of operation of the spacecraft.
(e)	Video Adder	– To sum the various signals which make up the video output signal illustrated in Figure 30.

8.2 DEFINITIONS

The following terms will be used in this description:

(i) Line is the period between transmitter pulses, occurring at a PRF of 45 pps.

(ii) Frame is the period of the voltage ramp applied to the VCO, being approximately 20 seconds in duration during extended mode and 10 seconds in the normal mode.

(iii) Flyback is the period following each sweep during which the voltage ramp returns from a maximum level to the start of sweep level (0.1 MHz), as shown in Figure 25.

(iv) Video is the detected output of the Sounder Receiver, and will include both an echo pulse and receiver and background noise.

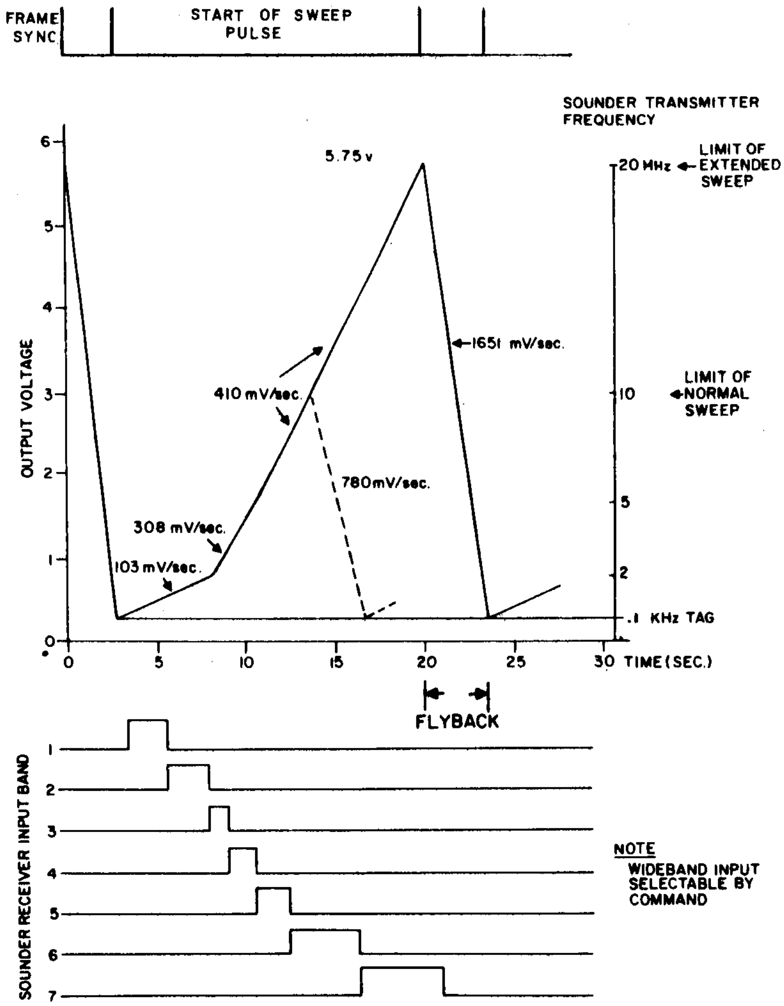


Fig. 25. Ramp and Band-Switching Control.

8.3 SOUNDER TECHNIQUES

A swept frequency signal is amplified in the class A, pulse biased wideband power amplifiers to provide an output of 400 watts pulse power* at 45 pps. A back-up 400 watt power amplifier is included in the system and may be selected by command. The power amplifiers are designated 400 W primary and 400 watt secondary; see Figure 27.

The transmitted swept frequency signal is derived from a voltage controlled varactor oscillator operating between 47.1 and 67 MHz. An additional mixer is used to obtain the sounder transmitter RF drive signal, which sweeps from 0.1 – 20 MHz.

The transmitter output feeds the sounder antennas via a passive network which provides cross-over coupling, as a function of frequency, at the interface between the transmitter and either the long (240 ft) or short (61.5 ft) sounder dipole antennas (Fig. 27). The cross-over frequency is 5 MHz, with a 12 dB minimum power isolation between antennas, below 4 MHz and above 6 MHz. A 30 MHz low-pass filter, also at this interface, attenuates signals to the sounder receiver above 30 MHz, and prevents desensitization of the command receivers by the sounder transmission.

* Pulse power output into a 400 ohm resistive load.

ISIS-II PCM ENCODER DATA ASSIGNMENTS AND SOUNDER TRANSMITTER TIMING

Bit Numbers →

Word Number ↓	1	2	3	4	5	6	7	8	
1	0	0	0	0	1	0	0	1	Frame Sync
*2	1	1	0	1	0	1	1	1	Frame Sync
3	Ret. Pot. Analyzer Range 1	Ret. Pot. Analyzer Range 2	Ret. Pot. Analyzer Range 3	Polar-ity	Sounder Freq. Marker	Dig. Sub-Comm #1	Clock Time Code	Solar Sensor Command Eye	Parallel Access Data
4	Dig. Sub-Comm #2	Clock Prog'r & Comm'd Total'r	Frame Counter Code Bits 2^5	2^4	2^3	2^2	2^1	2^0	Parallel Access Data
5	Ion Mass Spectrometer (High Mass Peaks)								Analog Data
6	Cylindrical Electrostatic Probe (Linear Amp. Output)								Analog Data
7	Cosmic Noise (Sounder Receiver AGC)								Analog Data
8	Red-Line Photometer (Intensity Level)								Analog Data
9	Analog Sub-Comm No. 1								Analog Data
*10	Analog Sub-Comm No. 2								Analog Data
11	Cylindrical E/S Probe (Log Amp/AC Amp Output)								Analog Data
12	Retarding Potential Analyzer								Analog Data
13	Energetic Particle Detector								Serial Digital
14	Energetic Particle Detector								Serial Digital
15	Soft Particle Spectrometer (Processor 'A')								Serial Digital
16	Soft Particle Spectrometer (Processor 'B')								Serial Digital
17	Ion Mass Spectrometer (High Mass Peaks)								Analog Data
*18	Cylind. E/S probe (linear Amp Output)								Analog Data
19	Cosmic Noise (Sounder Receive AGC)								Analog Data
20	VLF Impedance Phase Data OR Aurora Intensity								Analog Data
21	VLF Impedance Current Data								Analog Data
22	VLF Receiver AGC Level								Analog Data
23	Ion Mass Spectrometer (Low Mass Peaks)								Analog Data
24.	Cylind. E/S Probe (First Difference/Va)								Analog Data

* The sounder transmit pulse will occur sequentially at words 2, 10, 18, 2..... during bits 2 and 3, since the sounder pulse rate is 45 pps and the PCM 60 pps.

Fig. 26. Sounder System Timing Format

Note: At initial turn-ON the first fixed frequency period will be a nominal 7 seconds in the normal sweep mode or nominal 3.3 seconds in the extended sweep mode. This occurs as a natural characteristic of the flyback circuit.

Echo pulses arrive at the sounder receiver input via the common sounder antennas, crossover network and T/R switch. A single conversion type receiver is used, designed to minimize intermodulation distortion. The receiver contains the following:

(a) Seven bandpass filters, switched into operation individually;

Band (1)	0.1 –	1.0 MHz
(2)	1.0 –	2.0 MHz
(3)	2.0 –	3.0 MHz
(4)	3.0 –	5.0 MHz
(5)	5.0 –	8.0 MHz
(6)	8.0 –	13.0 MHz
(7)	13.0 –	20.0 MHz

(b) A single wideband filter, which can be substituted, on command, for the seven narrow band filters.

(c) A low noise preamplifier in front of band (1).

(d) A low noise preamp after the filters of bands (2) to (7).

(e) A low noise mixer, with a local oscillator frequency of 24.1 to 44 MHz.

(f) Two crystal bandpass filters centered at 24.016 MHz.

(g) A video amplifier.

(h) AGC detector and amplifier.

A block diagram of the sounder receiver is shown in Fig. 27. The band switching signals from the control unit are shown in Fig. 25. Selection of either one of the band modes is arranged by switching the dc power within the unit by means of the commands; "select switched band" or "select wideband". The receiver local oscillator signal between 24.1 MHz and 47 MHz, is derived from the RF generator VCO or one of the fixed frequency oscillators, and thus tracks the transmitter frequency. An IF centre frequency of 24.016 MHz chosen to allow an "offset" of 23 kHz for frequency shifts in the VCO (sweep modes) during the elapsed time between transmission and reception. Two crystal filters define the bandwidth of 55 kHz ± 5 kHz (-1.5 db points) with a centre frequency of 24.016 MHz.

The two separate data outputs from the receiver are a detected signal (video) from the IF amplifier, and an AGC output voltage (cosmic noise output voltage). The video output post detection response extends from dc to 15 kHz; this output is fed to the video adder to be combined with synchronizing and calibration signals. The pulse response characteristic is shown in Figure 28. For echo pulses the response characteristic is linear/logarithmic. For more slowly varying signals AGC is provided by a linear gain amplifier with an attack time of 60 mSec and decay time of 12 mSec. The AGC (cosmic noise) characteristic as a function of RF input signal is shown in Figure 29.

An on-board sounder receiver amplitude calibration facility is provided which, when in use, can be commanded to three operating conditions; command 1, 2 or 3. Outputs at specified levels are fed to the sounder input. Amplitude calibration will be present for up to a maximum of two frame periods. Care will be required

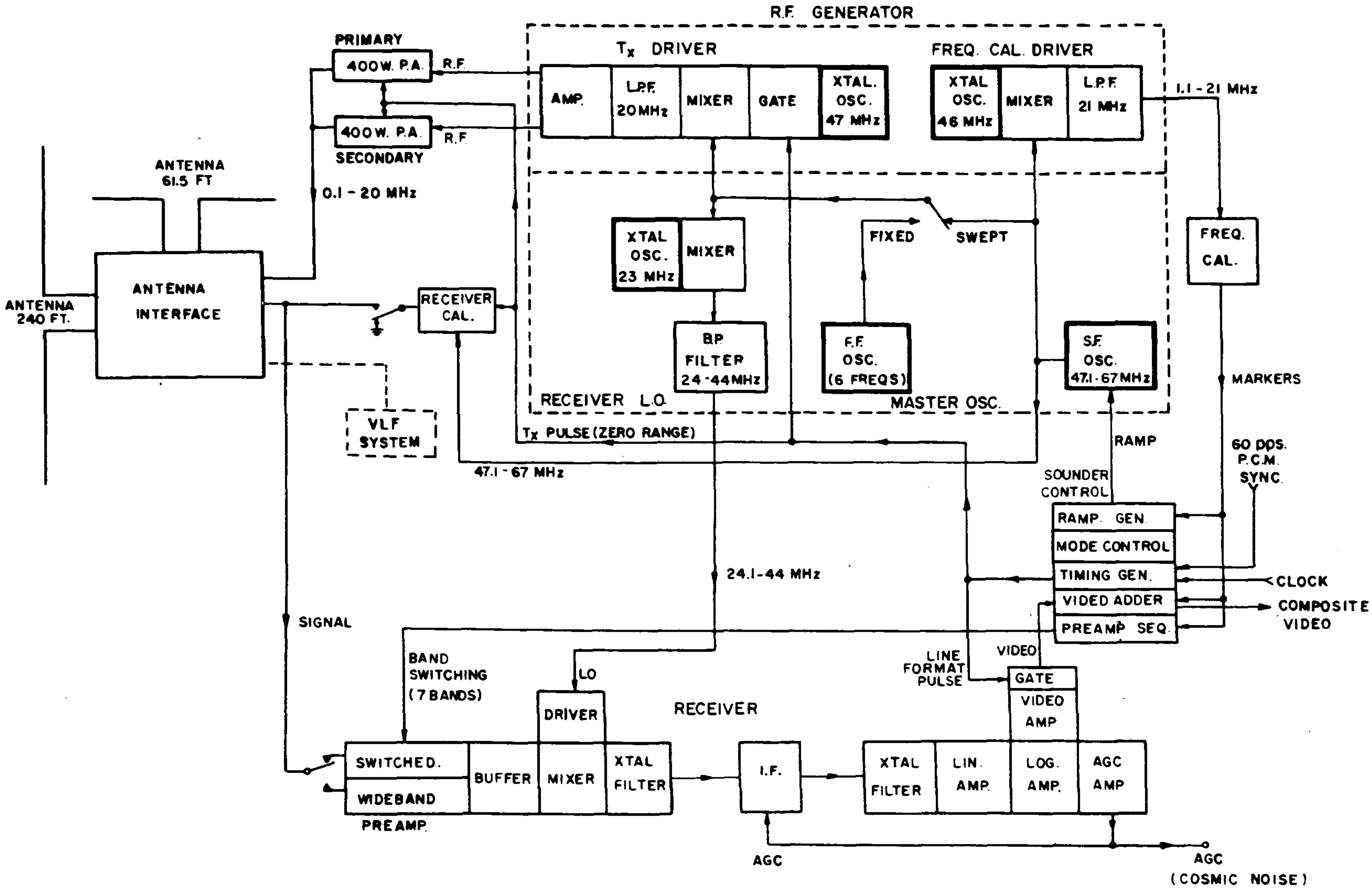


Fig. 27. Block Diagram of Sounder System.

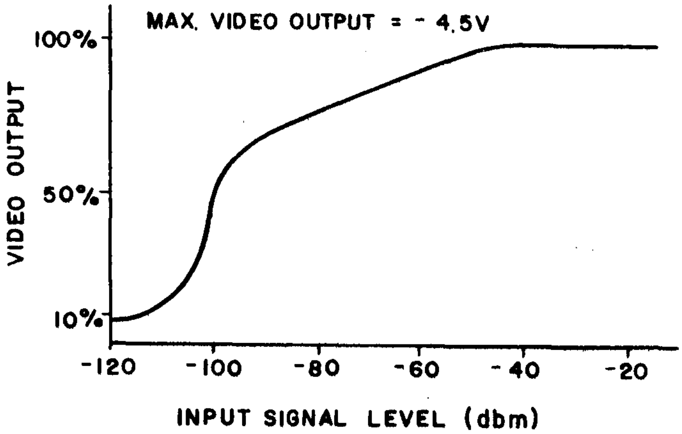


Fig. 28. Sounder R_x Pulse Response.

