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FINAL REPORT

AMPS DATA MANAGEMENT REQUIREMENTS STUDY

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama

Contract No. NAS8-31208

Space Sciences Department
TRW SYSTEMS, One Space Park
Redondo Beach, California 90278

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INTRODUCTION

The AMPS Data Management Requirements Study has been aimed at defining and developing the initial data simulation of AMPS instruments and associated control and display functions required to perform controlled active experiments from the AMPS laboratory. The four tasks that were undertaken to fulfill this aim are as follows:

Task 1 - Develop and provide to NASA the data output (raw and formated) for specific sensors and detectors.

Task 2 - Provide the signal and information formating required to activate and control AMPS instruments and instrument support units.

Task 3 - Specify display data and display formats. Provide supporting flowcharts for the AMPS simulation

Task 4 - Develop requirements and procedures for simulating a representative set of AMPS experiments.

This report has been organized to provide a comprehensive users guide for the data requirements and software developed for the following experiments:

1. Electromagnetic Wave Transmission Experiment.
2. Passive Observation of Ambient Plasmas.
3. Ionospheric Measurements with a Subsatellite.
4. Electron Accelerator Beam Measurements.
5. Lidar Trace of Acoustic Gravity Waves in the Sodium Layer.

In addition, the data requirements of a sixth experiment have been developed without the associated software flow charts. This experiment is

6. Determination of the Wake of a Test Body.

The data output of each of the sensors and detectors are presented in Section 1.0. This section essentially satisfies the requirements of Task 1 described previously. Section 2.0 defines the control requirements called for in Task 2. The complete simulation of 6 experiments is given in Section 3.0 of this report. The software requirements and flow charts for five of the six experiments described in Section 3.0 are presented in the Appendix.

1.0 RAW AND FORMATED DATA OUTPUT FOR AMPS SENSORS AND DETECTORS

The output requirements for the sensors and detectors listed in Table 1.0 are described in Section 1.1. The formated data is given in Section 1.2.

1.1 OUTPUT REQUIREMENTS

1.1.1 Remote Subsatellite Systems (2)

1.1.1.1 TV System. The subsatellite television system will be used to observe optical emissions at large distances from the Shuttle. Its data output will include its pointing direction, its sensitivity, the spectral content and finally the television picture itself. Because the data rate for the optical imaging will be so high, $>10^7$ bps, the data must be handled by special video channels and will not be processed by the spacelab computer. The pointing data, the spectral content (if a filter system is used) and the sensitivity data are all moderately slow and require only one 16 bit word once per second. Hereafter, housekeeping data will not be specifically described. However, when the telemetry frame format is presented there will be enough room in the format to accomodate all of the subcommutated housekeeping data.

Table 1.0 Sensors and Detectors

A. On Two Remote Subsatellite Systems

1. TV System
2. Triaxial Fluxgate Magnetometer
3. Search Coil Magnetometer
4. Cylindrical Electron Probe
5. Segmented Planar Trap
6. Ion Mass Spectrometer
7. Triaxial Hemispherical Analyzer
8. VLF/RF Receiver
9. Electric Field Meter

B. On Diagnostic Boom A

1. One Meter Loop Antenna
2. Short Electric Dipole Antenna
3. Triaxial Search Coil Magnetometer
4. Rubidium Magnetometer
5. Triaxial Fluxgate Magnetometer
6. 33 Meter Electric Dipole Antenna
7. Alignment TV
8. Ion Mass Spectrometer
9. Spherical Ion Probe
10. Cylindrical Electron Probe
11. Planar Segmented Probe
12. Neutral Mass Spectrometer
13. Triaxial Hemispherical Analyzer
14. Planar Electron Trap

C. On the Remote Sensing Platform

1. Scanning Grating Spectrometer
2. Fabry-Perot Interferometer
3. Filter Photometers
4. Total Energy Detector

1.1.1.2 Triaxial Fluxgate Magnetometer. This magnetometer will be be used to measure the magnetic attitude of the subsatellites and to measure slow period magnetic waves. The three axes will be mutually orthogonal. The maximum ambient signal could correspond to 50,000 gammas either positive or negative and a sensitivity of at least 1 gamma will be needed. Therefore there is a need for three channels of data each able to handle at least a range of 100,000 with accuracy of 1 part in 100,000. While the fluxgate data is actually analog it is assumed that the magnetometer will digitize its own data. The digital data format of the fluxgate requires 17 bits for each of the channels. A sampling rate of 200 times per second will be needed to obtain the proper number of points to do magnetic wave analysis. The fluxgate data will fit into four 16 bit words with 17 bits for each axis, 3 bits for polarity and 10 bits for housekeeping.

1.1.1.3 Search Coil Magnetometer. The search coil magnetometer will be used to detect magnetic field variations at frequencies above 30 Hz up to a limit of perhaps 10 or 20 MHz. The magnetometer should be able to give wideband data for this whole range of frequencies which means that it will exceed the capabilities of the spacelab computer and must be handled like a video signal. The data consists of a voltage signal level with a 20 megahertz bandwidth and a dynamic range of as much as 10^5.

1.1.1.4. Cylindrical Electron Probe. Cylindrical electron probes come in many varieties. The one used for this simulation measures ambient electron densities and temperatures by applying a sweep voltage to the probe. The data will consist of an electrical current value and a voltage value. The data are assumed to be digitized by the probe's own electronics. The current will take 20 bits and the voltage 10 bits each sampled at a rate of 1,000 times per second. The data format consists of two 16-bit words.

1.1.1.5. Segmented Planar Trap. The segmented trap is used to measure electron or ion densities, temperatures, or drift velocities. Usually it is used in the ion drift velocity mode of operation. The measurement consists in comparing the electrical current values for each of the segments. For this simulation we will assume that the trap has four separate segments and that there will also be a retarding potential voltage. The dynamic range of the current can be quite large, therefore each of the four segments of the trap will be given 20 data bits and a time resolution of 1/1000 seconds. The retarding potential voltage will get 11 data bits at the same time resolution. These data require six 16-bit words 1,000 times per second.

1.1.1.6 Ion Mass Spectrometer. The ion mass spectrometer will be used to separate the various ionospheric ions by mass and to determine either the relative or absolute ion density distributions. If only the ambient plasma ions were to be considered, a dynamic range for the density of 10^6 would be needed, however during some AMPS missions artificial plasma clouds will be made and their densities could be a factor of ten larger than ambient raising the needed dynamic range to 10^7. The mass resolution of the spectrometer needs to be at least one part in forty and the masses measured could possibly be as large as several hundred AMU for artificially produced ions. The sampling rate will be 400 per second. The digital format consists of two 16-bit words, 21 bits for the ion density current, 9 bits for the mass and 2 polarity bits.

1.1.1.7 Triaxial Hemispherical Analyzer. The hemispherical analyzers will be used to measure the flux and energy of charged particles whose energy lies in the range from 50 to 40,000 electron volts. The energy spectrum of the particles is obtained by sweeping a voltage between the two analyzer plates, and both electrons and ions can be measured by changing the polarity of the sweeping voltage. The maximum counting rates will be on the order of 10^7 particles per second. A fast time resolution will be needed because of the complex temporal behavior of energetic particles. The triaxial analyzer needs three separate detectors, but only one sweeping voltage which is applied to the three analyzers. Three 16-bit words with 13 bits devoted to each of the three counting data channels and 9 bits for the sweep voltage. These three words will be sampled 5,000 times per second.

1.1.1.8 VLF/RF Receiver. The VLF/RF receiver will be used to measure the amplitude of electric field fluctuations in the frequency range from 300 Hz to 20 MHz. The data will be contained within a 20 MHz broadband channel. The dynamic range may be as large as 10^6. Because the bandwidth will be so large these data must be treated like the television and search coil magnetometer data and processed outside of the spacelab computer.

1.1.1.9 Electric Field Meter. The electric field meter will be used to determine the amplitude and direction of the electric field vector in the frequency range from 0 to about 30 Hz. It will be a three axis detector.

Each axis has as an output a signal voltage level which is proportional to the electric potential difference between two sensors. The dynamic range of the instrument is about 10^4 and the sampling rate should be about 300 per second. This requires three 16-bit words with 15 bits for the signal voltage and 3 bits for polarity.

1.1.2 Diagnostic Boom A

1.1.2.1 One Meter Loop Antenna. The one meter loop antenna will be used to make measurements of higher frequency magnetic field variation. The frequency range will depend upon design details, but should cover the range from 1000 Hz to 20 MHz with a dynamic range as large as 10^6. The data channel must have a 20 MHz bandwidth and can not be processed through the spacelab computer. These data will be treated like video data.

1.1.2.2 Short Electric Dipole Antenna. The short electric dipole antenna is sensitive to electric field variations at the same frequencies as the loop antenna, from 1000 Hz to 20 MHz. Its dynamic range can be as large as 10^6. Its data can not be processed through the spacelab computer because of the large bandwidth, but must be treated like a video signal.

1.1.2.3 Triaxial Search Coil Magnetometer. Each axis of this instrument will be exactly like the subsatellite search coil magnetometer treated earlier. With three axes the bandwidth will be increased to 60 MHz and the data must be processed on video channels.

1.1.2.4 Rubidium Magnetometer. The rubidium magnetometer will make accurate measurements of the value of the total magnetic field at its location. This instrument is capable of accuracy of from 1 to 10 parts in 10^7. This magnetometer needs 23 bits for signal level and one bit for polarity 200 times per second to read out its data. This will require two 16-bit words and will leave 8 bits to be used for housekeeping.

1.1.2.5 Triaxial Fluxgate Magnetometer. This instrument has been described previously.

1.1.2.6 33 Meter Electric Dipole Antenna. The 33 meter dipole antenna measures VLF/RF electric fields in the frequency range from 300 Hz to 10 megahertz. This antenna can also be used as a low power transmitting antenna in the same frequency range. When used as a receiver its data output is the same as the VLF/RLF receiver.

1.1.2.7 Alignment Television. The alignment television system will be used to visually determine the position and orientation of the platform at the end of boom A and also to act as a viewing system for experiments carried out close to the Shuttle. If the system is used only for alignment, it can be black and white. But some experimental observations will need an accurate color system provided by an optical filter wheel. The data from the alignment television system will be assigned to a video channel and can not be processed through the spacelab computer.

1.1.2.8 Ion Mass Spectrometer. This ion mass spectrometer will be identical to the one described in Section 1.1.1.6.

1.1.2.9 Spherical Ion Probe. The spherical ion probe will be used to determine the ion density and temperature and will give some data on the distribution of the ion species. This probe operates by sweeping the probe voltage and measuring the probe current. The dynamic range of the current can be as large as 10^6. This requires 20 bits for the current while 10 bits for the sweep voltage on 2 polarity bits will also be needed. Two 16-bit words read 1,000 times per second will be sufficient for the spherical ion probe.

1.1.2.10 Cylindrical Electron Probe. This cylindrical electron probe will be identical to one on the subsatellite.

1.1.2.11 Planar Segmented Probe. The planar segmented probe will be identical to the segmented planar trap described earlier.

1.1.2.12 Triaxial Hemispherical Analyzer. This triaxial hemispherical analyzer will be identical to the one described earlier.

1.1.2.13 Planar Electron Trap. The planar electron trap is used as a retarding potential analyzer. The trap measures the current of electrons striking it as a function of the swept retarding potential and allows the electron density distribution function to be calculated. The current measurement will have a dynamic range of 10^6 requiring 20 data bits. The voltage will require 11 data bits. Two 16-bit words with a repetition rate of 1,000 times per second will be sufficient for the planar electron trap data.

1.1.3 Remote Sensing Platform

1.1.3.1 Scanning Grating Spectrometer. The scanning grating spectrometer will be used to obtain moderate wavelength resolution of atmospheric optical emissions over the range from 250 to 1,000 nanometers. The photodetector will be used in both a counting and a current mode with a dynamic range of 10^7 for the count mode and 10^5 for the current mode. The wavelength resolution should be about 0.01 nanometers and would require a range of 10^5. These requirements will give 24 data bits for the counts, 17 data bits for the current and 17 data bits for the wavelength. The sampling rate will be 1,000 times per second. Four 16-bit words could be used with 6 bits left over for housekeeping functions.

1.1.3.2 Fabry-Perot Interferometer. The Fabry-Perot interferometer will be used to obtain very high resolution spectra of atmospheric optical emissions in a wavelength region from 300 to 2,000 nanometers. The dynamic range for counting photons will be about 10^5 and for wavelength resolution will be about 10^7. The time resolution and the interferometer scanning time require 1,000 data samples per second. Three 16-bit words can be used to handle the Fabry-Perot interferometer data with 24 data bits for wavelength, 17 data bits for counts and 7 data bits for housekeeping.

1.1.3.3 Filter Photometers. The AMPS Shuttle payload will carry as many as eight photometers with separate filters on each used to delineate optical lines in the atmospheric emissions. The photometers will be used in the photon counting mode. They will be sampled 1,000 times per second and will be allocated one 16-bit word for each photometer.

1.1.3.4 Total Energy Detector. The total energy detector will measure the solar energy incident on the Earth in several wavelength intervals. This instrument does not need rapid time resolution nor does it need a wide dynamic range within a given wavelength interval. By using subcommutation within the instrument all of the total energy detector data can be handled by one 16-bit word read 100 times per second.

1.2 DATA FORMATING

The data formats for the sensors are given in Figure 1.0 through 1.5. There are many alternative ways of presenting the data, and the format selected is sufficiently general so that it can match the requirements of any data management system. The information flow rates shown in the figures range from 200 to 5000 measurements per second per instrument. Although the higher rates are beyond the capability of the CVT computer to generate and process, they represent what would be desirable from an experimenter's viewpoint if unlimited resources were available. It is noted that in the computer flowcharts for the CVT simulation presented in the Appendix the highest sensor data rates called for are about 100 measurements per second (lidar, Experiment #5), which is well within the capabilities of the Spacelab computer and CVT simulation computers.

1.2.1 Remote Subsatellites (2)

In this simulation the two subsatellite data requirements are treated as being identical. The discussion below encompasses the needs of one subsatellite.

The instruments on the subsatellite require both broadband analog and digital data transmission to the Shuttle. The television system, the search coil magnetometer and the VLF/RF receiver all together require a 60 megahertz broadband analog transmission which must have a very large dynamic range on a frequency modulated channel.

The digital data has been assumed to be grouped into 16-bit words in order to be compatible with both the spacelab computer and the Sum C system. There is a requirement for 25,500 words per second from the subsatellite instruments. The characteristics of the words for each of the instruments is shown in Figure 1.0. A possible telemetry format for these digital data uses a 16 by 16 word frame repeated at a rate of 100 times per second. Frame identifiers and housekeeping data are allocated to the first word in the frame and the other 255 words are comprised of the instrument words. Besides the first 16-bit word there are 16 bits per full frame available in the fluxgate magnetometer words for housekeeping data for a total of about 3,200 bits per second. Proper subcommutation of these bits should provide adequate instrumental housekeeping data. The housekeeping for the other subsatellite systems will require their own telemetry allocations. Figure 1.1 shows a schematic table of a possible instrumental main frame format for the subsatellite instruments.

1.2.2 Diagnostic Boom A

Because of the maneuverability of the boom it will probably be necessary to either telemeter the instrument data to the spacelab or have at most

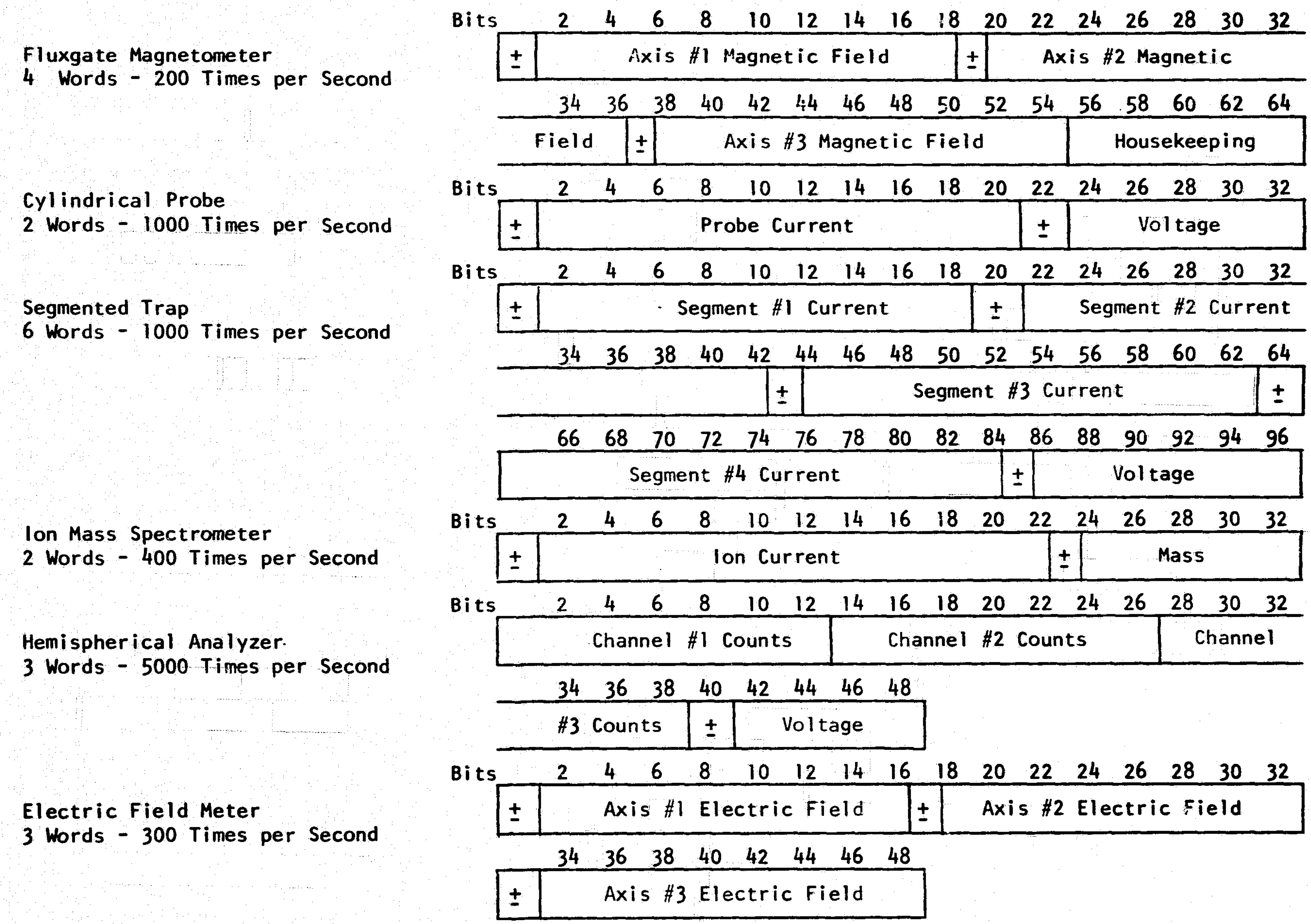


Figure 1.0. Possible Allocation of Digital Words for Subsatellite Instruments

H = Housekeeping + Identity

F = Fluxgate Magnetometer

C = Cylindrical Probe

S = Segmented Planar Trap

I = Ion Mass Spectrometer

A = Hemispherical Analyzer

E = Electric Field Meter

This Frame is repeated at the rate of one hundred times per second, and is read out from left to right and top to bottom. Each block is a 16-bit word.

Word Numbers →

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	(H)	$(F_1$	F_2	F_3	$F_4)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2
17	$A_3)$	$(E_1$	E_2	$E_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(I_1$
33	$I_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$
49	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5
65	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$
81	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2
97	$A_3)$	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	$(E_1$	E_2	$E_3)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4
113	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$
129	A_2	$A_3)$	$(F_1$	F_2	F_3	$F_4)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$
145	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$
161	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2
177	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(E_1$	E_2	$E_3)$	$(A_1$	A_2	$A_3)$
193	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$
209	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2
225	$A_3)$	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$
241	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$
	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256

Figure 1.1 Possible Telemetry Format for the Subsatellite Instruments

one or two very wide band coaxial cables. Therefore there is a need to format the transmission of data from the diagnostic boom.

The loop antenna, the short electric dipole antenna, the triaxial search coil magnetometer, the 33 meter dipole antenna, and the alignment TV all require wideband analog data channels. The total bandwidth for all of these instruments is 140 megahertz and must be accomodated on frequency modulated signals.

The digital data requirements of the diagnostic boom instruments are 29,300 16-bit words per second. The instruments on the boom are identical with those on the subsatellite with the following exceptions: (1) there is no electric field meter on the boom, (2) a spherical ion probe is added to the boom, (3) a rubidium magnetometer is added to the boom, and (4) a planar electron trap is added to the boom. Figure 1.2 shows the word formats for these three added instruments. A possible telemetry format for these digital words uses a 16 by 19 word frame repeated 100 times per second. There are 13 housekeeping words, which may also be considered to be spare data channels for instruments that might be added to the diagnostic package, as well as 16 bits per frame in the fluxgate magnetometer and 16 bits per frame in the rubidium magnetometer words. Figure 1.3 shows a possible configuration of this main telemetry frame for the diagnostic boom A.

1.2.3 Remote Sensing Platform

The data channels from the instruments on the remote sensing platform might be hardwired from each instrument to the spacelab data bus, however the interface might be simpler if the data were mutliplexed and sent on one signal wire. In that case the data from the remote sensing platform require 15,100 words per second. Figure 1.4 shows a possible format for data from each of the separate instruments. Figure 1.5 shows a possible format for the main data frame using a 16 by 10 word array with 9 words for housekeeping or as spares. There are also 60 bits in the scanning grating words and 70 bits in the Fabry-Perot words for further housekeeping data.

Rubidium Magnetometer
2 Words - 200 Times per
Second

Spherical Ion Probe
2 Words - 1000 Times per
Second

Planar Electron Trap
2 Words - 1000 Times per
Second

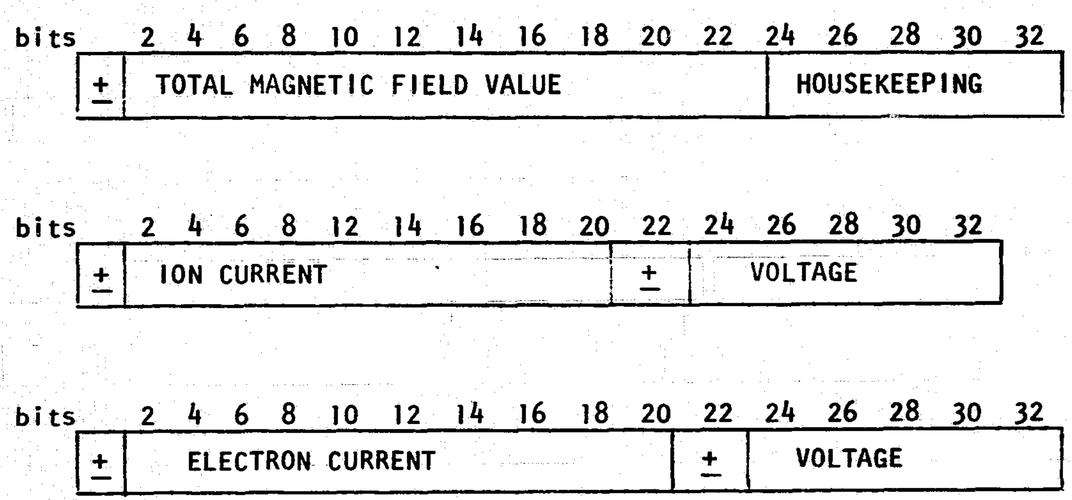


Figure 1.2. Possible Allocation of Digital Words for Diagnostic Boom A Instruments

H = Housekeeping + Identifiers + Spares
F = Fluxgate Magnetometer
C = Cylindrical Probe
S = Segmented Planar Probe
I = Ion Mass Spectrometer
A = Hemispherical Analyzer
R = Rubidium Magnetometer
P = Spherical Ion Probe
T = Planar Electron Trap. Frame is repeated 100 times per second.

Word Number ⟶

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	H	H	$(A_1$	A_2	$A_3)$	$(F_1$	F_2	F_3	$F_4)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4
17	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(R_1$	$R_2)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$
33	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$
49	A_2	$A_3)$	H	H	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2
65	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	H	H	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5
81	$S_6)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$
97	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	H	H
113	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(P_1$
129	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2
145	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(F_1$	F_2	F_3	$F_4)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$
161	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	H	H	$(A_1$
177	A_2	$A_3)$	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	$(R_1$	$R_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4
193	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2
209	$A_3)$	H	H	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(P_1$
225	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2
241	S_3	S_4	S_5	$S_6)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2
257	$A_3)$	$(T_1$	$T_2)$	$(A_1$	A_2	$A_3)$	$(I_1$	$I_2)$	$(A_1$	A_2	$A_3)$	$(S_1$	S_2	S_3	S_4	S_5
273	$S_6)$	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$
289	$(A_1$	A_2	$A_3)$	$(P_1$	$P_2)$	$(A_1$	A_2	$A_3)$	$(C_1$	$C_2)$	$(A_1$	A_2	$A_3)$	$(T_1$	$T_2)$	H
	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304

Figure 1.3. Possible Frame Format for Diagnostic Boom A Instruments

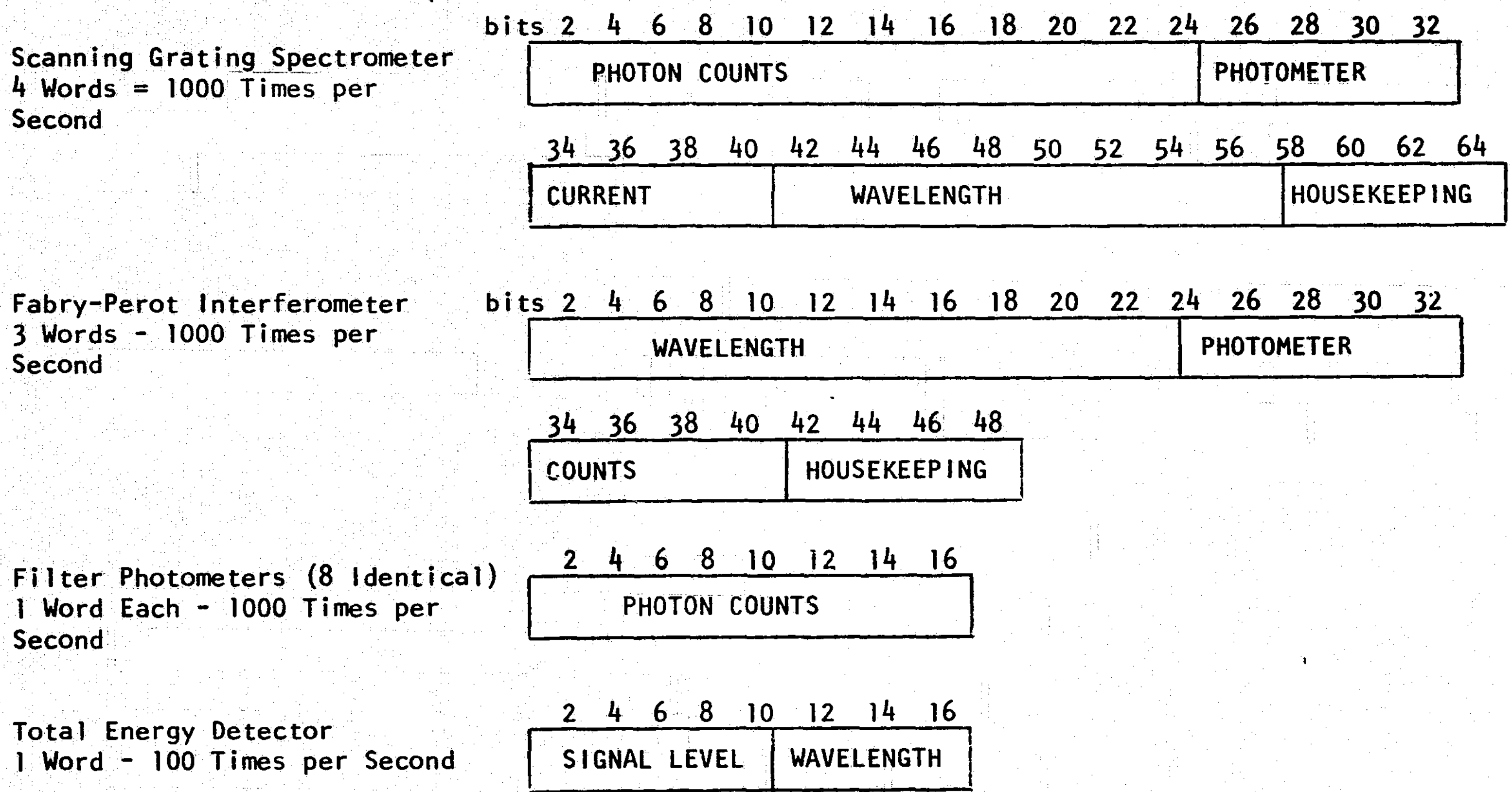


Figure 1.4. Possible Allocation of Digital Words for Remote Sensing Platform Instruments

G = Scanning Grating Spectrometer
FP = Fabray-Perot Interferometer
P1 = 1st Filter Photometer
P2 = 2nd Filter Photometer
P3 = 3rd Filter Photometer
P4 = 4th Filter Photometer
P5 = 5th Filter Photometer
P6 = 6th Filter Photometer
P7 = 7th Filter Photometer
P8 = 8th Filter Photometer
TE = Total Energy

Frame is read 100 times per second from left to right, top to bottom.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
17	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
33	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
49	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
65	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
81	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
97	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
113	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
129	H	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
145	TE	(G_1	G_2	G_3	G_4)	(FP_1	FP_2	FP_3)	P1	P2	P3	P4	P5	P6	P7	P8
	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Figure 1.5. Possible Frame Format for Remote Sensing Platform Instruments

2.0 SIGNAL AND INFORMATION FORMATING REQUIRED TO CONTROL THE AMPS INSTRUMENTS AND INSTRUMENT SUPPORT UNITS

The control requirements for the instruments and instrument support units listed in Table 2.0 are described below. In each case the first approximation to the information formating is supplied in the form of a conceptual block diagram showing the interface between the instrument system, the control buffer of the spacelab computer and the input-output (display) data.

Table 2.0 Instrument and Instrument Support Units

A. Remote Sensing Platform

B. Accelerator System

1. Ion Accelerator
2. Electron Accelerator
3. MPD Arc
4. The Gimbaling System
5. The Accelerator Pointing System
6. Accelerator Deployment System

C. High Power Transmitter/Antenna System

1. 10 kw, 200 kHz - 2 MHz Transmitter/Coupler
2. 10 kw, 2 MHz - 20 MHz Transmitter/Coupler
3. 1 kw, 300 Hz - 200 kHz Transmitter/Coupler
4. 1000 Foot Dipole Elements
5. Transmitter Deployment System

D. Diagnostic Boom A

1. Boom A Deployment System
2. Boom A Maneuvering Functions
3. Gimbaled Platform
4. 5 Meter Sub-booms
5. Electric Dipole Extension
6. Power Supply
7. Data System
8. Alignment TV System

E. Boom B

1. Boom B Deployment System
2. Boom B Maneuvering Functions
3. Target Deployment & Retraction
4. Wave Generator
5. Low Energy Electron Gun

F. Deployable Units

G. Deployable Subsatellites

1. Deployment Mechanism
2. TV System
3. Transponder
4. Telemetry System
5. Ranging and Control System

2.1 REMOTE SENSING PLATFORM

The control requirements for the remote sensing platform derive from the fact that the platform's pointing direction must be controlled so that the optical instruments placed on the platform can be pointed toward specific targets or regions of space. In some cases the platform will be turned to a specific direction and be held stationary, in other cases the platform will execute a scanning motion either in response to a preprogramed set of instructions or to an experimenter's active control commands. In all of these cases the initial commands will be given by the experimenter and the spacelab computer will serve as a buffer between the experimenter and the platform control motors. Figure 2.0 shows a conceptual block diagram of this command-control-display scheme.

The pointing accuracy requirements on the remote sensing platform will be on the order of ≤ 1 arc min relative to a coordinate system fixed on the Earth's horizon. For this reason it is likely that the position sensing unit will probably be referenced against an inertial coordinate generator. During either the point-and-hold mode or the preprogramed scan mode the computer will be in full control of the platform and will display position data to the experimenter. During the experimenter scan mode, the computer will act as a buffer and will do position calculations for display.

The control format for the experimenter or the programed scan consists of specifying two angular coordinates with an accuracy of better than 1 arc per minute. The experimenter will simply type in the two desired angles and the computer will translate the command into a motor control signal. The display output will be a realtime reading of the two angular values. For the purposes of a simulation of the remote sensing platform all one needs to specify is the rate at which the motors run and the time at which they begin running. The experimenter or the scan program will set the position to which the platform is to move and will start the platform motors. The computer will then run the angle variables as a function of time until the preset values are reached, and will display these values continuously. These angle values will also be needed to simulate the output of the instruments mounted on the platform. In actual use on board the Shuttle the computer will compare the preset angle values with the platform position sensors and turn the motors on and off in a manner to bring actual position into agreement with preset position.

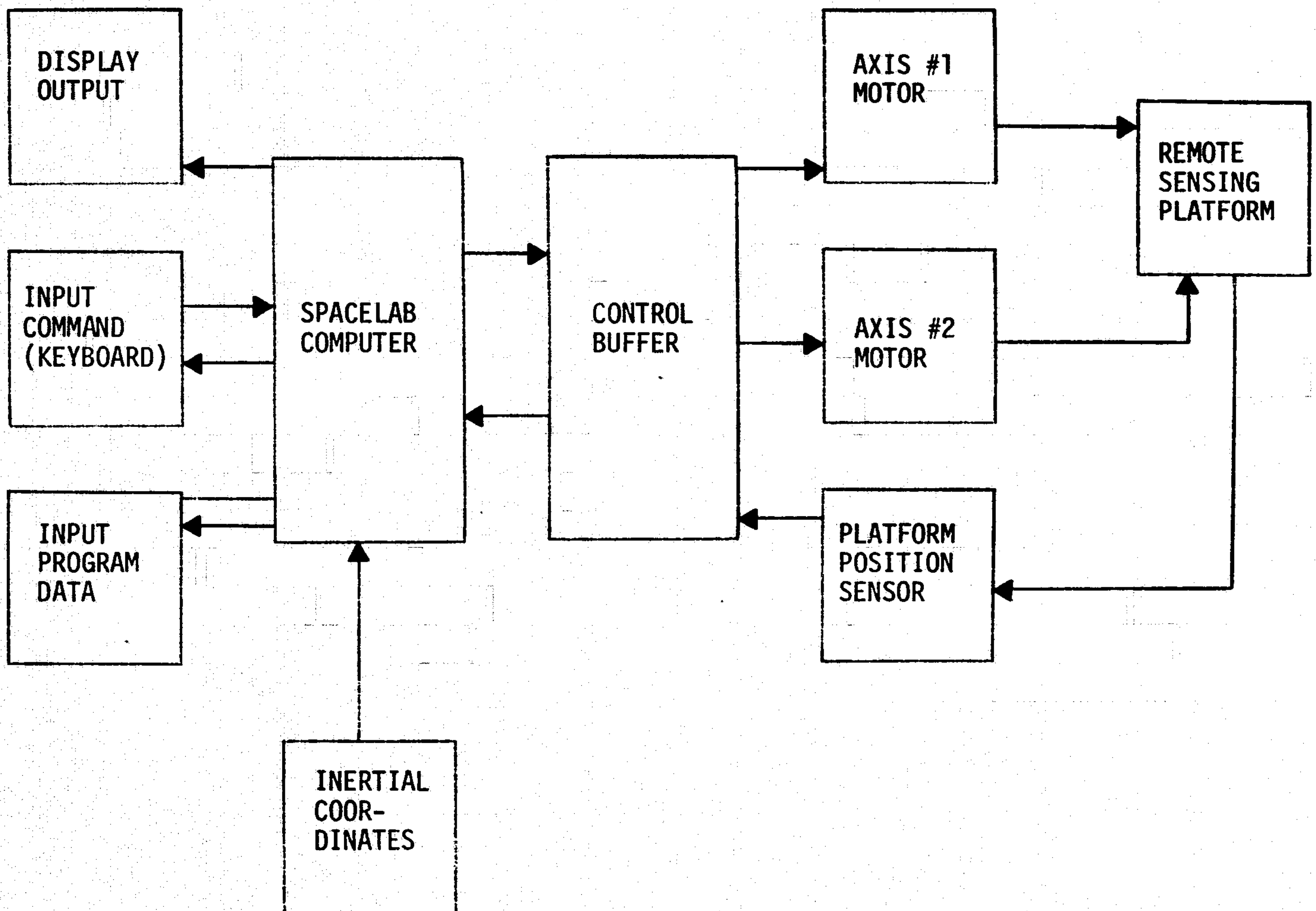


Figure 2.0 Conceptual Block Diagram of Remote Sensing Platform Control

2.2 GIMBALED ACCELERATOR SYSTEM

As the AMPS accelerator system is currently planned, there will be no gimbaled mount of the accelerator system. The directioning of the beams will be accomplished with magnetic bending coils. Therefore, in the following descriptions the bending coils rather than the gimbal system will be used.

