THE LOW ALTITUDE PLASMA INSTRUMENT (LAPI)

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Abstract. The Low Altitude Plasma Instrument on the Dynamics Explorer-B spacecraft provides high resolution velocity space measurements of positive ions and electrons from 5 eV to 32 keV and a monitor of electrons with energies above 35 keV. It consists of an array of 15 parabolic electrostatic analyzers spanning 180° in angle and two Geiger-Mueller counters mounted on a one-degree of freedom scan platform. The platform is controlled by a magnetometer that allows placement of the array to selected angles with respect to the magnetic field. Each parabolic analyzer simultaneously measures electrons and positive ions. The temporal resolution and energy range of the measurements and the detector complement to be sampled are programmable by ground command.

1. Objectives

The objective of the Low Altitude Plasma Instrument (LAPI) on the Dynamics Explorer-B (DE-B) spacecraft is to provide high resolution velocity space measurements of positive ions and electrons from 5 eV to 32 keV and from 0° to 180° in pitch angle. In addition, measurements of $E > 35$ keV electrons are made at two angles separated by 90°. Analysis of data from this instrument along with supporting measurements will be concerned with: (1) the identification and determination of intensities of Birkeland currents, (2) auroral particle source regions and acceleration mechanisms, (3) the existence and role of an electric field parallel to the magnetic field, (4) sources and effects of polar cap particle fluxes, (5) transport of plasma within and through the magnetospheric clefts, (6) loss cone effects of wave-particle interactions, (7) hot-cold plasma interactions, and (8) ionospheric effects of particle precipitation.

2. Instrument Description

The instrument contains an array of 15 parabolic electrostatic analyzers to obtain detailed pitch angle distributions of ions and electrons as a function of energy, and two Geiger-Mueller tubes to obtain the parallel to perpendicular flux ratio of energetic electrons. The basic mode of operations provides a 32-point energy spectrum in the energy range 5 eV to 32 keV every second from 16 data channels, but the voltages on the electrostatic analyzers and the set of analyzer outputs sampled are selectable to allow for greater space/time resolution over limited portions of the energy and angular distribution. The entire instrument is mounted on a one-axis scan platform whose purpose

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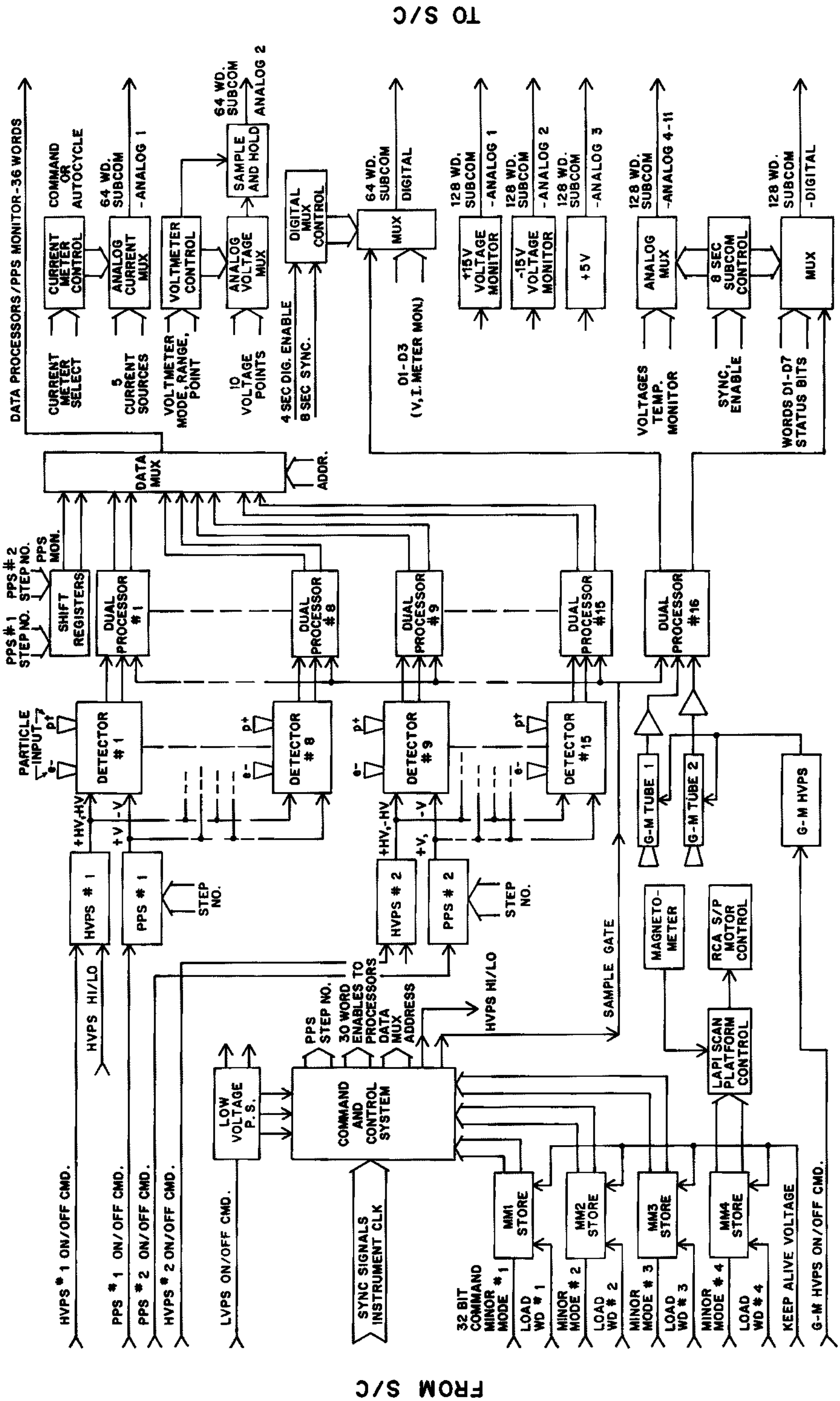