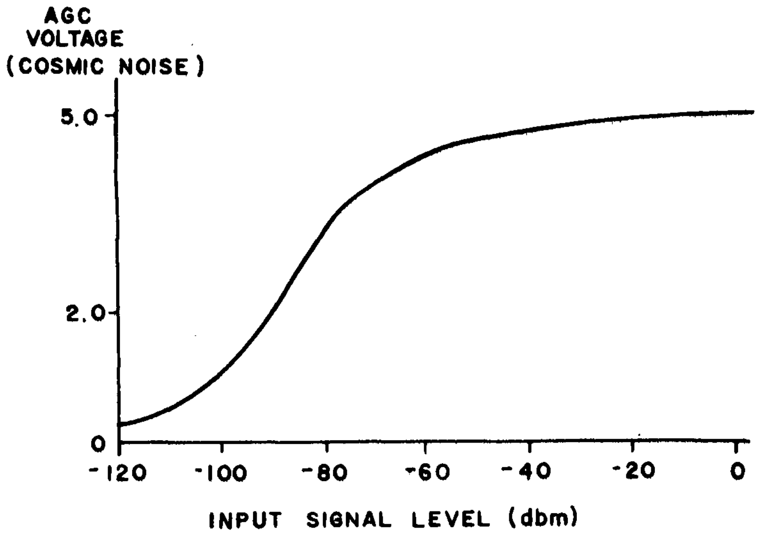


Fig. 29. Sounder R_x AGC Characteristics.

in timing the transmission of the command to ensure the maximum period of calibration data.

Command	Levels in dbm (0.1 to 20 MHz)		
	CW level	Cal. 1	Cal. 2
1	- 66	- 6	-36
2	- 86	-36	-66
3	-106	-66	-86

8.3.1 Composite Video Format (Figure 30)

The start of a fram of sounder video data is marked by a frame sync pulse of 16.67 msec duration, the leading edge of which is coincident with the start of flyback. For a 3.3 sec period following the frame sync, fixed frequency sounding can be selected. At the end of this period a 4 msec start-of-sweep pulse is generated followed immediately by a 100 kHz frequency marker which indicates the start of a sounder frequency sweep from 100 kHz to 10 MHz (or 20 MHz, if selected), figure 25. Figure 30 shows a typical line occurring during this frame. Five-level calibration is provided by the telemetry calibrate and video zero pulses.

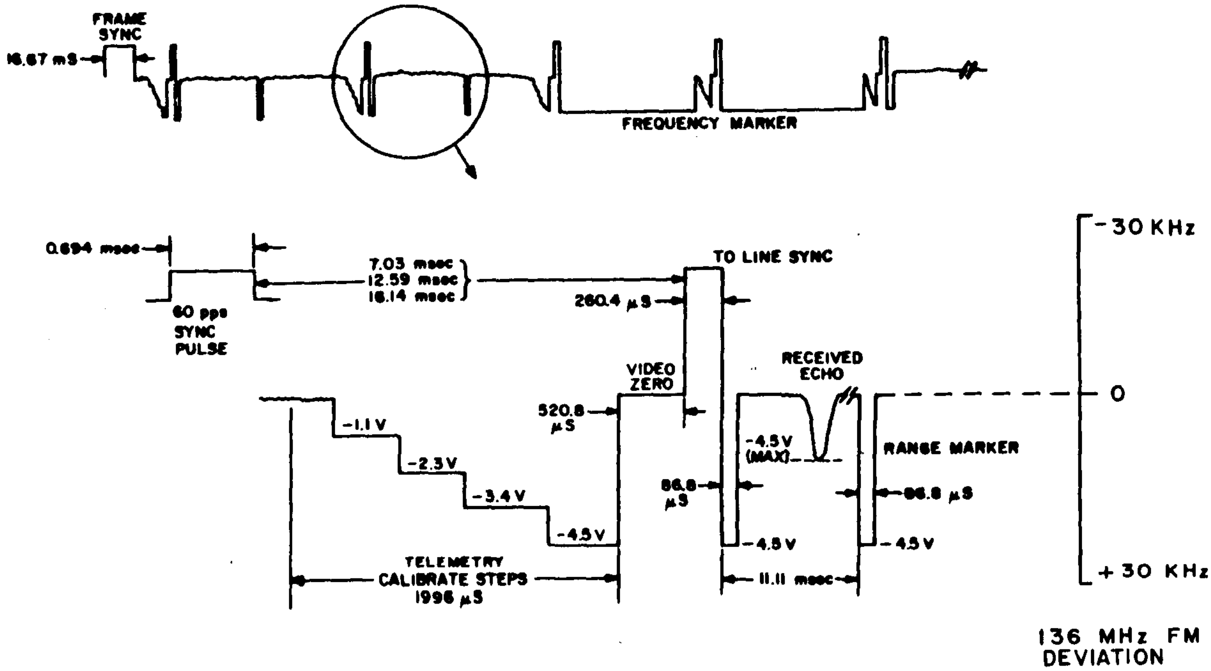


Fig. 30. Video Format.

Repetition Frequency	Signal	Nominal Deviation of 136 MHz FM Tx	Duration
	Frame sync pulse	26.4 kHz	16.67 msec
Frame	Start of sweep pulse	26.4 kHz	4.4 msec
	Telemetry Cal		
	1. (-1.125 volts)		499.1 μsec
	2. (-2.25 volts)		499.1 μsec
	3. (-3.375 volts)		499.1 μsec
	4. (-4.5 volts)		499.1 μsec
	Video zero	0 kHz	520 μsec
Line	Line sync	26.4 kHz	260 μsec
	Zero range	-18.0 kHz	86.8 μsec
	Receiver video output	-30 kHz max.	approx. 19 msec

8.3.2 Order of Precedence

The hierarchy of pulses in the video format is given below (1 – 4) and is such that the presence of a pulse listed in 1 below will blank all those of lower order and so on.

1. Frame sync, line sync, 100 kHz pulse.
2. Telemetry calibrate, zero range, range marker, video zero.
3. Frequency markers.
4. Receiver video.

8.3.3 Frequency Markers

Markers are one line wide minimum and two lines wide maximum.

9. EXPERIMENTS

9.1 SWEPT FREQUENCY SOUNDER (Principal Agency – Communications Research Centre, Ottawa, Ontario, Canada, (CRC) G. Lockwood/L. Petrie)

General

Solar irradiation of the earth's tenuous upper atmosphere ionizes the constituent gases and produces the ionospheric shell of ionization around the earth. The density of ionization rises from a very low value below an altitude of 100 km to a peak value which lies between 10^4 and 10^7 ion-electron pairs/cm^3 near a height of 300 km. Above the peak of the ionosphere ($h_{max}F_2$), the ionization density falls off with increasing height at a rate dependent on the local temperature, composition, magnetic field, gravity and production.

Until the advent of high-altitude rockets, the "topside" of the ionosphere (the region above the peak ionization density) had been studied only theoretically. The swept frequency topside sounders have made it possible to examine this region in detail and to answer a number of questions about its structure.

Objective

The objective of the ISIS-II swept frequency sounder is to determine the electron number density at and below the satellite, down to the peak of the F layer of the ionosphere, along the orbit of the satellite. The electron density as a function of distance below the satellite is determined from the delay time of high frequency radar echoes reflected from the ionosphere, as a function of frequency. From repetitive measurements, the height, latitudinal, longitudinal and diurnal variation of the electron density can be studied. Also, the data yield information about the size and location of irregularities in the ionosphere.

Description

The propagation of high frequency radio waves within the ionosphere is governed by the plasma frequency (or electron number density) of the region through which the wave travels. An ordinary wave (left-circular polarization) cannot enter, and is reflected at the boundary of, a region in which the plasma frequency is greater than the wave frequency. The distance from the satellite to the region can be determined by measuring the time required for the wave to travel to the region and return to the satellite. The swept frequency sounder, which contains a swept frequency transmitter and receiver, makes this measurement as a function of frequency. The upper and lower frequency limits of the sounder are determined by the range of plasma frequencies expected over the range of heights sounded by the satellite. Sample ionograms obtained from the topside sounders in Alouette I and ISIS-I are shown in Figures 31a, 31b, 32, 33 and 34.

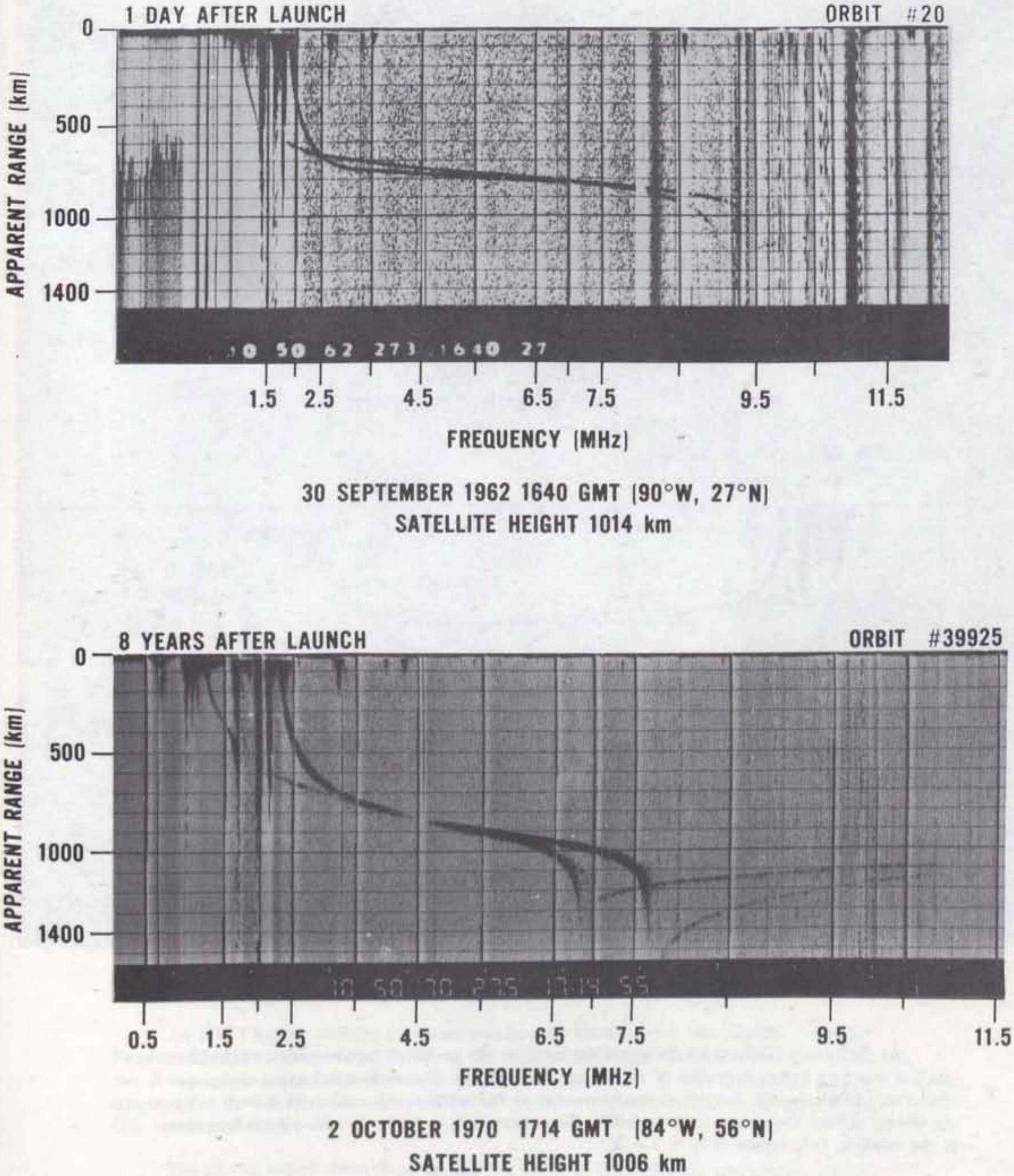
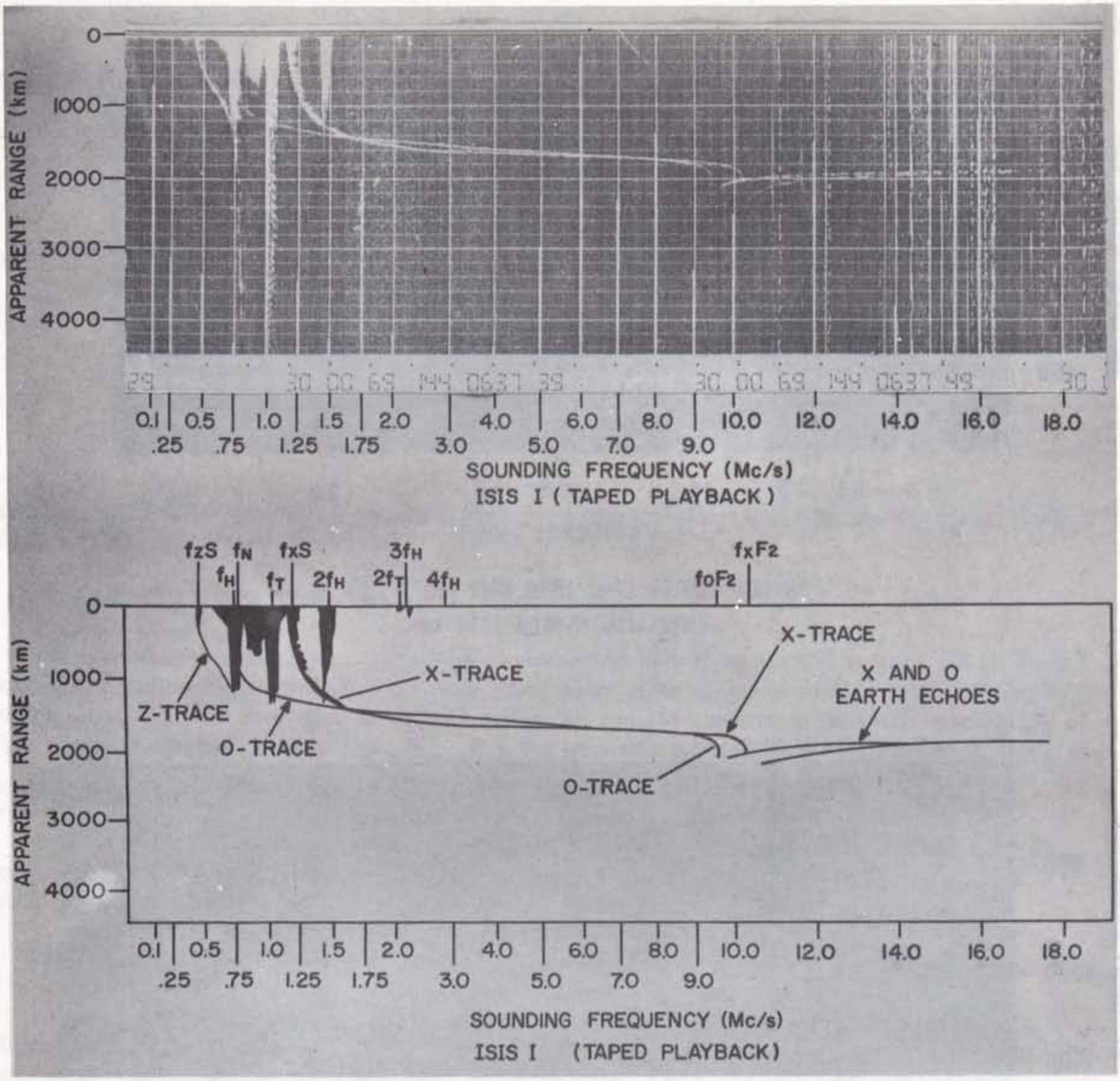