2.2.1 Ion Accelerator

The controls for the ion accelerator involve the regulation of the ion source, the choice of ions, the accelerating voltage, the beam current and the neutralization of the beam. Because the cyclotorn radius of even the hydrogen ion is large compared to the dimensions of the ion accelerator, no direct means is provided for varying the beam ejection direction. If the pitch angle of the ions must be varied, the Shuttle attitude must be changed. The control functions divide into two catagories: accelerator setup and beam characteristics. Figure 2.1 shows a conceptual block diagram of the ion accelerator control scheme.

The setup of the ion accelerator requires that the source power supply be turned on, that the current and voltage to the ion source be adjusted, that the gas supply to the source be selected for ion type and the flow regulated, and that the neutralizer power supply be turned on and the neutralizer be heated hot enough for copious electron emission. The on-off commands will be simple level changes initiated from the keyboard. The regulation of the source current and voltage and the neutralizer current and voltage requires that the experimenter be able to see a realtime display of these quantities while he selects new values. For the purposes of simulation the voltage and current values will be identical with the selected values. During an actual flight, there will be variations between selected and actual values. The regulation of the gas flow rate requires a realtime display of the source pressure while the experimenter selects new values of the flow rate. In the simulation there will be required a functional relationship between the source pressure and the flow rate while during an actual flight the pressure will be displayed as an independent variable. The selection for type of gas, which determines the ion species of the beam, will be given by the experimenter on the keyboard.

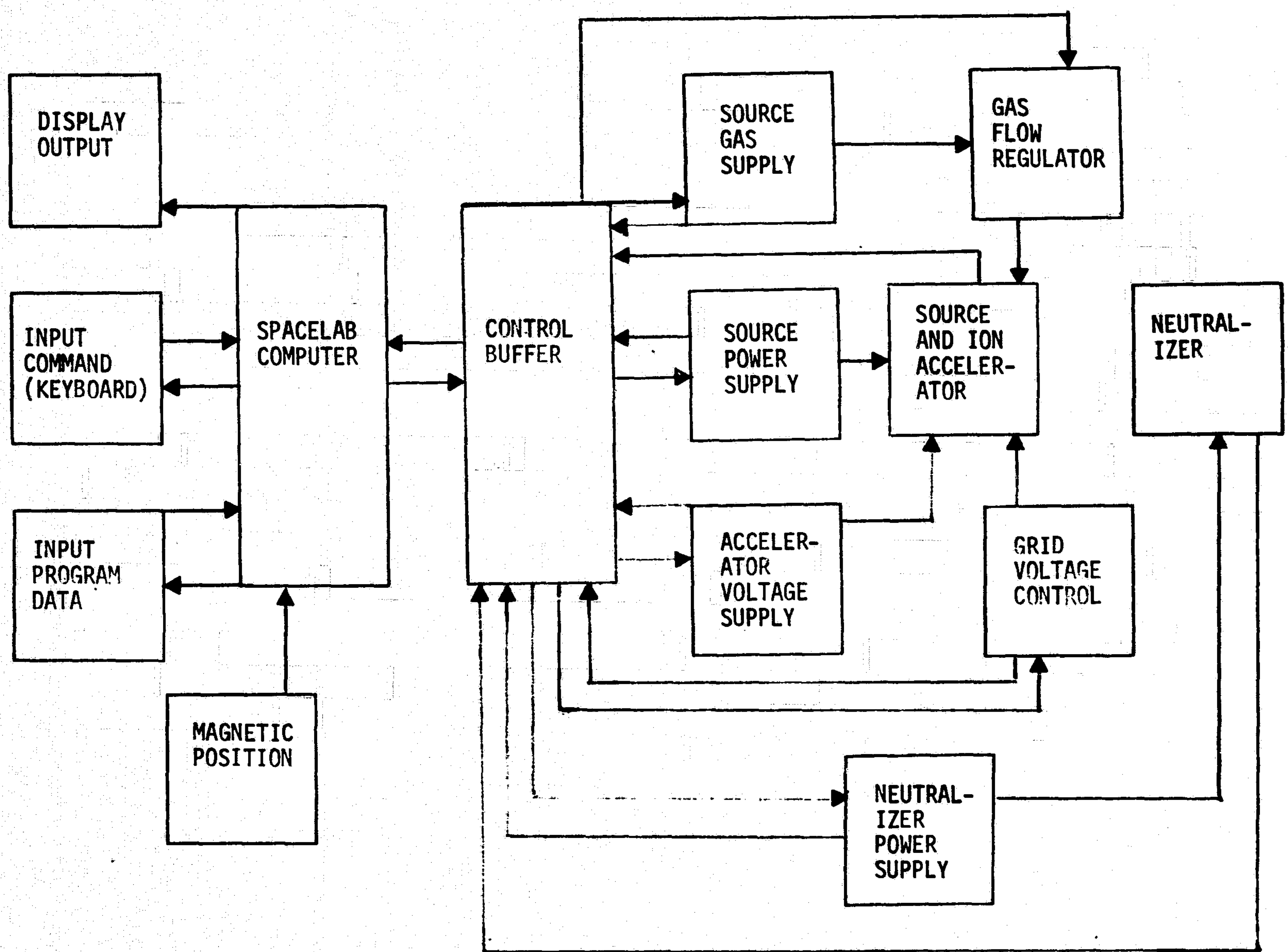


Figure 2.1 Conceptual Black Diagram of Ion Accelerator Control

The control of the beam characteristics will be done either by a preplanned program or by the experimenter from the keyboard. Only the beam current and accelerating potential will be controlled. Both the accelerator voltage and the current are controlled by a voltage signal level. The computer will act as a buffer between the experimenter or the control program and the actual accelerator controls. For the simulation, a functional form for the accelerator current in terms of the signal voltage level will be needed, however the accelerator voltage display will be the same as the selected value.

2.2.2 Electron Accelerator

Control functions are necessary for the electron beam source, the beam focusing lenses and to establish the beam ejection direction. Figure 2.2 shows a conceptual block diagram of the electron accelerator control scheme.

The experimenter will be able to select either a voltage or a current for the cathode heater which provides the source of electrons for the beam. The voltage and current values will both be displayed and he will be able to select new values from the keyboard. The beam current will be determined by the voltage level of a control grid which can be controlled by either the keyboard or a preplanned control program. The accelerating potential will be controlled in a similar fashion. Displays for each of these source functions: cathode current, cathode voltage, control grid voltage, control grid current, and accelerating potential will be required. The experimenter can view each display and select a new value if necessary. Here again the computer acts as a buffer between the experimenter or the preplanned program and the controlled instruments.

The focusing of the beam is done by two lenses. The first is a diverging lens and the second is a converging lens. Each of these lenses is controlled by a voltage which is set by the experimenter. Beam positioning is accomplished by running a current through two separate coils, one for movement in the Shuttle X-Z plane and the other for the Y-Z plane. The experimenter determines the magnitude of the current in each of the coils either from the keyboard, if the beam is not to be scanned rapidly, or with a preplanned program that is able to use the computer to impress rapid current variations or the coils. In these cases as nearly always the computer

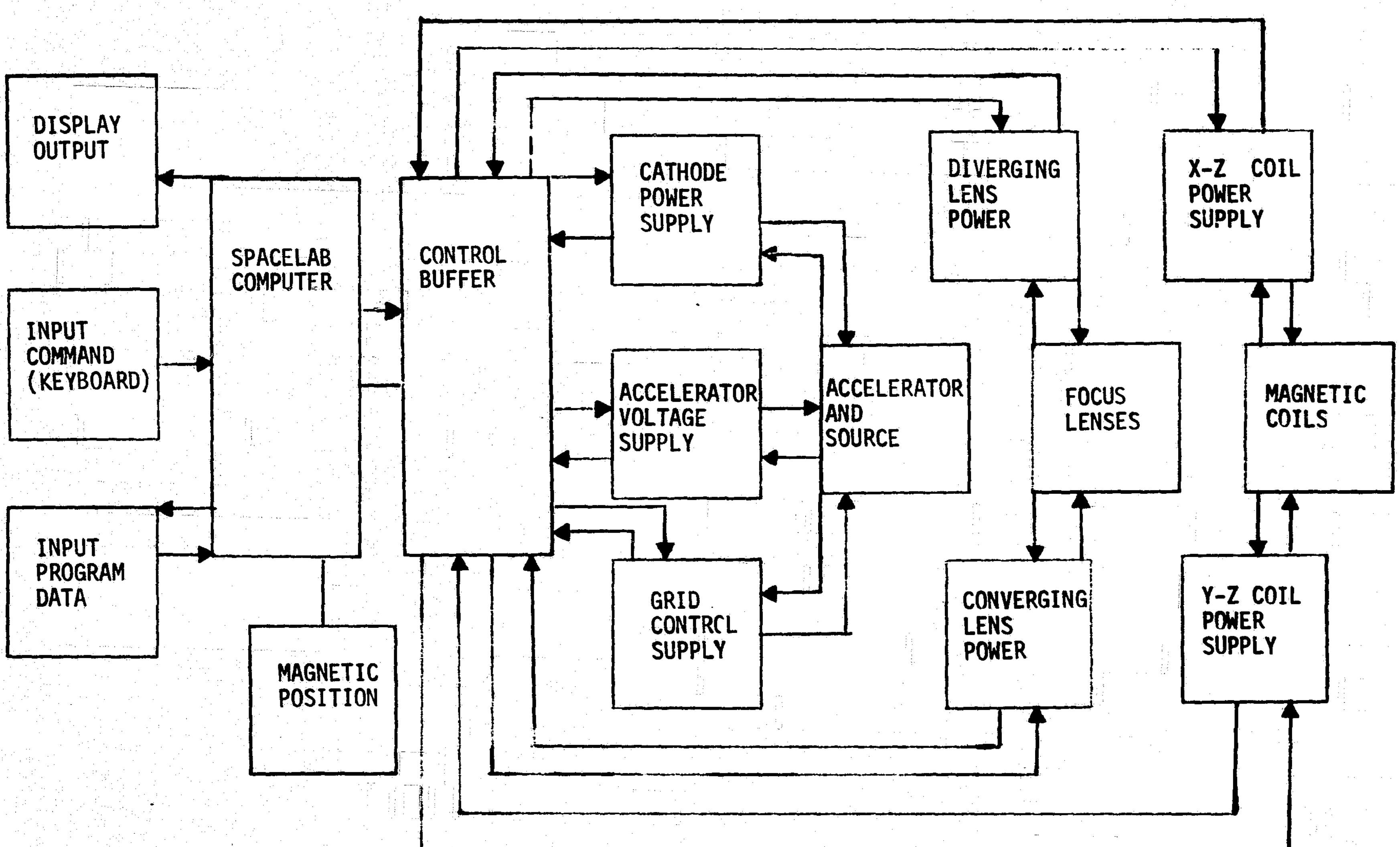


Figure 2.2 Conceptual Block Diagram of Electron Accelerator Control

acts as a buffer between the controlling agent and the controlled equipment. The computer also is required to record all command settings and displayed feedbacks.

2.2.3 The MPD Arc

The operation of the MPD arc is controlled in two steps. First an experimenter determined amount of gas is let into the arc chamber and then the electrical power bank is fired through the gas. Because the time between these two events is very short, a preplanned program will be used to fire the MPD arc. The experimenter will determine gas pressures and bank voltage and sequence times and then modify the firing program accordingly. He will then input the program into the computer together with a firing time. The computer will then send out the proper commands at the proper times. The experimenter will need to see displays of the chamber pressure and the arc voltage and current. A conceptual block diagram of the MPD arc control scheme is given in Figure 2.3. As with the ion accelerator the beam direction will be determined by using the Shuttle attitude system.

2.2.4 Gimbaling System

As stated at the beginning of this section, there will be no gimbaling of the accelerator system as it is presently planned.

2.2.5 Accelerator Pointing System

The accelerator system will be hard mounted on a pallet. The electron accelerator will have magnetic pointing coils as described above and the ion accelerator and MPD arc will be pointed by turning the whole Shuttle in the proper direction.

2.2.6 Accelerator Deployment

The only sort of deployment that can be considered as part of the accelerator system is the possible use of vacuum tight covers over the exit apertures of the accelerators. If such covers are used a simple experimenter command of open or close will be processed by the computer. Verification of the opening or closing would be either visual or by sensors mounted on the covers.

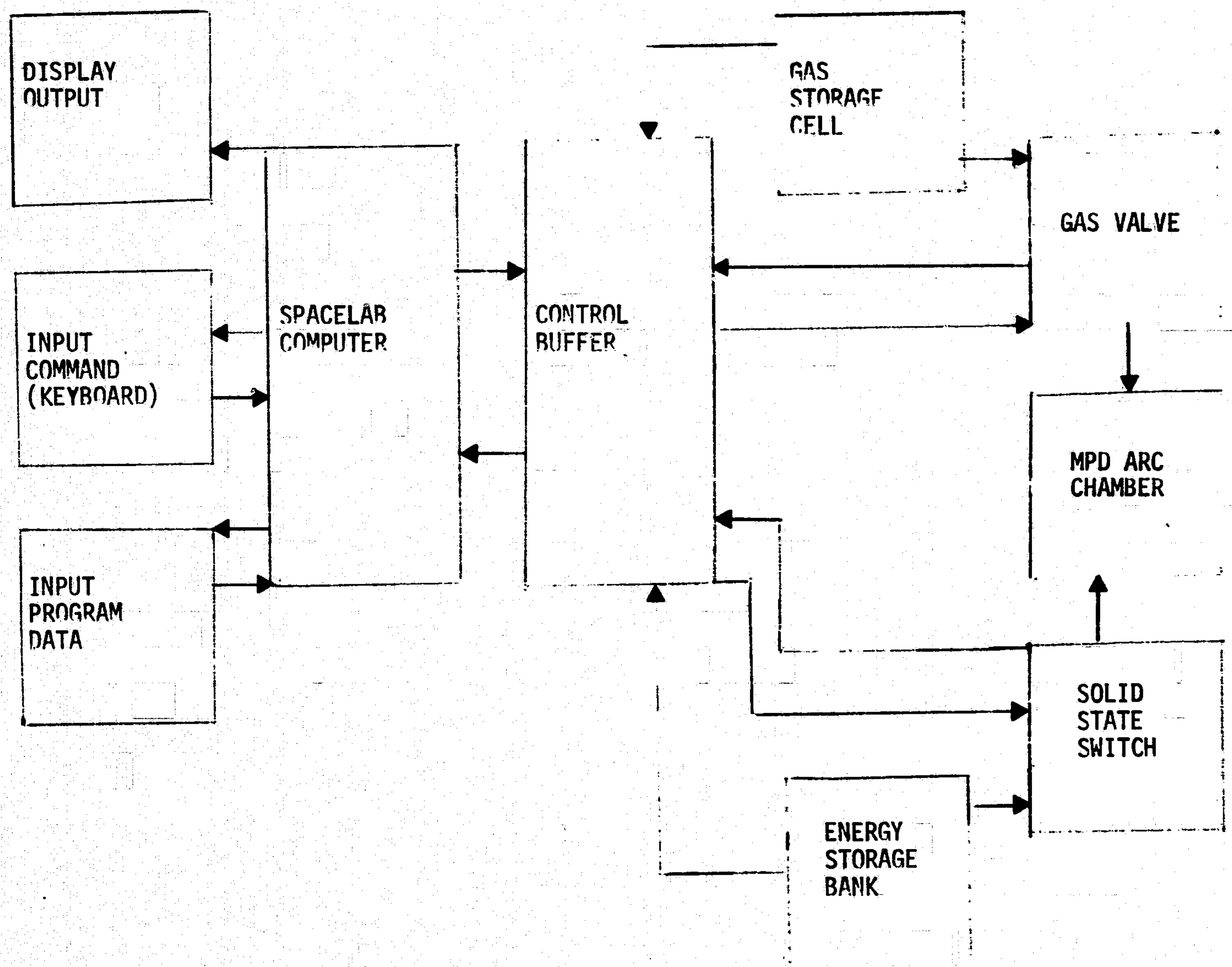


Figure 2.3 Conceptual Block Diagram of MPD Arc Control

2.2.7 Accelerator Power System

The power systems for each of the three accelerators have been combined into one energy storage bank and two power processor. The first processor takes 28 volt power and converts it to 500 volts. Commands and controls for this unit are needed to regulate the output voltage level and current. The experimenter will set the voltage level and current limit from the keyboard. The computer will keep check on the current and voltage and display their present values. The second power processing unit converts 500 volt power to power at >1,000 volts for use in the ion and electron accelerator. Here again the experimenter will set the voltage and current levels and the computer will check on them and display the present values. Finally the MPD arc draws its power from the storage bank through a solid state switch which will be controlled by the computer as it runs through the preplanned MPD arc firing program. Figure 2.4 shows a conceptual block diagram of the accelerator power system control scheme.

2.3 HIGH POWER TRANSMITTER/ANTENNA SYSTEM

While there are physically three separate power amplifiers for the transmitter corresponding roughly to the three frequency ranges: 300 Hz to 200 kHz, 200 kHz to 2 MHz and 2 to 20 MHz, the control functions will be identical.

2.3.1 Transmitter Systems

Control of the transmitter splits into two parts, control of the transmitted wave form and control of the output power. The power levels will be set first by choosing a maximum power consistent with the transmitter capability and the experimental requirements, and then by means of selecting an attenuation value. The experimenter must choose the proper power levels; and the computer must activate the transmitters and attenuators, and display and record their outputs. Figure 2.5 shows a conceptual block diagram of this control scheme.

The wave form of the transmitted waves can be generated by a separate piece of special purpose equipment. In general the frequencies of the waves are too large for the spacelab computer to simulate them. However, in simple cases the experimenter can use the computer to set up the special purpose equipment. In this case he will select the carrier frequency from

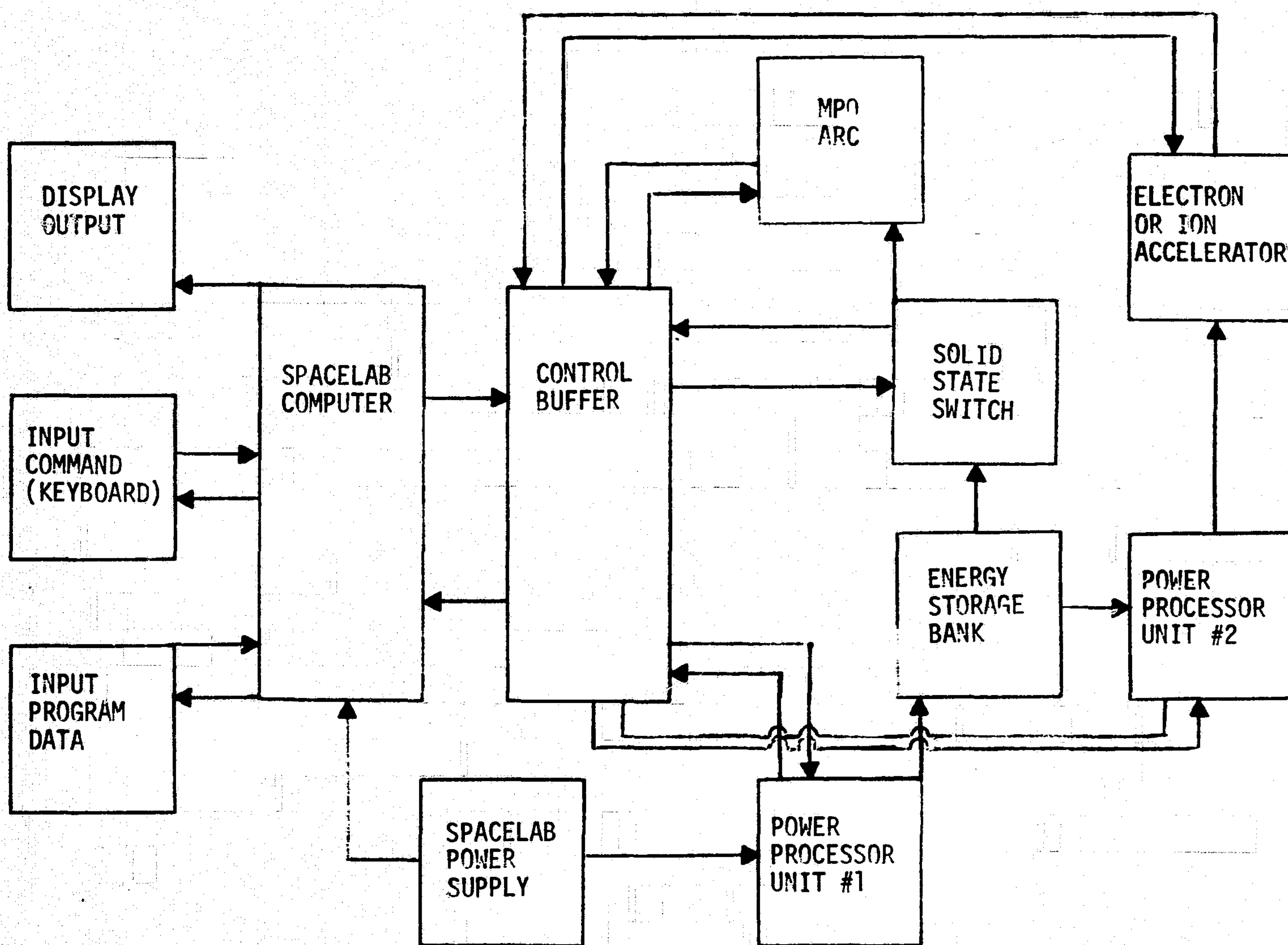


Figure 2.4 Conceptual Block Diagram of Accelerator Power Supply Control

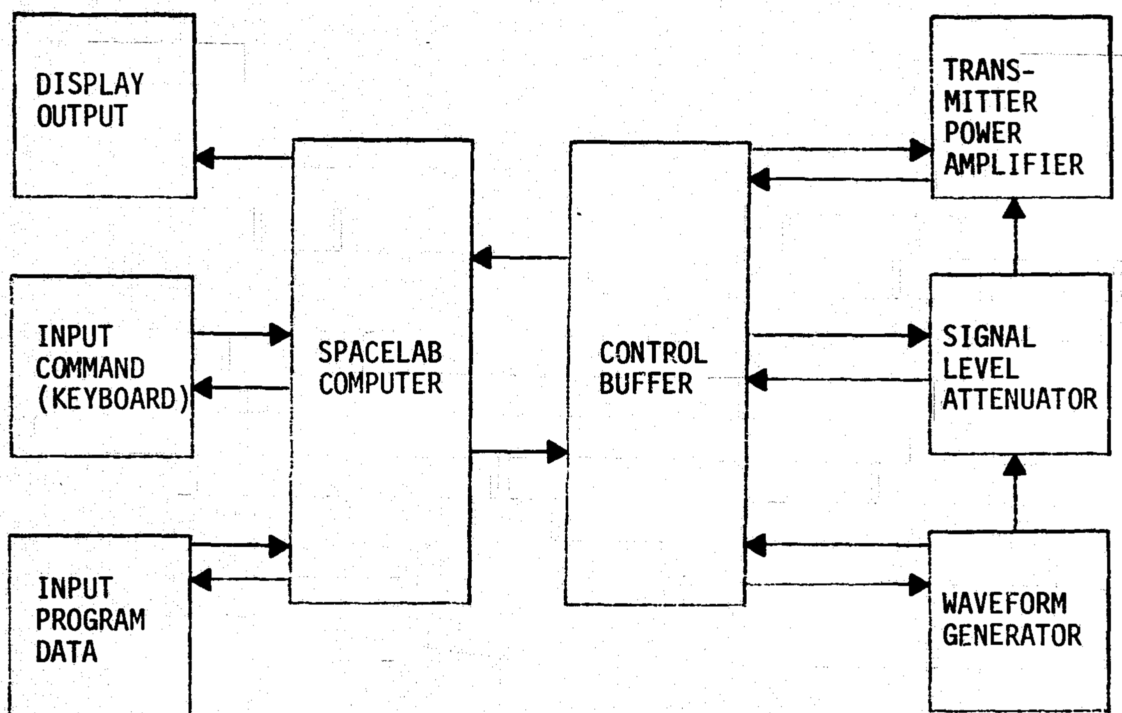


Figure 2.5 Conceptual Block Diagram of Transmitter Power Control

the keyboard, select either FM or AM modulation and the frequency of the modulation. It may be possible to let the experimenter select other experiment specific choices from the computer keyboard. Alternatively, the experimenter will set up the desired waveform using only the special purpose equipment and the computer will do no more than record all of the selected values. Figure 2.6 shows a conceptual block diagram of the waveform generator control scheme in which the computer keyboard is used.

Off-on controls for all transmitter associated equipment will be done by the experimenter from the computer keyboard.

2.3.2 1,000 Feet or 300 Meter Dipole Antenna

The length of the antenna will be controlled by an extension motor. The experimenter will select an antenna length. The computer will signal the motor to start and will run the motor until the antenna length sensor reaches the selected value when the motor will be stopped. One further control function is associated with the antenna system. This is the matching of the transmitter and antenna impedences. This function will probably be automatic once the experimenter has selected a carrier frequency and an antenna length. The computer will read the frequency and antenna length and select the proper matching network. Figure 2.7 shows a conceptual block diagram of the antenna control system.

2.3.3 Transmitter Deployment System

The transmitters and antenna are mounted to a pallet. The only deployment is the extension of the antenna which is treated in Section 2.3.2 above.

2.4 BOOM A, DIAGNOSTICS BOOM

2.4.1 Boom A, Deployment System

The deployment of Boom A is accomplished by having the experimenter select the desired boom length and turn the boom extension motor on. The computer will read the boom length sensor and stop the extension motor when the selected value is reached. Correction for length overshoot can be built into the computer software. The deployment system for Boom B is identical to that of Boom A and a conceptual block diagram of both systems is shown in Figure 2.8. This simulation will use a simple linear time dependence to display the boom length.

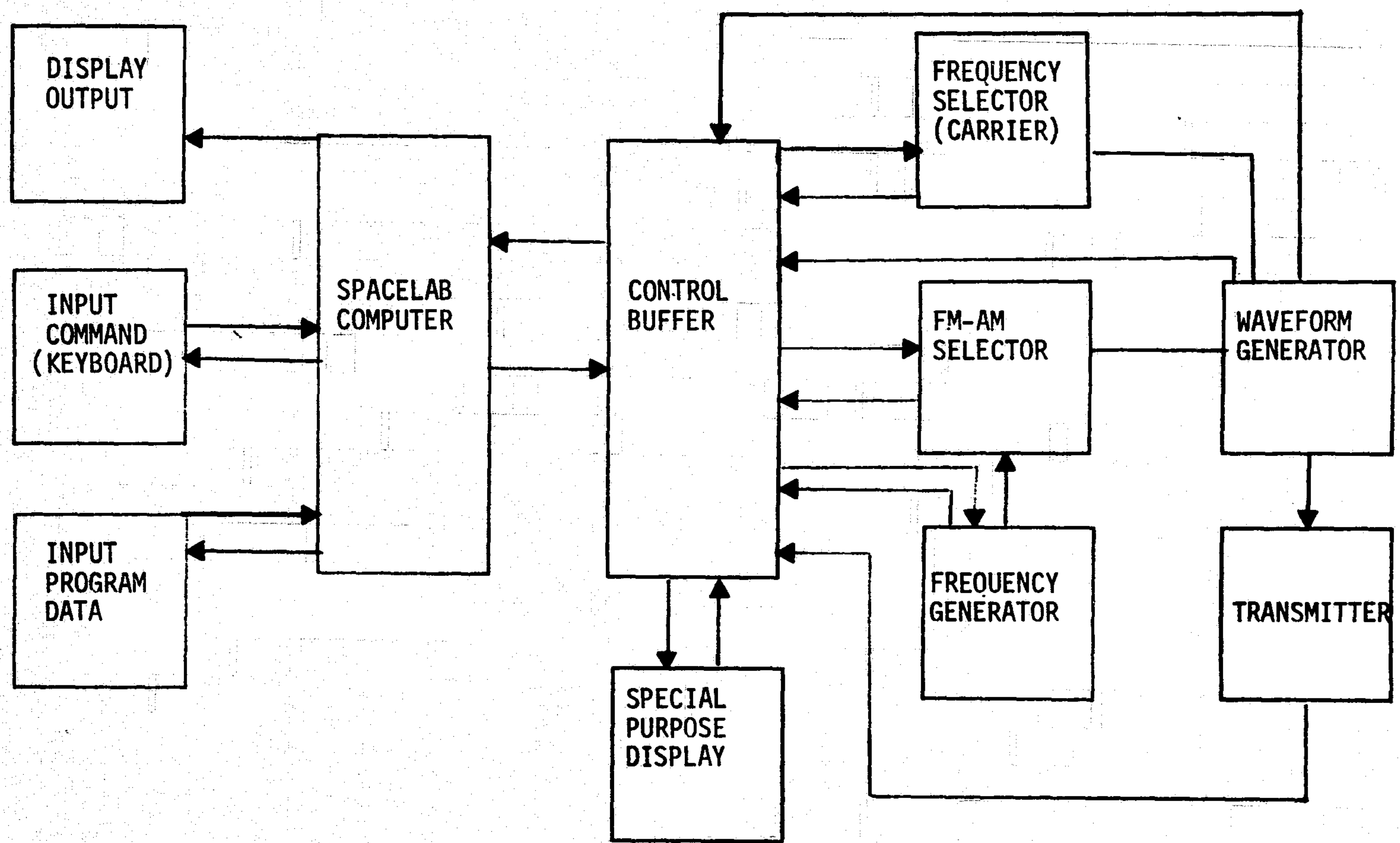


Figure 2.6 Conceptual Block Diagram of Transmitter Waveform Generator Control

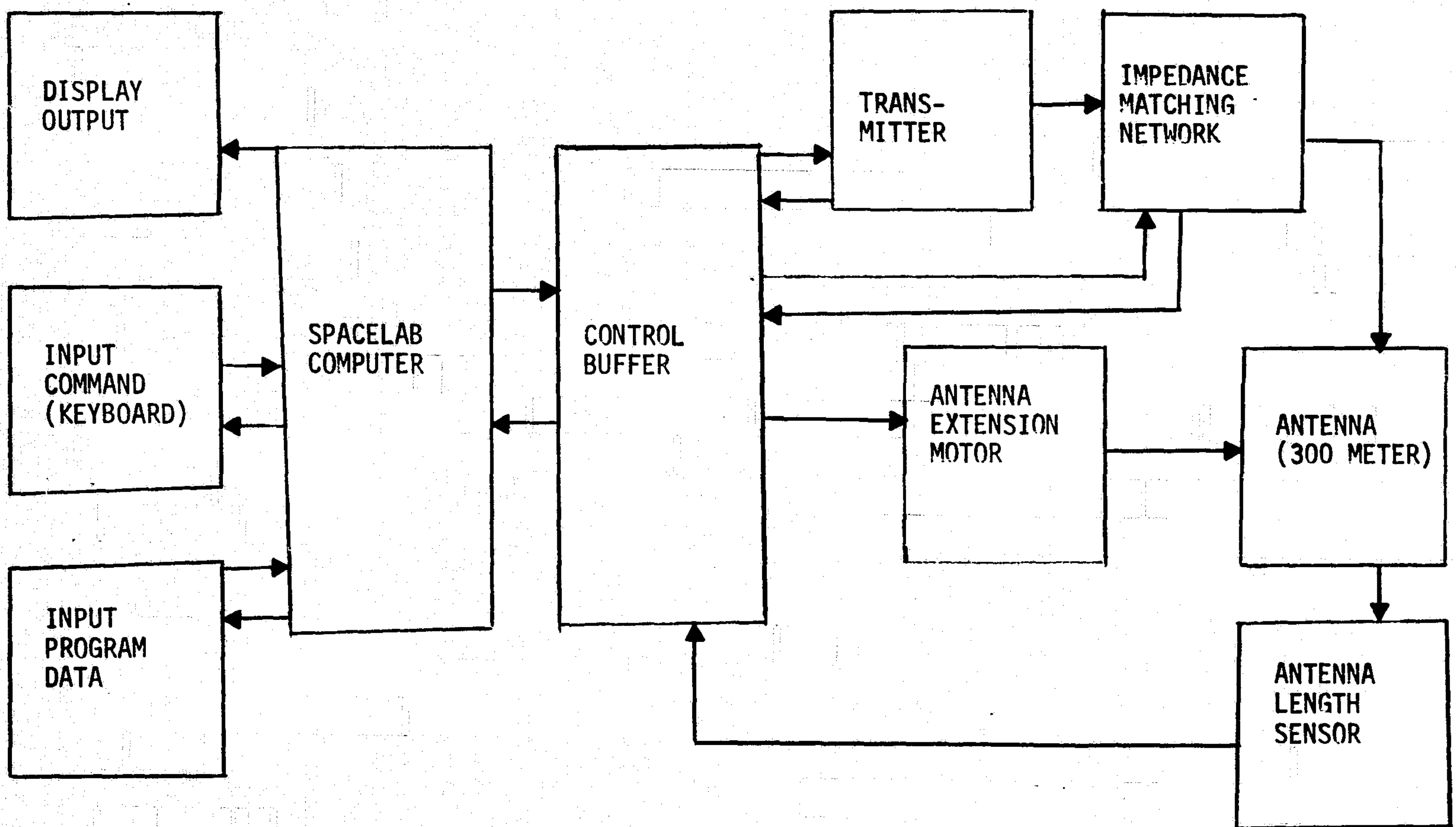


Figure 2.7 Conceptual Block Diagram of Antenna Control

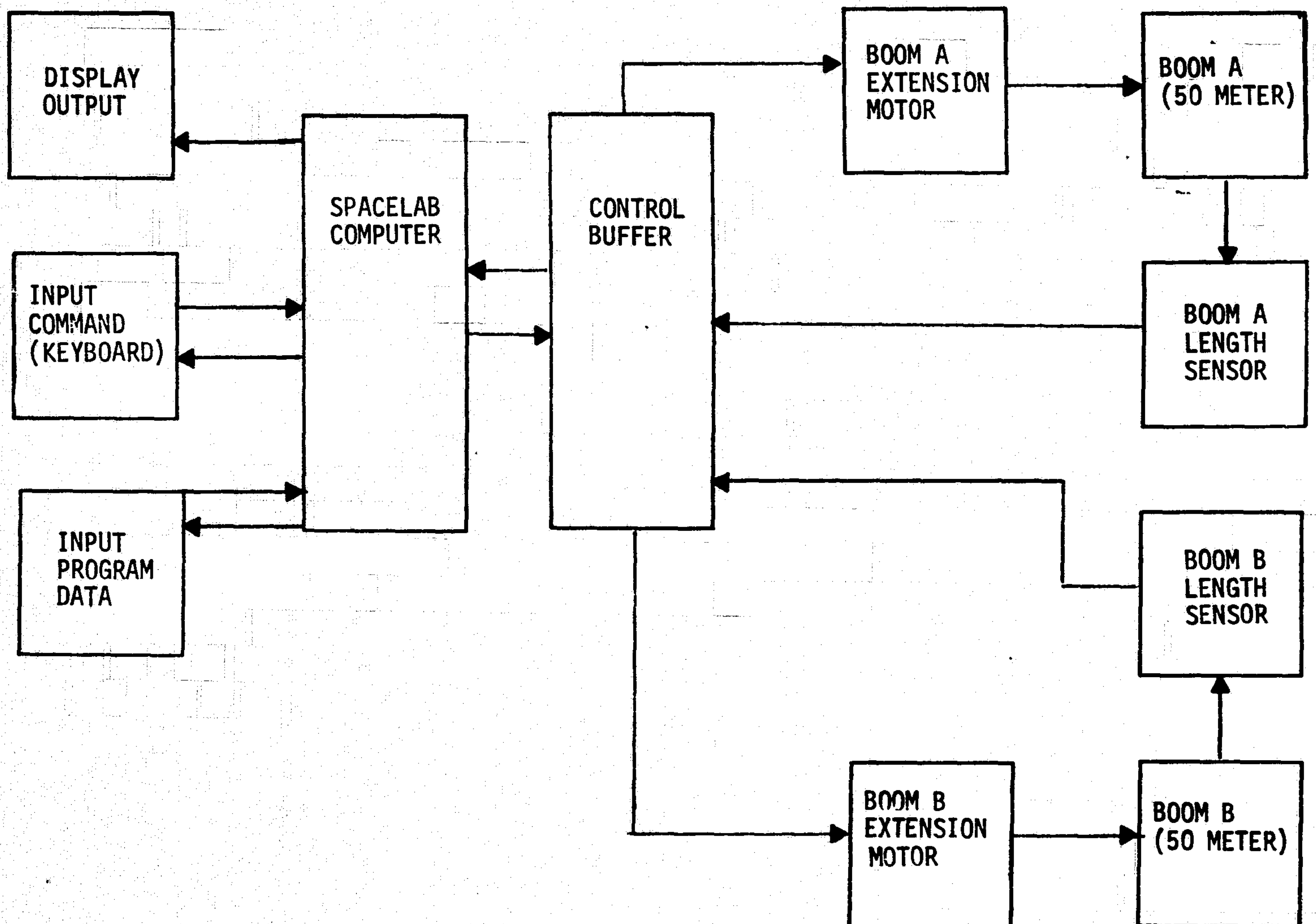


Figure 2.8 Conceptual Block Diagram of Boom A and Boom B Deployment Control

2.4.2 Boom A Maneuvering Function

It is necessary that Boom A be able to maneuver in two directions. If when the boom is stowed its extendable axis corresponds to the Shuttle Z axis, then denote the boom X and Y axes as those which correspond to the Shuttle X and Y axes, respectively. The two maneuvering direction correspond to angular rotations about the Shuttle Z axis and the boom axis. The experimenter or a preplanned program selects the desired value for each of these angles, and starts the rotator motors. The computer tracks the rotation sensors until the selected values are reached and stops the motors. In this simulation the angles are assumed to be linear functions of time and the computer simply displays the rotation angle as a constant multiple of the time that the rotating motors have been running. This simulation also assumes that the two angles can be varied independently of each other. In actual flight, it may be necessary to work out a software program which moves the booms in tandum because of constraints put upon their motion by Shuttle angular momentum considerations.