Fig. 1. Block diagram of the Low Altitude Plasma Instrument (LAPI).

is to maintain the detector array, which spans 180°, at a nearly constant angle to the magnetic field.

The LAPI is composed of the following major units:

(1) 15 electrostatic analyzer detectors grouped into 3 stacks of five detectors each.

(2) 2 Geiger-Mueller tube assemblies.

(3) 2 high-voltage Programmable Power Supplies (PPS).

(4) 2 High Voltage Power Supplies (HVPS).

(5) Central Electronics Package (CEP).

(6) Scan platform control magnetometer and deployable mast. A block diagram of the instrument is shown in Figure 1.

2.1. Detectors

The LAPI detectors use parabolic plate electrostatic analyzers to simultaneously provide energy analysis for electrons and positive ions. The analyzer is derived from those used on the ISIS-1 and -2 satellites and sounding rockets [1]. The particles are sensed with high current Channel Electron Multipliers (CEM), Type CEM-4816, from Galileo Electro Optics Corporation, with the entrance apertures and collectors specially modified for this application. The output from each sensor is detected by a charge sensitive amplifier/discriminator located within each detector housing and is then sent to its own

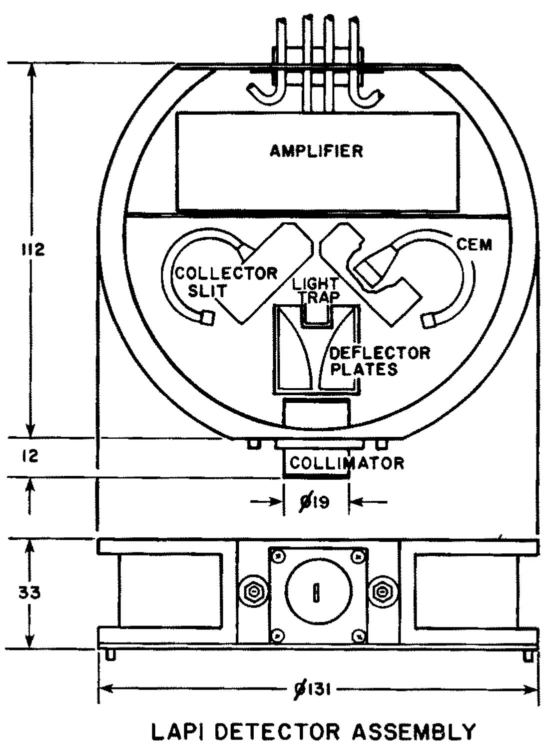

Fig. 2. Schematic drawing of the LAPI detector assembly. Dimensions are given in millimeters. ∅ indicates diameter.

data processor in the CEP where the pulses are accumulated and stored to await transmission to the spacecraft data handling systems.

All analyzers are identical and are composed of the subassemblies and parts shown in Figure 2. The choice of parabolic deflection plates to provide the electric field geometry for an energy per unit charge analyzer was made for the following reasons:

(1) Particles of opposite sign can be analyzed with a single set of plates. This greatly simplifies the calibration process and halves the number of analyzer modules needed.