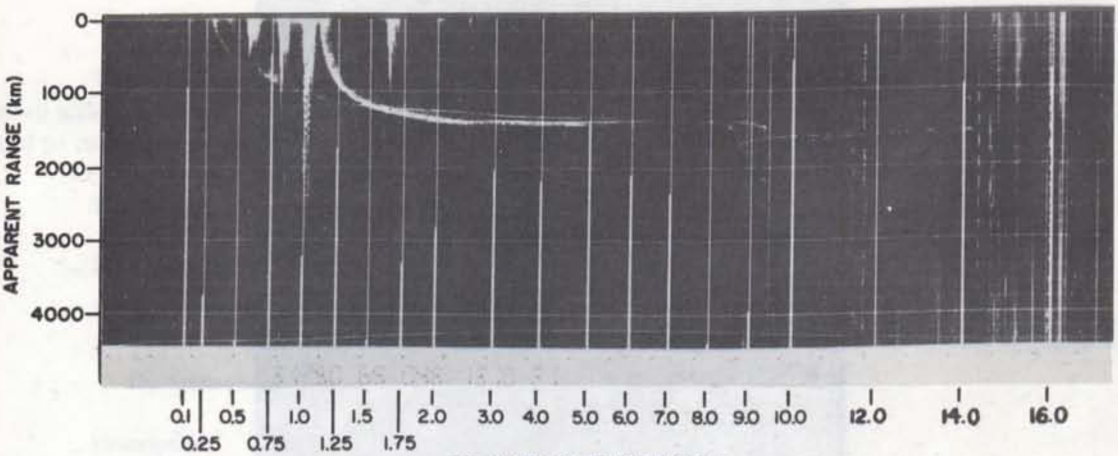
Fig. 31. Alouette I Ionograms.

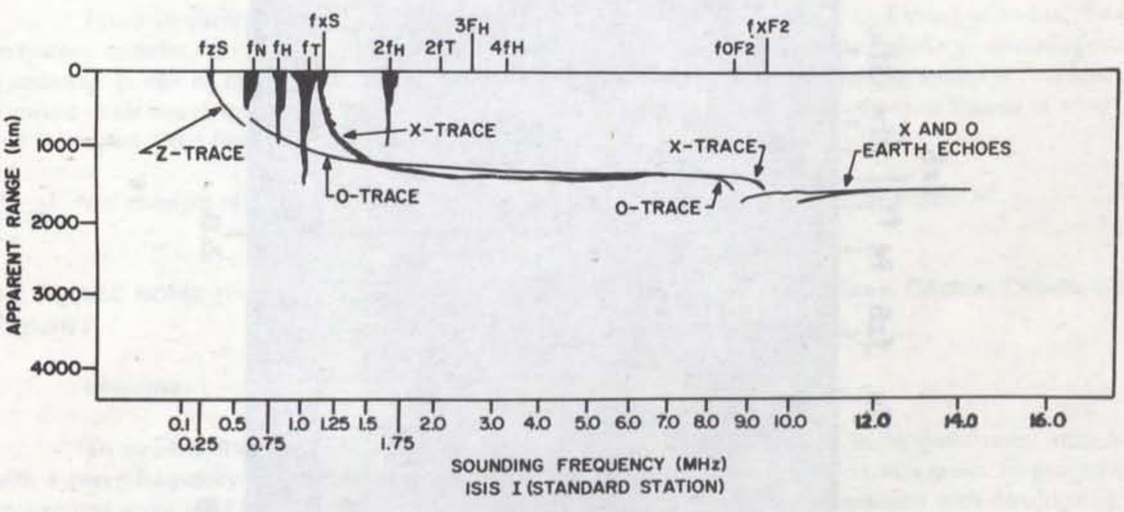


An ISIS I topside-sounder ionogram recorded by the on-board tape recorder when the satellite was near Perth, Australia, at an altitude of 1901 km. The various reflection traces are identified as follows: the Z-wave plasma frequency at the satellite, fzS, occurs at $X = 1 + Y$; the O-wave plasma frequency at the satellite, fN, occurs at $X = 1$; the X-wave plasma frequency at the satellite, fxS, occurs at $X = 1 - Y$.

The plasma spikes observed at the satellite occur at the following frequencies: fH, the electron gyrofrequency, at $Y = 1$; fN, the plasma frequency at $X = 1$; fT, the upper hybrid frequency, at $X = 1 - Y^2$; and nfH, the multiples of the electron gyrofrequency, at $Y = 1/2, 1/3, \ldots 1/n \ldots$.

Fig. 32. ISIS-I Ionogram (Recorder Playback).





An ISIS I topside-sounder ionogram recorded by Ottawa when the satellite was near Newfoundland, at an altitude of 1550 km. The various reflection traces are identified as follows: the Z-wave plasma frequency at the satellite, fzS, occurs at $X = 1 + Y$; the 0-wave plasma frequency at the satellite, fN, occurs at $X = 1$; the X-wave plasma frequency at the satellite, fxS, occurs at $X = 1 - Y$.

The plasma spikes observed at the satellite occur at the following frequencies: fH, the electron gyrofrequency, at $Y = 1$; fN, the plasma frequency, at $X = 1$; fT, the upper hybrid frequency, at $X = 1 - Y^2$; and nfH, the multiples of the electron gyrofrequency, at $Y = 1/2, 1/3, \dots 1/n \dots$

Fig. 33. ISIS-I Ionogram.

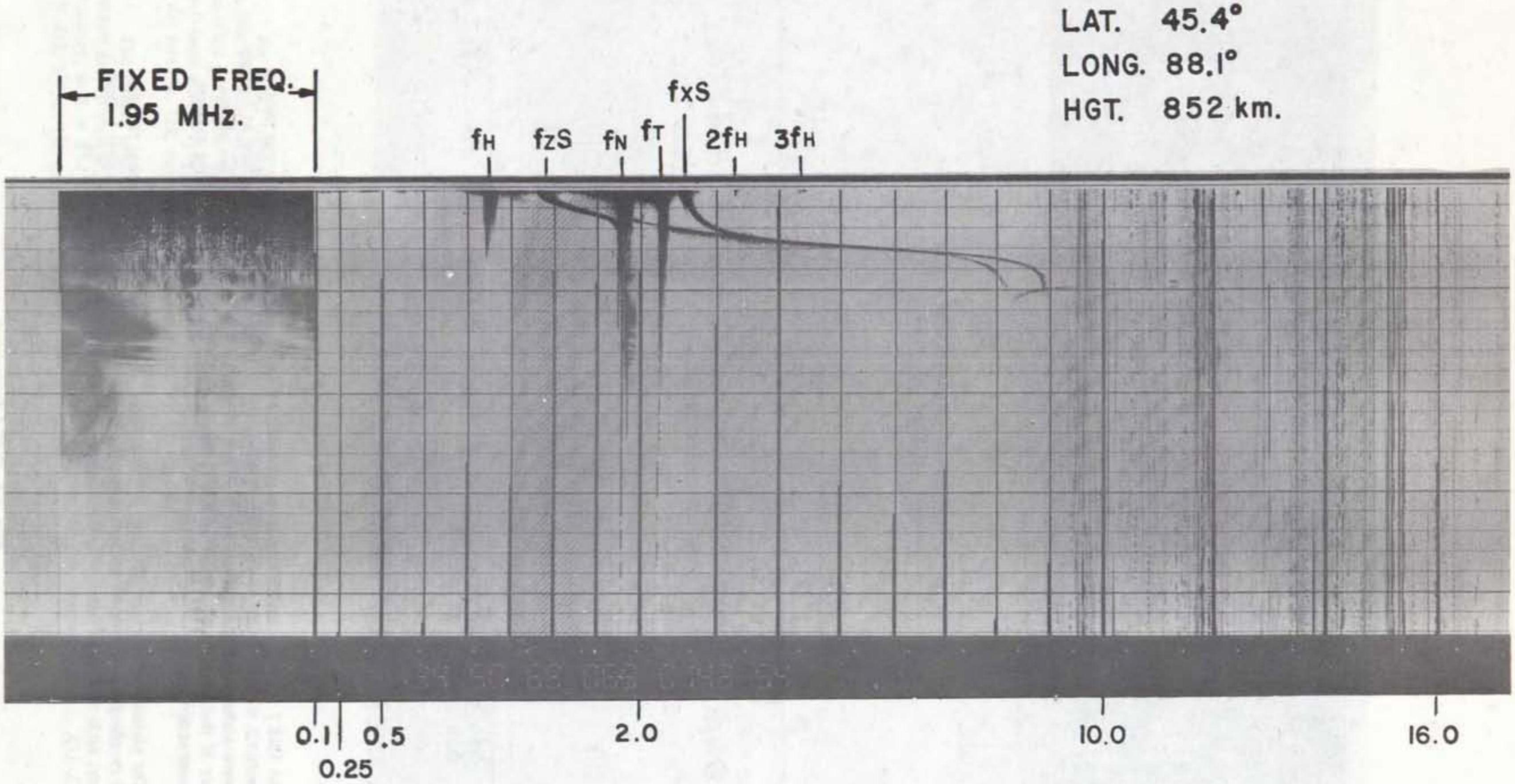


Fig. 34. ISIS-I Fixed Frequency Sounding.

9.2 FIXED FREQUENCY SOUNDER (Principal Agency – Communications Research Centre, Ottawa, Ontario, Canada (CRC) G. Lockwood/L. Petrie)

Objective

The fixed frequency sounder experiment on the ISIS-II spacecraft is designed to provide observation of small-scale irregularities which are too limited in extent to be easily investigated by the swept frequency sounder, and to complement the swept frequency sounders, particularly where rapid horizontal variations occur.

The primary scientific objectives of the fixed frequency sounder experiment are:

1. The study of irregularities in the high ionosphere.
2. The study of the fine structure of the plasma resonance phenomena.
3. The study of plasma mixing processes by observing the swept frequency receiver response while the transmitter remains at one of six selectable fixed frequencies.

Description

The fixed frequency sounder operates on six crystal controlled frequencies within the frequency range of the swept frequency sounder. These frequencies are 0.12, 0.48, 1.0, 1.95, 4.0, and 9.303 MHz.

Fixed frequency sounding will normally take place during the fly-back (3.3 secs.) period of the swept frequency sounder, but may be inhibited upon command. The sounder system is capable of operating with the transmitter in one of the six fixed frequencies, while the receiver performs a standard sweep in frequency ("mixed mode operation"). Another mode enables the sounder to operate with alternate frames of swept frequency and a selected fixed frequency.

An example of fixed frequency sounding obtained from ISIS-I is shown in Figure 34.

9.3 COSMIC NOISE (Principal Agency – Communications Research Centre, Ottawa, Ontario, Canada, (CRC) T. Hartz)

Objective

To measure the so-called cosmic noise, or more specifically the natural background radio noise level, with a sweep-frequency receiver orbiting substantially above the F-layer ionization maximum. In general the background noise level is determined by galactic noise, and information on its variation with direction in the galaxy and with observing frequency is desired, particularly at frequencies that cannot penetrate through the ionosphere. In addition, there are occasional noise enhancements above the galactic level which are of solar origin. These are associated with the ejection of material from the sun that can drastically affect the earth's upper atmosphere and ionosphere: a monitor of such solar noise emissions at low enough radio frequencies can provide detailed information of the passage of the solar particles through the sun's outer corona and into interplanetary space. Moreover, it appears that a study of such noise emissions can lead to quantitative determinations of electron density and temperature in the interplanetary regions.

Yet another contribution to the background noise level comes from radio emissions generated within the ionosphere and such noise, often of exceptionally great magnitude, is commonly observed at high latitudes. A detailed study of this phenomenon as a function of location, frequency, ionospheric parameters is desired, and particularly in a satellite which measures the local ionospheric conditions at the same time.

Description

The background noise data are obtained by monitoring the AGC voltage of the sweep-frequency sounder receiver (Fig. 29), which has been suitably calibrated.

9.4 VLF EXPERIMENT (Principal Agency – Communications Research Centre, Ottawa, Ontario, Canada, (CRC), R.E. Barrington)

VLF Receiver

The ISIS-II VLF experiment is basically a low frequency receiver covering the frequency range from .05 kHz to 30 kHz. Because of the large range in amplitude of naturally occurring VLF signals, the receiver has a dynamic range of about 80 dB, which is achieved by the use of an AGC system. The AGC level is telemetered to the ground along with the broadband output of the receiver which directly modulates the telemetry transmitter.