2.4.3 Gimbaled Platform

The platform at the end of Boom A must be able to rotate about three separate axes. The rotations are selected by the experimenter and executed by the computer in the same manner as Boom A maneuvers described in Section 2.4.2 above. The platform must also be able to remain at a fixed angle with respect to the Earth's magnetic field, the Shuttle velocity vector or an inertial frame. Therefore software must be provided so that the computer can maintain these fixed positions. Figure 2.9 shows a conceptual block diagram of the gimbaled platform control scheme. This simulation will display the platform angles as linear time functions and each angle will be independently variable.

2.4.4 5 Meter Sub-booms

The only controllable function of the sub-booms are their length which will be controlled in the same way as the Boom A or B extension described in Section 2.4.1. However, there will be no need to select the length of the sub-booms. They will either be extended or retracted.

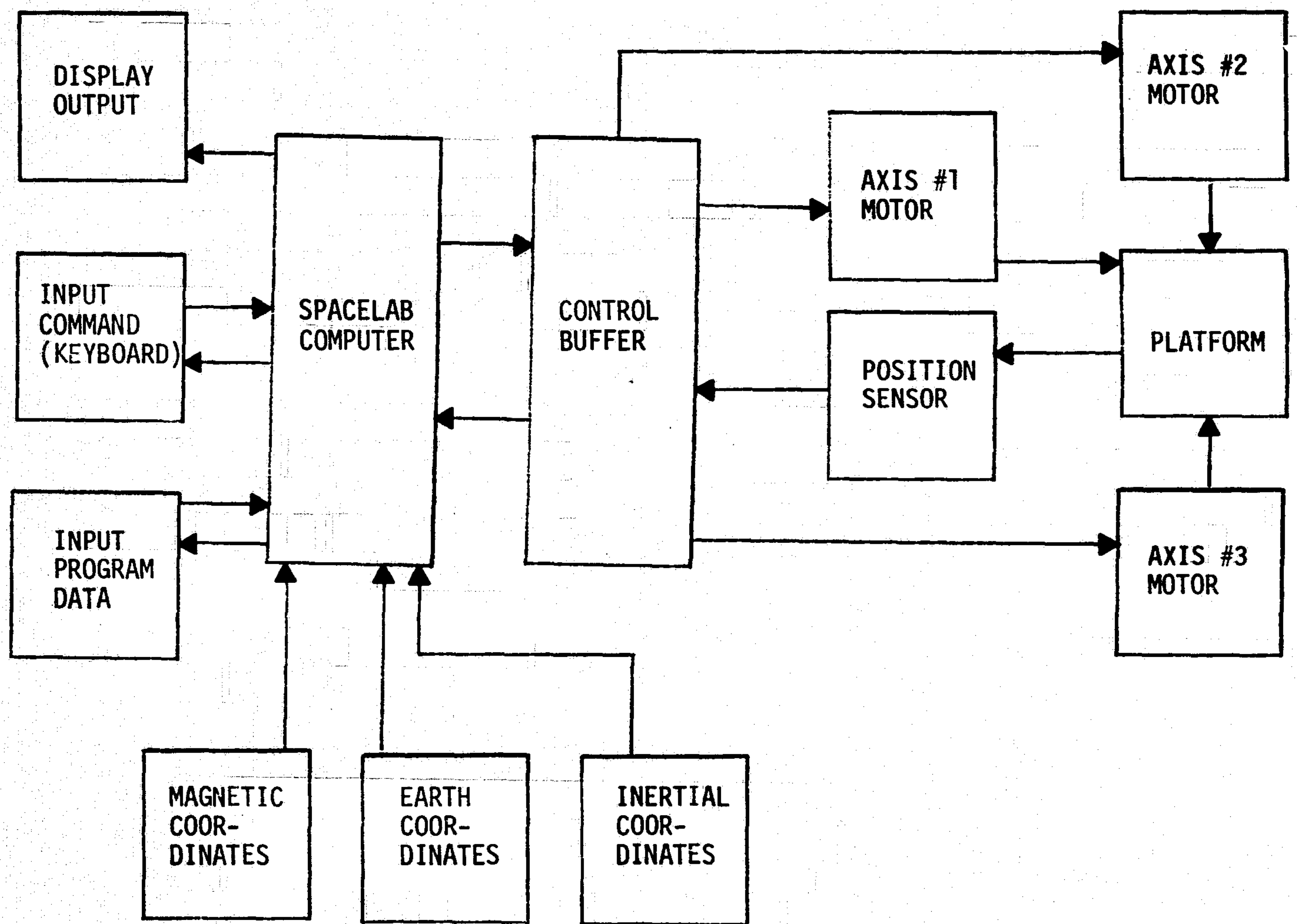


Figure 2.9 Conceptual Block Diagram of Gimbaled Platform Control

2.4.5 Electric Dipole Extension

The control functions of the electric dipole antenna are exactly the same as for the 1,000 foot dipole antenna described in Section 2.3.2.

2.4.6 Power Supply

The power supply on Boom A requires only on-off control and displays of the voltage level, the charging current and the discharging current.

2.5 BOOM B, PERTURBATION BOOM

2.5.1 Boom B Deployment System

The Boom B deployment system is exactly the same as the Boom A deployment system described in Section 2.4.1.

2.5.2 Boom B Maneuvering Function

Boom B and Boom A have nearly identical maneuvering functions. There is a possibility that Boom B will be able to rotate about a third axis—its own Z axis—in addition to the two axes required for Boom A. Figure 2.10 shows a conceptual block diagram of both Boom A and Boom B maneuvering control functions where a two axis rotation is assumed for Boom A and a three axis rotation for Boom B.

2.5.3 Target Deployment and Retraction

The target will be deployed by inflating it with gas. The targets may be made from an elastic material so that they can deflate themselves when a valve is opened, or they may be rolled onto a storage drum with the gas being ejected in the process, or finally, the targets may be jettisoned from the Shuttle when the experiment is finished. For this simulation we have assumed that target returns to its stowed position after a deflation gas valve is opened. The experimenter will be required to control both inflation and deflation gas valves using the computer display of the target pressure to guide him. Figure 2.11 shows a conceptual block diagram of the target deployment and retraction control scheme.

2.5.4 Wave Generator

The wave generator on Boom B is used for experiments in which plasma waves are propogated from one boom to the other. It consists of a transmitter and an antenna, and is nearly identical to the high power trans-

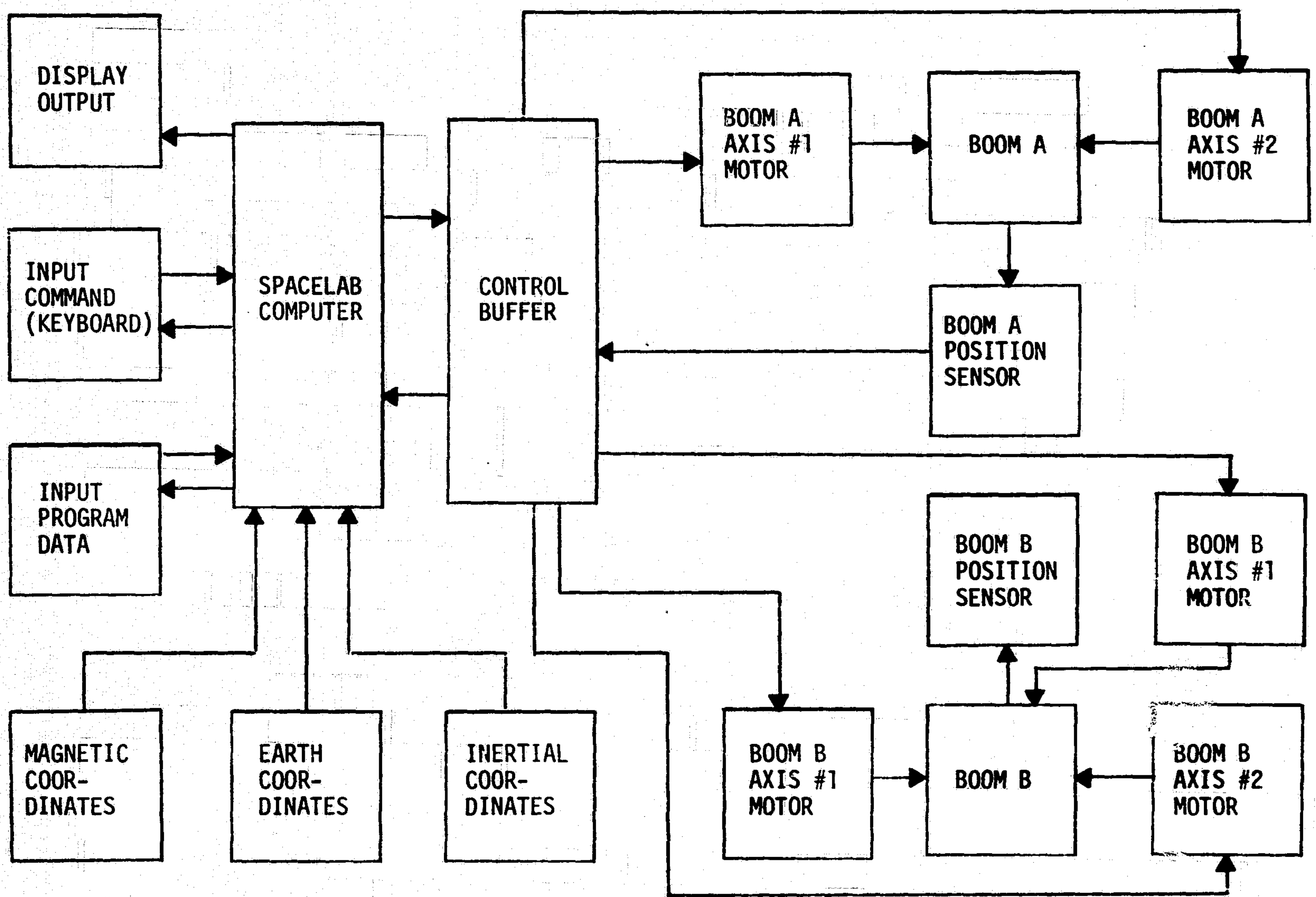


Figure 2.10 Conceptual Block Diagram of Boom A and Boom B Maneuvering Control

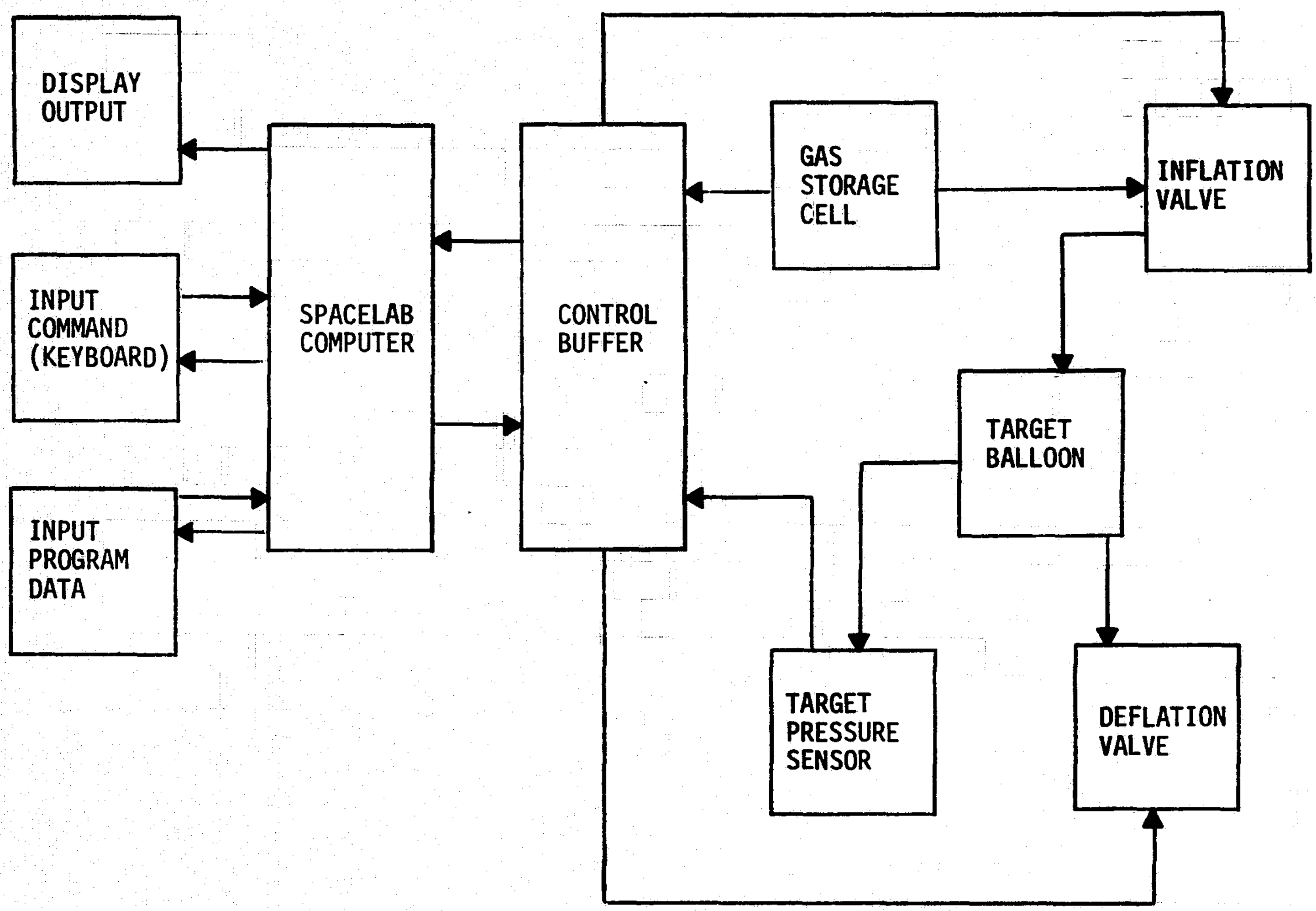


Figure 2.11 Conceptual Block Diagram of Target Deployment and Retraction Control

mitter/antenna system described in Section 2.3. The output power is less and the antenna length is less but in terms of the control functions this wave generator and the equipment described in Section 2.3 are identical.

2.5.5 Low Energy Electron Gun

The low energy electron gun resembles the electron accelerator. Its cathode must be heated and there must be an extractor grid whose potential controls the electron flux leaving the gun. The experimenter will control the cathode heater current, and the control grid voltage. Displays of the cathode heater current and voltage and the grid current and voltage will be made by the computer. Figure 2.12 shows a conceptual block diagram of the low energy electron gun control scheme. There will be no beam focusing or magnetic bending.

2.6 DEPLOYABLE SATELLITES

The entire command and control system for a satellite can be extremely complicated expecially for a satellite of the complexity planned for the AMPS Shuttle payloads. Therefore, the following description applies only for the simple controls that were necessary for the simulation of experiments.

2.6.1 Deployment Mechanism

The deployment of the satellite consists, for the most part, in checking out the proper functioning of the satellite systems and instruments before it is ejected from the Shuttle. The direction of ejection will be controlled by orienting the Shuttle itself and launching the satellite along the Shuttle plus Z-axis. Once the satellite has been checked and the Shuttle oriented, the experimenter will select the desired launch time and arm the ejection mechanism. The computer will eject the satellite at the correct time. However, the experimenter can override the computer at any time. Figure 2.13 shows a conceptual block diagram of the satellite deployment control scheme.

2.6.2 Television System

The television system requires extensive control by the experimenter. It will be assumed that the system is mounted on a two axis scan platform so that the TV system can be targeted without changing the attitude of the satellite. The experimenter will select the desired angular values for the two axis and the command will be telemetered to the satellite scan platform

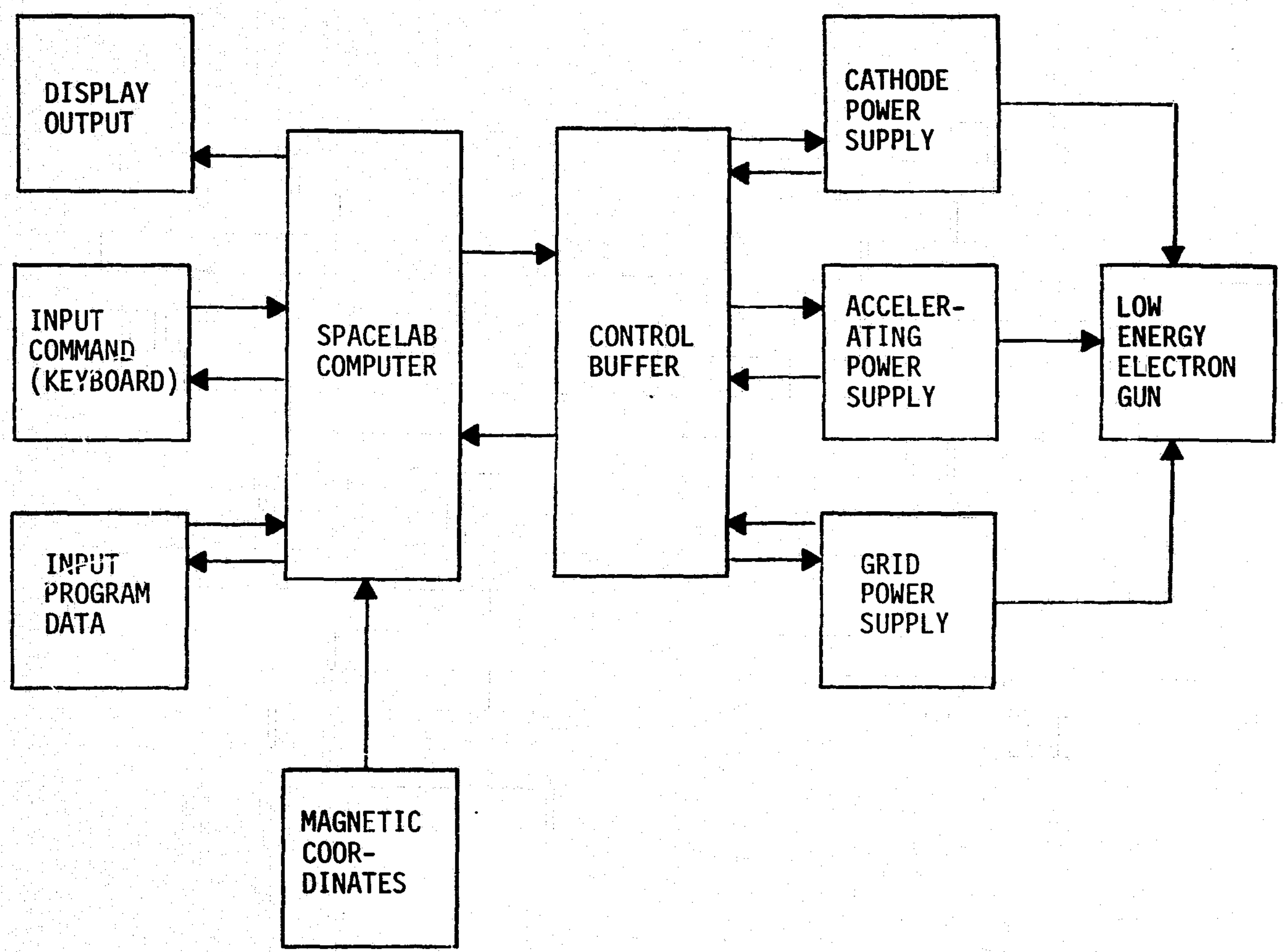


Figure 2.12 Conceptual Block Diagram of Low Energy Electron Gun Control

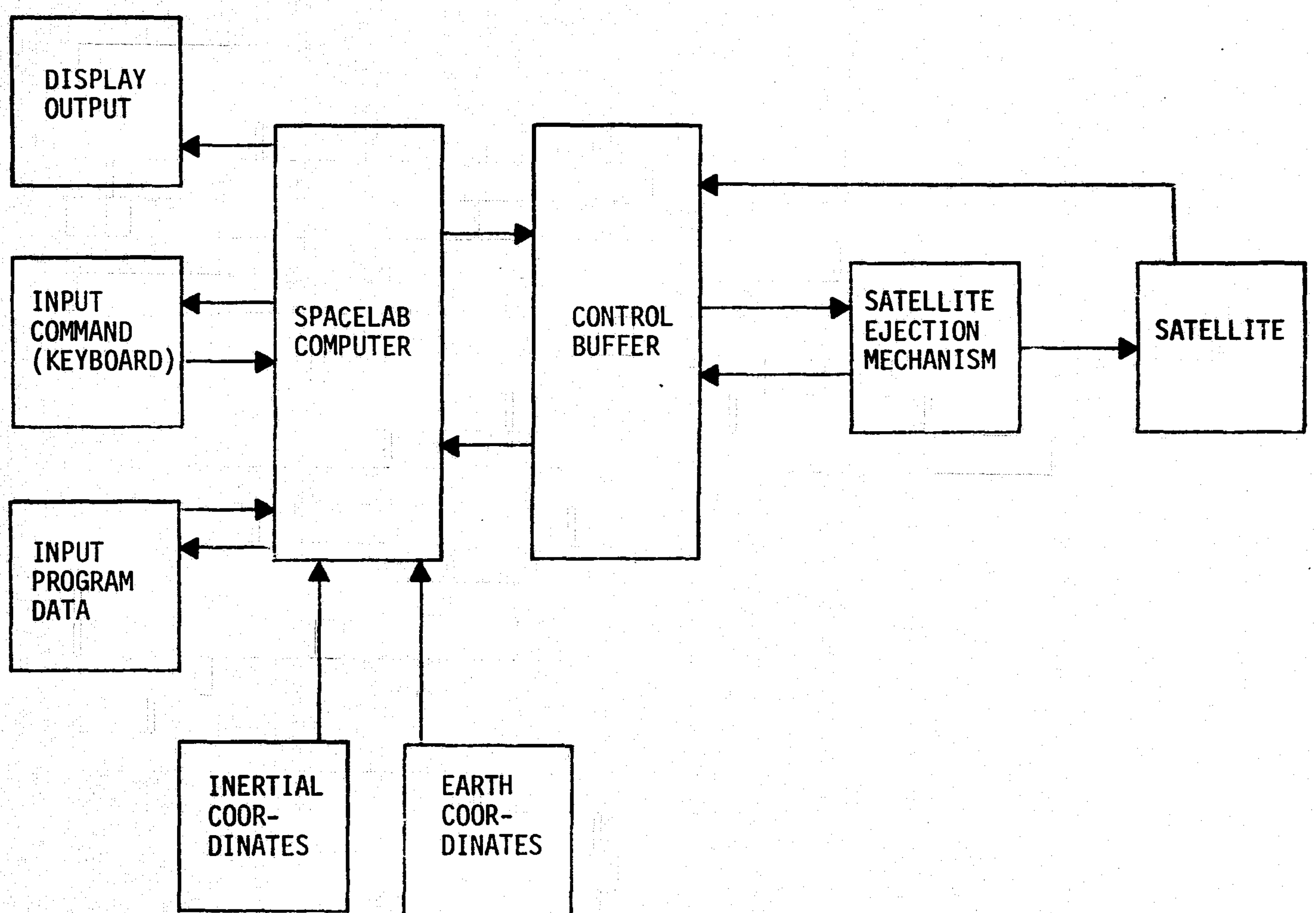


Figure 2.13 Conceptual Block Diagram of Satellite Deployment System Control

motors. The field of view of the TV system will be controllable and the magnification also. The experimenter will have on-off controls and the ability to change the photometric sensitivity. Finally, the wavelength of the received light will be selectable by changing optical filters. Figure 2.14 shows a conceptual block diagram of the satellite television system control scheme. The actual television picture data will not be processed through the spacelab computer because the data rate is too high.

2.6.3 Transponder

The only experimenter control of the satellite transponder is to turn it on or off. This function can be done either through the satellite—Shuttle umbilical line or by means of the telemetry system. Figure 2.15 shows a conceptual block diagram of these two methods of turning the transponder on or off.

2.6.4 Telemetry System

The only control the experimenter has on the satellite telemetry system will be to turn it on and off through the Shuttle-satellite umbilical system. Figure 2.16 shows a conceptual block diagram of the satellite telemetry system control scheme.

2.6.5 Ranging and Control System

The satellite range, attitude and spin rate will be controlled by telemetry from the Shuttle. The experimenter selects a range or alternatively a geographic position for the satellite and the computer controls the satellite thrusters in order to bring the satellite to the desired position. The attitude thrusters are then used to bring the satellite into the chosen orientation. Finally, the satellite is spun faster or slower to suit the experimenter. Figure 2.16 shows a conceptual block diagram of the satellite ranging and control system.

2.7 DEPLOYABLE UNITS

The control of the deployable units is divided into two parts. The first is concerned with the ejection of the unit and is exactly like the procedures described in Section 2.6.1. The second facet of the control of the deployable units involves the telemetering of commands from the experimenter to the unit. A conceptual black diagram of the deployable unit control shceme is shown in Figure 2.17.

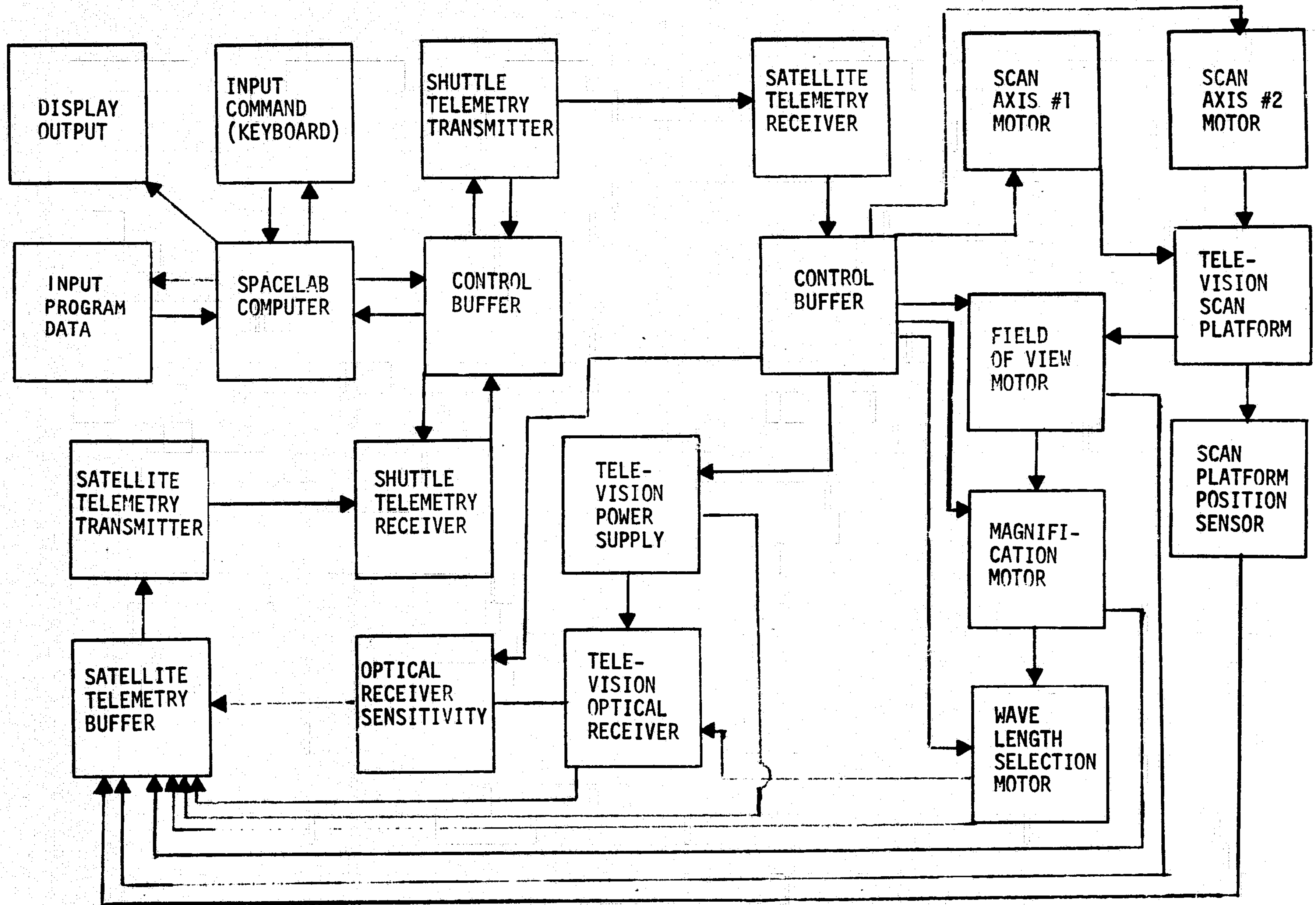


Figure 2.14 Conceptual Block Diagram of Satellite Television System Control

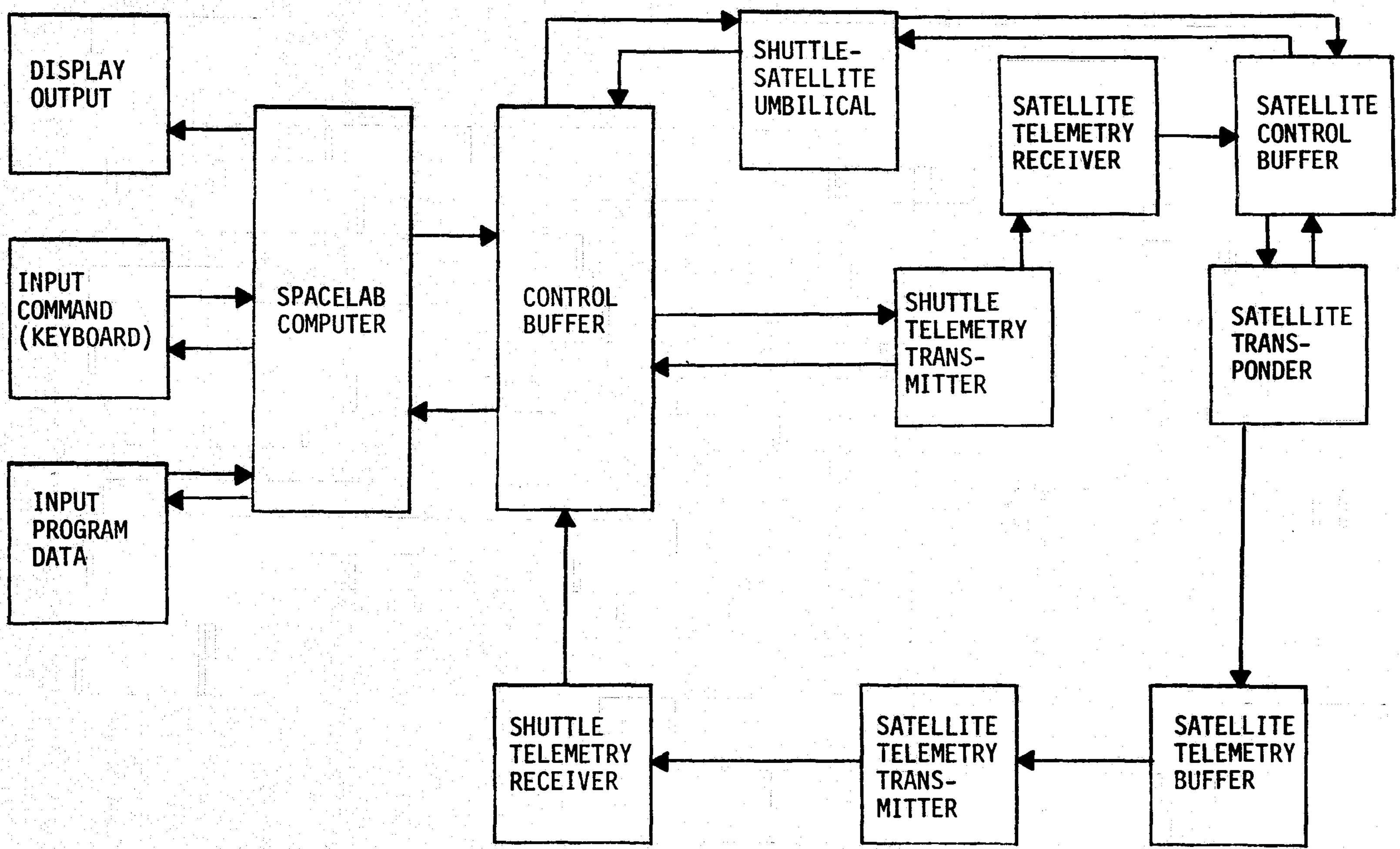


Figure 2.15 Conceptual Block Diagram of Satellite Transponder Control

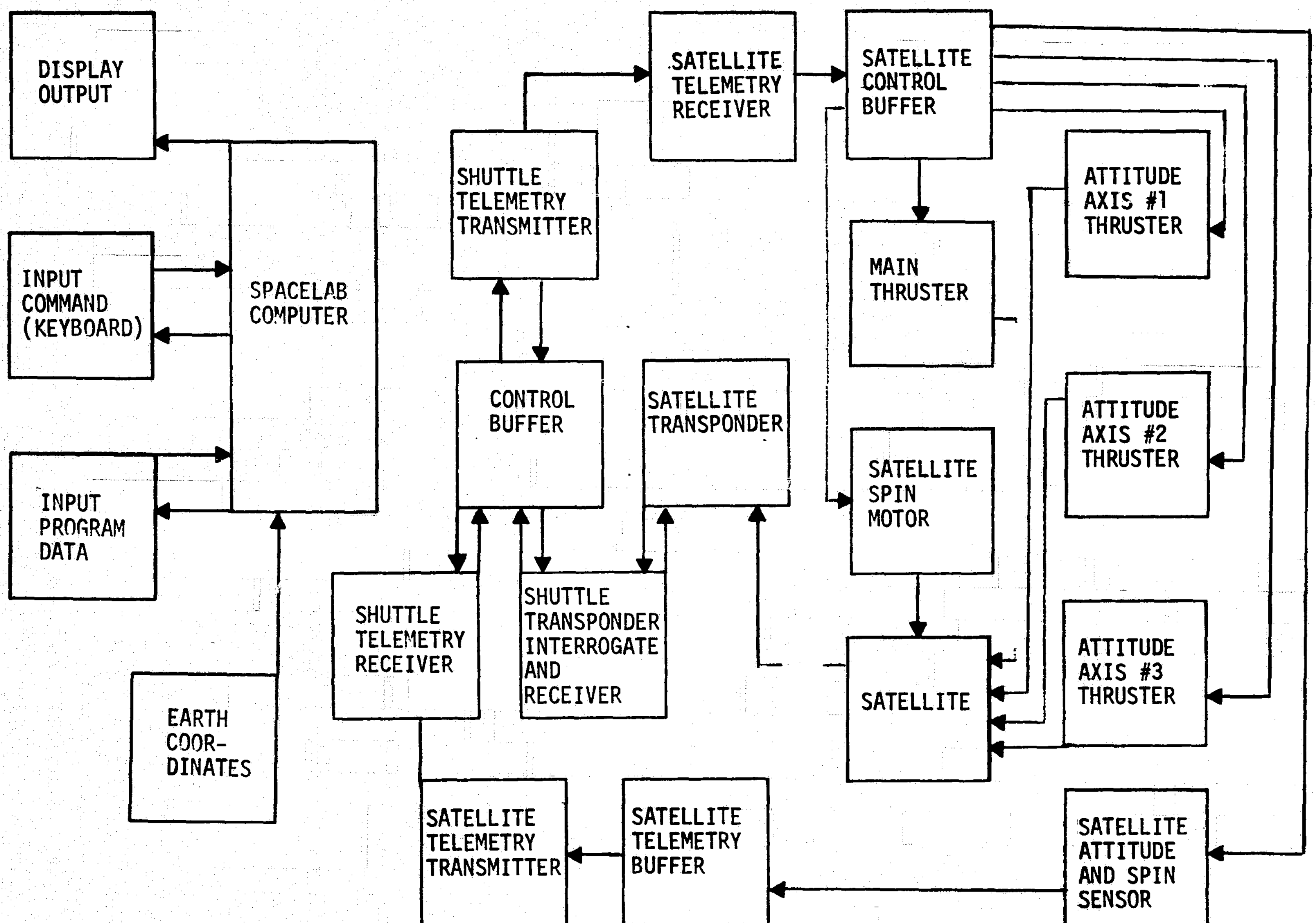


Figure 2.16 Conceptual Block Diagram of Satellite Ranging and Control System Control