(2) A trap (Figure 2) can be placed between the plates to eliminate background effects due to photons and undeflected particles.

(3) Background counts due to particles and photons striking the plates are essentially avoided because no direct path to the diverging plates is possible.

(4) As a result of the short collimation-deflection system (approximately 5 cm) and small deflection angle (approximately 25°), very low-energy (> 5 eV) electrons can be analyzed in the presence of large magnetic fields, i.e., the $V \times B$ effect is minimized. Similar systems on ISIS-1 and -2 have successfully measured terrestrial atmosperic photoelectrons.

In principle the parabolic electrostatic analyzer is analogous to an optical prism. Energy analysis is accomplished by an energy dependent divergence of a collimated particle beam. Energy resolution ($\Delta E/E$) and deflection sensitivity (energy divided by plate potential difference) are influenced by five parameters: (1) spacing between the

TABLE I

LAPI detector characteristics

Detector[a]	Stack	Geometric factor (cm^2 sr)	Full field of view[b]	$\Delta E/E$ % (FWHM) e^- and ions	$S(2E/\Delta V)$ e^- and ions
+0°	A	1.36×10^{-5}	5 × 5°	33	12.55
−0°	B	1.36×10^{-5}	5 × 5°	35	12.59
7.5°	B	2.13×10^{-4}	5 × 20°	34	12.39
15°	A	2.13×10^{-4}	5 × 20°	39	12.25
30°	A	2.13×10^{-4}	5 × 20°	33	12.72
45°	A	2.13×10^{-4}	5 × 20°	34	12.28
60°	A	2.13×10^{-4}	5 × 20°	33	12.59
97.5°	C	2.13×10^{-4}	5 × 20°	33	12.79
105°	C	2.13×10^{-4}	5 × 20°	34	12.37
112.5°	C	2.13×10^{-4}	5 × 20°	34	12.54
135°	B	2.13×10^{-4}	5 × 20°	32	12.58
165°	B	2.13×10^{-4}	5 × 20°	33	12.27
172°	B	2.13×10^{-4}	5 × 20°	33	12.63
+180°	C	1.36×10^{-5}	5 × 5°	32	12.18
−180°	C	1.36×10^{-5}	5 × 5°	32	12.09

[a] These angles are the mounting angles on the scan platform plate. The pitch angle of each detector depends on the pitch angle the 0° sensor is set to track. This angle can be varied by ground command.

[b] Full field-of-view angles and half field-of-view angles are defined at approximately 0.1% and at 50% of the peak response. Half angle fields-of-view are half of the full angle fields-of-view.

plates, (2) the flare of the plates, (3) the position and size of the gridded slit at the exit of the deflection plates, (4) the active area of the particle sensor placed behind the gridded slit, and (5) the position and shape of the collimator. The full-width, half-maximum energy resolution $R = \Delta E/E$ and deflection sensitivity $S = 2E/\Delta V$ (ΔV = potential difference between the plates) are given in Table I.

The input particle beam is defined by a three element collimator that also serves as a sunshade and off angle particle baffle (Figure 2). The geometric factor of the collimator is 3.04×10^{-4} cm^2-sr for the $5 \times 20°$ FFOV (full field of view) and 1.91×10^{-5} cm^2-sr for the $5 \times 5°$ FFOV. However, the energy dependent geometric factor is needed to normalize the results. Laboratory data and theoretical analysis give a value of 1.0 for the peak of the analyzer transfer function for $\Delta E/E \simeq 32\%$. However, the through-put is reduced by 29% by the screen mesh which covers the slit in front of the CEMs. This screen prevents a penetration of the CEM voltage into the deflection volume. Thus the maximum of the energy dependent geometric factor is 2.16×10^{-4} cm^2-sr and 1.36×10^{-5} cm^2-sr respectively.

The collimator internal surfaces, deflection plates, and gridded slit and screen are coated with gold black and roughened to suppress secondary emission and to decrease the internally scattered primary particles. Each detector samples a 2.5° azimuth and 10° polar angle FWHM (full width, half-maximum) sector (or $2.5 \times 2.5°$ for the 0° and 180° detectors) and the response is centered at 0° with respect to the analyzer normal.