The VLF experiment provides information on:

(a) the relative abundance of H^+, $H_e{}^+$ and 0^+ ions in the vicinity of the spacecraft,

(b) the harmonic mean mass of the positive ions in the vicinity of the spacecraft,

(c) the propagation of VLF waves of natural origin and from ground-based transmitters,

(d) the various ion and hybrid resonances of a plasma that lie in the VLF band, and

(e) the association between VLF noise or emissions and the intense fluxes of energetic particles that precipitate into the lower ionosphere at high latitudes.

The relative abundance of the various ion species in the ionosphere are determined from ion whistlers. The proton whistler was first discovered from Alouette I data and the helium whistler from Alouette II. These signals are never seen by ground based VLF receivers. Figure 39 shows an example of both a proton and a helium whistler that have been generated by the normal whistler mode signal that originates in a lightning discharge. The frequencies at which the ion whistler traces first separate from the fractional hop whistler, are directly related to the fractional abundances of the different ion species.

A satellite VLF receiver with a large electric dipole antenna observes considerably more noise than a similar receiver on the ground. Sometimes some of this additional noise is triggered by whistler signals while at other times there is no obvious interaction. This noise usually has a sharp cutoff on its low frequency edge, and the cutoff frequency has been found to be the lower hybrid resonance of the plasma in the vicinity of the spacecraft. Since this resonant frequency depends on the harmonic mean mass of the positive ions, such noise observations can be used to determine this mean mass. Figure 40 gives some examples of lower hybrid resonance noise. The noise in the second and third panels of Figure 40 has been triggered by whistler mode signals, while that in the first and last panels does not appear to be triggered.

In addition to the two phenomena that have been described, the VLF receiver detects VLF emissions of various forms, and the relation of these to incident particle fluxes can be studied. Many VLF transmitters radiate on frequencies that are contained within the pass band of the receiver. These signals can be detected in the satellite and provide valuable information on the propagation of such signals.

The VLF receiver sensitivity is 20 μV across approximately 20 kΩ and the instantaneous output dynamic range is 15 dB above the AGC threshold. The dynamic range of the AGC is 60 dB over which range the receiver output does not increase by more than 6 dB.

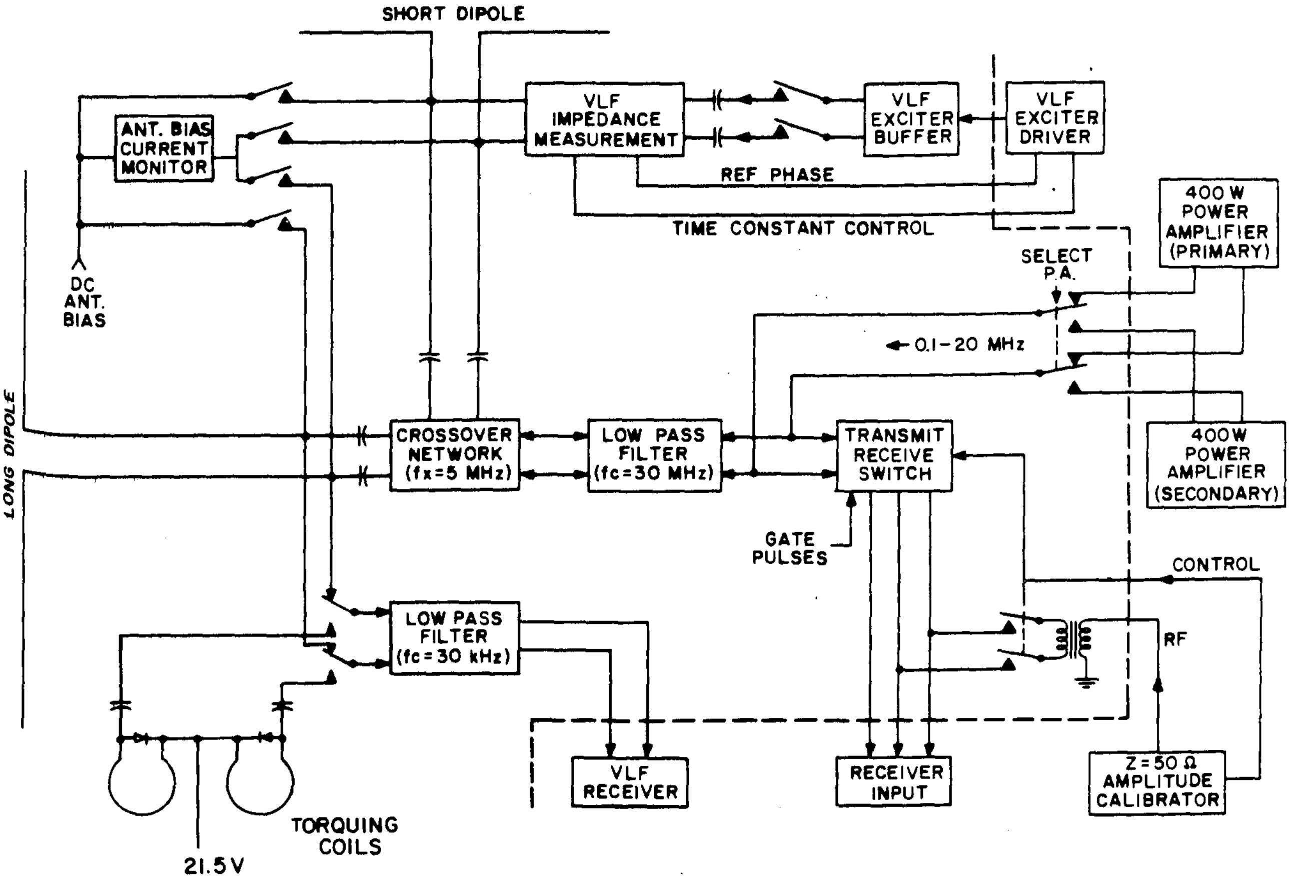


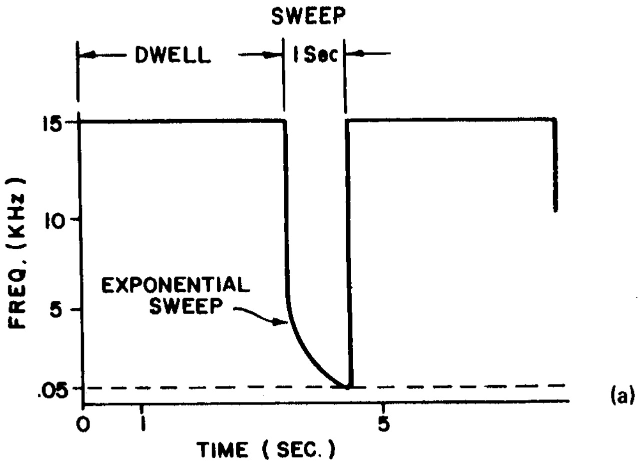
Fig. 35. VLF System

The data is telemetered in several ways:

(a) Real time via the 136 MHz (see page 28), or the 400 MHz transmitter. If the VLF is operated simultaneously with the sounder, the VLF output to the 136 MHz Tx is attenuated by a factor of 2.24:1 (maximum deviation ±13.4 kHz) and is blanked for 2.083 mS during the line format portion of the video train (Figure 30).

(b) Replay of tape recorded data in various ways on the 400 MHz Tx (see detailed Table on page 30).

	Freq. Range (kHz)	Deviation (kHz)
(i) VLF	0.2 – 100	± 100
(ii) VLF	0.2 – 40	± 100
(iii) VLF (simultaneous with sounder)	0.2 – 20	93 kHz SCO



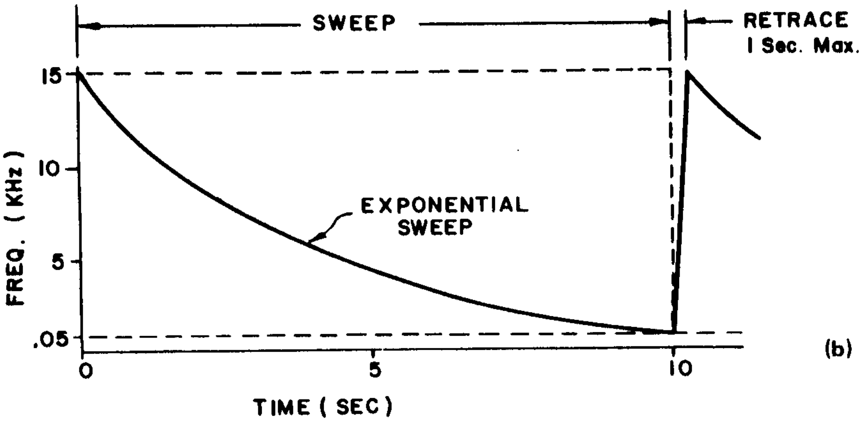


Fig. 36. (a) VLF Exciter Mode.
(b) Sounder Antenna Impedance Measurement Mode.

(c) The VLF AGC is encoded on word 22 of the PCM format. A faster sampling of the AGC data is also available on channel 29 of the essential housekeeping commutator.

VLF Swept Frequency Exciter

The Alouette I and II VLF receivers depended entirely on the observation of signals produced by natural causes. As has been indicated, such signals frequently provided information on the resonances of the plasma which enveloped the spacecraft. Much of the information obtained in this way was limited to particular latitudes, times of day, or heights depending on the nature of the phenomena that excites the resonances. In the VLF experiment of ISIS-I, a rather simple attempt was made to stimulate the ion resonances of the ambient plasma by an exciter contained within the spacecraft. A similar exciter will be included in the ISIS-II spacecraft.

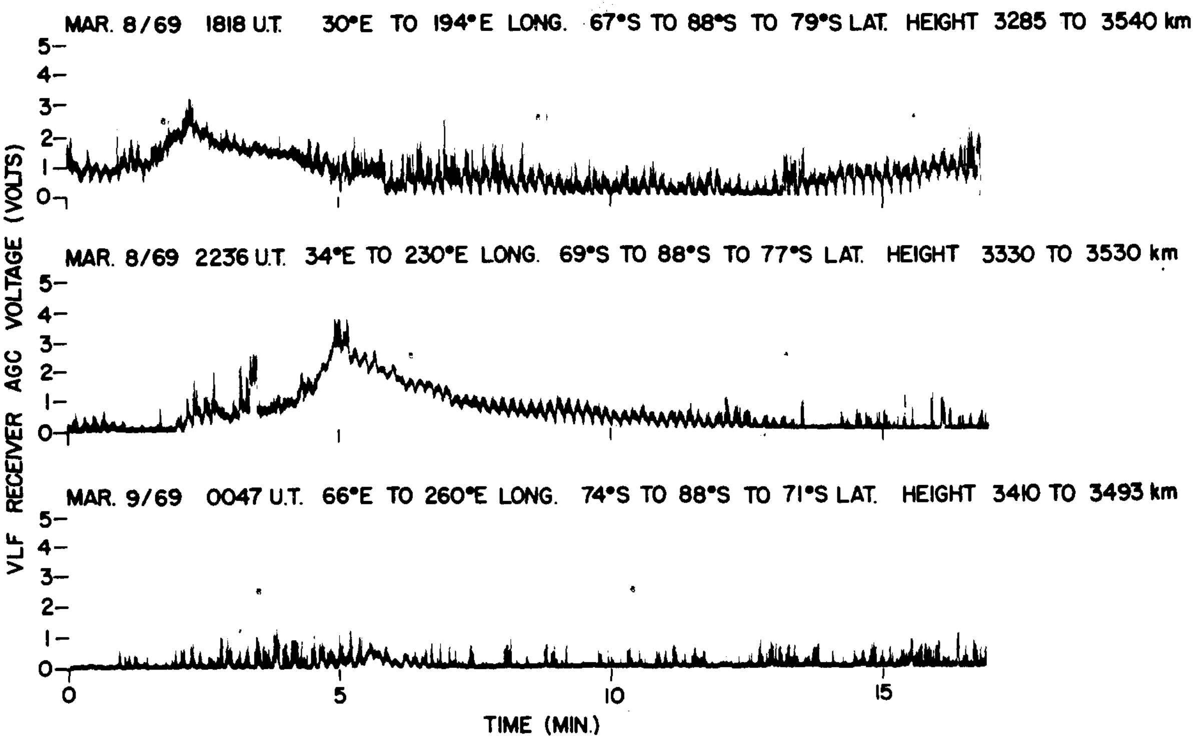


Fig. 37. ISIS-I Tape Dump.

The ISIS-II exciter produces a swept frequency audio signal, covering the range from 15 to .05 kHz in a period of about 1.0 seconds, (Figure 36 (a)). The output signal is fed to the short dipole sounding antenna. The output is approximately 5 volts peak-to-peak applied to the antenna. During these sweeps, the VLF receiver, which is connected to the long sounding antenna, observes the signals that are coupled between the two orthogonal sounding antennas by the ambient plasma, and also any noise signal that may have been generated in the plasma by the exciter.