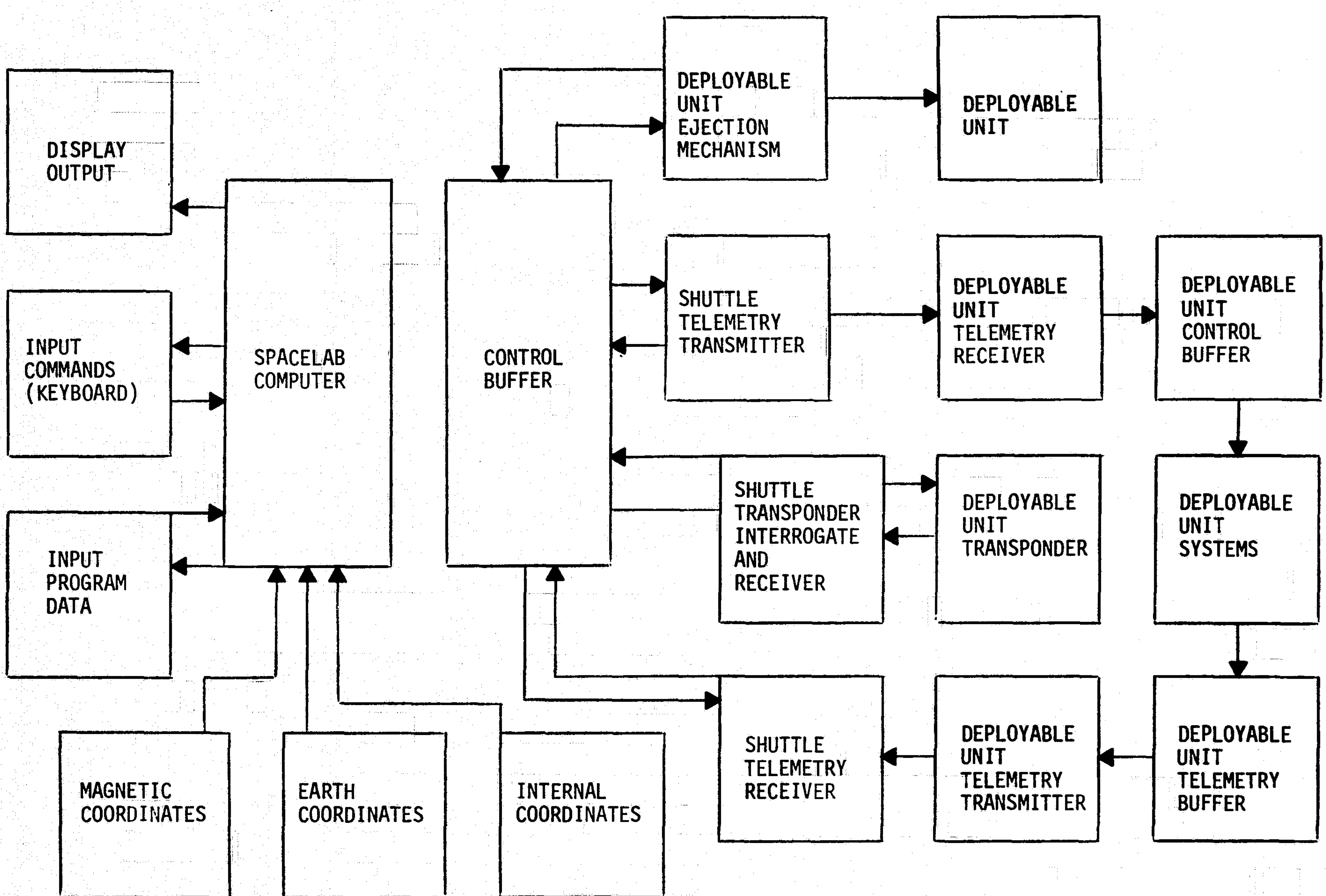


Figure 2.17 Block Diagram of Deployable Unit Control

3.0 EXPERIMENT SIMULATION

A complete description of the simulation requirements of six experiments are presented in the following sections.

Experiment 1: Electromagnetic Wave Transmission
Experiment 2: Passive Observation of Ambient Plasmas
Experiment 3: Ionospheric Measurements with a Subsatellite
Experiment 4: Electron Accelerator Beam Measurements
Experiment 5: Lidar Trace of Acoustic Gravity Waves in the Sodium Layer
Experiment 6: Determination of the Wake of a Test Body

For each experiment simulation, the responses of a subset of sensors and controllable systems listed in Table 1.0 and 2.0, respectively are described. The sensor and detector response are presented as a logical function of the relationship between the detector orientation with respect to its velocity vector, the orientation and velocity vector of the Shuttle, and its location in orbit. This includes the following factors:

a. The pointing, control, data acquisition and display of the remote sensing platform and the detectors and sensors thereon.

b. The deployment, pointing, operation and display of the gimbaled accelerator systems.

c. The deployment orientation and operation of the high power transmitter/antenna system.

d. The deployment, maneuvering, operation, control and display of Booms A and B including the operation and display of all instruments, sensors, detectors, and associated subsystems on each.

e. The deployment, tracking, and display of all deployable units.

f. The deployment, tracking, control, operations, and display of the two subsatellite units.

This section is subdivided into six parts, one for each of the experiments. Each part in turn is divided into three subparts: An experiment description, an experiment procedure and a theory and background section. The data formating requirements for each experiment are given in the appendix.

3.1 SIMULATION OF THE ELECTROMAGNETIC WAVE TRANSMISSION EXPERIMENT

3.1.1 Experiment Description

Experiment description uses the outputs of the following instruments described in Section 1.0.

1. One meter loop antenna
2. Short electric dipole antenna
3. Triaxial fluxgate magnetometer
4. 33 meter electric dipole antenna
5. Cylindrical electron probe

Furthermore in response to the requirements of Task 2 the experiment exercises the following controllable systems:

1. The high power transmitter antenna system
2. the Boom B perturbation boom
3. The Boom A diagnostics boom with platform.

The outputs of the instruments and controlled systems are flow charted in Section 4.0 as required by Task 3 and integrated into the experiment simulation as required by Task 4.

This experiment simulation has been carried out in great detail in order to demonstrate the flexibility and control that can be provided in a CVT simulation. This detail is particularly evident in the theory and in the euqation derivations. Furthermore each display presentation of instrument operation has been backed up with another display showing computer default values for experimenter choices, thus demonstrating the systems capability to handle default values.

A wave transmission experiment would be performed early in an AMPS mission. The theory of linear electromagnetic wave transmission is well understood so that an experiment like this one would give experimenters early practice in the use of the active experimental capability of the AMPS payload. This particular simulation experiment provides a test of the wave transmission and receiving equipment and could be carried out in a variety of orbital situations to ascertain that the equipment is functioning properly.

The simulation experiment consists of transmitting a wave of known frequency and amplitude from one center-fed dipole to a short dipole antenna and a loop antenna which measure the electric and magnetic fields of the transmitted wave. The transmitter is stepped in frequency from a frequency several times larger than the local plasma frequency down to a value very close to the plasma frequency. The experimental result is the ascertainment of the wave vector, k, as a function of transmitter frequency and ionospheric plasma frequency.

During the wave transmission experiment the cylindrical electron probe and the fluxgate magnetometer are making measurements of the ionospheric electron density and temperature, and the Earth's magnetic field. Because the transmitting and receiving antennas are mounted on separate booms, the experimenter has the ability to vary the distance and angle between them. A sample experimental procedure is presented in order to introduce the experimenter to the simulation format. Once he has learned how to get results, he will be able to vary some parameters at will. The simulation is limited in that the following quantities cannot be varied:

1. The electron density and temperature
2. The magnetic field value
3. The Shuttle orbital parameters.

However, there still remains a wide variety of experimental conditions available to the experimenters.

3.1.2 Experiment Procedure: Wave Transmission Experiment

EP1.1 Hold Shuttle in orientation with Y-axis along ambient magnetic field direction (orbiter control system)

EP1.2 Set boom B

- EP1.2.1 Set length to 50 meters relative to Shuttle
- EP1.2.2 Set θ-angle at 30° relative to Shuttle
- EP1.2.3 Set Ø-angle at 0° relative to Shuttle

EP1.3 Set boom A

- EP1.3.1 Set length to 50 meters relative to Shuttle
- EP1.3.2 Set θ-angle at 30° relative to Shuttle
- EP1.3.3 Set Ø-angle at 180° relative to Shuttle

EP1.4 Set boom A gimbaled platform

EP1.4.1 Platform in magnetic autolock mode

EP1.4.1.1 Set short electric dipole antenna axis parallel to ambient magnetic field [must display orientation] Numerical Table

EP1.4.1.2 Set autolock [Computer must check magnetic orientation and control]

EP1.5 Set wavegenerator length at 6 meters tip-to-tip

EP1.6 Generate background plasma data

EP1.6.1 Turn Boom A Power Supply ON

EP1.6.2 Cylindrical electron probe

EP1.6.2.1 Turn instrument ON

EP1.6.2.2 Check sweep voltage waveform CRT display

EP1.6.2.3 Check current versus voltage CRT display

EP1.6.2.4 Check probe orientation display probe not parallel velocity vector

EP1.6.2.5 Perform electron temperature calculation

EP1.6.2.5.1 Input model

EP1.6.2.5.1.1 Display Te = 1/10eV

EP1.6.2.5.1.2 Record

EP1.6.2.6 Perform electron density calculation

EP1.6.2.6.1 Display $n_e = 3 \times 10^5$ electron/cm^3

EP1.6.2.6.2 Record

EP1.6.3 Fluxgate magnetometer

EP1.6.3.1 Turn fluxgate ON

EP1.6.3.2 Display magnetic field values

EP1.6.3.3 Calculate electron cyclotron frequency

EP1.6.3.3.1 Display cyclotron frequency $\#F_{ce}$ = 840 kHz

EP1.6.3.3.2 Record

EP1.6.3.4 Record magnetic field values

EP1.6.4 Calculate plasma frequency

EP1.6.4.1 Input electron density 3×10^5

EP1.6.4.2 Display plasma frequency F_p = 4.9 MHz

EP1.6.4.3 Record

EP1.7 Generate electric field background survey from short electric dipole

EP1.7.1 Display short electric dipole is parallel to magnetic field vector

EP1.7.2 Connect electric field receiver to short dipole antenna

EP1.7.3 Set receiver bandpass

EP1.7.3.1 Upper level 20.5 MHz

EP1.7.3.2 Lower level 3.9 MHz

EP1.7.3.3 Square rolloffs

EP1.7.4 CRT display receiver output

EP1.7.5 Adjust gain so that background level exists >0 at all frequencies

EP1.7.6 Record electric background survey

EP1.8 Generate magnetic field background survey from loop antenna

EP1.8.1 Check loop antenna perpendicular to magnetic field vector

EP1.8.2 Connect magnetic field receiver to loop antenna

EP1.8.3 Set receiver bandpass

EP1.8.3.1 Upper level 20.5 MHz

EP1.8.3.2 Lower level 3.9 MHz

EP1.8.3.3 Square rolloffs

EP1.8.4 CRT display magnetic receiver output

EP1.8.5 Adjust gain so that background level exists >0 at all frequencies

EP1.8.6 Record magnetic background survey

EP1.9 If background levels are acceptable continue, if not, stop

EP1.10 Activate transmitter

EP1.10.1 Connect 33 meter antenna to transmitter

EP1.10.2 Turn transmitter to Ready

EP1.10.3 Set attenuation to maximum

EP1.10.4 Set carrier waveform to sine wave

EP1.10.5 Set carrier frequency to 19.60 MHz

EP1.10.6 Turn transmitter ON

EP1.11 Receivers

EP1.11.1 Set electric field receiver bandpass at 19.61 and 19.59

EP1.11.2 Set magnetic field receiver bandpass at 19.61 and 19.59

EP1.12 Adjust transmitter attenuation so that received signal level is 100 times background level

EP1.12.1 Display received Electric Field Signal

EP1.12.2 Adjust attenuator

EP1.12.3 Record all levels and settings

EP1.13 Measure fields

EP1.13.1 Electric field receiver

EP1.13.1.1 Digitize mean square electric field

EP1.13.1.2 Generate data for 30 seconds

EP1.13.1.3 Transmitter to Ready

EP1.13.1.4 Generate mean square electric field

EP1.13.1.5 Display mean square E-field

EP1.13.2 Magnetic field receiver

EP1.13.2.1 Digitize mean square magnetic field

EP1.13.2.2 Transmitter ON for 30 seconds

EP1.13.2.3 Transmitter to Ready

EP1.13.2.4 Generate mean square magnetic field

EP1.13.2.5 Display mean square B-field

EP1.14 Calculate k-value

EP1.14.1 Call for special program "calculate k-value"

EP1.14.2 Display k value

EP1.14.3 Record all calculations

EP1.15 Repeat steps EP1.10.3 to EP1.14.7, inclusive, and step EP1.6.4 frequencies as below

EP1.15.1 Set receiver bandwidth to F + .01 and F - .01 of transmitter frequency F

EP1.15.2 Set transmitter frequency F at

EP1.15.2.1 15.5 MHz

EP1.15.2.2 10.9 MHz

EP1.15.2.3 8.95 MHz

EP1.15.2.4 8.0 MHz

EP1.15.2.5 7.5 MHz

EP1.15.2.6 7.0 MHz

EP1.15.2.7 6.75 MHz

EP1.15.2.8 6.50 MHz

EP1.15.2.9 6.25 MHz
EP1.15.2.10 6.00 MHz
EP1.15.2.11 5.9 MHz
EP1.15.2.12 5.8 MHz
EP1.15.2.13 5.7 MHz
EP1.15.2.14 5.6 MHz
EP1.15.2.15 5.5 MHz
EP1.15.2.16 5.4 MHz
EP1.15.2.17 5.3 MHz
EP1.15.2.18 5.25 MHz
EP1.15.2.19 5.20 MHz
EP1.15.2.20 5.15 MHz
EP1.15.2.21 5.10 MHz
EP1.15.2.22 5.05 MHz
EP1.15.2.23 5.00 MHz
EP1.15.2.24 4.95 MHz
EP1.15.2.25 4.90 MHz
EP1.15.2.26 4.85 MHz
EP1.15.2.27 4.8 MHz
EP1.15.2.28 4.7 MHz
EP1.15.2.29 4.6 MHz
EP1.15.2.30 4.5 MHz
EP1.15.2.31 4.0 MHz

EP1.16 Terminate Experiment

EP1.16.1 Transmitter OFF
EP1.16.2 Electric Receiver OFF
EP1.16.3 Magnetic Receiver OFF
EP1.16.4 Disconnect Antennas
EP1.16.4.1 Transmitter from 33-meter Antenna
EP1.16.4.2 Receiver from Electric Dipole
EP1.16.4.3 Receiver from Loop Antenna
EP1.16.5 Reel in 33-meter antenna
EP1.16.6 Turn Fluxgate Magnetometer OFF
EP1.16.7 Turn Cylindrical Probe OFF
EP1.16.8 Stow both larger booms.

3.1.3 Theory and Background for Simulation of the Electromagnetic Wave Transmission Experiment

3.1.3.1 AMPS Instruments and Equipment Required. The following AMPS instruments and equipment are used in this experiment:

1) Transmitter
2) Wave generator (variable length antenna) on Boom B
3) Electric field receiver with dipole antenna on Boom A
4) Magnetic field receiver with loop antenna on Boom A
5) Boom A with gimbaled platform
6) Boom B
7) Fluxgate magnetometer on Boom A
8) Cylindrical probe on Boom A.

3.1.3.2 Simulation Controls. In the experiment simulation and experimeter can control the following parameters over the given ranges:

1)	ON-OFF functions for every instrument	ON-READY-OFF
2)	Transmitter frequency	3 to 25 MHz
3)	Transmitter amplitude and/or power	0.1 to 1000 watts
4)	Background E-M noise level	10 to 10^{-5} volts
5)	Wave generator (transmitter) antenna length	0-33 meters
6)	Electric field receiver bandpass	Any at frequencies from 3 to 25 MHz
7)	Electric field receiver gain	0 to 80 dB
8)	Magnetic field receiver bandpass	Any frequency from 3 to 25 MHz
9)	Magnetic field receiver gain	0 to 80 dB
10)	Boom A length	2-50 meters
11)	Boom A Θ angle	0-90°

12) Boom A ϕ angle 0-360^{0}

13) Platform χ angle 0-360^{0}

14) Platform ψ angle 0-90^{0}

15) Platform Ω angle 0-360^{0}

16) Boom B length 2-50 meters

17) Boom B Θ angle 0-90^{0}

18) Boom B ϕ angle 0-360^{0}

3.1.3.3 Simulation Displays. The following simulation displays are provided and are shown in Section 3.1.3.4.

1) Wave transmission experiment display
2) Boom B set-up display
3) Boom B set-up display default
4) Boom A set-up display
5) Boom A set-up display default
6) Platform set-up display
7) Platform set-up display default
8) Cylindrical electron probe set-up display
9) Cylindrical electron probe set-up display default
10) Cylindrical electron probe voltage vs time
11) Cylindrical electron probe current vs voltage
12) Fluxgate magnetometer set-up display
13) Fluxgate magnetometer set-up display default
14) Electric field receiver set-up display
15) Electric field receiver set-up display default
16) Magnetic field receiver set-up display
17) Magnetic field receiver set-up display default

18) Transmitter set-up display

19) Transmitter set-up display default

20) Wave transmission experiment $\overline{E^2}$ set-up display

21) Wave transmission experiment $\overline{E^2}$ set-up display default

22) Wave transmission experiment $\overline{B^2}$ set-up display

23) Wave transmission experiment $\overline{B^2}$ set-up display default

24) $\overline{E^2}$ data acquisition display

25) $\overline{E^2}$ data acquisition display default

26) $\overline{B^2}$ data acquisition display

27) $\overline{B^2}$ data acquisition display default

3.1.3.4 Special Purpose Equipment Required for Simulation. In order to perform this simulation the following special purpose equipment must be added:

1) Moderately fast oscilloscope, 200 MHz ability, preferably a storage type

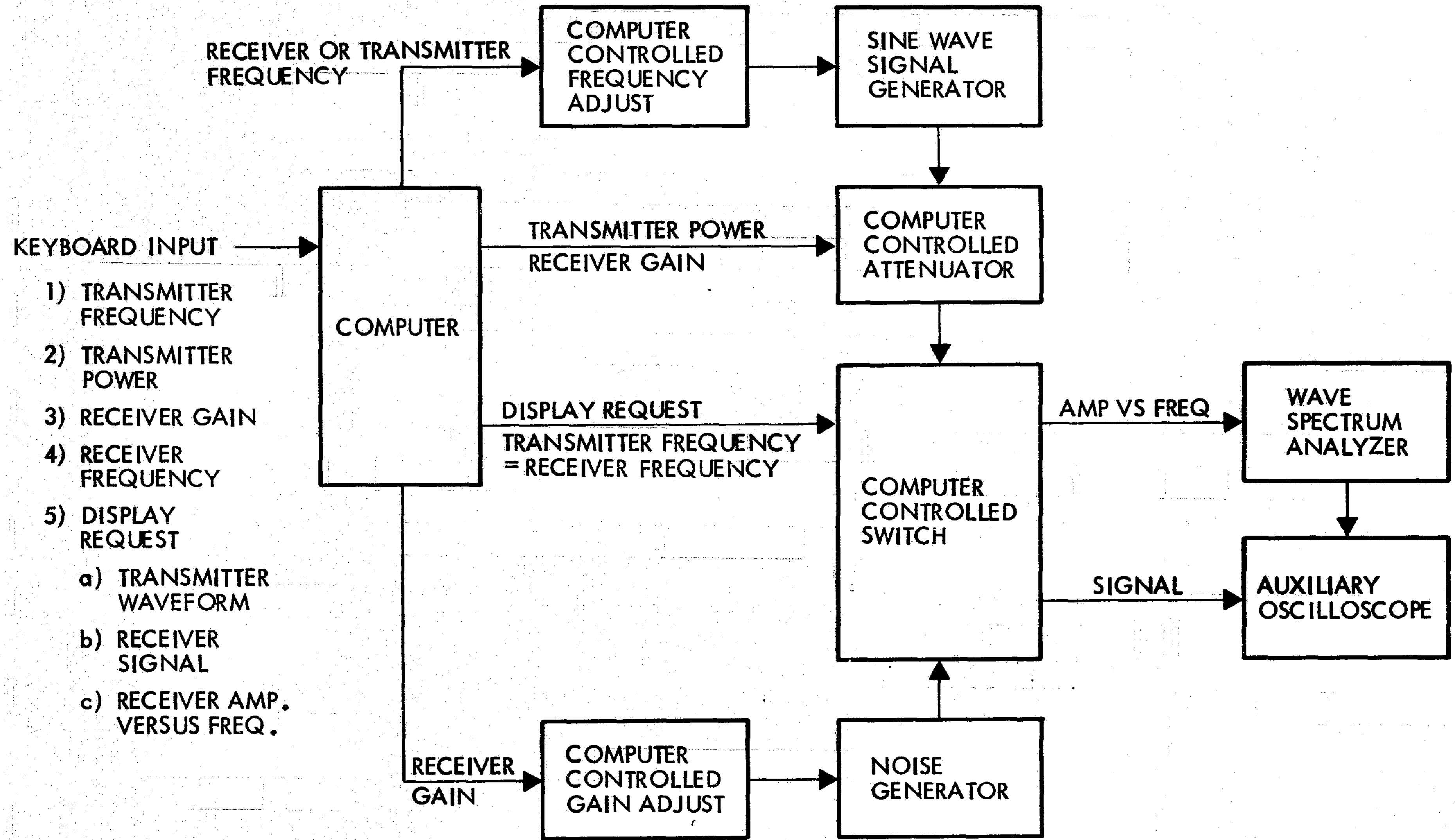
2) A sine wave source able to cover the frequency range from 3 to 25 MHz at 10 volts output into 1 MΩ.

3) A noise source able to output in the frequency range 3 to 25 MHz with voltage amplitudes on the order of 0.01 to 0.1 volt into 1 MΩ. This source need not be genuinely random, but it should at least look noisy.

4) A wave frequency spectrum analyzer having a bandwidth resolution on the order of 10 to 100 kHz in the frequency range from 3 to 25 MHz. The analyzer must have its own display or be compatible with the oscilloscope.

5) A switching panel able to be controlled by the computer and used to connect the noise or sine source or spectrum analyzer outputs to the oscilloscope or to the spectrum analyzer.

6) The noise source and the sine wave generator must be capable of having their amplitudes controlled by the computer. The sine wave generator frequency must also be computer controlled. Some piece of hardware will probably be needed to interface these sources with the computer.



Block Diagram of EP1.0 Special Equipment

3.1.3.5 Assumptions Used in Simulation. In order to do the simulation of the wave transmission experiment certain assumptions must be made concerning the Shuttle orbit, the state of the ionosphere and other determining factors. The following is a list of these assumptions for this one experiment:

1) The earth is a perfect sphere of radius 6371 km.

2) The earth's magnetic field is the result of an earth-centered dipole pointed at the north geographic pole and having a dipole moment of

$$8.07 \times 10^{25} \text{ gauss-cm}^3 = 8.07 \times 10^{15} \text{ teslas-m}^3.$$

3) The Shuttle is in a circular orbit of zero inclination at an altitude of 400 km above the earth.

4) The ionosphere is uniform at this altitude throughout the entire orbit.

5) The ionospheric electron density at this altitude is 3×10^{11} electrons per m^3.

6) The ionospheric electron temperature at this altitude is 1161^{o}K or 0.1 eV.

7) The level of background electromagnetic radiation is whatever the experimenter sets by using the noise source.

8) There are no other background, interference or environmental functions that affect this experiment, or that need be specified.

9) The phases of all oscillations are neglected. Assumptions made in boom simulation were:

   a) A motor running an angular variable runs at the rate of one degree per second in realtime.

   b) A motor running a length variable runs at the rate of 0.5 meter per second in realtime.

   c) Lengths are known to 0.1 meter and angles are known to 1.0 degree.

3.1.3.6 Wave Transmission Experiment Theory. Simplifying assumptions:

1) Everywhere in space the electric and magnetic fields are as they would be in a vacuum except that the plasma effects are accounted for by setting

$$\frac{\omega}{k} = \frac{c}{\sqrt{1 - (\omega_p/\omega)^2}}$$

instead of the usual

$$\omega/k = c \text{ and } \omega_p = \text{plasma frequency}$$

$$= \left(\frac{4\pi n_e e^2}{m}\right)^{1/2}, \quad n_e = \text{electron density}$$

2) The length of the transmitting antenna is small compared to either the wavelength or the separation between the transmitting antenna and the receiving antenna.

3) The transmitting antenna is treated as a simple center fed dipole.

4) Under the conditions of the experiment ω_{ci}, ω_{ce} are small and the dispersion relation for both the ordinary and extraordinary wave modes is given by

$$\omega/k = c/\left(1 - (\omega_p/\omega)^2\right)^{1/2}$$

when $\omega > \omega_p$, and no wave exists for $\omega < \omega_p$.

In gaussian units the dipole moment of the transmitting antenna is given by

$$\vec{p} = \frac{i\, I_o d}{2\omega}\, \hat{e}_y$$

where

d = antenna length

i = $\sqrt{-1}$

ω = driving frequency (1)

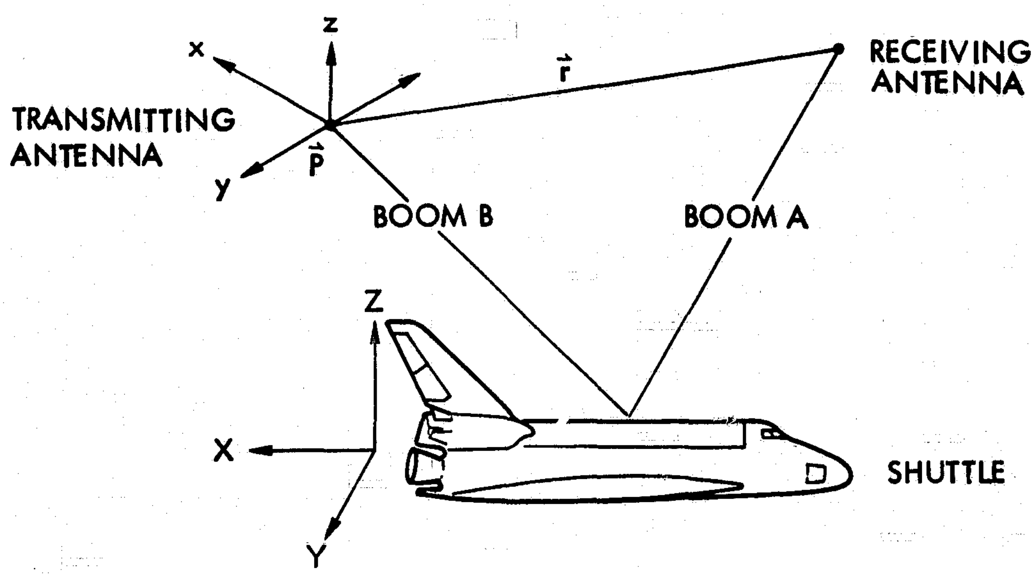
I_o = current leaving the transmitter

e_y = unit vector along the antenna length

or

$$\vec{p} = p_o\, \hat{e}_y$$

The figure shows the geometry of the experiment:



The coordinate system used in the theory is centered on the transmitting antenna (the tip of Boom B) and the antenna is pointed along the y-axis of this coordinate system.

The electric ($\vec{E}$) and magnetic ($\vec{B}$) fields at a point x, y, z are given by

$$\vec{E} = p_o e^{i(kr-\omega t)}\left[\left(\frac{3}{r^3} - \frac{3ik}{r^2} - \frac{k^2}{r}\right)\left(\frac{yx}{r^2}\hat{e}_x - \frac{(x^2+z^2)}{r^2}\hat{e}_y + \frac{yz}{r^2}\hat{e}_z\right) + \left(\frac{2}{r^3} - \frac{2ik}{r^2}\right)\hat{e}_y\right] \quad (2)$$

and

$$\vec{B} = \frac{i\omega p_o e^{i(kr-\omega t)}}{c\, r^2}\left(\frac{1}{r} - ik\right)\left(-z\,\hat{e}_x + x\,\hat{e}_z\right) \quad (3)$$

where $i = \sqrt{-1}$; k = wave number; c = speed of light in vacuum.

$r = \sqrt{x^2+y^2+z^2}$ = distance from center of transmitting antenna to point of measurement

p_o = dipole moment = $\frac{i\, I_{od}}{2\omega}$ $\qquad$ ω = wave frequency = transmitter frequency

$\hat{e}_x$, $\hat{e}_y$, $\hat{e}_z$ are unit vectors.

The electric field value actually measured by a short dipole at point (x,y,z) is given by

$$E_{measured} = \mathrm{Real}(\vec{E} \cdot \hat{R}) \text{ where } \hat{R} \text{ is a unit vector pointed along the receiving dipole antenna} \tag{4}$$

The magnetic field value actually measured by a loop antenna is given by

$$B_{measured} = \mathrm{Real}(B \cdot \hat{L}) \text{ where } \hat{L} \text{ is a unit vector normal to the antenna plane} \tag{5}$$

On the Shuttle the antenna orientation is such that $\hat{L} \cdot \hat{R} = 0$.

Thus we now know what E and B fields will be measured at any point in space when the transmitting antenna is being driven with a current I_0 at a frequency ω.

In doing the experiment to be simulated one wishes to determine what the wave number of an ordinary electromagnetic wave is as the frequency of the transmitted wave approaches the plasma frequency from the high side.

This determination is most easily done if one looks at the ratio of the time averaged square of the electric and magnetic fields measured by the receivers:

$$\alpha = \frac{\langle E^2_{measured} \rangle}{\langle B^2_{measured} \rangle} = \frac{\langle |\vec{E} \cdot \hat{R}|^2 \rangle}{\langle |B \cdot \hat{L}|^2 \rangle} = \left[\frac{c^2(9+3k^2r^2+k^4r^4)}{\omega^2 r^2(1+k^2r^2)} + \frac{4c^2}{\omega^2(r^2-y^2)} \right] \frac{\cos^2\gamma_E}{\cos^2\gamma_B} \tag{6}$$

where we have assumed that the loop and dipole receiving antennas are both located at point (x,y,z) with respect to the center of the transmitting antenna and $r^2 = x^2 + y^2 + z^2$; c = speed of light in vacuum; ω = transmitter frequency; and k = wave number.

The wave number, k, is given by

$$k = \left(\sqrt{\omega^2 - \omega_p^2}\right)/c \tag{7}$$

where

ω_p = plasma frequency = 30.77×10^6 rad/sec and $c = 3 \times 10^8$ meters/sec.

Now at any given transmitter frequency (ω), the relative position between the transmitting and receiving antennas (x,y,z), the transmitting antenna tip-to-tip length (d), the transmitter current (I_0), the receiving antenna orientation ($\hat{R}$), and the electric and magnetic signal strengths observed by the receivers can be calculated and displayed by controlling the amplitude of the sine wave generator.

The transmitter radiated power is given by

$$P_{cgs} = \frac{k^3\omega}{3} p_o^2 = \frac{k^3 I_o^2 d^2}{12\omega}, \text{ Total Power} = (R_{rad} + R_{ant}) I_o^2 ,$$

$$R_{ant}(6\text{m tip-to-tip}) = 0.176\Omega \qquad (8)$$

$$\text{Total Power} = \left(\frac{k^3 d^2}{12\omega} + 1.955 \times 10^{-13}\right) I_o^2 \text{ in cgs units}$$

where it is assumed that the antenna is only resistively coupled to the environment.

3.1.3.7 Angular Transformations for Boom Movement Used in Simulation. The following assumptions about the movement of the booms are made:

1) The booms are able to extend in length from 2 to 50 meters.

2) They are able to rotate about the Shuttle's Z axis by an angle ϕ.

3) They can rotate about their own y-axis, which is defined as the Shuttle Y-axis when ϕ = 0, by an angle Θ.