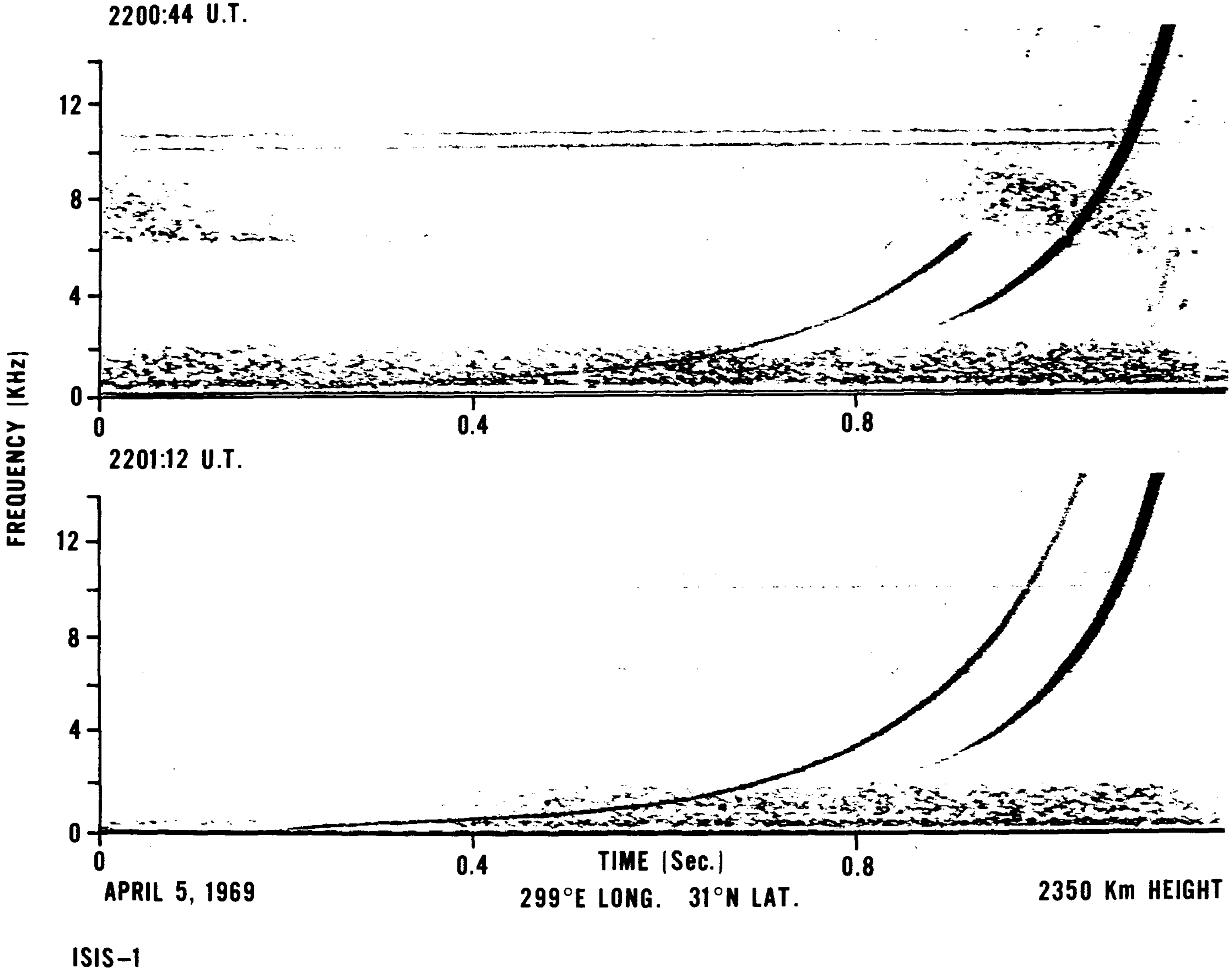


Fig. 38. VLF Data.

VLF Impedance Measurements (Figure 36(b))

At low frequencies, the behaviour of the long sounding antennas of the ISIS spacecraft is profoundly affected by the plasma in which they are enveloped. Even when dealing with field strengths at which the antennas behave as linear devices, the plasma greatly changes their impedance characteristics. Thus if the intensities of VLF signals are to be measured within the ionosphere it is mandatory that the impedance of the antenna be known. So far in the Alouette/ISIS program no measurements of antenna impedance have been made and hence only relative intensities of various types of VLF signals are known. With the ISIS-II experiment it is hoped that it will be possible to derive absolute values of field strength.

Since antenna impedance is a strong function of the plasma characteristics the possibility exists that the observed impedance can be related directly to some of the plasma parameters. If this proves possible then the impedance measurements become a new type of plasma probe. Of particular significance, in this context, is the fact that at low frequencies the ion composition of the plasma may be an important parameter in determining the antenna impedance especially in the vicinity of the lower hybrid resonance frequency. These possibilities can be evaluated only when data from the satellite becomes available, since the theory of antennas immersed in a plasma medium is not sufficiently well developed to provide reliable answers.

9.5 RETARDING POTENTIAL ANALYZER (Principal Agency – Goddard Space Flight Center, Greenbelt, Maryland, U.S.A., (GSFC), J. Donley, E. Maier)

Objective

The primary objective of the experiment is to measure the positive ion density, composition and temperature in the vicinity of the spacecraft. The secondary objective is to measure the thermal electron density and temperature, and the flux of suprathermal electrons. The effect on the measured quantities of special ionospheric events such as magnetic disturbances, red arcs, etc., will be studied. The long-term dependence of the composition, densities and temperatures upon geophysical parameters such as altitude, latitude, longitude, local time and season will be determined.

Description

The experimental hardware is a four-element sensor (three circular grids plus a circular collector) with associated electronics. The instrument is located on the satellite equatorial plane, and is operated alternately in an ion mode (for 24 seconds) and an electron mode (for 6 seconds). A varying voltage of 60 discrete steps is applied to one of the grids to retard the flow of ions or electrons from the ionosphere to the collector, the 60 steps taking one second. Appropriate potentials are applied to the collector and other grids to exclude particles of the opposite polarity and to suppress electron photoemission from the collector. The limits on the retarding voltage can be changed by ground command to take account of variation in the spacecraft electrical potential. The retarding voltage range is 6.6 volts for ions and 4.4 volts for electrons, except for one operational mode in which the lower limit on the electron range is -40 volts. The electrometer is calibrated and zero-adjusted every 30 seconds. For every value of retarding potential, the magnitude of the collected current is measured by a five-range, automatic-switching electrometer, and is subsequently telemetered. Analysis of the current-voltage curves (60 points making one curve) is carried out on the ground. The range of particle density determination is from about 10^2 to about $10^6/cm^3$.

9.6 ION MASS SPECTROMETER (Principal Agency – University of Texas, Dallas, Texas, John H. Hoffman)

The ion mass spectrometer in the ISIS-II satellite is a magnetic deflection instrument with two ion detector systems. The instrument scans the mass range 1–64 amu in two sections, 1–8 and 8–64, and measures the relative abundances of the ions collected in this mass range from the ambient ionosphere in the vicinity of the satellite. Two ion beams emerge from the magnet after traversing paths of radii 2.00" and 0.707" and are

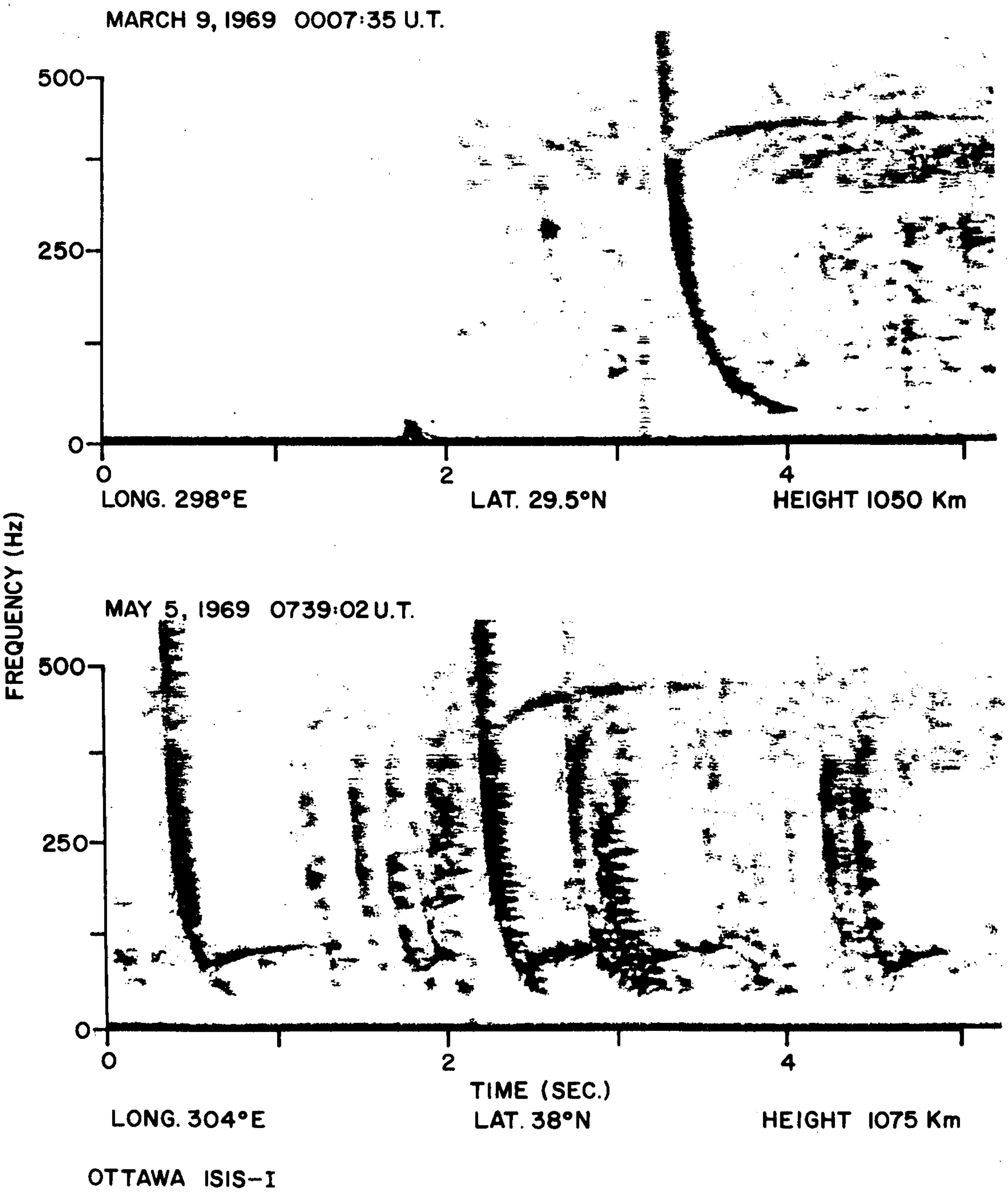


Fig. 39. ISIS-I Spacecraft Proton & Helium Whistler.

simultaneously detected by electron multipliers and log electrometer amplifiers. A "peaks" circuit following each amplifier detects the peak amplitude of the ion current. To reduce the required telemetry bandwidth the peak amplitudes rather than the entire mass data are telemetered. The complete mass range is scanned in 1 second when using the "peaks" detector. A backup mode is provided which produces an analog output with a sweep period of 8 seconds.

One of the problems to be studied by this mass spectrometer experiment is the composition, energy, and distribution in time and space of the polar wind particles. At altitudes of about 2500 km, some of the features of the polar wind are a predominance of O^+, total ion concentration of the order of 10^2 ions cm^{-3} (compared to about 10^4 ions cm^{-3} at mid latitudes), and upwards streaming of H^+ particles with velocities of 10 to 15 km sec^{-1}. Measurements made with Alouette II indicate that some of these effects are observable at altitudes well below the planned orbit of ISIS-II.

9.7 SOFT PARTICLE SPECTROMETER (Principal Agency – University of Texas, Dallas, Texas, W.J. Heikkila)

Objective

Intense fluxes of low energy particles, mainly electrons and protons, are the cause of auroral phenomena, and related geophysical disturbances. Unfortunately there have been but few observations of such particles in the past because of instrumentation difficulties. The soft particle spectrometer on ISIS-I has now provided good detailed information on the fluxes and energy spectra.

The flux and spectrum are found to vary considerably in space and in time. The spectrum often has a peak, sometimes a narrow one, on the 100 eV to 10,000 eV energy range. The energy deposition rate often reaches several ergs cm^{-2} sec^{-1}, and can represent the major energy input into the local upper atmosphere. Many other phenomena are closely related, e.g., ionospheric production and heating, optical and radio emissions, and geomagnetic disturbances. Because of the great variability of all these phenomena they cannot be understood quantitatively without simultaneous measurements of all the related parameters.

The soft particle spectrometer for the ISIS-II satellite is an improved version of that on ISIS-I. The energy resolution has been improved from $\frac{\Delta E}{E} = 0.8$ to $\frac{\Delta E}{E} = 0.2$; this will provide better data on the spectral line width and shape. Particles are detected in two separate beams, parallel (axial) and perpendicular (radial) to the satellite spin axis. The radial beam provides coverage over a range of pitch angles, while the axial beam monitors the flux at a pitch angle which is fixed over several spin periods, and which therefore provides a check on the variability of the flux on a short time scale.

Description

The particles of interest are admitted to the electron multipliers through small openings in the detector housing. The openings or collimator assemblies define beams of rectangular cross section with accurately known angular dimensions so that the solid angle viewed by the sensor is known. For each of the two beams, entrant particles of all energies pass through the collimator and between a pair of deflection plates one of which has a positive potential and the other an equal negative potential. The plates diverge slightly away from each other so that electron trajectories may curve one way, and positive ion trajectories the opposite way. For given potentials on the plates, the trajectories of electrons of a certain energy range will be such that these electrons strike a rectangular area defined by the first dynode of an electron multiplier. Electrons with lower energies will have more sharply curved trajectories and will miss this dynode area; they will be collected primarily by the deflection plates. Electrons with energies above the value determined by the deflector plate potentials will similarly miss the first dynode, and will be collected at the back of the instrument. An identical situation applies to the positive ions which of course are deflected in the opposite sense to a different electron multiplier. The two multipliers are mechanically identical, but their dynode chains are connected to ground at opposite ends.