Suppose the Boom B tip has Shuttle coordinates L_B, θ_B, ϕ_B. Furthermore, suppose there is another coordinate system frozen into the tip of the boom such that when $L_B = \theta_B = \phi_B = 0$ that axes x,y,z are aligned with the Shuttle X,Y,Z axes then the boom tip has Shuttle coordinates

$$\begin{aligned} X_b &= L_B \sin\theta_B \cos\phi_B \\ Y_b &= L_B \sin\theta_B \sin\phi_B \qquad (9) \\ Z_b &= L_B \cos\theta_B \end{aligned}$$

Boom A has coordinates

$$
\begin{aligned}
X_A &= L_A \sin\theta_A \cos\phi_A \\
Y_A &= L_A \sin\theta_A \sin\phi_A \\
Z_A &= L_A \cos\theta_A
\end{aligned}
\tag{10}
$$

In the theory we have used the quantities x,y,z to denote the coordinates with respect to the Boom B tip of the receiving antennas at the tip of Boom A. Coordinates are determined in the following manner. First, transform from the Shuttle coordinates to the x,y,z Boom B coordinates. The rotational transformation matrix to carry the Shuttle into Boom B is

$$
\begin{pmatrix}
\cos\theta_B \cos\phi_B & \cos\theta_B \sin\phi_B & -\sin\theta_B \\
-\sin\phi_B & \cos\phi_B & 0 \\
\sin\theta_B \cos\phi_B & \sin\phi_B \sin\theta_B & \cos\theta_B
\end{pmatrix} = T_{S\rightarrow B}
\tag{11}
$$

and the quantities used in the theory are then found from

$$
\begin{pmatrix} x \\ y \\ z \end{pmatrix} =
\begin{pmatrix}
\cos\theta_B \cos\phi_B & \cos\theta_B \sin\phi_B & -\sin\theta_B \\
-\sin\phi_B & \cos\phi_B & 0 \\
\sin\theta_B \cos\phi_B & \sin\phi_B \sin\theta_B & \cos\theta_B
\end{pmatrix}
\begin{pmatrix}
L_A \sin\theta_A \cos\phi_A \\
L_A \sin\theta_A \sin\phi_A \\
L_A \cos\theta_A
\end{pmatrix}
-
\begin{pmatrix} 0 \\ 0 \\ L_B \end{pmatrix}
\tag{12}
$$

$$
\begin{aligned}
x &= +L_a \sin\theta_A \cos\phi_A \cos\theta_B \cos\phi_B + L_A \sin\theta_A \sin\phi_A \cos\theta_B \sin\phi_B - L_A \cos\theta_A \sin\theta_B \\
y &= -L_A \sin\theta_A \sin\phi_A \sin\phi_B + L_A \sin\theta_A \sin\phi_A \cos\phi_B \\
z &= -L_B + L_A \sin\theta_A \cos\phi_A \sin\theta_B \cos\phi_B + L_A \sin\theta_A \sin\phi_A \sin\phi_B \sin\theta_B \\
&\quad + L_A \cos\theta_A \cos\theta_B
\end{aligned}
\tag{13}
$$

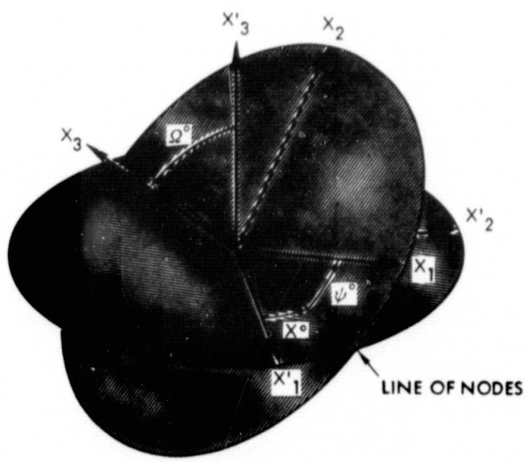
The distance from the transmitter to receiving antenna is found from

$$r = \sqrt{x^2+y^2+z^2}$$

One further problem is that measured signals depend upon the various angular orientation by Equations 4 and 5.

The unit vectors $\hat{R}$ and $\hat{L}$ which are expressed in a coordinate system fixed with respect to the gimbaled platform on Boom A must be transformed to boom coordinates.

THE X_1', X_2', X_3' OF BOOM A AND X, Y, Z OF BOOM B CORRESPOND IDENTICALLY TO THE SHUTTLE X, Y, Z AXES WHEN THE BOOMS ARE IN THE STOWED POSITION.



X'_1, X'_2, X'_3 ARE FIXED ON TIP OF BOOM A AND
X_1, X_2, X_3 ARE FIXED ON PLATFORM
WHEN $\Omega = X = \psi = 0$ THEY ARE IDENTICAL
CYLINDRICAL PROBE AXIS IS X_2 AND THE FLUXGATE HAS AXES CORRESPONDING TO X_1, X_2, X_3.
$R = X_2$ AND $L = X_3$

Let X,Ω,ψ be the usual Eulerian angles of the platform with respect to a coordinate system $\hat{x}_1',\hat{x}_2',\hat{x}_3'$ fixed in the tip of the Boom A similar to the one on the B Boom. We want to find orientation of $\hat{x}_1,\hat{x}_2,\hat{x}_3$ in terms of the x,y,z-Boom B coordinates

$$\begin{pmatrix}\hat{x}_1\\ \hat{x}_2\\ \hat{x}_3\end{pmatrix}_{\substack{\text{in Boom}\\ \text{B coordinates}}} = T_{S\to B}T_{A\to S}T_{p\to A}\begin{pmatrix}\hat{x}_1\\ \hat{x}_2\\ \hat{x}_3\end{pmatrix} \tag{14}$$

$T_{p\to A}$ = transformation from platform to Boom A

$$= \begin{pmatrix}\cos\psi\cos X - \cos\Omega\sin X\sin\psi & -\sin\psi\cos X - \cos\Omega\sin X\cos\psi & \sin\Omega\ \sin X\\ \cos\psi\sin X + \cos\Omega\cos X\sin\psi & -\sin\psi\sin X + \cos\Omega\cos X\cos\psi & -\sin\Omega\cos X\\ \sin\Omega\sin\psi & \sin\Omega\cos\psi & \cos\Omega\end{pmatrix} \tag{15}$$

$T_{A\to S}$ = transformation from Boom A coordinates into Shuttle coordinates

$$= \begin{pmatrix}\cos\theta_A\cos\phi_A & -\sin\phi_A & \sin\theta_A\cos\phi_A\\ \cos\theta_A\sin\phi_A & \cos\phi_A & \sin\phi_A\sin\theta_A\\ -\sin\theta_A & 0 & \cos\theta_A\end{pmatrix} \tag{16}$$

and $T_{S\to B}$ is already given in Equation 11. In particular, we want to find $\vec{E}\cdot\hat{R}$ and $\vec{B}\cdot\hat{L}$ where $\hat{R} \equiv \hat{x}_2$, $\hat{L} \equiv \hat{x}_3$.

$$E_{measured} = \mathrm{Real}(\vec{E}\cdot\hat{R}) = E_x T_{S\to B}T_{A\to S}T_{p\to A}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_x + E_y T_{S\to B}T_{A\to S}T_{p\to A}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_y$$
$$+ E_z T_{S\to B}T_{A\to S}T_{p\to A}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_z \tag{17}$$

where $\big|_x$, $\big|_y$, $\big|_z$ means the scalar magnitude of the x, y and z components of the vector.

$$T_{S\to B}T_{A\to S}T_{p\to A} = T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_x = \cos\theta_B\cos\phi_B\Big[\sin\phi_A(\sin\psi\sin X - \cos\Omega\cos X\cos\psi)$$
$$+ \sin\theta_A\cos\phi_A\sin\Omega\cos\psi$$
$$- \cos\theta_A\cos\phi_A(\sin\psi\cos X + \cos\Omega\sin X\cos\psi)\Big] \tag{18}$$

$$
\begin{aligned}
&+ \cos\theta_B \sin\phi_B\Big[\cos\phi_A(\cos\Omega \cos X \cos\psi - \sin\psi \sin X) \\
&+ \sin\phi_A \sin\theta_A \sin\Omega \cos\psi \\
&- \cos\theta_A \sin\phi_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi)\Big] \\
&- \sin\theta_B\Big[\sin\theta_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi) \\
&+ \cos\theta_A \sin\Omega \cos\psi\Big]
\end{aligned}
$$

$$
\begin{aligned}
T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_y &= \cos\phi_B\Big[\sin\phi_A \sin\theta_A \sin\Omega \cos\psi \\
&+ \cos\phi_A(\cos\Omega \cos X \cos\psi - \sin\psi \sin X) \\
&- \cos\theta_A \sin\phi_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi)\Big] \\
&- \sin\phi_B\Big[-\cos\theta_A \cos\phi_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi) \\
&+ \sin\phi_A(-\cos\Omega \cos X \cos\psi + \sin\psi \sin X) \\
&+ \sin\theta_A \cos\phi_A \sin\Omega \cos\psi\Big]
\end{aligned}
\tag{18}
$$

$$
\begin{aligned}
T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_z &= \sin\theta_B \cos\phi_B\Big[-\cos\theta_A \cos\phi_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi) \\
&+ \sin\phi_A(\sin\psi \sin X - \cos\Omega \cos X \cos\psi) \\
&+ \sin\theta_A \cos\phi_A \sin\Omega \cos\psi\Big] \\
&+ \sin\phi_B \sin\theta_B\Big[-\cos\theta_A \sin\phi_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi) \\
&+ \cos\phi_A(\cos\Omega \cos X \cos\psi - \sin\psi \sin X) \\
&+ \sin\phi_A \sin\theta_A \sin\Omega \cos\psi\Big] \\
&+ \cos\theta_B\Big[\sin\theta_A(\sin\psi \cos X + \cos\Omega \sin X \cos\psi) \\
&+ \cos\theta_A \sin\Omega \cos\psi\Big]
\end{aligned}
$$

3.1.3.8 Equations for Wave Transmission Experiment Simulation Displays

3.1.3.8.1 Received Signals

3.1.3.8.1.1 General Display of Received Signal Components $<E^2>$ and $<B^2>$. The values of mean square electric and magnetic fields displayed in graph form are calculated for values of all variables taken at t - 0.5 seconds. The point is plotted at t = t seconds. The value is calculated from

$$<E^2> = <E^2_{measured}> = <E^2 \sin(kr-\omega t+\delta)> = \frac{E^2}{2}$$

where δ is the phase angle and

$$E^2 = \frac{81 \times 10^{18} (\text{Power in watts}) d^2}{4\left(9 \times 10^9 \frac{k^3 d^2}{12\omega} + .176\right)\omega^2 r^6} f_E(\theta_A, \phi_A, \theta_B, \phi_B, L_A, L_B, X, \psi, \Omega)$$

$$\begin{aligned} f_E = \Bigg[& \left\{ (3-k^2r^2)\frac{yx}{r^2} T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_x - (3-k^2r^2)\frac{zy}{r^2} T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_z \right. \\ & \left. + \left(2 - \frac{(3-k^2r^2)(x^2+z^2)}{r^2}\right) T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_y \right\}^2 \\ & + \left\{ \frac{3kxy}{r} T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_x + \frac{3kyz}{r} T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_z \right. \\ & \left. + \left(2kr - \frac{3k(x^2+z^2)}{r}\right) T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_y \right\}^2 \Bigg] \end{aligned} \tag{19}$$

where

$$T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_{x,y,z}$$

are given in Equation 18 and all dimensions are measured in MKS units.

$$\langle B^2 \rangle = \langle B^2_{measured} \rangle = \langle B^2\left(\sin(kr-\omega t+\delta')\right)\rangle = \frac{B^2}{2}$$

$$B^2 = \frac{2.5 \times 10^{-15}(\text{Power in watts})\, d^2}{\left(9 \times 10^9 \frac{k^3 d^2}{12\omega} + .176\right)} \cdot f_B(\theta_A,\theta_B,\phi_A,\phi_B,L_A,L_B,X,\psi,\Omega)$$

$$f_B = \left\{\frac{x}{r} T_{p\to B}\begin{pmatrix}0\\0\\1\end{pmatrix}\Bigg|_z - \frac{z}{r} T_{p\to B}\begin{pmatrix}0\\0\\1\end{pmatrix}\Bigg|_x\right\}^2 + \left\{kx\, T_{p\to B}\begin{pmatrix}0\\0\\1\end{pmatrix}\Bigg|_z - kz\, T_{p\to B}\begin{pmatrix}0\\0\\1\end{pmatrix}\Bigg|_x\right\}^2 \qquad (20)$$

and

$$T_{p\to B}\begin{pmatrix}0\\0\\1\end{pmatrix}\Bigg|_{z \text{ or } x}$$

is calculated in some fashion as was

$$T_{p\to B}\begin{pmatrix}0\\1\\0\end{pmatrix}\Bigg|_{z \text{ or } x}$$

in Equation 18 from Equations 11, 14, 15, and 16.

8.1.2 Received Signal at Fixed EP1.0 Boom Positions

In EP1.0 the received signals are measured with the boom fixed such that $L_A = L_B = 50$ meters,

$$\theta_A = \theta_B = 30^o,\ \phi_A = 180^o,\ \phi_B = 0$$

and

$$X = \Omega = \psi = 0$$

In this case the mean square electric and magnetic fields reduce to

$$\langle E^2\rangle = \langle E^2_{\text{measured}}\rangle$$

$$= \frac{2.33 \times 10^{10}}{\omega^2} \frac{(P)\ (1 - k^2\ 2.5\text{x}10^3 + k^4\ 6.25\text{x}10^6)}{\left(2.7 \times 10^{10}\ \frac{k^3}{\omega} + .176\right)} \left(\frac{\text{volts}}{\text{meter}}\right)^2$$

where P is the power in watts as chosen by keyboard

$$k = \frac{\sqrt{\omega^2 - 9.4668 \times 10^{14}}}{3 \times 10^8} \text{ per meter}$$

$$\omega = 2\pi f$$

where f is the transmitted frequency and

$$\langle B^2\rangle = \langle B^2_{\text{measured}}\rangle$$

$$= 5.4 \times 10^{-21}\ (1 + k^2\ 2.5\text{x}10^3) \frac{P}{\left(2.7\text{x}10^{10}\ \frac{k^3}{\omega} + .176\right)} \text{ teslas}^2$$

3.1.3.8.2 Cylindrical Probe Angles. For experiment EP1.0 we assume that the Shuttle is moving in the minus X direction, e.g., $\vec{V} = -V_o\ \hat{X}$.

The angle Q between the cylindrical probe axis (= $\hat{x}_2$ of platform) and V is given by

$$\cos Q = \hat{X} \cdot \hat{x}_2 = -T_{A\text{-}S} T_{p\text{-}A} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}\Bigg|_X \tag{21}$$

$$= \cos\theta_A \cos\phi_A\ (+\sin\psi \cos X + \cos\Omega \sin X \cos\psi)$$

$$- \sin\phi_A\ (\sin\psi \sin X - \cos\Omega \cos X \cos\psi)$$

$$- \sin\theta_A \cos\phi_A \sin\Omega \cos\psi$$

3.1.3.8.3 Fluxgate Magnetometer - Magnetic Field Components. To find the measured components of the magnetic field B_x, B_y, B_z called for in the fluxgate magnetometer display the total B field vector, which during this experiment lies in the plus Y Shuttle axis, e.g., $B = B_T \hat{Y}$, is transformed into the platform coordinates, $\hat{x}_1, \hat{x}_2, \hat{x}_3$, so that the field values at the magnetometer are given by

$$B_X = T^{-1}_{p\to A} T^{-1}_{A\to S} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} B_T \Big|_{\hat{x}_1} \tag{22}$$

$$B_Y = T^{-1}_{p\to A} T^{-1}_{A\to S} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} B_T \Big|_{\hat{x}_2} \tag{23}$$

$$B_Z = T^{-1}_{p\to A} T^{-1}_{A\to S} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} B_T \Big|_{\hat{x}_3} \tag{24}$$

$$BTOT = B_T = 25997 \text{ GAMMA}$$

during the whole experiment, and

$$T^{-1}_{A\to S} = \begin{pmatrix} \cos\theta_A \ \cos\phi_A & \cos\theta_A \ \sin\phi_A & -\sin\theta_A \\ -\sin\phi_A & \cos\phi_A & 0 \\ \sin\theta_A \ \cos\phi_A & \sin\phi_A \ \sin\theta_A & \cos\theta_A \end{pmatrix}$$

$$T^{-1}_{p\to A} = \begin{pmatrix} \cos\psi \ \cos X - \cos\Omega \ \sin X \ \sin\psi & \cos\psi \ \sin X + \cos\Omega \ \cos X \ \sin\psi & \sin\Omega \ \sin\psi \\ -\sin\psi \ \cos X - \cos\Omega \ \sin X \ \cos\psi & -\sin\psi \ \sin X + \cos\Omega \ \cos X \ \cos\psi & \sin\Omega \ \cos\psi \\ \sin\Omega \ \sin X & -\sin\Omega \ \cos X & \cos\Omega \end{pmatrix}$$

3.1.3.8.4 Angles Between Magnetic field and the Antennas or Booms. The angle between receiving short dipole antenna and magnetid field RB is given by

$$\cos RB = \hat{Y} \cdot \hat{x}_2 = T_{A\to S} T_{p\to A} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \Bigg|_{Y \text{ component}}$$

between the magnetic field and the loop antenna LB

$$\cos LB = \hat{Y} \cdot \hat{x}_3 = T_{A\to S} T_{p\to A} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \Bigg|_{Y \text{ component}}$$

between the transmitting antenna and the magnetic field TB

$$\cos TB = T^{-1}_{S\to B} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \Bigg|_{Y \text{ component}}$$

The cosine of the angles between the magnetic field and the coordinate cirections of the boom A, boom B and platform coordinate systems are given below:

BOOM A		PLATFORM		BOOM B	
Direction	Cos of Angle	Direction	Cos of Angle	Direction	Cos of Angle
$\hat{X}'_1$	$T_{A\to S} \begin{matrix} 1 \\ 0 \\ 0 \end{matrix}\ _Y$	$\hat{X}_1$	$T_{A\to S} T_p\ A \begin{matrix} 1 \\ 0 \\ 0 \end{matrix}\ _Y$	X	$T^{-1}_{S\to B} \begin{matrix} 1 \\ 0 \\ 0 \end{matrix}\ _Y$
$\hat{X}'_2$	$T_{A\to S} \begin{matrix} 0 \\ 1 \\ 0 \end{matrix}\ _Y$	$\hat{X}_2$	$T_{A\to S} T_p\ A \begin{matrix} 0 \\ 1 \\ 0 \end{matrix}\ _Y$	Y	$T^{-1}_{S\to B} \begin{matrix} 0 \\ 1 \\ 0 \end{matrix}\ _Y$
$\hat{X}'_3$	$T_{A\to S} \begin{matrix} 0 \\ 0 \\ 1 \end{matrix}\ _Y$	$\hat{X}_3$	$T_{A\to S} T_{p\to A} \begin{matrix} 0 \\ 0 \\ 1 \end{matrix}\ _Y$	Z	$T^{-1}_{S\to B} \begin{matrix} 0 \\ 0 \\ 1 \end{matrix}\ _Y$

3.1.3.8.5 Angles Between the Various Antennas. The angle between the transmitting antenna and the receiving short dipole antenna TR

$$\cos TR = T_{S \to B} T_{A \to S} T_{p \to A} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \Bigg|_{Y \text{ component}}$$

between the transmitting antenna and the loop antenna TL

$$\cos TL = T_{S \to B} T_{A \to S} T_{p \to A} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \Bigg|_{Y \text{ component}}$$

3.1.3.8.6 The Actual Transmitter Power Output

$$P_{actual} = (P_{max})(\text{Signal Level})^2 \, 10^{\frac{-\text{Attenuation dB}}{10}}$$

3.2 EP2.0 PASSIVE OBSERVATION OF THE AMBIENT PLASMA

3.2.1 Description

In order to carry out active experiments in the ionosphere it is necessary to have an accurate knowledge of the ambient state of the ionosphere. Passive ionospheric measurements have been carried out for nearly 40 years and during the last 20 years there have been a large number of in-situ satellite and rocket measurements of the ionosphere. The AMPS Shuttle payload must be equipped with a large set of instruments capable of making the necessary ambient ionospheric measurements.

In this simulation a simple model of the ionospheric region from 120 to 400 km is developed. The model shows local time, latitude, and altitude dependencies of the ionospheric state function. The outputs of the various ionospheric instruments on the Shuttle respond to the variations in the model. The experimenter is able to vary the Shuttle orbit altitude, inclination, attitude, and the boom orientation. For this simulation it has been assumed that the presence of the Shuttle in no way affects the ability of the instruments to measure the ambient. During an actual flight there will exist a considerable wake region around the Shuttle where it will be impossible to make ambient measurements.

3.2.2 Experiment Procedure - EP 2.0 Passive Observation of the Ambient Plasma

EP 2.1 Determine Shuttle Orbit

- 2.1.1 Select manual control
- 2.1.2 Shuttle altitude equal 300 km
- 2.1.3 Set Shuttle inclination equal 57 deg
- 2.1.4 Set local time of southward moving node equal 0000:00
- 2.1.5 Set universal time of descending node equal 0000:00

EP 2.2 Determine Shuttle Attitude

- 2.2.1 Select manual control
- 2.2.2 Set Γ = 0 deg
- 2.2.3 Set Λ = 0 deg
- 2.2.4 Set Δ = 0 deg
- 2.2.5 Hold Shuttle at these angles

EP 2.3 Set Boom A

- 2.3.1 Set length to 50 meters
- 2.3.2 Set θ = 0 deg
- 2.3.3 Set ϕ = 0 deg

EP 2.4 Set Platform

- 2.4.1 Set χ = 0 deg
- 2.4.2 Set ψ = 0 deg
- 2.4.3 Set Ω = 0 deg

EP 2.7 Fluxgate Magnetometer

- 2.7.1 Fluxgate to GO status
  - 2.7.1.1 Fluxgate to ON
  - 2.7.1.2 Wait for Fluxgate READY
  - 2.7.1.3 Fluxgate to GO
- 2.7.2 Observe magnetic field values
- 2.7.3 Record all future data

EP 2.8 Rubidium Magnetometer

- 2.8.1 Rubidium to GO status
  - 2.8.1.1 Rubidium to ON
  - 2.8.1.2 Wait for Rubidium READY
  - 2.8.1.3 Rubidium to GO
- 2.8.2 Observe magnetic field value
- 2.8.3 Record all future data

EP 2.9 Cylindrical Electron Probe

2.9.1 Cylindrical probe to GO status

2.9.1.1 Probe to ON
2.9.1.2 Wait for probe READY
2.9.1.3 Probe to GO

2.9.2 Observe probe output

2.9.2.1 Electron temperature
2.9.2.2 Electron density
2.9.2.3 Probe voltage versus time
2.9.2.4 Probe current versus voltage

2.9.3 Check that angle between Shuttle velocity vector and probe axis is greater than 10 deg
2.9.4 Record all future data

EP 2.10 Spherical Ion Probe

2.10.1 Spherical probe to GO status

2.10.1.1 Probe ON
2.10.1.2 Wait for probe READY
2.10.1.3 Probe to GO

2.10.2 Set probe in electron rejection mode
2.10.3 Observe probe output

2.10.3.1 Probe voltage versus time
2.10.3.2 Probe current versus voltage
2.10.3.4 Ion temperature
2.10.3.5 Total ion density

2.10.4 Record all future data

EP 2.11 Ion Mass Spectrometer

2.11.1 Ion mass spectrometer to GO status

2.11.1.1 Spectrometer to ON
2.11.1.2 Wait for spectrometer READY
2.11.1.3 Spectrometer to GO

2.11.2 Set mass range

2.11.2.1 Lower mass limit = 1 Amu (Atomic Mass Unit)
2.11.2.2 Upper mass limit = 40 Amu
2.11.2.3 Resolution = 1 Amu

2.11.3 Observe spectrometer data

2.11.3.1 Check spectrometer angle of attack
2.11.3.2 Display ion current versus mass
2.11.3.3 Display ion density versus mass
2.11.3.4 Total ion density

2.11.4 Record all future data

EP 2.12 Neutral Mass Spectrometer

2.12.1 Neutral mass spectrometer to GO status

2.12.1.1 Spectrometer to ON
2.12.1.2 Wait for spectrometer READY
2.12.1.3 Spectrometer to GO

2.12.2 Set mass range

2.12.2.1 Lower mass limit = 1 Amu
2.12.2.2 Upeer mass limit = 40 Amu
2.12.2.3 Resolution = 1 Amu

2.12.3 Observe spectrometer data

2.12.3.1 Check spectrometer angle of attack
2.12.3.2 Display neutral current versus mass
2.12.3.3 Display neutral density versus mass
2.12.3.4 Display total neutral density

EP 2.13 Planar Electron Trap - Retarding Potention Analyzer

2.13.1 Planar electron trap to GO status

2.13.1.1 Trap to ON
2.13.1.2 Wait for trap READY
2.13.1.3 Trap to GO

2.13.2 Choose electron mode
2.13.3 Set energy range

2.13.3.1 Lower energy = 1 electron volt
2.13.3.2 Upper energy = 1000 electron volts
2.13.3.3 Sweep linear voltage versus time

2.13.4 Observe trap data

2.13.4.1 Display electron current versus voltage
2.13.4.2 Electron density versus electron energy

2.13.5 Record all future data

EP 2.14 Planar Segmented Probe Trap

2.14.1 Planar segmented probe to GO status

2.14.1.1 Probe to ON
2.14.1.2 Wait for probe READY
2.14.1.3 Probe to GO

2.14.2 Probe into ion mode
2.14.3 Observe probe data

2.14.3.1 Probe current versus time
2.14.3.2 Display of angle of plasma flow

2.14.4 Record all future data

EP 2.15 Special Displays

2.15.1 Densities versus time

2.15.1.1 Electrons
2.15.1.2 O^+
2.15.1.3 O_2^+
2.15.1.4 NO^+
2.15.1.5 O
2.15.1.6 O_2
2.15.1.7 N_2
2.15.1.8 He

2.15.2 Position as function of time

2.15.2.1 Local time
2.15.2.2 Latitude
2.15.2.3 Altitude
2.15.2.4 Magnetic dip angle
2.15.2.5 Universal time

2.15.3 Angular position

2.15.3.1 Γ
2.15.3.2 Λ
2.15.3.3 Δ
2.15.3.4 θ_A
2.15.3.5 ϕ_A
2.15.3.6 R
2.15.3.7 Ω
2.15.3.8 χ
2.15.3.9 ψ
2.15.3.10 Υ = angle between Shuttle velocity vector and the platform x_1 axis

EP 2.16 How Call Up? (By Time, By Latitude, By Longitude?)

EP 2.17 Stop All Data Recording

EP 2.18 All Instruments to OFF

EP 2.19 Stow Boom A

END EXPERIMENT

3.2.3 Theory and Background - EP 2.0

3.2.3.1 Location of the Shuttle. Assume the Shuttle is in a circular orbit at altitude H with some nonzero inclination angle = i in degrees. Assume Shuttle moves from west to east. At some time the Shuttle will be moving southward when it crosses the equator. We begin orbit time at this instant at the descending node, i.e., the point in space where the Shuttle crosses the equator moving southward.

The local time and Greenwich mean time of the first descending node are set by the keyboard:

$$\text{Initial local time} = LT_o \text{ in hours:minutes:seconds} \tag{201}$$

$$\text{Initial universal time} = GMT_o \text{ in hours:minutes:seconds} \tag{202}$$

The initial east longitude of first descending node is:

$$LON_o = |(LT_oH - UT_oH)|_{\text{modulo } 24} \times 15 \text{ deg} \tag{203}$$

where LT_o and GMT_o are equal to LT_oH and UT_oH expressed in hours.

The initial orbit time:

$$OT_o = 0 \text{ seconds} \tag{204}$$

Once the Shuttle is started in its orbit the elapsed orbit time and the Greenwich mean time will advance in real time second for second. If the orbit is advanced by OTSi seconds from the descending node the equations, computed in seconds for updating the orbit, are:

$$\dot{t} \text{ (seconds)} = OTSi \tag{205}$$

$$UTS = UT_oS \tag{206}$$

where t is the time from the start of the orbit program. We assume that sidereal and synodic time are equal so that the local time of the descending node is fixed. We also assume the sun is at the equinox position and stays there.

Define the orbital angular velocity which is a constant of the motion in our circular orbit:

$$\omega = \frac{R_e}{R_e + H} \left(\frac{g}{R_e + H}\right)^{1/2} \text{ radians/sec} \tag{207}$$

where

R_e = earth radius = 6371 km

g = surface gravity = 9.807×10^{-3} km/sec^2

H = orbit altitude in kilometers, a constant

The east longitude of the Shuttle portion at any time t is given by:

$$\text{LON} = \left|\text{LON}_o + \tan^{-1}\left(\frac{\sin\omega t \cos i}{\cos\omega t}\right)\right|_{\text{modulo } 360 \text{ deg}} \tag{208}$$

The south latitude of the Shuttle is given by:

$$\text{LAT} = +\cos^{-1}(-\sin\omega t \sin i) - \frac{\pi}{2} = +\sin^{-1}(+\sin\omega t \sin i) \tag{209}$$

The local time in the orbit is given by:

$$\text{LT} = \left|\text{UT}_o\text{H} + \frac{t}{3600} + (\text{LON}/15)\right|_{\text{modulo } 24} \tag{210}$$

in hours if t is in seconds and LON is in degrees.

Time is displayed in the following fashion:

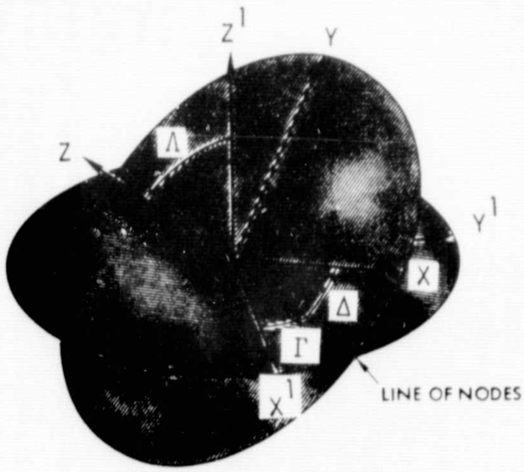
21:45:32 UT or LT

where 21 represents the hour, 45 represents the minutes past that hour, and 32 represents the seconds past that minute.

Time is kept to the nearest second. However, whenever a time is used in a formula it must be expressed in either decimal hours or seconds. The orbit period is given by:

$$\text{TORBIT} = \frac{2\pi}{\omega} \text{ in seconds} \tag{211}$$

3.2.3.2 Shuttle Attitude. Consider the transformation needed to get from an Earth-based inertial frame into the Shuttle XYZ frame. Consider the quasi-inertial frame X'Y'Z' whose center is on the Shuttle XYZ origin but where X' always points south Y' east and Z' always points radially upward. Let gamma, lambda, and delta be the three usual Eulerian angles.



Let X'Y'Z' be called the Earth frame even though it is traveling around the Earth on the Shuttle orbit. The transformation that takes vectors in this Earth frame into vectors in the Shuttle frame is given by

$$T_{e\to s} = \begin{pmatrix} \cos\Delta\cos\Gamma - \cos\Lambda\sin\Gamma\sin\Delta & \cos\Delta\sin\Gamma + \cos\Lambda\cos\Gamma\sin\Delta & \sin\Lambda\sin\Delta \\ -\sin\Delta\cos\Gamma - \cos\Lambda\sin\Gamma\cos\Delta & -\sin\Delta\sin\Gamma + \cos\Lambda\cos\Gamma\cos\Delta & \cos\Delta\sin\Lambda \\ \sin\Lambda\sin\Gamma & -\sin\Lambda\cos\Gamma & \cos\Lambda \end{pmatrix} \quad (212)$$

It should be noted that the X'Y'Z' frame is not a real inertial frame. The Shuttle attitude control system must be active in order to maintain a fixed setting of gamma, lambda, and delta throughout an orbit. The X'Y'Z' coordinates are, in effect, spinning at the rate of one revolution per orbit about an axis perpendicular to the orbit plane passing through the origin of X'Y'Z'.

3.2.3.3 Shuttle Velocity Vector. In Earth centered R, Θ, Φ, coordinates starting at line of nodes:

$$R = (R_e + H)1000\Theta = \cos^{-1}(-\sin\omega t \sin i) \qquad \Phi = \tan^{-1}(\tan\omega t \cos i)$$

The Shuttle velocity has components VΘ and Vϕ only, and because of our choice of X', Y', Z', one can easily see that the Shuttle velocity vector is given by:

$$\overline{V}_s = V_{X'}\hat{X}' + V_{Y'}\hat{Y}'$$

where $\hat{X}'$ and $\hat{Y}'$ are unit vectors and:

$$V_{X'} = \omega R \frac{\sin \cos\omega t}{(1 - \sin^2 i \sin^2 \omega t)^{1/2}} \tag{213}$$

$$V_{Y'} = \omega R \frac{\cos i}{(1 - \sin^2 i \sin^2 \omega t)^{1/2}}$$

$$|\overline{V}_s| = \omega R \text{ meters/sec}$$

$$R = (R_e + H)\ 1000 \text{ meters}$$

Given this formulation of $\overline{V}_s$, one can transform it into any relevant coordinate axis on the Shuttle. In particular, one parameter that appears often is the angle between the Shuttle velocity vector and the χ_1 coordinate axis of the platform:

$$\text{ANGLE } VX_1 = \frac{\cos^{-1}(\nabla_s \cdot \hat{\chi}_1)}{\omega R} \tag{214}$$

$$\overline{V}_s \cdot \hat{\chi}_1 = T_{A \to P}\, T_{S \to A}\, T_{E \to S} \begin{pmatrix} V_{X'} \\ V_{Y'} \\ 0 \end{pmatrix} \Bigg|_{\chi_1 \text{ component}} \tag{215}$$

where

$$T_{A\to P} = \begin{pmatrix} \cos\psi\cos\chi-\cos\Omega\sin\chi\sin\psi & \cos\psi\sin\chi+\cos\Omega\cos\chi\sin\psi & \sin\Omega\sin\psi \\ -\sin\psi\cos\chi-\cos\Omega\sin\chi\cos\psi & -\sin\psi\sin\chi+\cos\Omega\cos\chi\cos\psi & \sin\Omega\cos\psi \\ \sin\Omega\sin\chi & -\sin\Omega\cos\chi & \cos\Omega \end{pmatrix} \quad (216)$$

and

$$T_{S\to A} = \begin{pmatrix} \cos\theta_A\cos\phi_A & \cos\theta_A\sin\phi_A & -\sin\theta_A \\ -\sin\phi_A & \cos\phi_A & 0 \\ \sin\theta_A\cos\phi_A & \sin\phi_A\sin\theta_A & \cos\theta_A \end{pmatrix} \quad (217)$$

The angles θ_A, ϕ_A, ψ, χ, Ω were defined in EP 1.0.

Explicitly:

$$j = \text{ANGLE } VX_1 = \cos^{-1}\left[\frac{T_{A\to P}\ T_{S\to A}\ T_{e\to S}\begin{pmatrix}\sin i\cos\omega t\\ \cos i\\ 0\end{pmatrix}}{(1-\sin^2 i\ \sin^2\omega t)^{1/2}}\right]_{\chi_1 \text{ component}} \quad (218)$$

3.2.3.4 Earth's Magnetic Field. The Earth's magnetic field is assumed to be a centered, due-south pointing dipole field whose dipole moment = 8.07×10^{15} Teslas - m^3 = M.

The equation for the magnetic field vector in the X', Y', Z' system is:

$$\overline{B}_{earth} = B_{X'}\ \hat{X}' + B_{Z'}\ \hat{Z}' \quad (219)$$

where

$$B_{X'} = -\frac{8.07 \times 10^{15} \times \sin\lambda}{(R_e + H)^3} \text{ in gammas}$$

$$B_{Z'} = -\frac{1.614 \times 10^{16} \times \cos\lambda}{(R_e + H)^3} \text{ in gammas}$$

In this equation, λ is given by:

$$\lambda = \mathrm{LAT} + \pi/2 = \cos^{-1}(-\sin\omega t \sin i) \tag{220}$$

and

$$0 \leq \lambda \leq 180 \text{ deg}$$

The magnetic dip angle is given by:

$$\text{dip angle} = \frac{\cos^{-1}|\overline{B}\cdot\hat{Z}'|}{|B|} = \cos^{-1}\left[\frac{-2\cos\lambda}{(3\cos^2\lambda + 1)^{1/2}}\right] \tag{221}$$

$$= \cos^{-1} \frac{2\sin\omega t \sin i}{(3\sin^2\omega t \sin^2 i + 1)} \; \overline{2}$$

The dip angle is measured from the local vertical.

The total magnetic field in gammas is given by (R_e and H in kilometers):

$$|B_T| = \frac{(8.07 \times 10^{15})(3\sin^2\omega t \sin^2 i + 1)^{1/2}}{(R_e + H)^3} \text{ in gammas} \tag{222}$$

The magnetic field measured by the three-axis fluxgate magnetometer is given by:

$$BX = T_{e\to p}\begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix}\Bigg|_{X_1} \text{ component} \tag{223}$$

$$BY = T_{e\to p}\begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix}\Bigg|_{X_2} \text{ component}$$

$$BZ = T_{e\to p}\begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix}\Bigg|_{X_3} \text{ component}$$

where $B_{X'}$ and $B_{Z'}$ is given by Equation (219) and:

$$T_{e\to p} = T_{A\to p}\, T_{S\to A}\, T_{e\to S} \tag{223.5}$$

3.2.3.5 Neutral Atmosphere Model

a) Temperature. For this model assume that the neutral, ion, and electron temperature are equal at all times in the given altitude range of 120 to 400 km. Inactuality, the electron temperature is usually significantly higher than the other two, but this fact is neglected in the model.