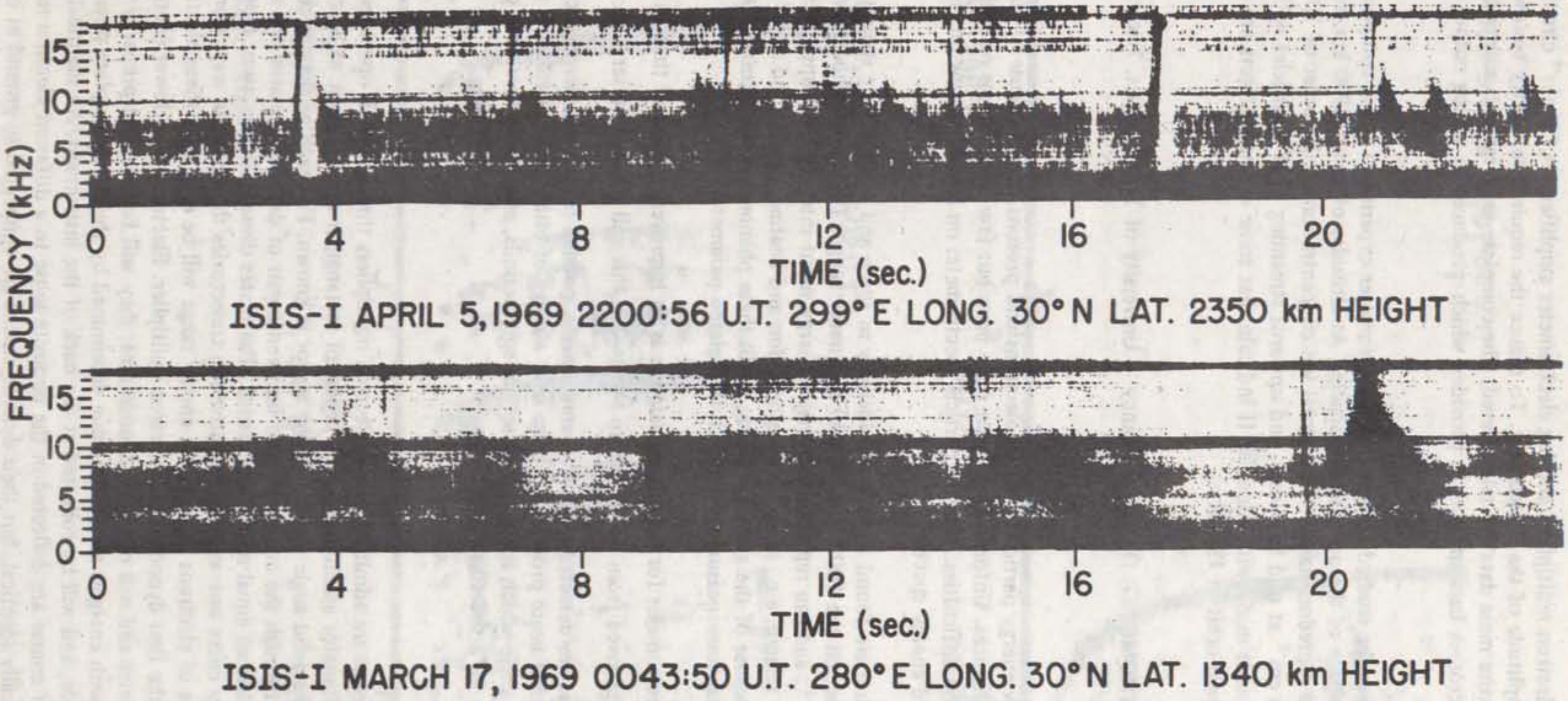


Fig. 40. ISIS-I VLF LHR Noise Band – Exciter On.

The energy of the particle striking the first dynode is thus a function of deflector plate potential. This potential can be changed in a wide variety of ways by means of "stored programs" selected by command.

Each particle striking the first dynode produces a cascade of secondary electrons along the dynodes, resulting in a shower of electrons which are collected by the anode. The shower lasts for 10 or 15 nanoseconds and produces a negative pulse at the anode. These output pulses are amplified, shaped, and counted.

By means of electronic gates, these pulses are admitted to the counter only during timed intervals of about 11 milliseconds' duration. These samples are taken at a rate of 60/sec and telemetered in digital format. The maximum and minumum pulse rates are about 2×10^7 per second and 20 per second; the latter figure is determined mostly by system noise including background activity.

The data processor is an assemblage of digital circuit elements, the main purpose of which is to compress the raw data count from a maximum of 18 binary bits to a uniform output code of 8 binary bits. Four of these bits are the 2nd, 3rd, 4th, and 5th most significant bits of the original count; (the most significant bit is known to be 1 and is not telemetered), and the other four comprise an "exponent" which indicates in a gross way the size of the original count. This method of compression still allows the original count to be known to within ±3 per cent with a dynamic range of 2×10^6.

Another essential component of the experiment is the programmed high voltage power supply which provides the program of voltages applied to the deflector plates. A separate balanced supply is used for each pair of plates (for each of two radial beams). The output voltage ranges from ±2.3 volts to ±2300 volts and is available either in swept or stepped format. In the swept mode the voltage rises to 2300 volts in 0.1 seconds and then decays exponentially to 2.3 volts in 0.9 seconds. In the other mode, 16 fixed voltages are selected in a predetermined sequence at a rate of 1 per second, or alternatively, any one of these may be selected by command and held indefinitely. This feature allows detailed spatial and temporal studies to be made of particles of a particular energy for each of the two beams. It also allows the experiment to be adapted to conditions found to exist after launch by examining the telemetered data. Since the experiment is supposed to operate for a year, there is sufficient time to do this.

A programmer provides electric waveforms which initiate and time the operations of the data processor. A control unit accepts the input commands and uses these to control the output waveform of the deflector plate power supplied.

Digital flag bits which define each of the various modes of operation are telemetered to ground stations along with the primary data.

Power consumption is about 3 watts and total weight about 10.5 pounds.

9.8 ENERGETIC PARTICLE EXPERIMENT (Principal Agency – National Research Council, Ottawa, Ontario, Canada, (NRC), (I.B. McDiarmid, J.R. Burrows).

Objective

The objective of the energetic particle experiment is to provide data which will aid in the understanding of:

(a) the mechanisms responsible for the production and control of the particles which populate the outer radiation zone and which sometimes precipitate into the atmosphere,

(b) the related problem of entry into the earth's magnetic field of solar flare particles,

(c) the nature of the distortions which occur in the earth's magnetosphere as a result of its interaction with the solar wind.

The experiment is designed to measure intensity, angular distributions, and energy spectra of electrons and protons. An energy range of 1 keV to 1 MeV is covered for electrons. There are two energy ranges for protons, "auroral" energies 2–20 keV and "solar flare" energies 0.8–30 MeV.

The Particle Detector System

The particle detectors can be divided into two groups: 1) those primarily sensitive to electrons and 2) those primarily sensitive to protons. All sensors sample directional fluxes, with directionality being provided by brass or aluminum collimators in front of the detectors. All sensors except two are mounted perpendicular to the spacecraft spin axis and thus provide angular distribution data with the periodicity of the satellite spin period. In order to interpret the angular distribution of the particle fluxes, the experiment's orientation with respect to the magnetic field is also required. This is provided by the satellite's magnetometers. The basic sampling rate or data readout is 3.75 frames/sec.

Spectral information is provided at low energies (1–10 keV for electrons and 2–20 keV for protons) by a stepped differential energy spectrometer. At higher energies, integral fluxes are measured at a selected set of energy thresholds.

The two axial detectors are thin window Geiger counters measuring integral fluxes of electrons with energies greater than ~20 keV and 40 keV respectively. Their response to protons occurs only at much higher energies (>250 and >500 keV respectively).

Much more complete spectral information is obtained from the array of radially mounted detectors. The differential energy spectrometer samples 8 energy channels sequentially every 1.067 seconds by means of a curved plate electrostatic analyzer operating from a programmed power supply.

Two channeltron multipliers are mounted behind the electrostatic analyzer to count the 0.6–10 keV electrons and the 2–20 keV protons respectively. The higher energy integral electron fluxes are measured by a Geiger counter and three silicon junction diode counters which simultaneously sample integral fluxes greater than 20, 40, 60, 90, 120, 150, 220 and 1200 keV at the data sampling rate of 3.75 frames/sec. Three other diode counters measure three differential energy bands of protons over the range 0.8–30 MeV and are essentially insensitive to electrons.

The various energy bands are selected for the diode detectors by linearly amplifying the proportional outputs of the detectors and discriminating the pulse heights at amplitudes corresponding to the required energies.

The particle detectors with their associated analog circuits, amplifiers, etc. and power supplies are contained in the detector (EL) unit. Data storage and readout is done by digital circuits in the encoder (EV) unit.

The experiment's 3 watt power converter operates at 3.0 kHz while the 0.2 watt supply for the electrostatic analyzer operates at 35–50 kHz. The following voltages >25V are employed in the experiment.

1)	+380V zenered down to +100V and +120V	junction diodes
2)	+760V regulated to +680V	Geiger counters
3)	+3100V	channeltrons
4)	+3400V → 340V eight step staircase waveform	electrostatic analyzer

Data Storage and Readout

Data storage and readout is provided by the experiment's data encoder. Counts from the various energy channels of the detectors are accumulated in parallel in thirteen 15 bit binary scalers and three smaller capacity scalers and read out serially into word positions 13 and 14 of the satellite's PCM encoder upon receipt of the word synchronization signal. Thus the experiment's 16 word subcommutator is read out in 16/60 sec giving a frame rate of 3.75 frames/sec. The serial readout to the PCM encoder is clocked by the 11.52 kHz bit synchronization signal. A sixteenth bit is added to each word upon readout to generate odd parity. A 16 bit frame marker word with evenpparity is generated once per frame. Figure 41 shows a block diagram of the experiment's data encoder. Only one scaler word is shown in detail. The others are identical except for small differences to accommodate the smaller scalers, the faster sampling rate of the stepped spectrometer (7.5 steps/ sec.) and some flag bit information.

The sequence of operations is as follows. The signal gate is normally open to accumulate counts into the scaler. On the leading edge of the word sync. signal, the 16 position word commutator is advanced to the next word (i.e., scaler #1) and the bit scanner is preset to the most significant bit position. The signal input gate is shut while the output scaler gate is opened for 1/60 second, and the parity generator is preset. The bit scanner then steps sequentially through the 15 data bit positions at 11.52 kHz clock rate and the output is fed through the output scaler gate and also to the parity generator. The sixteenth bit gate reads the parity generator state to complete readout in 13.9 sec. The stepped power supply is advanced on the leading edge of every eighth word synchronization signal.

List of Detectors

Parallel to spin axis

G_1	> 40 keV electrons > 0.5 MeV protons
G_2	> 20 keV electrons > 0.25 MeV protons

Perpendicular to spin axis

G_3	> 20 keV electrons > 0.25 MeV protons
CE	0.6 – 10 keV electrons
CP	2 – 20 MeV protons
DE1	4 integral channels: > 40 keV electrons > 60 keV electrons > 90 keV electrons > 120 keV electrons
DE2	> 145 keV electrons > 200 keV electrons
D_1	0.8 – 3.4 MeV protons 3 – 13 MeV alphas
D_2	3.4 – 12 MeV protons
D_3	1 MeV electrons 12 – 30 MeV protons

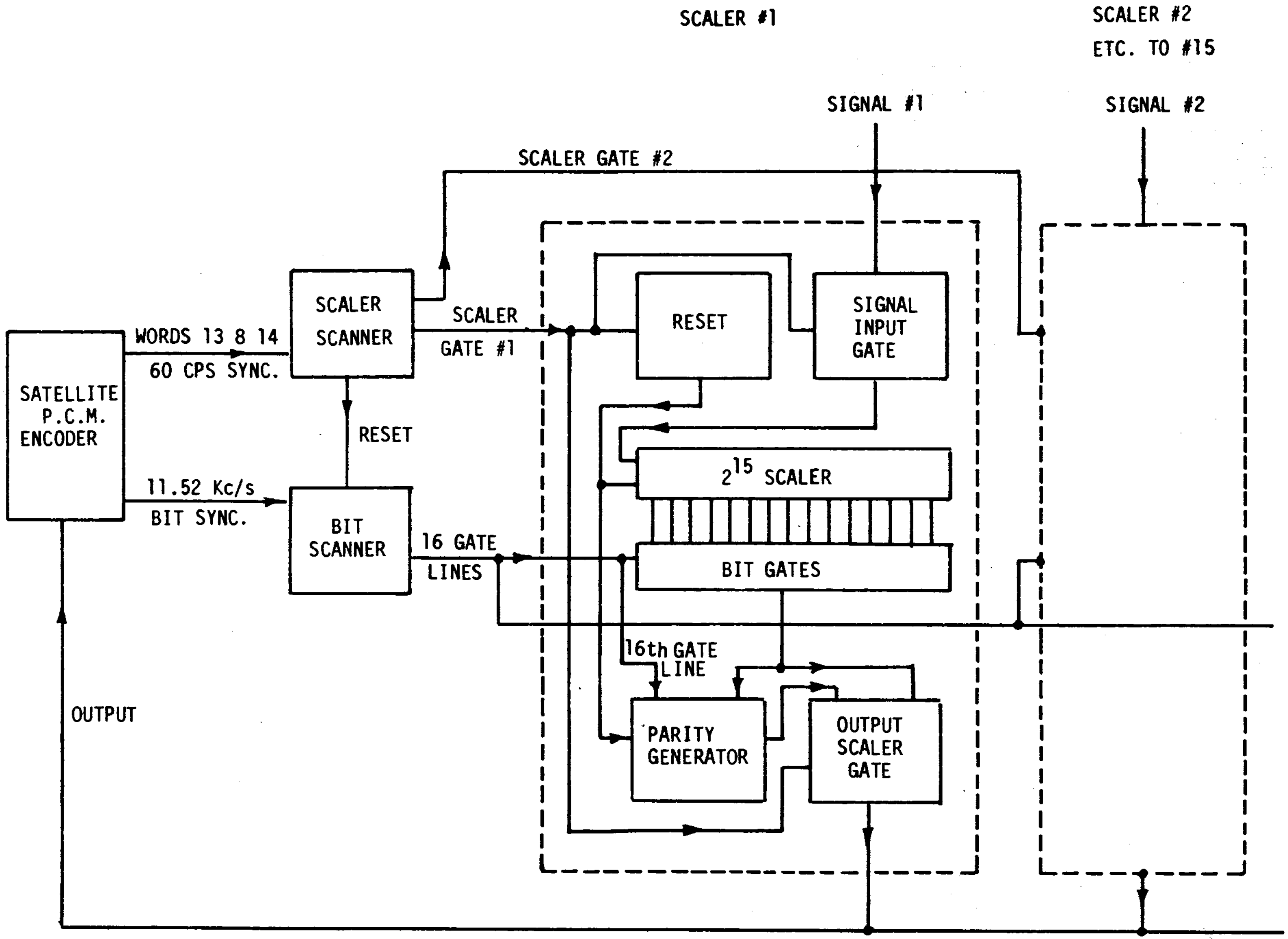


Fig. 41. The EPD Data Encoder.