Consider the temperature at a given altitude H, latitude LAT, and local time LT. All temperatures will be in °K. The maximum temperature at the altitude is:

$$TMAX = 2100 - 9000\, e^{-(0.0137\, H)} \tag{224}$$

The temperature at some LAT and LT at this altitude H is given by:

$$T = \left(\frac{TMAX}{1.28}\right)\left(1 + 0.28 \sin^{1.5}|LAT/2|\right)\left(1 + A \cos^{2.5}\left(\frac{\tau}{2}\right)\right) \tag{225}$$

where

$$A = \frac{(0.28)\left[\cos^{1.5}|LAT/2| - \sin^{1.5}|LAT/2|\right]}{1 + 0.28 \sin^{1.5}|LAT/2|} \tag{226}$$

We want the sine and cosine of the absolute value of LAT/2 to the 1.5th power.

τ is an angle that depends upon the solar hour angle, SHA:

$$\tau = SHA - 45 \text{ deg} + 12 \text{ deg} \sin(SHA + 45 \text{ deg}) \tag{227}$$

The solar angle is given in terms of the local time expressed in decimal hours:

$$SHA = \left|180 \text{ deg} + \frac{24}{LT}(360 \text{ deg})\right|_{\text{modulo } 360 \text{ deg}} \tag{228}$$

Thus given H, LAT, and LT, the temperature at the Shuttle's position is defined by Equation (225). T will always represent this temperature.

b) Neutral Atmosphere Density. For this model, consider the neutral atmosphere to consist of only four components: atomic oxygen, molecular oxygen, molecular nitrogen, and helium. The model will be defined in terms of the maximum density of these constituents at the 120 km altitude level:

$$NMAX_O = 7.60 \times 10^{16} \text{ atoms per cubic meter} \tag{229}$$

$$NMAX_{O2} = 7.50 \times 10^{16} \text{ molecules per cubic meter}$$

$$NMAX_{N2} = 4.00 \times 10^{17} \text{ molecules per cubic meter}$$

$$NMAX_{HE} = 3.40 \times 10^{13} \text{ atoms per cubic meter}$$

(U.S. Standard Atmosphere, 1966)

Each constituent will be distributed as a function of altitude and temperature or altitude and LAT and LT by way of Equation (225).

Define a scale height for each species:

$$\tilde{H}_i = \frac{kT(R_e + H)^2}{M_i g\, R_e^{\,2}} = \frac{kT}{M_i w^2 (R_e + H)} \tag{230}$$

where

M_i = atomic weight in AMU species i

T = temperature at the point of measurement in °K.

$k/g = 0.880$ km/°K

Therefore:

$$\tilde{H}_0 = \frac{0.880\ T(R_e + H)^2}{16\ R_e^{\,2}} \tag{231}$$

$$\tilde{H}_{O2} = \frac{0.880\ T\ (R_e + H)^2}{32\ R_e^2}$$

$$\tilde{H}_{N2} = \frac{0.880\ T\ (R_e + H)^2}{28\ R_e^2}$$

$$\tilde{H}_{HE} = \frac{0.880\ T\ (R_e + H)^2}{4\ R_e^2}$$

Each species is distributed in the following fashion:

$$\frac{dn_i}{n_i} = -\frac{dH}{\tilde{H}_i} - \frac{dT}{T} \qquad (232)$$

so that:

$$N(H,\ LAT,\ LT)_i = NMAX_i\ (\frac{355}{T}) \exp^{-} \int_{120}^{H} \frac{dH}{\tilde{H}_i} \qquad (233)$$

gives the density of species i, at altitude H, latitude LAT, and local time LT. If the variation of $(R_e + H)^2$ with H is neglected because $R_e >> H$, then the integral can be done and:

$$N_i = NMAX_i \left(\frac{355}{T_{120}}\right) \left[\left(\frac{T_{120}}{T}\right)^{1 + \frac{M_i R_e^2}{0.880 T_\infty (R_e+H)^2 (0.0137)}}\right] \exp \frac{M_i R_e^2 (120 - H)}{0.880 T_\infty (R_e+H)^2} \qquad (234)$$

where

$$T_\infty = (\frac{2100}{1.28})(1 + 0.28\ \sin^{1.5}|LAT/2|)(1 + A\ \cos^{2.5} \frac{\tau}{2})$$

Refer to Equations (224) and (225) for $H = \infty$. T_{120} is given by Equation (225) with $H = 120$ km. $NMAX_i$ is given for each species, i, in Equation (229). M_i is the atomic weight in AMU of species i:

$$M_O = 16$$

$$M_{O_2} = 32$$

$$M_{N_2} = 28$$

$$M_{HE} = 4$$

Each neutral species density is now fully described as a function of altitude, local time, and latitude or of altitude, orbit inclination, and orbit time. The total neutral density at any point in the orbit is given by:

$$NTOTAL = N(O) + N(O2) + N(N2) + N(HE) \tag{235}$$

3.2.3.6 Ionospheric Density Model (Electrons). The equation that governs the density of electrons or ions in the ionosphere is:

$$\frac{dn}{dt} = q - \alpha n^2 \text{ for electrons} \tag{236}$$

where

q = the photoionization rate

α = the recombination rate

It has been assumed that all ions have equal recombination rates so that the ratio of any single ion species to the total ion density does not change.

a) Electron Density. From Nawrocki and Papa, "Atmospheric Processes," page 1-61, an empirical formula for the photoionization rate is obtained. We put in a latitude dependence. If $|LAT| \leq 85$ degrees:

$$120 \leq H \leq 180 \text{ km} \qquad q_i = 3000 \cos|LAT| \tag{237.1}$$

$$180 \leq H \leq 400 \text{ km} \qquad q_2 = 3000 \cos|LAT| \exp \frac{180 - H}{73.5} \tag{237.2}$$

If $|LAT| > 85$ degrees:

$$120 \leq H \leq 180 \text{ km} \qquad q_3 = 3000 \cos|85 \text{ deg}| \tag{238.1}$$

$$180 \leq H \leq 400 \text{ km} \qquad q_4 = 3000 \cos|85 \text{ deg}| \exp \frac{180 - H}{73.5} \tag{238.2}$$

Thus, there are four separate regions where q is defined so that one must determine LAT and H before defining the proper q value to be used below.

Therefore, at a fixed H and LAT, the local time dependence of the electron density is given by Equation (236). We have simplified considerably by making q a constant during daylight. Of course at night $q = 0$ and we assume night begins at all altitudes and latitudes at 1800 LT and ends at 0600 LT.

During the day $0600 \leq LT \leq 1800$. Equation (236) has the solution. LT is measured in decimal hours:

$$n(LT) = n^* \tanh\left[\frac{q\ 3600(LT - 6)}{n^*} + C_1\right] \tag{239}$$

where

$$C_1 = \tanh^{-1}\left[\frac{\tanh\left(\frac{q\ 4.32 \times 10^4}{n^*}\right) - 1}{\left(1 + \frac{q\ 4.32 \times 10^4}{n^*}\right)\tanh\left(\frac{q\ 4.32 \times 10^4}{n^*}\right)}\right]$$

At night the solution must be divided into the two intervals $1800 \leq LT \leq 2400$ and $000 \leq LT \leq 0600$ because of the way we keep $LT < 2400$. For $1800 \leq LT \leq 2400$:

$$n(LT) = n^*\left[\frac{q\ (LT - 18)\ 3600}{n^*} + C_2\right]^{-1} \tag{240}$$

where

$$C_2 = \left[\frac{q\ 4.32\times10^4}{n^*} + \tanh\left(\frac{q\ 4.32\times10^4}{n^*}\right)\right]\left[\tanh\left(\frac{q\ 4.32\times10^4}{n^*}\right) - 1\right]^{-1}$$

For 0000 $\leq$ LT $\leq$ 0600:

$$n(LT) = n^*\left[\frac{q\ (LT + 6)_{\text{modulo } 24} \times 3600}{n^*} + C_2\right]^{-1} \tag{241}$$

n^* is the daytime equilibrium density at latitude LAT and H. It is related to the equatorial equilibrium concentration by:

$$n^* = n_o \cos^{1/2}(LAT) \text{ for } 0 \text{ deg} < |LAT| < 85 \text{ deg} \tag{242.1}$$

and

$$n^* = n_o \cos^{1/2} 85 \text{ deg for } |LAT| > 85 \text{ deg} \tag{242.2}$$

All that remains to be done is to define the altitude dependence of n_o. An empirical relationship for 120 $\leq$ H $\leq$ 240:

$$n_o = 4.9 \times 10^{11} \exp\left(\frac{H - 240}{116}\right) \text{ electrons/m}^3 \tag{243.1}$$

For 240 $\leq$ H $\leq$ 400:

$$n_o = 4.9 \times 10^{11} \exp\left(\frac{240 - H}{165}\right) \text{ electrons/m}^3 \tag{243.2}$$

This completes the description of the electron density as a function of altitude, local time, and latitude.

b) Ion Density. This model assumes that only the ions of atomic oxygen, molecular oxygen, and nitric oxide are present. The masses of these ions are:

$$O^+ = 16 \text{ AMU} \tag{244}$$

$$O_2^+ = 32 \text{ AMU}$$

$$NO^+ = 30 \text{ AMU}$$

Assume that at any given altitude the ion density of a single species is directly proportional to the electron density at that altitude:

$$N(02+) = F(02+)\ n(LT) \tag{245}$$

$$N(NO+) = F(NO+)\ n(LT)$$

$$N(0+) = [1 - F(02+) - F(NO+)]\ n(LT)$$

where F(02+) is this fraction for 0_2^+, F(NO+) for NO^+, and n(LT) is given by Equations (239) to (241).

The fractions are defined empirically in three altitude ranges. For $120 \leq H \leq 210$ km:

$$F(02+) = (0.436)\exp(\frac{H}{160} - \frac{H}{116}) \tag{246.1}$$

$$F(NO+) = (0.814)\exp(\frac{H}{138} - \frac{H}{116}) \tag{246.2}$$

For $210 \leq H \leq 240$:

$$F(02+) = (0.22)\exp(9.57 - \frac{H}{28} - \frac{H}{116}) \tag{247.1}$$

$$F(NO+) = (0.47)\exp(8.63 - \frac{H}{32} - \frac{H}{116}) \tag{247.2}$$

Finally, for $240 < H$:

$$F(02+) = (0.22)\exp(6.05 - \frac{H}{28} + \frac{H}{165}) \tag{248.1}$$

$$F(NO+) = (0.47)\exp(5.11 - \frac{H}{32} + \frac{H}{165}) \tag{248.2}$$

Each of the three species' densities is now fully defined as a function of altitude, local time, and latitude.

3.2.3.7 Instruments

A) Electric Field Receiver and Magnetic Field Receiver: In this simulation these two instruments are turned on, but they respond only to the random noise source and there is no way of calculating the mean square field value. A request for the plot of mean square field should be answered with NOT AVAILABLE FOR EP 2.0. Otherwise the two instruments are fully functional using the random noise generator as a signal source.

B) Fluxgate Magnetometer and Rubidium Magnetometer. Equations (219) through (223) give all needed information to determine the magnetic fields observed by these instruments.

C) The Cylindrical Electron Probe. The electron temperature is given by Equations (224) to (228).

The electron density is given by Equations (237) to (243).

The current versus voltage display must be calculated in the following fashion: Let

P = probe potential in volts

T = electron temperature in ^{o}K

$n(LT)$ = electron density in $(\text{meter})^{-3}$ Equations (239) to (241)

e = electron charge = 1.6×10^{-19} coulombs

k = Boltzmann's constant = 1.38×10^{-23} joules/^{o}K

m = electron mass = 9.11×10^{-31} kg

A = probe area of cylinder diameter 0.1 cm, 35 cm long = 1.1×10^{-3} meter^2

$\vec{V}_s$ = Shuttle velocity in METERS/SEC not km/sec

$\hat{x}_2$ = Platform unit vector in x_2 direction.

There are two cases for the probe current. If $P \leq 0$, probe current is given by

$$I^- = I_e^- - I_i^- \qquad I_e \text{ electron current} \tag{249}$$

I_i ion current

$$I_e^- = A\,n(LT)\,e\left(\frac{kT}{2\pi m}\right)^{1/2} \exp(eP/kT) \tag{250}$$

Remember that P is negative

$$I_i^- = A\,n(LT)\,e\left[\left(\frac{2e|P|}{m}\right)^{1/2} + \left|\frac{(\vec{V}_s \cdot \hat{x}_2)}{\pi}\right|\right] \tag{251}$$

$$V_s \cdot \hat{x}_2 = T_{A\to P}\, T_{S\to A}\, T_{e\to s} \begin{pmatrix} V_{x'} \\ V_{y'} \\ 0 \end{pmatrix}\Bigg|_{\hat{x}_2 \text{ component}} \tag{252}$$

NOTE: V_s is in meters/sec.

Defined I as positive when electrons flow into the probe.

If $P > 0$

$$I^+ = I_e^+ - I_i^+ \tag{253}$$

$$I_i^+ = \frac{A\,n(LT)\,e}{\pi}\,|\vec{V}_s \cdot \hat{x}_2| \tag{254}$$

$$\begin{aligned} I_e^+ = A\,n\,(LT)\,e \;&\left[\left(\frac{kT}{2\pi m}\right)^{1/2} \exp(-eP/kT)\right. \\ &\left. + (eP/m)^{1/2}\left(1 + \Phi\left(\sqrt{\frac{eP}{kT}}\right)\right)\right] \end{aligned} \tag{255}$$

where

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\,dt = \text{error function.}$$

The angle between the probe axis and the velocity vector is given by

$$CPV = \cos^{-1} \frac{(\vec{V}_s \cdot \hat{x}_2)}{R\omega} \tag{256}$$

D) Spherical Probe. Each one of the ions O^+, NO^+, O_2^+ contributes a separate current to the spherical probe. Each one of the three ion currents has the form given approximately by

$$I_i = \pi r^2 N_i e \frac{V_s}{2}\left[1 - \Phi\left((V_e - V_s)\sqrt{\frac{M_i}{2kT}}\right) + \left(\frac{2kT}{V_s^2 M_i}\right)^{1/2} \exp\frac{-M_i (V'_e - V_s)^2}{2kT}\right] \tag{257}$$

where

r^2 is the sphere's radius = 0.05 meter

N_i is the density of ion species i given by Equation (245)

$e = 1.6 \times 10^{-19}$ coulombs

V_s' = shuttle velocity = $R\omega \times 10^3$ see Equation (213). V_s must be measured in meters/second

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt = \text{error function}$$

M_i = particular ion mass in kilograms

$$M_{O^+} = 16 \times 1.66 \times 10^{-27} \text{ kg}$$

$$M_{O_2^+} = 32 \times 1.66 \times 10^{-27} \text{ kg} \tag{258}$$

$$M_{NO^+} = 30 \times 1.66 \times 10^{-27} \text{ kg}$$

$$V_e = (2dP/M_i)^{1/2} \tag{259}$$

P = electric potential on the probe >0 in volts

T = temperature Equation (225) in $^{\circ}K$

k = Boltzmann constant = 1.38×10^{-23} joules/$^{\circ}K$

The total ion current at any voltage, P, is given by the sum of each of the currents at that voltage.

$$I_{measured} = I_{O^+} + I_{O_2^+} + I_{NO^+} \tag{260}$$

The ion temperature is given by

$$T_{ion} = T \tag{261}$$

T is given by Equation (225).

Ion density is given by

Ion density = n(LT) is given in Equations (239), (240), and (241) depending on the local time, altitude and latitude. (262)

The plot of $\log_{10} I_{measured}$ is simply what it says:

log base ten of probe current nanoamps

$$= +9 + \log_{10} I_{measured} \tag{263}$$

Current in nanoamps = $10^9 \, I_{measured}$ of Equation (260) (264)

E) Planar Segmented Probe. For this experiment we use the probe to investigate the angle between its axis and the ion streaming velocity

Angle PSPV = Angle VX_1 as given by Equation (218) (265)

To shorten the notation below, let

$$\gamma = \text{Angle PSPV} \tag{266}$$

The probe is constructed with radius 0.05 meter and the sides of the probe are 0.05 meter high. For this simulation it is not necessary to find the current in each probe segment. The total current is sufficient. The expression for the current is in two parts. If

$|\tan \gamma| \leq 2$

then

$$I = 2r^2\ eNR\ \omega \cos \gamma \left[\sin^{-1}\left(1 - \frac{\tan \gamma}{2}\right) - \left(1 - \frac{\tan \gamma}{2}\right)(4 \tan \gamma - \tan^2 \gamma)^{1/2}\right] \tag{267}$$

where

r = 0.05 meter

$e = 1.6 \times 10^{-19}$ coulombs

N = total ion density = N(LT) given by Equations (239) to (241)

R = Orbiter geocentric radius in meters

ω = orbital angular velocity in Equation (207)

γ = angle PSPV in Equations (266) or (218)

If $|\tan \gamma| > 2$, then

$$I = 0 \tag{268}$$

Current measured in nanoamps = $10^9 I$ of Equation (267) (269)

Log base 10 of probe current in nanoamps = $9 + \log_{10} I$ (270)

F) Planar Electron Trap. The current from the planar trap at any potential P, assuming that the ions are being rejected is

$$I(P) = \pi r^2\left(\frac{k}{2\pi m}\right)^{1/2} e\left[N(LT)\sqrt{T}\exp(-mV_e^{\,2}/2kT) + N_1\sqrt{T_1}\exp(-mV_e^{\,2}/2kT_1) + N_2\sqrt{T_2}\exp(-mV_e^{\,2}/2kT_2)\right] \tag{271}$$

where

r = 0.05 meter
$k = 1.38 \times 10^{-23}$ joules/$^{\circ}$K
$e = 1.6 \times 10^{-19}$ coulombs
N(LT) = electron density given by Equations (239) to (241)
T = temperature given by Equation (225)

$m = 9.11 \times 10^{-31}$ kg

$N_1 = 7.16 \times 10^8$ electrons/m^3

$T_1 = 2 \times 10^4$ ^oK

$N_2 = 4.75 \times 10$ electrons/m^3

$T_2 = 4.64 \times 10^8$ ^oK

$V_e^2 = 2eP/m$

P = trap potential in volts.

Log base 10 of current in nanoamps = $9 + \log_{10} I(P)$ (272)

Log base 10 of electron energy in electron volts = $\log_{10} P$ (273)

The log base 10 of the electron density in electrons per cubic meter is the log of the density of electrons in the range E to E = dE; E = energy.

$$N(E) = \frac{1}{\sqrt{2\pi}}\left[N(LT)\sqrt{\frac{eP}{kT}}\exp(-eP/kT) + N_1\sqrt{\frac{eP}{kT_1}}\exp(-eP/kT_1) + N_2\sqrt{\frac{eP}{kT_2}}\exp(-eP/kT_2)\right] \tag{274}$$

All terms defined as in Equation (271).

Log base 10 of electron density = $\log_{10} N(E)$ of Equation (274) (275)

G) <u>Ion Mass Spectrometer</u>. For the ion mass spectrometer there will be data only at masses $O^+ = 16$, $NO^+ = 30$, and $O_2^+ = 32$.

The log base 10 of ion density in ions per meter^3 is for Ion Mass = 16 AMU

log base 10 ion density = $\log_{10} N(O^+)$ from Equation (245) (276)

Ion Mass = 30 AMU

log base 10 ion density = $\log_{10} N(NO^+)$ from Equation (245) (277)

Ion Mass = 32 AMU

log base 10 ion density = $\log_{10} N(O_2^+)$ from Equation (245) (278)

C. 2

All other masses have no display of log base 10 of ion density.

A general expression for the ion current is

$$I(M_i) = \pi r^2 N_i \; e \frac{V_s}{2} \cos\gamma \Big[1 + \Phi(V_s \cos\gamma \sqrt{M_i}/\sqrt{2kT}) + (2kT/M_i)^{1/2} \exp-(M_i V_s^2 \cos^2\gamma/2kT)(V_s \cos\gamma)^{-1} \Big] \quad (279)$$

where

r = 0.02 meter

N_i is the number density of species i equals Equation (245)

e = 1.6×10^{-19} coulombs

V_s = Shuttle velocity in meters/second

$\cos\gamma = (\vec{V}_s \cdot \vec{x}_1)/|V_s|$ Equations (214) to (218)

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt = \text{error function}$$

M_i = mass of each species in kg. See Equation (258)

T = temperature See Equation (225)

k = 1.38×10^{-23} joules/^oK

The current at mass 16, 30 and 32 is obtained by choosing the proper N_i and M_i in this above equation. All other masses have zero current.

Ion current in nanoamps = 10^9 $I(M_i)$ of Equation (279) (280)

Total ion density = N(LT) of Equations (239) to (241) (281)

The angle between spectrometer axis and Shuttle velocity vector is

ANGLE IMSV = ANGLE VX_1 of Equations (214) or (218) (282)

H) <u>Neutral Mass Spectrometer</u>. The angle between spectrometer axis and velocity vector is the same as ion mass spectrometer in Equation (282).

The total neutral density is given by Equation (235) (283)

This model has only neutral masses 4, 16, 28, 32 AMU, all other mass numbers have no displays for Neutral Mass = 4

log base 10 density = $\log_{10}N(HE)$ from Equation (234) for HE (284)

Neutral Mass = 16

log base 10 density = $\log_{10}N(0)$ from Equation (234) for 0 (285)

Neutral Mass = 28

log base 10 density = $\log_{10}N(N2)$ from Equation (234) for N2 (286)

Neutral Mass = 32

log base 10 density = $\log_{10}N(02)$ from Equation (234) for 02 (287)

The neutral current is given by Equation (279) where for

Mass 4

$$M_i = 4 \times 1.6 \times 10^{-27} \text{ kg}$$

N_i = N(HE) from Equation (234) for HE (288)

Mass 16

$$M_i = 16 \times 1.6 \times 10^{-27} \text{ kg}$$

N_i = N(0) from Equation (234) for 0 (289)

Mass 28

$$M_i = 28 \times 1.6 \times 10^{-27} \text{ kg}$$

$N_i = N(N_2)$ from Equation (234) for N2 (290)

Mass 32

$$M_i = 32 \times 1.6 \times 10^{-27} \text{ kg}$$

$$N_i = N(O2) \text{ from Equation (234) for O2} \qquad (291)$$

all other currents are zero.

$$\text{Ion current in nanoamps} = 10^9 \; I(M_i) \text{ from Equation (279)} \qquad (292)$$

3.2.3.8 Special Displays.

A) Ion densities are given by Equation (245)

B) Electron density is given by Equations (239) to (241)

C) Neutral densities are given by Equation (234)

D) Temperature is given by Equation (225)

E) Times are explained in Equations (201) to (210)

F) Locations are explained in Equations (201) to (210)

G) Magnetic field is explained in Equations (219) to (223)

H) All the angles except XIV are set by the keyboard. Angle XIV is given by Equation (218).

THE END

3.3 IONOSPHERIC MEASUREMENTS WITH THE SUBSATELLITE

3.3.1 Experiment Description

Ionospheric Measurements with the Subsatellite EP 3.0.

The subsatellite system which provides the ability to make measurements at great distances from the Shuttle is an extremely valuable tool for atmospheric and space physics measurements. In this simulation the procedures for launching the subsatellite are outlined in a general fashion, and a large number of the subsatellite instruments are used. The experiment is concerned with the measurement of ionospheric densities, species and temperature at large distances from the Shuttle. The ionospheric model is the same one used in EP 2.0. The altitude, inclination and attitude of the subsatellite can be varied over a wide range of values.

3.3.2 Experiment Procedure

EP 3.0 Ionospheric Measurements with the Subsatellite

EP 3.1 Deploy Subsatellite

- 4.1.1 Check area clear for ejection
  - 4.1.1.1 TV picture
  - 4.1.1.2 Safety and warning systems
- 4.1.2 Eject Subsatellite
  - 4.1.2.1 Check subsatellite power systems GO
  - 4.1.2.2 Check subsatellite telemetry system GO
  - 4.1.2.3 Check subsatellite transponder system GO
  - 4.1.2.4 Check subsatellite control system GO
  - 4.1.2.5 If all systems GO push ejection button
- 4.1.3 Turn subsatellite instruments on
  - 4.1.3.1 3-axis fluxgate magnetometer
  - 4.1.3.2 Cylindrical electron probe
  - 4.1.3.3 Segmented plana trap
  - 4.1.3.4 Ion mass spectrometer
  - 4.1.3.5 Electric field meter

EP 3.2 Determine Subsatellite Position and Attitude

- 4.2.1 Set subsatellite altitude = 300 km
- 4.2.2 Set subsatellite orbit inclination = 10°
- 4.2.3 Set local time of descending node = 0000:00
- 4.2.4 Set universal time of descending node = 0000:00
- 4.2.5 Set spin rate at one revolution per orbit

4.2.6 Set initial attitude angles

4.2.5.1 SPHI = 90° - i_s = 80°
4.2.5.2 STHETA = 270°
4.2.5.3 SPSI = 0°

4.2.7 Start subsatellite orbit

EP 3.3 Generate Subsatellite Data

4.3.1 Check 3-axis magnetometer outputs

4.3.2 Check cylindrical probe outputs

4.3.3 Check segmented trap outputs

4.3.4 Check ion mass spectrometer output

4.3.5 Check electric field meter outputs

4.3.6 Record all data

EP 3.4 Turn All Subsatellite Instruments Off

4.4.1 3-axis fluxgate off

4.4.2 Cylindrical probe off

4.4.3 Segmented trap off

4.4.4 Ion mass spectrometer off

4.4.5 Electric field meter off

3.3.3 Theory and Background: Ionospheric Measurements with the Subsatellite

3.3.3.1 Subsatellite Orbit. The subsatellite orbit is treated exactly like the Orbiter.

3.3.3.2 Subsatellite Attitude. The three axes of the subsatellite are denoted by s_1, s_2, s_3. X_s, Y_s, Z_s represents the coordinate system fixed on the subsatellite orbit with X_s always pointing southward, Y_s always pointing eastward, and Z_s always pointed upward. Let the subsatellite velocity in the X^1, Y^1, Z^1 system be $\overline{V} = V_X 1X^1 + V_Y 1Y^1$ for an orbit inclined at i degrees at altitude H then

$$V = \begin{matrix} R_W \dfrac{\sin i \cos wt}{(1 - \sin^2 i \sin^2 wt)^{1/2}} \\ \\ R_W \dfrac{\cos i}{(1 - \sin^2 i \sin^2 wt)^{1/2}} \end{matrix} = \begin{pmatrix} V_X{}^1 \\ V_Y{}^1 \\ 0 \end{pmatrix} \tag{312}$$

where $R = (R_e + H) \times 1000$ and $V_X 1$ and $V_Y 1$ are in meters/sec, and

$$\text{where } w_s = \frac{R_e}{R_e + H}\left(\frac{g}{R_e + H}\right)^{Y_Z} = \text{subsatellite orbital angular velocity}$$

$R_e = 6371$ km

$g = 9.807 \times 10^{-3}$

H = altitude in kilometers

It is assumed that the subsatellite will rotate in a positive direction about its own s_3 axis with an angular velocity w_{sp}.

$$w_{sp} = 2\pi \text{ (subsatellite spin rate)} \tag{313}$$

If we apply the transformation

$$T_{X\rightarrow V} = \begin{pmatrix} \frac{V_X 1}{|V|}\cos(w_{sp}-w)t & \frac{V_Y 1}{|V|}\cos(w_{sp}-w)t & -\sin(w_{sp}-w)t \\ -\frac{V_X 1}{|V|}\sin(w_{sp}-w)t & -\frac{V_Y 1}{|V|}\sin(w_{sp}-w)t & -\cos(w_{sp}-w)t \\ -\frac{V_Y 1}{|V|} & \frac{V_X 1}{|V|} & 0 \end{pmatrix} \tag{314}$$

to a vector in the $X^1Y^1Z^1$, we transform it into a frame whose z-axis is perpendicular to the orbit plane and which is rotating about its z-axis with angular velocity w_{sp}. This is exactly the frame in which we wish to place the subsatellite axes s_1, s_2, s_3 in order to make the measurements of the physical phenomena. With this orientation the s_1 axis always points in the direction of V if $w_{sp} = w_s$. THEREFORE WE WILL ALWAYS PUT THE SUBSATELLITE IN ITS ORBIT WITH s_3 perpendicular to the orbit plane and s_1 aligned with V at the beginning of the orbit ($t = 0$). If $w_{sp} = w$ then s_1 will always stay aligned. The $T_{s\rightarrow V}$ matrix will then transform to:

$$T_{s \to V} = \begin{pmatrix} \frac{V_X 1}{|V|} & \frac{V_Y 1}{|V|} & 0 \\ 0 & 0 & -1 \\ \frac{-V_Y 1}{|V|} & \frac{V_X 1}{|V|} & 0 \end{pmatrix} \qquad (315)$$

If not, then s_1 will rotate about s_3 out of the local horizontal.

Define the three Eulerian angles PHI, THETA, PSI which rotate X^1, Y^1, Z^1 into s_1, s_2, s_3. In general the transformation

$$T_{X^1Y^1Z^1 \to s_1s_2s_3}$$

$$= \begin{pmatrix} \cos\psi\cos\phi - \cos\theta\sin\phi\sin\psi & \cos\psi\sin\phi + \cos\theta\cos\phi\sin\psi & \sin\psi\sin\theta \\ -\sin\psi\cos\phi - \cos\theta\sin\phi\cos\psi & -\sin\psi\sin\phi + \cos\theta\cos\phi\cos\psi & \cos\psi\sin\theta \\ \sin\theta\sin\phi & -\sin\theta\cos\phi & \cos\theta \end{pmatrix}$$

Rotates a vector from $X^1Y^1Z^1$ into $s_1s_2s_3$. In particular if

$$\phi = \cos^{-1}\frac{\sin i\cos wt}{(1 - \sin^2 k\sin^2 wt)^{1/2}}, \quad \theta = -\pi/2 \text{ and } \psi = (w_{sp} - w)t \qquad (316)$$

then $s_1s_2s_3$ will be the frame described by $T_{X \to V}$ Equation (414) - the one we want to make our observation from. The initial values of ϕ, θ, ψ will always be

$$\text{Initial } \phi = \phi_o = \pi/2 - i \qquad (317)$$

$$\text{Initial } \theta = \theta_o = -\pi/2 = \frac{3\pi}{2} \qquad (318)$$

$$\text{Initial } \psi = \psi_o = 0 \qquad (319)$$

3.3.3.3 Display of Subsatellite Realtime Values

3.3.3.3.1 Orbit and Attitude. Universal time in hours is given by $UT = UT_oH + \frac{t}{3600}$. UT_oH in decimal hours is converted from GMT_o (keyboard entry) in hours, units, seconds.

Magnetic dip angle is given by

$$\text{dip angle} = \cos^{-1} \frac{2 \sin wt \sin i}{(3 \sin^2 wt \sin^2 i + 1)^{1/2}} \tag{320}$$

PHI is given by

$$PHI = \cos^{-1} \frac{\sin i \cos wt}{(1 - \sin^2 i \sin^2 wt)^{1/2}} \tag{321}$$

THETA is given by

$$THETA = 270° \tag{322}$$

PSI is given by

$$PSI = (w_{sp} - w)\ t \tag{323}$$

The procedure for EP 3.0 is written with $w_{sp} = w$ so that

$$PSI = 0° \tag{324}$$

The line of sight distance to Shuttle is given by Equation (311).

3.3.3.3.2 Subsatellite Fluxgate Magnetometer.

$$B_X 1 = \frac{8.07 \times 10^{15} \sin \lambda}{(R_e + H)^3} \text{ in gammas} \tag{325}$$

$$B_Z 1 = \frac{-1.614 \times 10^{16} \cos \lambda}{(R_e + H)^3} \text{ in gammas} \tag{326}$$

$$\lambda = LAT + \pi/2 = \cos^{-1} (-\sin wt \sin i) \tag{327}$$

For subsatellite fluxgate whose three axis X, Y, Z correspond to s_1, s_2, s_3, respectively, we have

$$BTOT = \frac{(8.07 \times 10^{15})\ (3 \sin^2 wt \sin^2 i + 1)^{1/2}}{(R_e + H)^3} \text{ in gammas} \tag{328}$$

$$BX = T_{X \to SV} \begin{pmatrix} B_X 1 \\ 0 \\ B_Z 1 \end{pmatrix} \Bigg|_{s_1 \text{ component}} \tag{329}$$

$$BY = T_{X \to SV} \begin{pmatrix} B_X 1 \\ 0 \\ B_Z 1 \end{pmatrix} \Bigg|_{s_2 \text{ component}} \tag{330}$$

$$BZ = T_{X \to SV} \begin{pmatrix} B_X 1 \\ 0 \\ B_Z 1 \end{pmatrix} \Bigg|_{s_3 \text{ component}} \tag{331}$$

where $T_{X \to SV}$ is given by (414.5) and $B_X 1$, $B_Z 1$ by Equations (325 and 326).

3.3.3.3.3 Subsatellite Cylindrical Electron Probe. Remembering that everywhere a local time, altitude, orbit time or velocity is mentioned it refers to the subsatellite and not to the Shuttle we can take over the whole formalism of EP 2.0.

Electron temperature is given by Equations (224) to (228) EP 2.0.

Electron density is given by Equations (237) to (243) EP 2.0.

Current versus voltage displays is given by Equations (249) to (255) of EP 2.0.

The angle between probe axis and the velocity vector is given by

$$CPV = \pi/2 + (w_{sp} - w)\ t \tag{332}$$

3.3.3.3.4 Subsatellite Planar Segmented Trap. The current is given by Equations (267) to (270) EP 2.0 except that the angle γ is given by

$$\gamma = (w_{sp} - w)\ t \tag{333}$$

3.3.3.3.5 Subsatellite Ion Mass Spectrometer. Equations (276) through (281) describe the ion mass spectrometer current and density displays.

The angle between spectrometer axis and the velocity vector is:

$$\gamma = \text{ANGLE IMSV} = (w_{sp} - w)\ t \tag{334}$$

3.3.3.3.6 Subsatellite Electric Field Meter. For this simulation the only electric field will be that produced by the motion of the subsatellite across the magnetic field lines.

The electric field is given by

$$E_{southward} = E_X 1 = (V_Y 1)\ (B_Z 1)\ (10^{-6}) \text{ millivolts/meter} \tag{335}$$

$$E_{eastward} = E_Y 1 = (V_X 1)\ (B_Z 1)\ (10^{-6}) \text{ millivolts/meter} \tag{336}$$

$$E_{upward} = E_Z 1 = (V_Y 1)\ (B_X 1)\ (10^{-6}) \text{ millivolts/meter} \tag{337}$$

and $B_X 1$ and $B_Y 1$ are given exactly by Equations (325) and (326). The total electric field in millivolts/meter is

$$\text{ETOT} = (E_X^2 1 + E_Y^2 1 + E_Z^2 1)^{1/2} \tag{338}$$

3.4 ELECTRON ACCELERATOR BEAM MEASUREMENTS

3.4.1 Experiment Description

Electron Accelerator Beam Measurements EP 4.0.

Electron beam experiments have already been done in the ionosphere and the technique is applicable in many areas of magnetospheric and plasmas physics in space. The AMPS Shuttle payloads will probably contain a high powered electron accelerator.

Before the electron beams can be used in ionospheric experiments from the Shuttle it will be necessary to map out the characteristics of the beam as it leaves the accelerator. The following simulation attempts to describe the initial behavior of the beam as it expands from its initial dimensions because of its own self-field and because of the Earth's magnetic field.

The beam current, energy, direction of propagation and divergence are controllable by the experimenter over a wide range of values. The measurements of the beam are made by a Faraday cup placed seven meters from the accelerator's exit aperture. In this simulation the magnetic steering coils of the accelerator are used to sweep the beam back and forth across the face of the Faraday cup so that the beam profile can be mapped without moving the Faraday cup.