9.9 BEACON EXPERIMENT (Principal Agency, University of Western Ontario, London, Ontario, Canada, P.A. Forsyth, G. Lyon)

The beacon experiment aboard ISIS-II is an improved version of the equipment aboard ISIS-I. The purpose of the experiment is to detect and measure inhomogeneities in the ionosphere between the spacecraft and a number of ground stations. The inhomogeneities are detected by the modifications in direction of propagation, amplitude and polarization imposed on the radio waves in propagating through the irregularities. These are detected by angle-of-arrival (relative phase), amplitude and polarization measurements made in the ground equipment. When the orbits of the ISIS-I and ISIS-II satellites are suitable, the beacons on both satellites will be used to obtain data in quick succession on the same volume of ionosphere.

The spacecraft contains two transmitters (at frequencies of 136.41 and 137.95 MHz) and the ground station consists of several separated, linearly polarized antennas and one hybrid left-and-right circularly polarized antenna. Appropriate phase measuring receivers are connected to the antennas. Angle-of-arrival is measured by means of the relative phase between separated antennas and polarization by relative phase between the two polarization components. By comparison of these measurements and the amplitude variations of the signal large and small scale inhomogeneities can be studied. The density ionization does not have strength of the ionization; its distribution in space and rate of formation and decay can be studied for individual irregularities or groups of irregularities. The two frequencies are used to remove ambiguities which arise in single-frequency measurements.

The beacon antenna configuration of ISIS-I does not allow the detailed polarization measurement outlined above to be used for Faraday rotation studies and a much coarser substitute technique has been devised for use with that satellite. The improved antenna configuration of ISIS-II should eliminate the problem, and allow the much more accurate measurements to be made.

9.10 ATOMIC OXYGEN RED LINE PHOTOMETER (Principal Agency, York University, Toronto Ontario, Canada, G. Shepherd)

Objective

The purpose of this experiment is to map the global distribution in the intensity of the 6300 Å line emission from the D level of atomic oxygen. This upper level lies only 2 eV above the ground state; hence it can be excited by a number of mechanisms and the emission is useful in interpreting the physical processes of the F-region. (The emission is strongly collisionally deactivated by N_2 and does not appear at lower altitudes.) The mechanisms to be studied are auroral excitation by electrons and protons, mid-latitude red arcs, photodissociation of 0_2, dissociative recombination of 0_2+, excitation by photoelectrons generated both locally and at the magnetically conjugate point, and thermal electron excitation. The global behaviour patterns and the simultaneous measurements of other experiments aboard ISIS-II should make it possible to delineate these mechanisms.

Experiment Description

The experiment has two optical inputs, directed at 180° to one another and both perpendicular to the spacecraft spin axis. The main channel is characterized by a full width half maximum bandwidth of 10 Å at 6300 Å and a relative peak response of unity. The second channel has a bandwidth of 100 Å and a relative peak response of 0.1. These inputs are combined and fed into a single photomultiplier detector. The two inputs have equal integrated responses to white light but the ratio of the responses to 6300 Å line is 10:1, allowing the latter to be extracted from scattered moonlight and sunlight. As the spacecraft rotates, one channel views the earth while the other points at the dark sky; 6300 Å emission will be evident as an alternation in level between successive scans.

The field of view is 2.5° angular diameter, which corresponds to a viewing area of about 140 km diameter on the ground. This is the distance along the subsatellite path, corresponding to one 20 sec spin period, hence a raster-type scan of the earth results. On a single pass, a roughly diamond-shaped region corresponding to

180° in latitude and 90° in longitude will be mapped.

The dynamic range of the instrument is from 100R ± 10 per cent to 1 MR ± 10 per cent (1R = 1 rayleigh = 10° photons/sec emitted from a 1 cm column along the line of sight.) This is adequate to cover all geophysical conditions for the 6300 Å emission. (A photomultiplier-preamplifier combination produces two outputs: a low level output that covers the 0 – 1kR range linearly and a dc logarithmic output for 0 to 1 MR range.)

Extensive baffling of the optical inputs permits the experiment to be operated with the spacecraft in sunlight, provided the sun is more than 50° off the optical axis. When the signal level reaches 1 MR, a back bias is applied to the photocathode for protection for 0.16 sec and then removed. If intense light is still present, the cycling continues, at light levels above 100 MR one of four photofets maintains the back bias.

Two internal tungsten lamps are used for intensity calibration of the photomultiplier system. The calibration sequence, which is initiated whenever the experiment is turned on, takes 12 seconds. The lamps are on alternately for two-second intervals during the 12 second period.

The signal information is carried as one word on the PCM encoder. Alternative words indicate the levels of the linear and logarithmic outputs.

9.11 CYLINDRICAL ELECTROSTATIC PROBE EXPERIMENT (Principal Agency, Goddard Space Flight Center, Greenbelt, Maryland, USA (GSFC), L.H. Brace and J.A. Findlay)

The objectives of the ISIS-II Cylindrical Electrostatic Probe Experiment (CEP) are:

1. To extend through the waning phase of the 11-year solar cycle the study of the global behaviour of electron temperature and density that was begun with data from the ISIS-X (Alouette II and Explorer XXXI) and ISIS-I satellites.

2. By use of the extended resolution of this instrument, to examine in greater detail polar cap and magnetosphere/plasmasphere interactions, and

3. To look at global behaviour of ionosphere from a circular polar orbit, thus avoiding mixing the effects of altitude and latitude.

Although basically the same type of experiment as was flown on the earlier ISIS satellites, the ISIS-II CEP provides:

1. Greater electrometer sensitivity allowing more complete coverage in low density regions such as over the polar cap in the main trough.

2. Very high resolution of plasma density fine structure (down to approximately 10 meters in extent and less than 1 per cent in amplitude).

3. On-board signal processing of the electron temperature data with back-up to provide data in nearly identical format to that of earlier experiments.

As in the earlier CEP experiment, two cylindrical sensors are employed each consisting of a collector electrode 0.057 cm diameter and 46 cm long, with a coaxially-mounted guard electrode 0.17 cm diameter extending half the length of the collector electrode. The sensors are mounted through coaxial helical springs to allow the sensors to be stowed during launch. The sensors are located one at each end of the spacecraft along the spin axis for the ISIS-II experiment.

The electronics is considerably different from that flown on previous satellites. The main difference is the on-board signal processing of electron temperature data with back-up capability of relaying basic volt/ampere curves as in previous instruments. With this system an ionospheric sample is taken each six seconds providing an independent measurement of electron temperature, electron density, ion current slope as a function of collector voltage, vehicle potential and ionospheric fine structure.

The signal processing includes:

1. Automatic sensing of the vehicle potential and provision for inserting a compensating voltage of opposite polarity in series with the applied voltage to the sensors by command.

2. Automatic electrometer range switching to provide optimum resolution of the sample current for both electron density and electron temperature determination.

3. Determination of ion current contribution to the total current to the sensor, and provision for generating a compensating signal of opposite polarity to allow automatic separation of electron current for temperature determination.

4. Electron temperature determination by scaling the slope of the natural log of the electron current collected as a function of a time-varying negative applied voltage:

$$T_e = 1.16 \times 10^4 \, dV_a/\ell n I_e)$$

5. Amplification of any variation in the frequency range 1 Hz to 400 Hz as a fixed positive voltage is applied to the sensor for a period of approximately 3 seconds.

Calibration is provided internally each time the instrument is turned on and upon ground command, and data may be taken sequentially between sensors or from one or the other continuously upon ground command. Back-up is provided through the ability to substitute fixed functions for all normally automatic functions and sequential operation of the automatic range switching circuitry. The instrument is housed in a package of approximately 90 cubic inches internal volume, having overall dimensions of 2.6 x 5.75 x 6.2 inches, weighs approximately 4 lbs. total, and requires 2.5 watts of power over an input voltage range of 19.0 to 27.0 volts.

9.12 AURORA SCANNER 3914/5577Å (Principal Agency, University of Calgary, Calgary, Alberta, Canada, C.D. Anger)

The ISIS-II scanning photometer is designed to map the distribution of auroral emissions at 5577Å and 3914Å over the portion of the dark earth visible to the spacecraft. A combination of internal electronic scanning and the natural orbital and rotational motions of the spacecraft causes a dual wavelength photometer to scan systematically across the earth. The data will be reproduced directly in the form of separate pictures representing emissions at each wavelength. The pictures will be used to study the large-scale distribution and morphology of auroras, to study the ratio of 3914Å to 5577Å emissions (thought to depend upon the energies of exciting particles), and to compare auroral activity with phenomena recorded by other instruments on board the spacecraft and on the ground.

In simple terms, the instrument is the photometric equivalent of an All-Sky color camera which will view the aurora from above instead of below with a much wider spatial coverage and free from problems of cloud and haze. In one satellite pass, the instrument will be capable of surveying the entire polar region in which auroras normally occur.

Optical System

The optical system is shown in Figure 40. Light is accepted from two directions which are 180° apart and is brought to focus at the same point on a single image dissector photomultiplier tube. Light from each

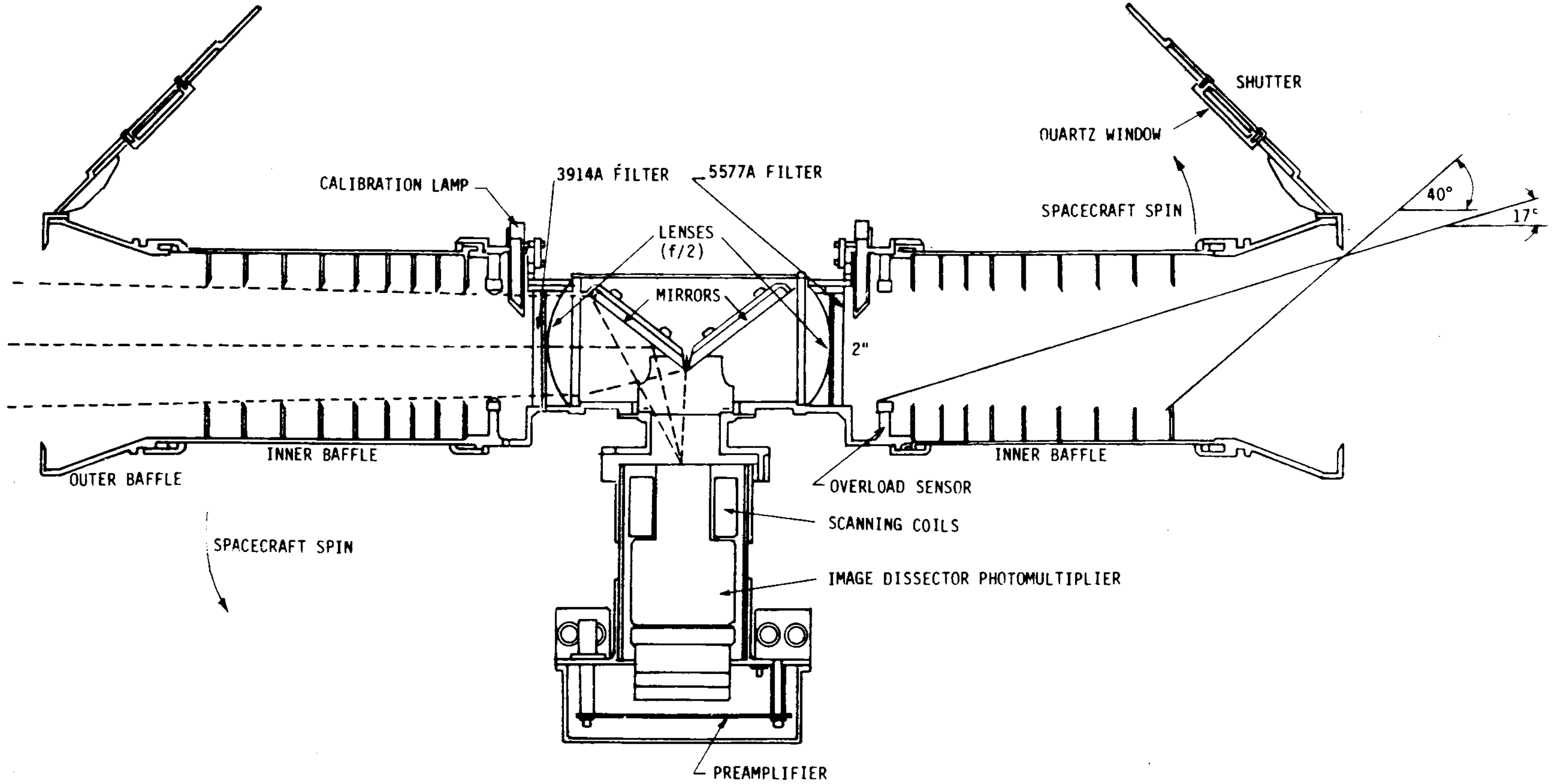


Fig. 42. Scanning Auroral Photometer Optical System.

direction passes through its own lens, interference filter, and mirror. Light which comes in from the right is restricted by the filter to the wavelength range 5577Å ± 7Å. The corresponding range for light coming from the left is 3914Å ± 13Å. Since only one of the two optical systems will be pointing at the earth at any one time (while the other looks into space), there will normally be no interference between the two systems.

The single element f/2 spherical lenses are constructed from Suprasil. The interference filters are constructed of materials with high radiation resistance. None of the optical elements show serious degradation at radiation dosages comparable to one year in orbit. The 3914 filter is affected the most, and in one test showed a drop in transmission from 24 per cent to 19 per cent after exposure to 1.5×10^5 Rads.

The baffle tubes are designed to shield the optics from light coming directly from the sun or from the sunlit earth.

It will be quite a common situation for the instrument to be looking down at a dark earth while the satellite itself is in direct sunlight.

The baffle is a two-stage assembly, With an inner baffle which is shielded by an outer baffle. The design is intended to permit observations of aurora when the outer baffle is illuminated by direct sunlight, i.e., when the sun is more than $\sim 40° - 55°$ (depending upon the direction) away from direction of viewing – see Figure 42. It may also be possible to obtain data when some portion of the inner baffle system is illuminated by the sunlit earth. In order to achieve the desired performance the optical system must attenuate the light coming from sources outside the field of view by a factor of $\sim 10^{12}$. Measurements on the Engineering Model give an attenuation of $\sim 10^8$ from the inner baffle system alone; thus, it appears that the design goals will probably be met.