3.4.2 Experiment Procedure

EP 4.0 Electron Accelerator Beam Measurement

EP 4.1 Determine Shuttle Orbit

4.1.1 Set Shuttle altitude at 400 km
4.1.2 Set Shuttle orbit inclination at 0°
4.1.3 Set local time of descending node = 0000:00
4.1.4 Set universal time of descending node = 0000:00

EP 4.2 Set Shuttle attitude with Z-axis parallel to Earth's Magnetic field

4.2.1 Set ∇ = 270°
4.2.2 Set Λ = 90°
4.2.3 Set Δ = 0°
4.2.4 Hold Shuttle in this attitude for remainder of experiment

EP 4.3 Set up accelerator lens focus

4.3.1 Set diverfing lens voltage = 100 volts
4.3.2 Set converging lens voltage = 100 volts

EP 4.4 Set up accelerator scanning

4.4.1 Set BPH1 = 0°
4.4.2 Set cathode heater current = 4.0 amps
4.4.3 Set beam into programmed scanning mode

4.4.3.1 Selected programmed mode
4.4.3.2 Set $W_1 = 2\pi$
4.4.3.3 Set $W_2 - 20\pi$

EP 4.5 Accelerator tests

4.5.1 Test beam azimuth and deflection action
4.5.2 Test beam current value
4.5.3 Test grad current value

EP 4.6 Turn Faraday cup on

4.6.1 Set photoelectron suppressor voltage
4.6.2 Set Faraday cup current amplifier gain
4.6.3 Set Faraday cup bias and scale factor

EP 4.7 Final accelerator preparation

4.7.1 Set accelerator voltage P to 10,000 volts
4.7.2 Set cathode heater current to 4.0 amps
4.7.3 Set grid voltage to 100 volts
4.7.4 Set firing duration to 1.00 seconds
4.7.5 Turn charging current ON, observe accelerator READY

EP 4.8 Time-to-go until firing

4.8.1 Ser time-to-go at 60 seconds

EP 4.9 Set countdown to GO wait until beam has fired

EP 4.10 Check data

4.10.1 Check electron accelerator beam current versus time

4.10.2 Check beam firing angles

4.10.3 Check Faraday cup current

4.10.4 Check beam angle with respect to Earth's magnetic field

EP 4.11 Refire

4.11.1 If want to refire beam

4.11.1.1 No changes in beam parameters 4.11.1.1 reset firing time in 4.7 and continue

4.11.1.2 Change beam parameters 4.11.1.2 Repeat steps 4.4 to 4.10 with desired changes

4.11.2 If no refire

4.11.2.1 Turn accelerator OFF

4.11.2.2 Turn Faraday cup OFF

3.4.3 Theory of Background

3.4.3.1 Motion of an Electron in an Electron Beam Fired in the Presence of a Magnetic Field (General Information). In the following an attempt has been made to describe the current that would be measured by a Faraday cup placed a fixed distance above the exit aperture of an electron accelerator. The Faraday cup has an entrance aperture area of 10 square centimeters. The exit aperture of the electron accelerator is circular of radius 50 centimeters.

An attempt is made to describe the Faraday cup current as a function of:

1) Accelerator current (I)
2) Accelerator Potential = Beam Energy (P)
3) Orientation of the ejected beam with respect to the ambient magnetic field (Ω_1, ϕ_1)
4) The magnitude of the ambient magnetic field (B)
5) The distance between the Faraday cup and the accelerator aperture (Z_o)
6) The beam dispersion angle (ψ)

The electron accelerator is located on the Shuttle X-axis, a distance $+X_b$ from the origin of the Shuttle X, Y, Z coordinate system. It is assumed that the Faraday cup is mounted at a distance Z_c = 700 centimeters from the accelerator.

3.4.3.2 The Beam Radius. The general motion of the particle in the beam is given by

$$m \frac{dv}{dt} = e\left(E + \frac{V \times B}{C}\right)$$

$$\nabla \cdot E = 4\pi\rho$$

$$\nabla \cdot B = 0 \tag{401}$$

$$\nabla \times E = \frac{-1}{C} \frac{\delta B}{\delta t}$$

$$\nabla \times B = \frac{4\pi}{C} J + \frac{1}{C} \frac{\delta E}{\delta t}$$

$$\frac{\delta\rho}{\delta t} + \nabla \cdot J = 0$$

subject to the initial position and velocity of the electron and the beam.

The initial density $\rho_o = 1.34 \times 10^7\ IP^{1/2}$ I = accelerator current in amps. P = accelerator potential in volts and ρ_o is in electrons per cubic centimeter.

A closed form, self-consistent solution for the electron position cannot be generated and so it is necessary to make many approximations in order to bring the problem into relative simplicity. We shall divide the problem into two parts. The first treats the expansion of the beam due to the self-electric field. The second treats the expansion due to the beam divergence.

3.4.3.2.1 Radial Expansion due to Self-Field. For this problem let us go into a cylindrical coordinate system (r, ϕ, Z) that travels up the Z-axis at the beam velocity. The equation of motion are:

$$\ddot{r} - r\dot{\phi}^2 = \frac{eEr}{m} + rw\dot{\phi} \qquad \dot{r} = \frac{dr}{dt} \tag{402}$$

$$r\ddot{\phi} + 2\dot{r}\dot{\phi} = w\dot{r} \qquad \dot{\phi} = \frac{d\phi}{dt} \tag{403}$$

$$w = \frac{eB}{mc} \qquad \frac{eE}{m} = \frac{2e^2\rho_o\pi R_o^{\ 2}}{mr} = \frac{a^2}{r} \tag{404}$$

R_o = radius of beam when expansion starts = 50 cm

M = electron mass = 9.1×10^{-28} grams

e = electric charge of electron = 4.8×10^{-10} ESU

ρ_o = electron density at t = 0 = 1.34×10^7 $IP^{-1/2}$ el/cc

c = speed of light = 3×10^{10} m/sec

We have at $t = 0$, $\phi = 0$, $\dot{\phi} = 0$, $r = R_o$, $\dot{r} = 0$ as the initial conditions.

Equation (403) gives $$\dot{\phi} = \frac{w}{2}\left(\frac{R_o^{\ 2}}{r^2} - 1\right) \tag{405}$$

and Equation (402) gives

$$\ddot{r} = \frac{a^2}{r} - \frac{w^2 r}{4} + \frac{w^2 R_o^{\ 4}}{4r^3} \tag{406}$$

integrating

$$\frac{\dot{r}}{\sqrt{2}} = \left(a^2 \ln r/R_o - \frac{w^2 R_o^{\ 4}}{8r^2}\left(\frac{r^2}{R_o^{\ 2}} - 1\right)^2\right)^{1/2} \tag{407}$$

We shall assume in this section that the term

$$\frac{w^2 R_o^{\ 4}}{8r^2}\left(\frac{r^2}{R_o^{\ 2}} - 1\right)^2 << a^2 \ln r/R_o \tag{408}$$

so that

$$\int_0^t dt = \frac{R_o}{\sqrt{2}} \int_1^{r/R_o} \frac{dx}{a\sqrt{1mx}} = \frac{R_o\sqrt{2}}{a} \int_0^{\sqrt{\ln r/R_o}} e^{u^2} du$$

where r is now the radius to which the beam has expanded after a time t. The integral cannot be done in closed form so we expand it roughly by

$$\int_0^b e^{x^2}\, dx = \left(\frac{1 + e^{b^2}}{2}\right) b \text{ or} \tag{409}$$

$$\frac{at\sqrt{2}}{R_o} \approx (1 + r/R_o)\ \sqrt{\ln r/R_o} \tag{410}$$

$$\frac{at\ \sqrt{2}}{R_o} = (1 + r/R_o)\ \frac{\sqrt{\ln 8}}{7}\ (r/R_o - 1) \tag{411}$$

in the region $1 \leq r/R_o \leq 10$ approximately. This gives approximately

$$\left(-1 + r^2/R_o^{\ 2}\right) = \frac{7at}{R_o} \tag{412}$$

or

$$r/R_o = (1 + \frac{7at}{R_o})^{1/2} \tag{413}$$

$$R_o = 50 \text{ cm}$$

$$a = 1.46 \times 10^8\ R_o\ I^{1/2}\ P^{-1/4} \text{ cm/sec} \tag{414}$$

Thus the pure electric field expansion will be approximated by

$$r_b = 50\ (1 + 10.22 \times 10^8\ I^{1/2}\ P^{-1/4}\ t)^{1/2} \text{ cm} \tag{415}$$

where r_b is the radius of the beam at time t.

All of the many approximations given above will prove to be not too bad so long as the measurements are made within 10 meters of the accelerator aperture.

3.4.3.2.2 Radial Expansion due to Beam Dispersion

$$R'_c = \frac{V_b}{w} \sin (\psi \sin \frac{r\pi}{2r_b}) \tag{416}$$

V_b = beam velocity = $5.93 \times 10^7 P^{1/2}$ cm/sec

$w = \frac{eB}{mc} = 1.76 \times 10^7$ B sec^{-1} B = mag field in gauss

ψ = dispersion angle

r_b = beam radius at time t

r = distance from center of beam $\leq r_b$

After a time t an electron which started at distance r_o will travel to a distance

$$r_1(t) = [1 + 2x^2 (1 - \sqrt{1 \times 1/x^2} \cos (wt + ctn^{-1} x))]^{1/2} r_o \tag{417}$$

where $x = \frac{R'_c}{r_o}$

If the density of the beam were uniformly distributed along the r-direction from 0 to r_b then the electron charge density at time t would be given by

$$\rho(t) = \frac{\rho_o R_o^2}{r_b^2(t)} \tag{418}$$

However because the actual dispersion of the beam is given by

$$\psi \sin \frac{r\pi}{2r_b} \tag{419}$$

instead of ψ alone, the density is not uniformly distributed in r.

The actual density becomes

$$\rho(r,t) = \frac{\rho_o R_o^2}{r_b^2(t)} \frac{\pi^2 \cos\left(\psi \sin \frac{r\pi}{2r_b}\right)}{4\pi^2 - \psi^2 (1 + \pi^2/4)} \tag{420}$$

provided ψ is not too large. if $r \leq r_b$ and

$$\rho(r,t) \equiv 0 \text{ for } r > r_b \tag{421}$$

3.4.3.2.3 Combined Dispersion and Self-Field Radius

We shall assume that the electric field acts upon a dispersively expanding beam as follows:

$$r_1(t) = r_o' [1 + 2x^2 (1 - \sqrt{1 + 1/x^2}(\cos wt + \text{ctn}^{-1} x)]^{1/2} \tag{422}$$

where r_o' is the self field radius

$$r_o = r_o [1 + 10.22 \times 10^8 I^{1/2} P^{-1/4} t]^{1/2} \tag{423}$$

In particular the total radius of the beam after a time t is given by

$$r_b(t) = 50 \left[1 + 1.02 \times 10^9 I^{1/2} P^{-1/4} t\right]^{\frac{1}{2}} [1 + 2x^2 (1 - \sqrt{1 + 1/x^2}$$

$$\cos(wt + \text{ctn}^{-1} x)]^{1/2} \text{ cm} \tag{424}$$

I = beam current in amps

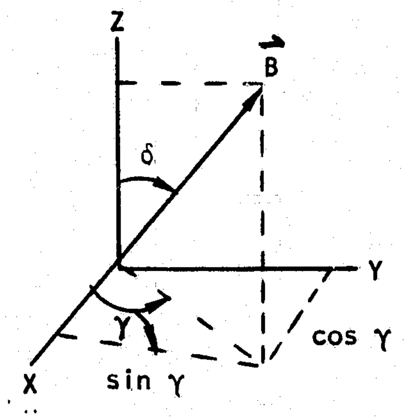
P = beam potential in volts

$x = 6.75 \times 10^{-2} (P^{1/2} B^{-1} \sin \psi)$, P in volts, B in gauss

$w = \frac{eB}{mc} = 1.76 \times 10^7 B \text{ sec}^{-1}$

and $\rho(r,t)$ is given by Equation (420) and (421) with $r_b(t)$ given by (424 and R_o = 50 cm.

3.4.3.3 <u>Motion of the Center of the Beam.</u> If the Shuttle Z-axis is not pointed along the magnetic field direction then



the angles δ and γ define its position and the transformation $T_{s\to M}$ will take a vector in the Shuttle X, Y, Z system into a vector in the magnetic field system X_1, Y_1, Z_1, which has the Z_1 axis pointed in the direction of the magnetic field

$$B = |B|\ \hat{Z}_1$$

where

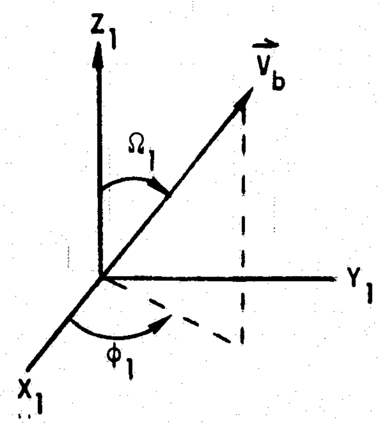
$$T_{s\to M} = \begin{pmatrix} -\sin\gamma & \cos\gamma & 0 \\ -\cos\delta\cos\gamma & -\cos\delta\sin\gamma & \sin\delta \\ \sin\delta\cos\gamma & \sin\delta\sin\gamma & \cos\delta \end{pmatrix} \quad \text{and} \quad \begin{aligned} \sin\gamma &= \frac{B_y}{(B_x^2 + B_y^2)^{1/2}} \\ \cos\delta &= \frac{B_z}{B_z^2 + B_x^2 + B_y^2)^{1/2}} \end{aligned} \tag{425}$$

The beam is ejected with velocity V_b at angles BOMEGA and BPHI in the Shuttle X, Y, Z system

Let, initially

$$\text{BOMEGA} = \Omega_o$$
$$\text{BPHI} = \phi_o \tag{426}$$

In the magnetic system X_1, Y_1, Z_1



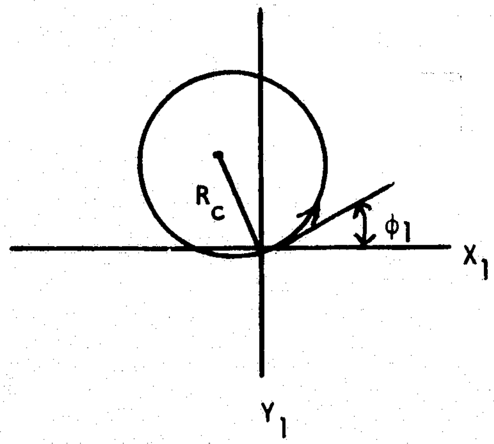
let the orientation angels be Ω_1 and ϕ_1 where

$$\cos \Omega_1 = \cos \Omega_o \cos \delta - \sin \Omega_o \sin \delta \cos (\phi_o - \gamma) \tag{427}$$

and

$$\phi_1 = \text{ctn}^{-1} [\sin \delta \text{ ctn } \Omega_o \csc(\phi_o - \gamma) - \cos \delta \text{ ctn } (\phi_o - \gamma)] \tag{428}$$

The motion of the beam in the magnetic field is helical; the sum of a uniform motion in the Z_1 direction at velocity $V_b \cos \Omega_1$ and a circular motion in the X_1-Y_1 plane with velocity $V_b \sin \Omega_1$ at frequency $w = \frac{eB}{mc}$. Looking at the projection of the motion of the beam in the X_1-Y_1 plane we see



The center of the circle is at $X_1 = R_c \sin \phi_1$, $Y_1 = R_c \cos \phi_1$. Let us go into a coordinate system

$$X_2 = X_1 + R_c \sin \phi_1 \qquad R_c = \frac{V_b \sin \Omega_1}{w} \tag{429}$$
$$Y_2 = Y_1 - R_c \cos \phi_1$$

which is centered at the center of the circle, then the center of the beam moves with coordinates

$$x_2 = R_c \sin(wt + \phi_1) \tag{430}$$
$$y_2 = R_c \cos(wt + \phi_1)$$

and finally let us consider the coordinates system of the beam center

$$\begin{aligned} x_3 &= x_2 - R_c \sin (wt + \phi_1) \\ y_3 &= y_2 + R_c \cos (wt + \phi_1) \end{aligned} \tag{431}$$

We see that if

$$x_3^2 + y_3^2 \leq r_b^2(t) \tag{432}$$

then we are in the beam and will measure an electron flux. If

$$x_3^2 + y_3^2 > r_b^2 \tag{433}$$

we are outside of the beam and will not measure a flux. Going back from the x_3, y_3 to the Shuttle X, Y, Z system we have

$$\begin{aligned} r^2 = {} & [\sin \gamma\ (X_b - X) + Y \cos \gamma + R_c\ (\sin \phi_1 - \sin (wt + \phi_1))]^2 + \\ & [\cos \delta \cos \gamma\ (X_b - X) - Y \cos \delta \sin \gamma + Z \sin \delta + R_c \\ & (\cos(wt + \phi_1) - \cos \phi_1)]^2 \end{aligned} \tag{434}$$

where X_b is the X-coordinate of the electron accelerator. We arbitrarily take

$$X_b = 200 \text{ cm} \tag{435}$$

This value of r is the one for which $\rho(r,t)$ is defined in Equations (420) and (421).

Finally we shall need to know the velocity of the beam in the Z-direction

$$\frac{dZ}{dt} = V_b\ [\sin \delta \sin \Omega_1 \sin (wt + \phi_1) + \cos \delta \cos \Omega_1] \tag{436}$$

3.4.3.4 <u>Electron Accelerator Storage Bank</u>. The storage bank supplies the energy for the electron beam. Ordinarily when an experiment is started the energy stored will be zero and the experimentor will ask the computer to charge the storage bank. We assume the charging current comes from a 500 volt source and that the maximum energy stored is 100 kilojoules.

Let

$E(t)$ be energy stored at time t in joules

i_{ch} be charging current in amps

$D(t_b)$ = time to reach full charge

$E(0)$ = energy stored at time zero assumed = 0 joules

E_o = maximum energy stored = 100,000 joules

$$D(t_b) = 17.3 \ln (100 - 0.32 \sqrt{E(t_b)} \tag{437}$$

If $E(0) = 0$ then $D(t_b) \approx 80$. This represents an approximate value of the number of seconds to reach full charge. The charging current is

$$i_{ch} = \left(23 - \frac{\sqrt{2.5\ E(t)}}{21.7}\right) \exp(-0.058\ t) \tag{438}$$

from a 500 volt source.

There are two cases for $E(t_b)$, one when the beam has been fired and some energy remains and the other with $E(t_b)$ starting from zero energy.

4.4.1 Beam Energy Remaining from Previous Firing

Let τ_b be the time duration that the beam was fired on the previous firing. Let E_o be the energy stored at the time the beam started firing the previous time, then the energy left after the previous firing, taking into account that the charging current was left on during the firing is

$$E(\tau_b) = -IP_{\tau_b} + (0.4)\left[500 + (\sqrt{2.5E_o} - 500)\ \exp -0.058\tau_b\right]^2 \tag{439}$$

I - beam current in amps   P = beam potential in volts

3.4.3.4.1 Beam Not Being Fired

If the beam has never been fired and the bank is charging up from 0 joules.

$$E(t) = 100{,}000\ (1 - \exp - 0.058t)^2 \qquad (440)$$

$$E(t_b) = E_o(1 - \exp - 0.058t)^2 \qquad (441)$$

actually $E(t) \neq E_o$ for finite t_B but if we round $E(t_b)$ upward to E_o at $E(t_B) = (E_o - 2000)$ joules we obtain realistic charging times.

If the beam has been fired for a time τ_B, first calculate $E(\tau_b)$ from Eq. 439. Then calculate $E(t_b)$, from:

$$E(t_B) = 0.4\left[500 + (\sqrt{2.5\ E(\tau_b)} - 500)\ \exp - 0.058\ t_B\right]^2 \qquad (442)$$

3.4.3.5 Accelerator Current. The accelerator current depends upon the temperature of the cathode and the potential of the grid. The temperature of the cathode depends upon the cathode heater current.

V_g = grid voltage $\qquad$ I_g = grid current

I_h = cathode heater current $\qquad$ V_h = cathode heater voltage

I_B = beam current

I_h and V_g are set by the keyboard.

$$I_B = \left(7.05\ I_h^{1/4} + 75\ V_g\ I_h^{-1/4}\right) \exp\left(-11.4\ V_g\ I_h^{-1/2}\right) \text{amps} \quad (443)$$

and is independent of t as long as beam is being fired.

$$I_g = 10^{-3}\ I_B \text{ milliamps} \quad (444)$$

$$V_h = 6I_h \text{ volts} \quad (445)$$

3.4.3.6 Storage Bank Drain Time. The beam power is $I_b P$ and we calculate the approximate drain time τ_d of the bank by

$$\tau_d = \text{Drain Time} = \frac{E_o}{I_b P - 11500} \text{ seconds} \quad (446)$$

I given by Eq. 443

If drain time >1000 seconds or if $I_B P \leq 11500$ watts then the display should read

Drain Time = >1000 seconds.

3.4.3.7 Cathode Heater.

Cathode heater current = set from keyboard.

Heater voltage = $6I_h$

3.4.3.8 Diverging and Converging Lens. The lens voltages are set from the keyboard and control the divergence of the beam by

$$\psi = (0.09) \exp\left(\frac{|V_d - V_c|}{P}\right) \quad (447)$$

where V_d = diverging lens voltage and V_c = converging lens voltage.

3.4.3.9 Beam Aiming Coils. The angles BOMEGA = Ω_o and BPHI = ϕ_o are set from the keyboard. If the BPHI and BOMEGA scan program is chosen the computer will compute values of Ω_b and ϕ_b so that

$$\phi_b = W_1 \; t_A + \phi_o \tag{448}$$

$$\Omega_b = \frac{\Omega_o}{2} \left(1 + \sin W_2 \; t_A\right) \tag{449}$$

where t_A starts at t = 0 when the beam is fired and stops when $t = \tau_b$. The display values of Beam Firing Angles are taken from Eqs. 448 and 449.

The coil currents are

$$\text{X-axis coil current} = \frac{2 \cos \phi_b}{P^{1/2} \; \tan \Omega_b} \tag{450}$$

P = accelerator potential in volts

$$\text{Y-axis coil current} = \frac{2 \sin \phi_b}{P^{1/2} \; \tan \Omega_b} \tag{451}$$

3.4.3.10 Grid Voltage and Current. Grid voltage is set from the keyboard. Equation 443 gives the test beam current (identical to beam current) and Equation 444 gives the grid current.

3.4.3.11 Accelerator Potential is Set from the Keyboard.

3.4.3.12 Firing the Beam. It is important that the beam is not allowed to fire longer than the approximate drain time given by Eq. 446.

3.4.3.13 Beam Angle with Respect to the Earth's Magnetic Field. If the Shuttle orbit and attitude are allowed to vary then in the Shuttle X,Y,Z system

$$B_X = T_{e\to S} \begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix} \Bigg|_{X\ \text{component}} \tag{452}$$

$$B_Y = T_{e\to S} \begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix} \Bigg|_{Y\ \text{component}} \tag{453}$$

$$B_Z = T_{e\to S} \begin{pmatrix} B_{X'} \\ 0 \\ B_{Z'} \end{pmatrix} \Bigg|_{Z\ \text{component}} \tag{454}$$

where $B_{X'}$, $B_{Z'}$ are given in gammas by Eq. 219 and $T_{e\to S}$ is given by Eq. 212.

Equation 425 gives the expression for γ and δ in terms of the B_X B_Y B_Z of Eqs. 452-54.

The angle between the beam axis and the magnetic field is given by Ω_1 of Eq. 427 except we must now allow Ω_o and ϕ_o to vary if the beam scan program is used, i.e., replace Ω_o by Ω_b and ϕ_o by ϕ_b:

$$\cos \Omega_1 = \cos \Omega_b \cos \delta - \sin \Omega_b \sin \delta \cos(\phi_b - \gamma) \tag{456}$$

where Ω_b and ϕ_b are given by Eqs. 448 and 449.

3.4.3.14 The Faraday Cup Current. The electron current into Faraday cup is

$$I_c = e(\text{area of cup})(\text{density of beam at cup})(\text{velocity normal to cup})$$

$$= (10)(e)(\rho(r,t))\ \frac{dz}{dt}$$

First we must determine if the cup is in the beam. The time between an electron leaving the accelerator and its reaching the cup is

$$t_1 = \frac{Z_c}{V_b} (\sin \delta \sin \Omega_1 \sin \phi_1 + \cos \delta \cos \Omega_1)^{-1} \text{ seconds} \tag{458}$$

where Z_c = 700 cm is the cup distance above the accelerator and V_b is the beam velocity = $5.93 \times 10^7 \times P^{1/2}$ cm/sec, and Ω_1 and ϕ_1 given by Eqs. 427 and 428.

1) There will be no current to the cup for timer $t < t_1$

2) After time t_1 the current to the cup will be if $r \leq r_b$

$$I_{cup} = 1.27 \times 10^{-3} I_B \pi^2 \left[\cos\left(\psi \sin \frac{r\pi}{2r_b}\right)\right] \left[4\pi^2 - \psi^2(1 + \pi^2/4)\right]^{-1} \times \tag{459}$$

$$[\sin \delta \sin \Omega_1 \sin(wt_1 + \phi_1) + \cos \delta \cos \Omega_1] \times$$

$$[1 + X^2(1 - \sqrt{1 + 1/X^2} \cos (wt_1 + \text{ctn}^{-1} X)]^{-1} \times$$

$$[1 + 1.02 \times 10^9 I_b^{1/2} P^{-1/4} t_1]^{-1} \text{ amps.}$$

where

I_b = accelerator current Eq. 443

P = accelerator potential

$$r^2 = 2R_c^{\ 2}(1-\cos wt_1) + Z_c^{\ 2} \sin^2 \delta + 2Z_c R_c \sin \delta \left[\cos (wt_1 + \phi_1) - \cos \phi_1\right]$$

$$R_c = \frac{V_b \sin \Omega_1}{w} = 3.37\ P^{1/2}\ |B_T^{-1}| \sin \Omega_1\ 10^{+5}\ \text{cm} \qquad (460)$$

$$Z_c = 700\ \text{cm}$$

$$r_b^{\ 2} = 2500\ [1 + 2x^2\ (1 - \sqrt{1 + 1/x^2}) \cos\ (wt_1 + \text{ctn}^{-1} x)]$$
$$[1 + 1.02 \times 10^9\ I_b^{\ 1/2}\ P^{-1/4} t_1] \qquad (461)$$

$$X = 6.75 \times 10^{-2}\ P^{1/2}\ |B_T^{-1}| \sin \psi \times 10^5 \qquad (461.1)$$

ψ from Equation (447)

δ from Equation (425)

Ω_1 from Equation (456)

ϕ_1 from Equation (428) with $\Omega_o = \Omega_b$ and $\phi_o = \phi_b$ of (448) and (449)

$w = \frac{eB}{mc} = 1.76 \times 10^7\ |B_T| \times 10^{-5}\ \text{secs}^{-1}$

t_1 from Equation (458)

if $r > r_b$ then

$$I_{cup} \equiv 0\ \text{amps}$$

$$I_{(\text{cup in amps})} = 10^{-3}\ I_{(\text{cup in milliamps})} \qquad (462)$$

The only time dependence of the cup after $t = t_1$ comes from the fact that Ω_1 and ϕ_1 will vary in time of the beam scan program is used.

3.5 LIDAR TRACE OF ACOUSTIC GRAVITY WAVES IN THE SODIUM LAYER

3.5.1 Experiment Descriptions EP 5.0 Lidar Trace of Acoustical Gravity Waves in the Sodium Layer

Description

Atmospheric sodium is concentrated in a layer from 70 to 100 km above the ground. The characteristics of this sodium layer have been studied both experimentally and theoretically. Recent advances in laser technology have made possible accurate measurements of sodium densities versus altitude. The AMPS Shuttle payload can provide a suitable platform for these lidar measurements of the sodium layer.

One experiment that is possible, if the return signals from the sodium layer are large enough, is the determination of the existence of acoustic gravity waves traveling in and through the sodium layer. In the following simulation the magnitude of the density variations caused by the gravity waves is modeled from experimental data and then the simulated laser data is used to reproduce the modeled wave densities. The detection of the waves has been simplified by assuming that all of the wave energy is in one frequency mode and that the unperturbed sodium density is constant throughout the 80-100 kilometer altitude range.

The experimenter is able to control the laser pulse energy, wavelength and the pulse repetition rate. Preanalysis of the return laser signals into specified altitude intervals has been assumed so that the actual data rates are not beyond the capability of the CVT hardware. During an actual AMPS flight, this kind of preanalysis will be done by a special lidar dedicated computer.

3.5.2 Experiment Procedures EP 5.0 Lidar Trace of Acoustical Gravity Waves in the Sodium Layer

EP 5.1 Determine Shuttle Orbit

- 5.1.1 Set Shuttle altitude at 180 km
- 5.1.2 Set Shuttle orbit inclination at 27°
- 5.1.3 Set local time of descending mode = 1800:00
- 5.1.4 Set universal time of descending mode = 1800:00

EP 5.2 Set Shuttle altitude with z-axis toward nadir

- 5.2.1 Set $\Gamma = 180^{\circ}$
- 5.2.2 Set $\Lambda = 180^{\circ}$

5.2.3 Set $\Delta = 0^{o}$

5.2.4 Hold Shuttle in this position for remainder of experiment

EP 5.3 Set up lidar system

5.3.1 Select dye

5.3.1.1 Rhodamine 6G

5.3.2 Select spectral control elements

5.3.2.1 Broad tune grating

5.3.2.2 Fine tuning Fabry-Perot

5.3.3 Select laser output monitors

5.3.3.1 Power meter

5.3.3.2 Absorption cell

5.3.3.3 Spectrometer

5.3.3.4 Photometer #3 - Direct

5.3.4 Select power supply control

5.3.4.1 Manual fire

5.3.4.2 Select maximum power = 1000 watts

5.3.4.3 Select laser pulse energy = 0.1 joules

5.3.4.4 Select laser pulse repetition rate = 2 Hz

5.3.5 Adjust laser transmitter

5.3.5.1 Select automatic alignment

5.3.5.2 Select beam divergence = 1.00 milliradians

5.3.5.3 Select azimuth = 0.00^{o}

5.3.5.4 Select elevation = 0.00^{o}

5.3.6 Adjust lidar receiver

5.3.6.1 Set aperture = 100

5.3.6.2 Set convergence = 0

5.3.6.3 Select sodium D interference filter

5.3.6.4 Select Fabry-Perot filter

5.3.6.5 Set detector high voltage at 3000 volts

5.3.6.6 Select detector #1

5.3.6.7 Set field stop = 1.00 milliradians

EP 5.4 Activate lidar system

5.4.1 Open dust cover

5.4.2 Turn lidar dye pump to GO

5.4.2.1 Check that dye is flowing

5.4.3 Put broad tune grating in the beam

5.4.4 Select broad tune wavelength = 589.0 nm

5.4.5 Turn Fabry-Perot tuning motor to ON

5.4.6 Set fine tune to 0

5.4.7 Put Fabry-Perot in the beam

5.4.8 Set wavelength resolution at 0.01 nm

5.4.9 Turn spectrometer on lidar output to GO

5.4.9.1 Turn photometer #1 to GO

5.4.9.2 Set upper wavelength range = 800.0 nm

5.4.9.3 Set lower wavelength range = 300.0 nm

5.4.9.4 Set resolution = 10 nm

5.4.10 Turn power meter to GO

5.4.10.1 Set upper wavelength = 590 nm

5.4.10.2 Set lower wavelength = 580 nm

5.4.11 Turn phototube #3-direct to GO

5.4.12 Adjust absorption cell

5.4.12.1 Put absorption cell in the beam

5.4.12.2 Turn cell temperature control to GO

5.4.12.3 Set cell temperature = 300°C

5.4.12.4 Turn phototube #2 to GO

5.4.13 Turn lidar flashlamp power supply to GO

5.4.14 Set maximum power level 1000 watts

5.4.15 Select fire time as fire at will

EP 5.5 Fire laser

5.5.1 Turn laser fire to GO (laser will fire at 2 Hz, 0.1 joules until laser fire is turned to NO-GO)

EP 5.6 Adjust laser spectral output

5.6.1 Observe display of spectrometer on laser output

5.6.2 Adjust fine tuning Fabry-Perot until line width is 0.01 nm and central wavelength is 588.996 nm

5.6.3 Check absorption cell transmission = 0%

EP 5.7 Stop laser select laser fire = NO-GO

EP 5.8 Select laser energy per pulse = 10 joules

EP 5.9 Fire laser select laser fire = GO

EP 5.10 Check laser output

5.10.1 Read output power = 10 joules

5.10.2 Read absorption cell transmission = 0%

EP 5.11 Stop laser fire; laser fire = NO-GO

EP 5.12 Select automatic laser fire

EP 5.13 Activate transmitter

5.13.1 Automatic alignment system to GO

5.13.2 Beam divergence to GO

5.13.2.1 Check beam divergence = 1.00 mrad

5.13.3 Azimuth and elevation to GO

5.13.3.1 Check azimuth = 0.00°

5.13.3.2 Check elevation = 0.00°

EP 5.14 Activate receiver

5.14.1 Turn detector high voltage power supply to GO

5.14.2 Turn aperture control to GO

5.14.3 Turn field stop to GO

5.14.3.1 Check field stop = 100.00 mrad

5.14.4 Put sodium D filter in the beam

5.14.5 Adjust Fabry-Perot filter

5.14.5.1 Adjustment motor to ON

5.14.5.2 Set central wavelength = 588.99 nm

5.14.5.3 Set bandpass = ± 0.01 nm

EP 5.15 Select data analysis parameters

5.15.1 Set upper altitude = 110 km

5.15.2 Set lower altitude = 70 km

5.15.3 Set altitude resolution = 0.10 km

EP 5.16 Fire laser; select laser fire = GO

EP 5.17 Check lidar data summary display

5.17.1 Shuttle altitude = 180 km

5.17.2 Shuttle latitude

5.17.3 Shuttle longitude

5.17.4 Shuttle local time

5.17.5 Sun is down = YES (If sun down = NO, discontinue experiment until sun is down = YES)

5.17.6 Angle between z-axis and nadir = 0^{o}

5.17.7 Laser power = 10 joules

5.17.8 Laser central wavelength = 588.99 nm

5.17.9 Laser divergence = 1.00 milliradians

5.17.10 Receiver field stop = 100.00 milliradians

5.17.11 Receiver central wavelength = 588.99 nm

5.17.12 Data upper altitude = 110 km

5.17.13 Data lower altitude = 70 km

5.17.14 Data height resolution = 0.10 km

EP 5.18 Check data displays

5.18.1 Raw count rate versus altitude

5.18.1.1 If count rate less than 1000 counts adjust laser parameters to higher counts

5.18.2 Sodium density versus altitude

5.18.3 Average sodium density versus altitude

5.18.4 Sodium density minus average density versus altitude

5.18.5 Sodium density minus average sodium density versus position

5.18.5.1 Select altitude = 90 km

5.18.5.2 Select altitude = 100 km

5.18.5.3 Select altitude = 80 km

5.18.6 Sodium density minus average sodium density versus altitude versus position (3-dimensional projected display)

EP 5.19 Gather data for one event in local time

5.19.1 Record all data and instrument settings

EP 5.20 Stop laser fire; select laser fire = NO-GO

EP 5.21 Turn instruments off

5.21.1 Dust cover to closed

5.21.2 Fabry-Perot filter adjustment motor to OFF

5.21.3 Sodium D filter out of beam

5.21.4 Field stop to OFF

5.21.5 Aperture control to OFF

5.21.6 Detector high voltage to OFF

5.21.7 Azimuth and elevation to OFF

5.21.8 Beam divergence to OFF

5.21.9 Automatic alignment system to OFF

5.21.10 Lidar flashlamp power supply to OFF

5.21.11 Phototube #2 to OFF

5.21.12 Set absorption cell temperature to = 30°C

5.21.13 Absorption cell out of beam

5.21.14 Phototube #3-direct to OFF

5.21.15 Power meter to OFF

5.21.16 Phototube #1 to OFF

5.21.17 Spectrometer on lidar output to OFF

5.21.18 Fine tuning Fabry-Perot out of beam

5.21.19 Fabry-Perot tuning motor to OFF

5.21.20 Broad band tune grating out of beam

5.21.21 Absorption cell temperature control to OFF

5.21.22 Lidar dye pump to OFF

END OF EXPERIMENT

3.5.3 Theory and Background: EP 5.0 Lidar Trace of Acoustical Gravity Waves in the Sodium Layer

3.5.3.1 Wave Theory

According to Yeh and Liu [Rev. Geophys. and Sp. Sc. 12, 193 (1974)] the dispersion relation for the acoustic gravity wave assuming an isothermal atmosphere is given by:

$$(k_x^2 + k_y^2)\left(1 - \frac{\omega_b^2}{\omega^2}\right) + k_z^2 = \frac{\omega^2}{c_o^2}\left(1 - 1.23\,\frac{\omega_b^2}{\omega^2}\right) \tag{501}$$

and the group velocity is given by

$$\vec{V}_g = \left[\hat{x}\, k_x(\omega^2-\omega_b^2) + \hat{y}\, k_y(\omega^2-\omega_b^2) + \hat{z}\, k_z\omega^2\right]\left(\omega c_o^2/(\omega^4-\omega_b^2(k_x^2+k_y^2)c_o^2\right) \tag{502}$$

From Yeh and Liu we can obtain values for

$$\omega_b \approx \frac{2\pi}{300} = 2.1 \times 10^{-2} \text{ sec}^{-1} \tag{503}$$

$$c_o \approx 280 \text{ m/sec} = \text{speed of sound} \tag{504}$$

in the altitude range from 80 to 100 kilometers.

For our purposes here we can take $k_y = 0$. Kochanski [J.G.R. 69, 3651 (1964)] has shown that at the 80-100 km range the major wave-like components of the atmosphere are traveling mainly to the East with a velocity of about 40 meters/sec and that the vertical wavelength is 10 kilometers. We shall call the x-direction East. Then if

$$k_x = \alpha\beta\,\frac{\omega_b}{c_o} \qquad \omega = \alpha\,\omega_b \tag{505}$$

the dispersion relation gives

$$\beta^2 = \frac{1.23 - \alpha^2 + \frac{c_o^{\,2} k_z^{\,2}}{\omega_b^2}}{1 - \alpha^2} \tag{506}$$

and the velocity expression gives

$$\alpha^2 = \frac{1 - \frac{V_x \beta}{c_o}}{1 - \frac{V_x}{\beta c_o}} \tag{507}$$

Using the experimental data of Kochanski, one obtains

$$k_z = 5.84 \times 10^{-4} \text{ meters}^{-1} \tag{508}$$

$$V_x = 40 \text{ meters/sec} \tag{509}$$

Using these values in Eqs. 506 and 507 one can obtain the approximate solutions

$$\beta = 10.5 \tag{510}$$

and

$$\alpha = 0.5 \tag{511}$$

These give

$$k_x = 3.94 \times 10^{-4} \text{ meters}^{-1} \tag{512}$$

$$\lambda_x = \frac{2\pi}{k_x} = 16 \text{ kilometers} \tag{513}$$

$$\omega = 1.05 \times 10^{-2} \text{ sec}^{-1} \tag{514}$$

$$T_w = 600 \text{ sec} = \text{period of wave.} \tag{515}$$

For our purposes we shall consider that all of the acoustic gravity waves are restricted to this one mode in the altitude range 80-100 km. We shall try to observe these waves by measuring the sodium density as a function of z = altitude and x = eastward position.

To obtain the density fluctuation associated with the wave we shall equate the time-averaged energy density with the wave's kinetic energy density. Yeh and Liu give

$$E = \left|\frac{\rho'}{\rho_o^{1/2}}\right|^2 \left(\omega^4 - \omega_b^{\,2} c_o^{\,2}(k_x^{\,2} + k_y^{\,2})\right) \Big/ 2\omega^2 c_o^{\,2}(\omega^2 - \omega_b^{\,2}) \tag{516}$$

where ρ' is the first order term of the pressure variation. This transforms into

$$E = \frac{\left(\frac{\rho'}{\rho_o^{1/2}}\right)^2 c_o^{\,2}(\alpha^2 - 1)(\alpha^2 - \beta^2)}{2\left[\left(\alpha^2 - \frac{\gamma}{2}\right)^2 + \gamma^2 H^2 k_z^{\,2}\right]} \tag{517}$$

where

$$\gamma = 1.4 \tag{518}$$

$$H = \text{scale height} = 5\text{ km} \tag{519}$$

$$\rho' = \text{first order density variation} \tag{520}$$

$$\rho_o = \text{zero order ambient density } \alpha,\ \beta,\ c_o,\ k_z \text{ as before} \tag{521}$$

We set

$$E = \frac{\rho_o V_x}{2} = 20\ \rho_o \tag{522}$$

and obtain

$$\rho' = 0.0319\ \rho_o \tag{523}$$

Therefore, the density at any point x, z, y and time t is given by

$$\rho(x,y,z,t) = \rho_o(x,y,z,t)\Big[1 + 0.0319 \exp i(k_x\ x - k_z\ z - \omega t)\Big] \qquad (524)$$

where we have assumed the wave is traveling upward. Or since

$$\rho \neq \rho(z)$$

$$\rho(x,z,t) = \rho_o\Big[1 + 0.0319 \cos(k_x\ x - k_z\ z - \omega t)\Big] \qquad (525)$$

where k_x is given by Eq. 512, k_z by Eq. 508 and ω by Eq. 514.

3.5.3.2 The Ambient Sodium Density. For the purposes of this simulation we shall define the sodium density as follows:

$$\rho(\text{Na}) = 3 \times 10^3 \text{ atoms/cm}^3 \quad \text{for} \quad 80 \leq z \leq 100 \text{ km} \qquad (526)$$

and

$$\rho(\text{Na}) = 0 \quad \text{for} \quad \begin{matrix} z < 80 \text{ km} \\ z > 100 \text{ km} \end{matrix} \qquad (527)$$

where z is the altitude from the ground.

3.5.3.3 The Wave Perturbed Sodium Density. The following function describes the sodium density

$$80 \leq z \leq 100$$

$$\rho(\text{Na}) = 3 \times 10^3\Big[1 + .0319 \cos(.394x - .548(z-90) - .01t)\Big]\text{atoms/cc} \qquad (528)$$

where x is the distance Eastward in kilometers on a given latitude line from 0°LON. z is the altitude in kilometers and t is the local time in seconds

$$\rho(\text{Na}) = 0 \quad \text{for} \quad 80 > z > 100 \qquad (529)$$

If LON = Shuttle longitude in degrees and LAT = Shuttle latitude and H = Shuttle altitude in kilometers, then

$$x = (R_e + H)(\cos \mathrm{LAT})(\mathrm{LON})\frac{2\pi}{360} \text{ kilometers} \tag{530}$$

R_e = 3371 kilometers

3.5.3.4 Day and Night. If

$$(R_e + H)^2 \cos \mathrm{LAT} \sin[\mathrm{LON} + 15(\mathrm{UT}-18)] > R_e(H^2 + 2HR_e)^{1/2} \tag{531}$$

then the Shuttle is in the dark and the sodium measurement can be made. If the Shuttle is in sunlight it is unlikely that the return signal from the 80-100 km sodium layer could be detected. Also if the moon is up, it may make the measurement impossible depending on the spectral distribution of moonlight and the Earth's albedo. However, we shall ignore lunar effects here.

3.5.3.5 Laser Pulse. The number of photons in the laser pulse is given by

$$N_{ph} = \frac{E_\ell \; 6 \times 10^{18} \; \lambda_\ell}{1240} \text{ photons} \tag{532}$$

E_ℓ = pulse energy in joules

λ_ℓ = laser pulse wavelength in nanometers

3.5.3.6 Laser Interaction with Sodium Layer. Let

Z = altitude of observed sodium above the ground

$\rho(\mathrm{Na})$ = sodium density (Eq. 525)

ε = detector efficiency = 0.2

α_o = sodium atomic absorption cross section

N_{ph} = number of photons in the laser pulse

Δz = height interval being observed

A_c = receiver collecting area = .785 m^2

then the number of photons counted by the detector from the height interval Δz is

$$N_c = A_c \varepsilon \, \Delta z \, \alpha_o \, N_{ph} \, \rho(Na) [4\pi(H-z)]^{-2} \qquad (533)$$

where we have assumed that the optical depth of the layer is very small.

For a laser tuned to the sodium D line

$$\alpha_o = 8.97 \times 10^{-12} \sqrt{\frac{221}{T}} \text{ cm}^2 \text{ (T is sodium temperature in } ^oK) \qquad (534)$$

$$\lambda = 588.996 \text{ nm} \qquad (535)$$

and the counts at this wavelength are

$$N_c = 3.32 \times 10^4 \frac{\rho(Na) \; \Delta z \; E_\ell}{(H-z)^2} \qquad (536)$$

$\rho(Na)$ in atoms/cc

E_ℓ = laser energy in joules

Δz, H, Z in kilometers

if $\lambda_\ell \neq 588.996 \pm 0.1$ nm then $N_c = 0$

3.5.4 Details of Experiment Displays

3.5.4.1 Laser Dye. Rhodamine 6G is by far the best dye to use for the sodium experiment. It will give a detectable response in the wavelength range 565-625 nm. We shall approximate its response by

$$\text{relative response} = \exp - \frac{(\lambda - 588.9)^2}{900} \qquad (537)$$

i.e. if you are not at λ = 588.9 nm you get less light energy.

3.5.4.2 <u>Dye Pump</u>. The dye pump must be GO before:

Laser can fire. "Dye in flowing" is automatically YES if pump is GO

Number of firings with this dye is simply the running total of fires during a given simulation.

3.5.4.3 <u>Laser Wavelength Settings</u>. The laser wavelength is roughly set by broad tune grating and finely by the Fabry-Perot. Actual laser wavelength

$$\lambda_{\ell} = BT + 0.1 \exp\left(\frac{FT}{100}\right) \qquad (538)$$

where BT is the broad-tune wavelength set by keyboard and FT is the fine tune setting set by keyboard.

The actual line has a shape given by

$$I(\lambda) = I_o \exp -[(\lambda-\lambda_{\ell})^2/RES^2] \qquad (539)$$

where RES is the wavelength resolution set by keyboard and where I is the intensity.

3.5.4.4 <u>Laser Output Spectra</u>. The spectrometer on the lidar output measures the spectral content of the laser beam. The upper and lower wavelengths determine the range of the display. The resolution determines how many points are plotted.

If the range is 300 to 800 nm and the resolution is 10 nm, there will be 50 points plotted. If resolution = 0.001 nm then 5×10^5 points would be plotted. If the ranges were 588.8 to 589.2 and resolution = 0.001 then 400 points would be plotted.

The formula for the displayed curve of laser output spectrum is

$$I(\lambda) = \exp\left[\frac{-(\lambda_\ell - 588.9)^2}{900} - \frac{(\lambda - \lambda_\ell)^2}{(RES)^2}\right] \tag{540}$$

where λ = wavelength of plotted point

λ_ℓ is given by Eq. 538 in nanometers.

3.5.4.5 Laser Output Energy and Photon Count. If the spectral range on the power meter does not include λ_ℓ then energy should = 0 joules.

Let E_ℓ = pulse energy set from keyboard the actual pulse energy will be

$$E_{act} = E_\ell \exp -\left(\frac{\lambda_\ell - 588.9}{30}\right)^2 \text{ joules} \tag{541}$$

5.7.14 -

Photon content is given by

$$N_{ph} = (E_{act})\, \lambda_\ell\, 5 \times 10^{15} \text{ photons} \tag{542}$$

E_{act} given by Eq. 541

λ_ℓ given by Eq. 538.

3.5.4.6 Absorption Cell. The absorption cell heats up linearly and stops at temperature set by keyboard

$$T = (10^\circ C)t + T_o \tag{543}$$

where T_o is cold cell temperature = 30°C t is time in seconds from turning on the cell. Example: keyboard set for T = 500°C. Turn on cell takes t = 47 seconds to get to 500°C and then it stays fixed.

Percent transmission is given by

$$\% = 100[1 - \exp - (\lambda_{\ell} - 588.996)^2] \tag{544}$$

3.5.4.7 Laser Firing. Power level must be set at least 100 times greater than the keyboard set energy per laser pulse.

"Fire at will" means that once laser fire is GO the laser will fire at whatever rep rate is set. If time is picked instead of "Fire at will", the laser will start firing at that time if all systems are GO and continue at the set rep rate.

Laser flashlamps are READY if Lidar flashlamp power supply (5-17) is GO.

3.5.4.8 Lidar Receiver Setup. Automatic alignment must be GO to obtain receiver signals. Divergence is given by keyboard setting azimuth and elevation must be GO and must be set to 0.00 to obtain s receiver signal in this simulation.

Detector high voltage must be GO and >2000 volts to have a received signal. Voltage level is set by keyboard. Aperture control must be GO. Receiver signal depends on setting

$$N_c \propto \left(\frac{AP}{100}\right)^2 \tag{545}$$

where N_c is received counts and AP is aperture setting.

Field stop must be GO, and if beam divergence is greater than the field stop

$$N_c \propto \left(\frac{FS}{BD}\right)^2 \quad \text{if} \quad FS < BD \tag{546}$$

FS = field stop value

BD = beam divergence

Sodium filter must be in the beam.

Fabry-Perot adjustment motor must be GO. The receiver response

$$N_c \propto \exp[-(\lambda_\ell - \lambda_{FP})^2 / RES_{FP}^2] \tag{547}$$

λ_{FP} is the receiver Fabry-Perot wavelength setting. RES_{FP} = receiver bandpass.

3.5.4.9 Lidar Receiver Data Displays. For this simulation there is no detector response for altitudes out of the range 80 to 100 kilometers.

The altitude resolution is picked to make the detector count rate acceptably large. The larger the resolution the more counts.

Shuttle altitude is set by keyboard LAT given by Eq. 209; LON given by EQ. 208; and LT given by Eq. 210 in hours. Angle between Shuttle Z axis and nadir = Λ-180° with Λ set by keyboard. All other values are set by keyboard.

The number of counts versus altitude is a function of

$\rho(Na)$ = sodium density given by Eqs. 528, 529 where
t = (LT in hours)(3600) seconds.

Z = altitude being observed in km

H = altitude of Shuttle in km

x = distance Eastward given by Eq. 530

λ_ℓ = laser wavelength in nanometers given by Eq. 538

Δz = data height resolution in km

RES = wavelength resolution of the laser beam

RES_{FP} = wavelength resolution of the receiver

λ_{FP} = wavelength of the receiver

AP = receiver aperture setting

BD = beam divergence

FS = field stop

E_{act} = actual laser energy given by Eq. 541

The number of counts is given by

$$N_c = 3.32 \times 10^4 \rho(Na) \Delta z E_{act} (H-Z)^{-2}$$

$$\times \exp -\left[\left(\frac{\lambda_\ell - \lambda_{FP}}{RES_{FP}}\right)^2 + \left(\frac{\lambda_\ell - \lambda_{FP}}{RES}\right)^2 + (\lambda_\ell - 588.996)^2\right] \tag{548}$$

$$\times \left(\frac{AP}{100}\right)^2 \times Q(BD,FS)$$

the term $(\lambda_\ell - 588.996)^2$ comes from the fact that the sodium D line filter is in the receiver beam. The function Q(BD,FS) is

$$BD \leq FS$$

if

$$Q = 1 \tag{549}$$

$$BD > FS$$

$$Q = \left(\frac{FS}{BD}\right)^2 \tag{550}$$

Because of the nature of $\rho(Na)$, in this simulation $N_c \equiv 0$ if Z is not in the range $80 \leq Z \leq 100$ km. For complete accuracy one should worry about the fact that the term Δz might include some altitudes outside of the range 80-100 km, but no corrections will be made for this effect.

The display will show altitude from chosen lower limit to upper limit and there will be one data point for each Δz in that interval.

The display of sodium density versus altitude is a plot of Eqs. 528 and 529.

$$\rho(Na) = 3 \times 10^3[1 + 0.0319 \cos (.394x - .589(z-90) - .01t)] \quad (528)$$

with a data point for each Δz.

The average sodium density is averaged over time, distance x and altitude z.

$$\overline{\rho(Na)} = 3 \times 10^3 \text{ atoms/cm}^3 \qquad 80 \leq z < 100 \quad (551)$$

$$\overline{\rho(Na)} \equiv 0 \qquad 80 > z > 100 \quad (552)$$

5.7.28 -

The density of sodium minus average density is as a function of z.

$$\rho(Na) - \overline{\rho(Na)} = 95.7 \cos [.394x_1 - .589(z-90) - .01t_1] \quad (553)$$

where x_1 and t_1 are position and time of the previous laser firing. Get on point for each Δz.

The density of sodium minus average density is as a function of x

$$\rho(Na) - \overline{\rho(Na)} = 95.7 \cos[.394x - .589(z_1-90) - .01t] \quad (554)$$

where z_1 is the altitude selected and one gets an x,t point for each laser fire. The operator should be able to control the total number of points, i.e. the position scale value.

Finally there is

$$\rho(Na) - \overline{\rho(Na)} = 95.7 \cos[.394x - .589(z-90) - .01t] \quad (555)$$

as a function of both (x,t) and z. One set of Δz points for each laser fire (x,t).

3.6 DETERMINATION OF THE WAKE OF A TEST BODY

3.6.1 Experiment Description

As a body moves through the ionosphere it produces a wake by sweeping particles out of its way. Several theories and some experiments have been carried out in order to investigate the wakes of satellites traveling through the ionosphere. The AMPS Shuttle payload offers an excellent platform from which to carry out detailed wake measurements.

In this simulation an inflatable balloon is deployed on one of the 50-meter booms and the plasma diagnostic package is mounted on the other 50-meter boom. Because of complexity of the ionospheric wake problem the simulated wake ignores the effect of electric and magnetic fields.

The experimenter is able to vary the Shuttle orbit altitude, inclination and attitude; and the relative position of the two booms. By varying the boom position, he is able to trace out the wake region and measure its properties.

3.6.2 <u>Experiment Procedure:</u> EP6.0 Determination of the Wake of a Test Body

EP6.1 Determine Shuttle orbit
- 6.1.1 Select manual control
- 6.1.2 Set Shuttle altitude = 300 km
- 6.1.3 Set Shuttle orbit inclination = 10^{o}
- 6.1.4 Set local time of descending node = 0000:00
- 6.1.5 Set universal time of descending node = 0000:00 UT

EP6.2 Determine Shuttle attitude
- 6.2.1 Select manual control
- 6.2.2 Set $\Gamma = 0^{o}$
- 6.2.3 Set $\Lambda = 0^{o}$
- 6.2.4 Set $\Delta = 0^{o}$
- 6.2.5 Hold Shuttle at these angles

EP6.3 Deploy subsatellite
- 6.3.1 Check clear area for ejection
  - 6.3.1.1 TV coverage
  - 6.3.1.2 Safety and warning systems
- 6.3.2 Eject subsatellite
  - 6.3.2.1 Check subsatellite power systems GO
  - 6.3.2.2 Check subsatellite telemetry system GO
  - 6.3.2.3 Check subsatellite transponder system GO
  - 6.3.2.4 Check subsatellite control system GO
  - 6.3.2.5 If all systems are GO push ejection button
- 6.3.3 Turn subsatellite instruments ON
  - 6.3.3.1 Three-axis fluxgate
  - 6.3.3.2 Cylindrical electron probe
  - 6.3.3.3 Segmented planar trap
  - 6.3.3.4 Ion mass spectrometer
  - 6.3.3.5 Electric field meter
- 6.3.4 Determine subsatellite position and attitude
  - 6.3.4.1 Set subsatellite altitude 300 km
  - 6.3.4.2 Set subsatellite orbit inclination = 10^{o}
  - 6.3.4.3 Set local time of descending node = 0000:00
  - 6.3.4.4 Set universal time of descending node = 0000:01
  - 6.3.4.5 Set spin rate at one revolution per orbit
  - 6.3.4.6 Set initial attitude angles

6.3.4.6.1 $\phi = \pi/2 - i_s = 80^\circ$

6.3.4.6.2 $\theta = -\pi/2 = 270^\circ$

6.3.4.6.3 $\psi = 0$

EP6.4 Start both Shuttle and subsatellite orbits at same orbit time

EP6.5 Set Boom B

6.5.1 Set length = 25 meters

6.5.2 Set $\theta_B = 0^\circ$

6.5.3 Set $\phi_B = 0^\circ$

EP6.6 Inflate target balloons

6.6.1 Check volume clear to inflate with Boom A alignment TV

6.6.2 Check pressure in fill bottle

6.6.3 Fill balloon

6.6.3.1 Start fill operation

6.6.3.2 Monitor balloon pressure

6.6.3.3 Stop fill operation when pressure = 10 Newton/meter^2

EP6.7 Generate background data from subsatellite

6.7.1 Turn instruments ON

6.7.1.1 Cylindrical electron probe

6.7.1.2 Ion mass spectrometer

6.7.1.3 Three-axis fluxgate magnetometer

6.7.1.4 Segmented electron trap

6.7.1.5 Electric field meter

6.7.2 Examine all data output and record

EP6.8 Set Boom A

6.8.1 Set $\theta_A = \tan^{-1} .167 = \theta_0$

6.8.2 Set $\phi_A = 0^\circ$

6.8.3 Set length = 20 meters

EP6.9 Set platform

6.9.1 Set $\chi = 0^\circ$

6.9.2 Set $\Omega = \theta_0^\circ = \tan^{-1} .167$

6.9.3 Set $\psi = 0^\circ$

EP6.10 Turn Boom A diagnostic instruments ON and look at data outputs

6.10.1 Three-axis fluxgate

6.10.2 Cylindrical probe

6.10.3 Segmented planar trap

6.10.4 Ion mass spectrometer

6.10.5 Rubidium magnetometer

6.10.6 Spherical probe

6.10.7 Neutral mass spectrometer

6.10.8 Planar trap

EP6.11 Scan diagnostic package around balloon

6.11.1 Record output of all Boom A diagnostics continuously

6.11.2 Extend Boom A length from 20 to 50 meters

6.11.3 Increase θ_A by 5^o

6.11.4 Retract Boom A length from 50 to 20 meters

6.11.5 Increase θ_A by another 5^o

6.11.6 Repeat 6.11.2 to 6.11.5 until $\theta_A \geq 60^o$

6.11.7 Set length = 50 meters

6.11.8 Set $\theta_A = \cos^{-1} 0.60$

6.11.9 Scan boom around balloon

6.11.9.1 Let ϕ_A runs from 0^o to 360^o

6.11.9.2 As ϕ_A runs set platform angle $\chi = \phi_A$ at all times

6.11.9.3 When $\phi_A = 360^o$ stop

6.11.10 Decrease θ_A by 10^o

6.11.11 Set boom length at $30/\cos \theta_A$ meters

6.11.12 Repeat Steps 6.11.9 to 6.11.11 until $\theta_A \leq 10^o$ and stop

EP6.12 Stop recording data

EP6.13 Stow Boom A

6.13.1 All Boom A instruments OFF

6.13.2 Platform angles to 0^o

6.13.3 Length to 2 meters

6.13.4 $\theta_A = \phi_A = 0^o$

EP6.14 Stow Boom B

6.14.1 Deflate balloon

6.14.2 Boom B length to 2 meters

EP6.15 Subsatellite to standby

6.15.1 All subsatellite diagnostic instruments OFF

3.6.3 Theory and Background

3.6.3.1 The Wake. This experiment is similar to EP2.0 in many ways. The physical phenomena that are being measured are: 1) electron density, 2) electron temperature, 3) ion species, 4) ion temperatures, 5) ion densities, 6) neutral species, 7) neutral temperatures, 8) neutral densities, and 9) the DC electric field. The difference between this experiment at EP2.0 which measured the ambient plasma is that here we deploy a target balloon which forms a wake region behind it as the Shuttle moves through the ionosphere.

A full description of the electron and ion distribution functions involves the solution of the coupled set of equations

$$\vec{V}_e \cdot \nabla f_e + \frac{e}{m_e}(\nabla\phi - \vec{V}_e \times \vec{B}_0) \cdot \nabla_{V_e} f_e = 0$$

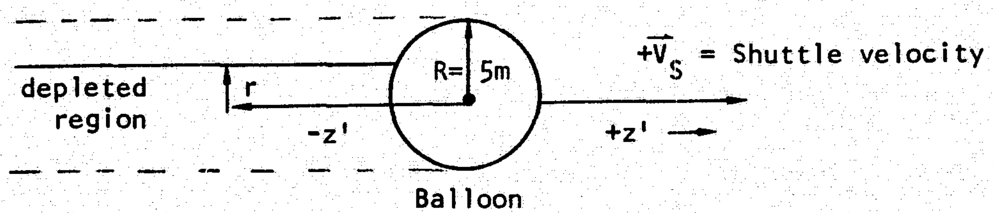
$$\vec{V}_i \cdot \nabla f_i - \frac{e}{m_i}(\nabla\phi - \vec{V}_i \times \vec{B}_0) \cdot \nabla_{V_i} f_i = 0 \qquad (1)$$

$$\nabla^2\phi = -4\pi e(N_i - N_e)$$

where

$$\int f_e dV_e = \frac{N_e}{N_o} \qquad \int f_i dV_i = \frac{N_i}{N_o}$$

and the boundry conditions at the balloons surface and at infinity must be met. In general the solution is difficult and must be done numerically. In the following we assume all electrons, ions and neutrals striking the balloon are absorbed, and that the flow back into the depleted region behind the balloon is one dimensional and is controlled by the ion and neutral temperature of the ambient.



The coordinate system in which the physics is most easily worked is cylindrical with the z axis on the line through the center of the balloon which contains the Shuttle velocity vector.

The density of any ion or neutral species with mass m_i and temperature T which has an ambient density $N(m_i)$ given by EP 2.0 is for $r \leq R$ = balloon radius and $z < 0$

$$\rho(r,z',m_i) = N(m_i) \exp - \left(\frac{R-r}{z'}\right)^2 \frac{m_i V_S^2}{2kT} \tag{2}$$

the electron density is

$$\rho(r,z',m_e) = \sum_{m_{ions}} N(m_i) \exp - \frac{m_i V_S^2}{2kT} \left(\frac{R-r}{z'}\right)^2 \tag{3}$$

and is independent of m_e.

For $r > R$ and/or $z' > 0$ all densities are ambient densities as given in EP 2.0. This expression for the wake is moderately simple in this coordinate system, however we must transform it into the coordinate system in which the measurements are being made, namely the Boom A platform coordinates.

Let us define a new coordinate system at the center of the balloon, x'y'z' such that the z' axis lies along the Shuttle velocity vector. Then

$$r = + \sqrt{x'^2 + y'^2} \tag{4}$$

We must express the Shuttle velocity vector in this system. Start with the velocity in the Boom B system

$$V_S = V_x \hat{e}_x + V_y \hat{e}_y + V_z \hat{e}_z \tag{5}$$

where

$$\begin{pmatrix} V_x \\ \\ V_y \\ \\ V_z \end{pmatrix} = T_{S\to B}\, T_{e\to S} \begin{pmatrix} (R_e+H)w \dfrac{\sin i \cos wt}{\left(1 - \sin^2 i \sin^2 wt\right)^{1/2}} \\ \\ (R_e+H)w \dfrac{\cos i}{\left(1 - \sin^2 i \sin^2 wt\right)^{1/2}} \\ \\ 0 \end{pmatrix} \tag{6}$$

See Eqs. 212, 213 of EP2.0. The transformation

$$T_{B\to V} = \begin{pmatrix} -\sin \tan^{-1} \dfrac{V_y}{V_x} & \cos \tan^{-1} \dfrac{V_y}{V_x} & 0 \\ -\dfrac{V_z}{V_S} \cos \tan^{-1} \dfrac{V_y}{V_x} & -\dfrac{V_z}{V_S} \sin \tan^{-1} \dfrac{V_y}{V_x} & \sin \cos^{-1} \dfrac{V_z}{V_S} \\ \sin\left(\cos^{-1} \dfrac{V_z}{V_S}\right) \cos \tan^{-1} \dfrac{V_y}{V_x} & \sin\left(\cos^{-1} \dfrac{V_z}{V_S}\right) \sin \tan^{-1} \dfrac{V_y}{V_x} & \dfrac{V_z}{V_S} \end{pmatrix}$$

or

$$T_{B\to V} = \begin{pmatrix} -\dfrac{V_y}{\sqrt{V_x^2 + V_y^2}} & \dfrac{V_x}{\sqrt{V_x^2 + V_y^2}} & 0 \\ -\dfrac{V_z V_x}{V_S \sqrt{V_x^2 + V_y^2}} & -\dfrac{V_z V_y}{V_S \sqrt{V_x^2 + V_y^2}} & \dfrac{\sqrt{V_x^2 + V_y^2}}{V_S} \\ \dfrac{V_x}{V_S} & \dfrac{V_y}{V_S} & \dfrac{V_z}{V_S} \end{pmatrix} \tag{7}$$

where

$$V_S = \sqrt{V_x^2 + V_y^2 + V_z^2}$$

applied to $\vec{V}_S$ gives

$$T_{B\to V}\begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ V_S \end{pmatrix} \tag{8}$$

i.e., $T_{B\to V}$ creates a new coordinate system whose z-axis is pointed along the Shuttle velocity vector. This is precisely the x', y', z' coordinate system in which Eqs. 2, 3 and 4 are defined. If θ_A, ϕ_A, L_A, θ_B, ϕ_B, L_B V_S are given we wish to be able to determine if the instruments on the platform at the end of Boom A are within the wake region defined for Eq. 2; i.e., is $\sqrt{x_A'^2 + y_A'^2} \le R$ and $z_A' < 0$ where x_A', y_A', z_A' are the coordinates of the Boom A tip in the x', y', z' balloon wake systems and

$$\begin{pmatrix} x_A' \\ y_A' \\ z_A' \end{pmatrix} = T_{B\to V}\left[T_{S\to B}\begin{pmatrix} L_A \sin\theta_A \cos\phi_A \\ L_A \sin\theta_A \sin\phi_A \\ L_A \cos\theta_A \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ L_B + 5 \text{ meters} \end{pmatrix}\right] \tag{9}$$

$$T_{S\to B} = \begin{pmatrix} \cos\theta_B \cos\phi_B & \cos\theta_B \sin\phi_B & -\sin\theta_B \\ -\sin\phi_B & \cos\phi_B & 0 \\ \sin\theta_B \cos\phi_B & \sin\phi_B \cos\theta_B & \cos\theta_B \end{pmatrix}$$

see Eqs. 11 and 12 of EP 1.0.

and the term (L_B + 5 meters) appears because the center of the balloon is taken 5 meters beyond the tip of the Boom B.

If $\sqrt{x_A'^2 + y_A'^2} \le R$ and $z_A' < 0$ then everywhere the ion, neutral or electron density $N(m_i)$ or N_e appears in an equation defining the output of an instrument the expressions in Eqs. 2 and 3 must be used.

3.6.3.2 Boom A Instruments. The output of every instrument used in EP3.0 is the same as it was in EP2.0 so long as it is not in the wake region. When it is in the wake region $\sqrt{x_A'^2 + y_A'^2} \le R$, $z_A' < 0$, then the ambient density goes into the wake density of Eqs. 2 and 3 of EP3.0.

Example: $i = 10^\circ$, $H = 300$ km, $t = 1355$ seconds, $\phi_B = \theta_B = 0$
$LT_0 = UT_0 = 0000{:}00$ $LON_0 = 0$ $LON(t) = 90^\circ$ $LAT(t) = i = 10^\circ$
$LT = 0622{:}35$ $\Lambda = \Gamma = \Delta = 0$ $\phi_A = 270^\circ$ $\theta_A = 21^\circ$ $L_A = 36.33$ meters
$LB = 25$ meters $V_x = V_z = 0$ $V_y = (R_e + H)w$

$$T_{B\to V} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \tag{11}$$

$$\begin{pmatrix} x'_A \\ y'_A \\ z'_A \end{pmatrix} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \begin{bmatrix} 0 \\ -L_A \sin\theta_A \\ L_A \cos\theta_A - L_B - 5 \end{bmatrix} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 0 \\ -11.52 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -11.52 \end{pmatrix} \tag{12}$$

so that $z'_A < 0$ and $r = 0$ is ≤ 5 meters we are inside the wake region. Say that we want to know the current to the segmented planar trap given by Eq. 267 in EP2.0. If the platform Enlerian angles are $\chi = 270^\circ$ $\Omega = \theta_A$ $\psi = 270^\circ$ then

$$T_{A\to P} = \begin{pmatrix} -\cos\theta_A & 0 & -\sin\theta_A \\ 0 & -1 & 0 \\ -\sin\theta_A & 0 & \cos\theta_A \end{pmatrix} \tag{13}$$

$$T_{e\to S} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{14}$$

$$T_{S\to A} = \begin{pmatrix} 0 & -\cos\theta_A & -\sin\theta_A \\ 1 & 0 & 0 \\ 0 & -\sin\theta_A & \cos\theta_A \end{pmatrix} \tag{15}$$

angle between velocity vector and x_1 platform axis is Eqs. 218, 265 and 266 of EP 2.0.

$$\gamma = \cos^{-1}\left[T_{A\to P}\, T_{SA}\, T_{eS} \left.\begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}\right|_{x_1} \right] \tag{16}$$

$$\gamma' = \cos^{-1} \begin{pmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \Bigg|_x = \cos^{-1} 1 = 0 \tag{17}$$

and finally we can obtain from Eq. 267 of EP2.0

$$I = \pi r^2 \; e \; N \; (R_e + H)w \tag{18}$$

At this point we note that the N appearing in Eq. 318 EP3.0 must be modified because we are in the wake region. Ordinarily one would use the expression in Eq. 239 of EP2.0.

$$n(LT) = n^* \tanh \left[\frac{q \; 3600(LT-6)}{n^*} + c_1\right] \tag{19}$$

however we must now use the total ion density from Eq. 302 of EP3.0.

$$N = N(0^+) \exp(-KM_{0^+}) + N(02+) \exp\left(-KM_{0_2^+}\right) + N(NO+) \exp - KM_{NO+} \tag{20}$$

where $N(0^+)$, $N(02+)$ and $N(NO+)$ are given by Eqs. 245 through 248 of EP2.0 and M_{0^+}, $M_{0_2^+}$, M_{NO+} are the atomic weights in kilograms and

$$K = \left(\frac{5}{11.52}\right)^2 \frac{V_S^{\,2}}{2kT}$$

V_S = Shuttle velocity in meters/sec

$k = 1.38 \times 10^{-23}$ joules/^oK

T = temperature given in Eq. 225 EP2.0

The outputs of all the instruments on Boom A can be treated in a similar fashion.

3.6.3.3 Target Balloon. The pressure-bottle pressure always starts at

$$P_o = 2 \times 10^6 \text{ Newtons/meter}^2 \tag{63}$$

Here we must keep track of the time, T, that the fill gas valve is in the OPEN position. We assume the pressure bottle is a sphere of radius 15 cm.

$$\text{Pressure-Bottle Pressure} = 54 + 2 \times 10^6 \exp[-(.2T)] \tag{64}$$

$$\text{Actual Pressure in the Balloon} = 54[1 - \exp(-.2T)] \tag{65}$$

while the fill valve is open.

Pressures both read last value with fill valve closed. Deflate value open causes gas to leave balloon. Let t = time since deflate valve open. Pressure in bottle stays at last value. Pressure in balloon is

$$P_{\text{balloon}} = P_{\text{last value}}(\exp -t) \tag{66}$$

Example: Experimenter opens fill valve for 10 seconds. At end of this time experimenter closes fill valve.

$$\begin{aligned} P_{\text{pressure bottle}} &= 54 + 2 \times 10^6 [\exp(-2)] \\ P_{\text{balloon}} &= 54[1 - \exp(-2)] \end{aligned} \tag{67}$$

Then he opens deflate valve for 3 seconds and closes it.

$$P_{\text{pressure bottle}} = 54 + 2 \times 10^6[\exp(-2)] \quad \text{no change}$$

$$\begin{aligned} P_{\text{balloon}} &= 54[1 - \exp(-2)](\exp -3) \\ &= 54(e^{-3} - e^{-5}) \end{aligned} \tag{68}$$

END OF EXPERIMENT