The edges of the baffle plates have been honed to a sharp edge, to present the minimum cross-section for scattering. The interior of the baffles, including the baffle plates, have been coated with 3M Black Velvet paint. Total hemispheric reflectance of a coated surface has been measured to be 2.8 per cent.

Electronics

The electronic portion of the instrument consists of modules which amplify and count output pulses from the image dissector tube and convert these into a high rate pulse code modulated output and a low rate analog output. Drive voltages for the image dissector scanning coils are also provided, as well as various control, monitoring, and protection functions. A block diagram is shown in Figure 43.

Image Dissector Photomultiplier

The image produced by the optical assembly is focused on the photocathode of an image dissector photomultiplier tube. This device is similar to an ordinary photomultiplier tube except for an electrostatic imaging system and aperture which are interposed between the cathode and first dynode. The effect of the aperture is to pass only photoelectrons originating from a small region on the photocathode. Magnetic fields produced by deflection coils cause the sensitive region to be moved across the cathode surface, thus scanning the optical image. In this experiment the dissector is scanned in one direction only so as to obtain information from thirteen elements along a line at right angles to the direction of scan produced by the rotational motion of the spacecraft (see Fig. 44).

Pulse Counting and Scanning Electronics

Each photoelectron passing through the imaging electron optics and aperture of the image dissector tube is multiplied by about 10^7 by the dynode chain. The resulting output pulse is amplified by a high speed pulse preamplifier, which produces standard pulses suitable for driving high speed digital logic. These pulses are accumulated in a digital logarithmic accumulator, the seven-bit output of which is transferred to a buffer and shifted out (with the most significant bits coming out first) in standard PCM format (NRZ-S) at 630 words per

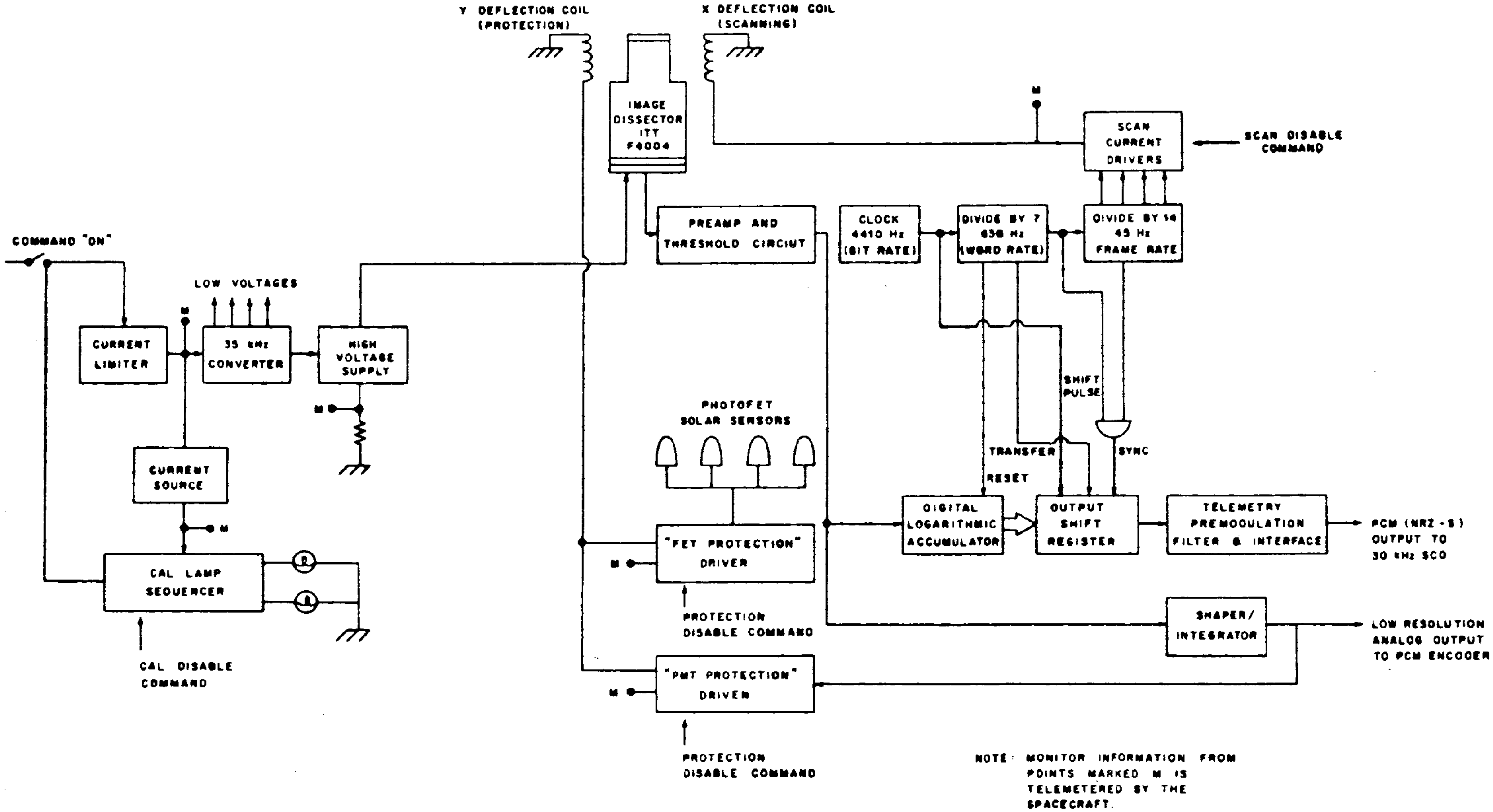
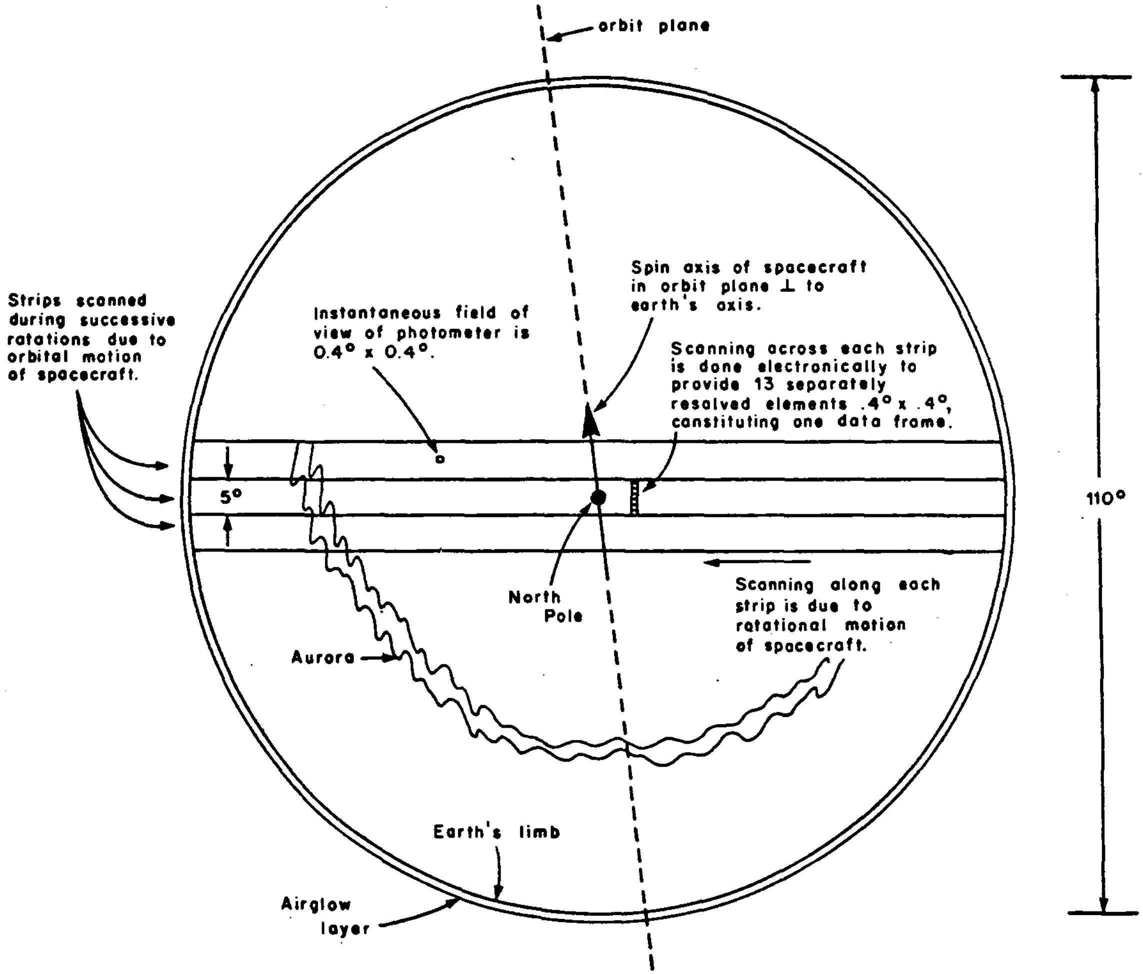


Fig. 43. Scanning Auroral Photometer Electronics.



The earth as it would appear from the spacecraft 1400 km above the pole, with scanning pattern of photometer superimposed.

Fig. 44. Scanning Pattern of Auroral Photometer.

second, 4410 bits per second. After each 13 word frame, constituting one complete scan across the dissector cathode, a frame synchronization word (1110101) is inserted. The same circuitry which generates the PCM output also controls a digital-to-analog converter which drives the scanning coil on the image dissector.

The digital data stream is fed to a 30 kHz ± 7 1/2 per cent subcarrier oscillator which in turn modulates the 136.08 MHz transmitter (along with the sounder and VLF experiment outputs).

Because of interruptions in the telemetry of the scanner data, and also because it was not possible to include the scanner PCM output among the data recorded by the on-board tape recorder, it was decided to provide an additional (analog) output with a reduced data bandwidth which could by command be connected to the main spacecraft PCM encoder.

The analog output is obtained by integrating the shaped pulses from the pulse amplifier so as to give an output which depends logarithmically on the pulse rate. The output is smoothed so as to have a rise-time of approximately 20 milliseconds, the net effect of which is to provide an output which is generally representative of the average intensity across one thirteen-element scan.

Calibration System

Two calibration light sources, employing tungsten filament miniature lamps, have been built into the optical assembly (see Fig. 42) – one for each wavelength.

The purpose of the sources is to enable in-flight calibration and evaluation of system performance over the lifetime of the experiment.

The calibration is initiated whenever the experiment is turned ON. One complete cycle consists of six two-second intervals in which the 5577 Å calibration source is ON separated by six two-second intervals in which the 3914 Å source is ON. This duration is sufficient to ensure that both photometer barrels will be looking away from the earth into dark "space" during some portion of the calibrate cycle.

The 3914 Å source is intended to produce a reasonably uniform illumination across the thirteen scanned elements. In addition to providing a 3914 Å calibration reference, this source will monitor the uniformity of response of the image dissector across its field of view.

The 5577 Å source includes a collimating lens whose purpose is to produce a light level in some of the scanned elements which is near the top of the system's dynamic range. Other elements will experience light levels near the lower end of the dynamic range. This source will monitor the performance of the electronics near the extremes of its dynamic range, and will also test the sharpness of focus of the optical system and the image dissector.

Sunlight Protection System

Exposure of any photomultiplier tube to excessibely high light levels can have effects ranging in severity from temporary increases in dark current to total destruction of the tube. In this instrument, several features combine to make the problems arising from solar illumination of the optics and direct viewing of the sunlit earth much less severe than might be expected:

1) Narrow band interference filters restrict the wavelength range which is passed on to the dissector.

2) The f/2 geometry restricts the effective solid angle viewed by the photocathode to about 0.2 steradians.

3) Large (1.5 MΩ) dynode resistors have been employed to limit the anode current to about 100 μA, well below the maximum ratings of the tube.

It appears from limited tests that the foregoing may be sufficient to prevent permanent damage to the tube; however, two electronic protection systems have also been built into the instrument. Both operate by deflecting the photocathode region being scanned off to the side where it is shaded by internal baffling of the optical system. This is sufficient to decrease the anode current by three orders of magnitude and effectively prevents troublesom increases in dark current (which is normally at the very low rate of $\sim 60^{-1}$).

The first protection system, termed "Overload Protection", is triggered when the analog output reaches the top of its allowed range (equivalent to $\sim 5 \times 10^6$ Rayleighs at 5577Å). After 0.15 seconds the protection switches off, but immediately comes in again if the analog output goes back up.

The second (FET) protection system is triggered by output from photo-field effect transistors mounted inside the baffle tubes at the edges of the lenses (see Fig. 42, page 76).

10. CONCLUSION

The ISIS-II spacecraft development and integration is completed and after environmental testing at the Goddard Space Flight Center, Maryland, will be launched from the Western Test Range late in March 1971. A final assessment of its performance cannot be made until after it is in orbit.

Each of the spacecraft so far launched, Alouette I, Alouette II and ISIS-I have successfully completed their mission objectives. Alouette I is still providing 1/2 an hour of data per day after 8 1/2 years in orbit. Extensive testing of units and sub-systems before integration into the spacecraft, has probably contributed significantly to this level of reliability. During the thermal vacuum testing of high voltage units, it was found difficult to monitor local outgassing and intermittent corona or breakdown; in future particular attention should be given to instrumentation for measurement of this kind.

International co-operation has been a major feature of the ISIS programme both in the use of scientific data, and in the engineering. The programme itself is international, with scientists from agencies throughout the world, in particular from the United Kingdom, France, Norway, India, Japan, Australia and New Zealand actively involved. Scientific data are placed in the World Data Centre for free use by any interested scientists. In addition, visiting engineers and scientists from several of these countries have participated in studies at the CRC laboratories in Canada.

11. ACKNOWLEDGEMENT

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