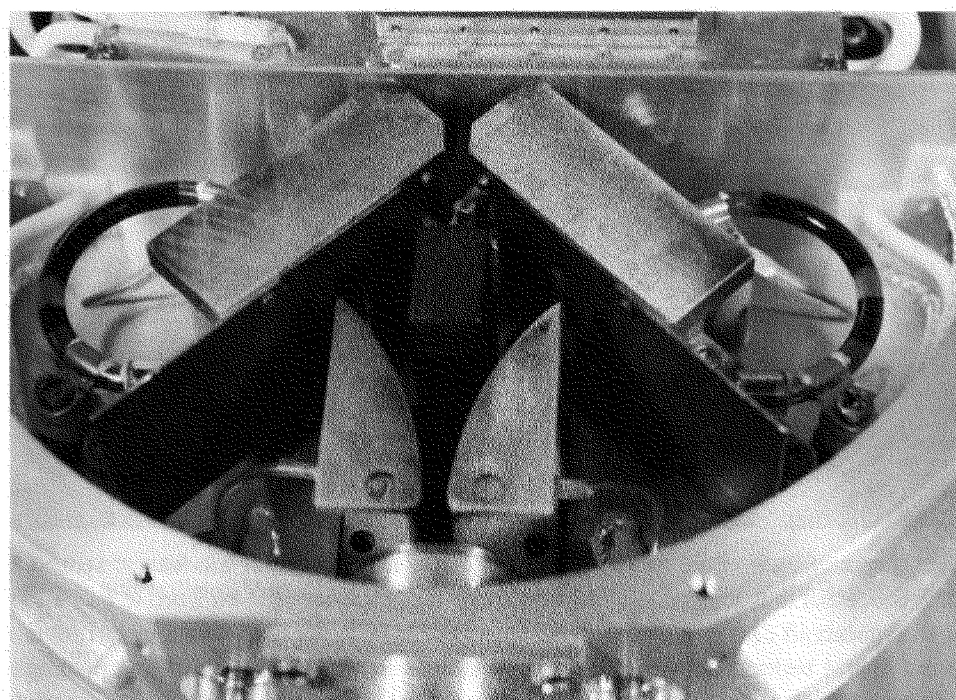

Fig. 3. Photograph of a LAPI detector assembly, especially displaying the parabolic electrostatic analyzer, light trap, and circular channel electron multipliers.

Experience has shown that the avoidance of outgassing materials in the vicinity of the CEMs will significantly increase their expected lifetimes. No potting materials are used for CEM mounting. Instead they are mounted by bolting their electrical leads to high voltage standoffs (see Figure 3). CEM counting lifetimes in excess of 10^{12} total accumulated counts are anticipated through the maintenance of a clean environment and through the use of a variable gain capability.

Each CEM is biased for positive or negative particle measurements by the proper connection to high voltage power supplies. Post acceleration after energy analysis of $+200$ V for electrons and -2400 V for ions will normally be used to achieve high detection efficiencies. The CEM output pulse is coupled to the thick-film hybrid charge sensitive preamplifier which feeds a hybrid discriminator and dead-time circuit. These hybrid circuits are improved versions of those previously flown on other satellites.

The 15 detectors are divided into three stacks of 5 each (see Figure 4 and Table I). In the table the + and − for the 0° and 180° detectors indicate that the detectors have their center-of-view either $+5°$ or $-5°$ out of the X-Y plane.

Two Geiger-Mueller tubes are mounted at 0° and 90° in the scan platform coordinate system on the top plate of the LAPI that supports the magnetometer mast (Figure 4). Their conical fields of view (30° at 0° and 50° at 90°) are adjusted so that the 0° detector measures only loss cone fluxes and the 90° detector only trapped fluxes. However, their geometric factors are equal (2×10^{-3} cm^2–sr) so that the ratio of their counting rates gives a direct measure of the anisotropy of the higher energy electrons.

2.2. Programmable power supplies

Two high voltage Programmable Power Supplies (PPS) operate 7 and 8 electrostatic deflection systems, respectively. Each PPS is separately controlled by 6 parallel bits from the command and control system to provide 2^6 or 64 voltage steps at constant increments on a logarithmic scale. The manner in which these control bits are programmed is discussed under Operation Mode Control.

2.3. High voltage power supplies

The sensor high voltage power supplies provide CEM bias voltages. One supply provides voltages to 14 sensors and the other unit to 16 sensors. Either one of two voltage levels (2650 or 2950 V) may be provided upon command.

2.4. Data processors

The output of each of the pulse amplifiers located in the detector modules is sent to a data processor that compresses 18 bits of binary data into an eight-bit word to be shifted to the spacecraft data handling system as required. The data processors are constructed using hybrid techniques with two processors plus input gating logic in one package. Circuits with the same basic design have been flown in satellite and sounding rocket payloads.

The algorithm for converting an 8-bit data word to decimal count is given by

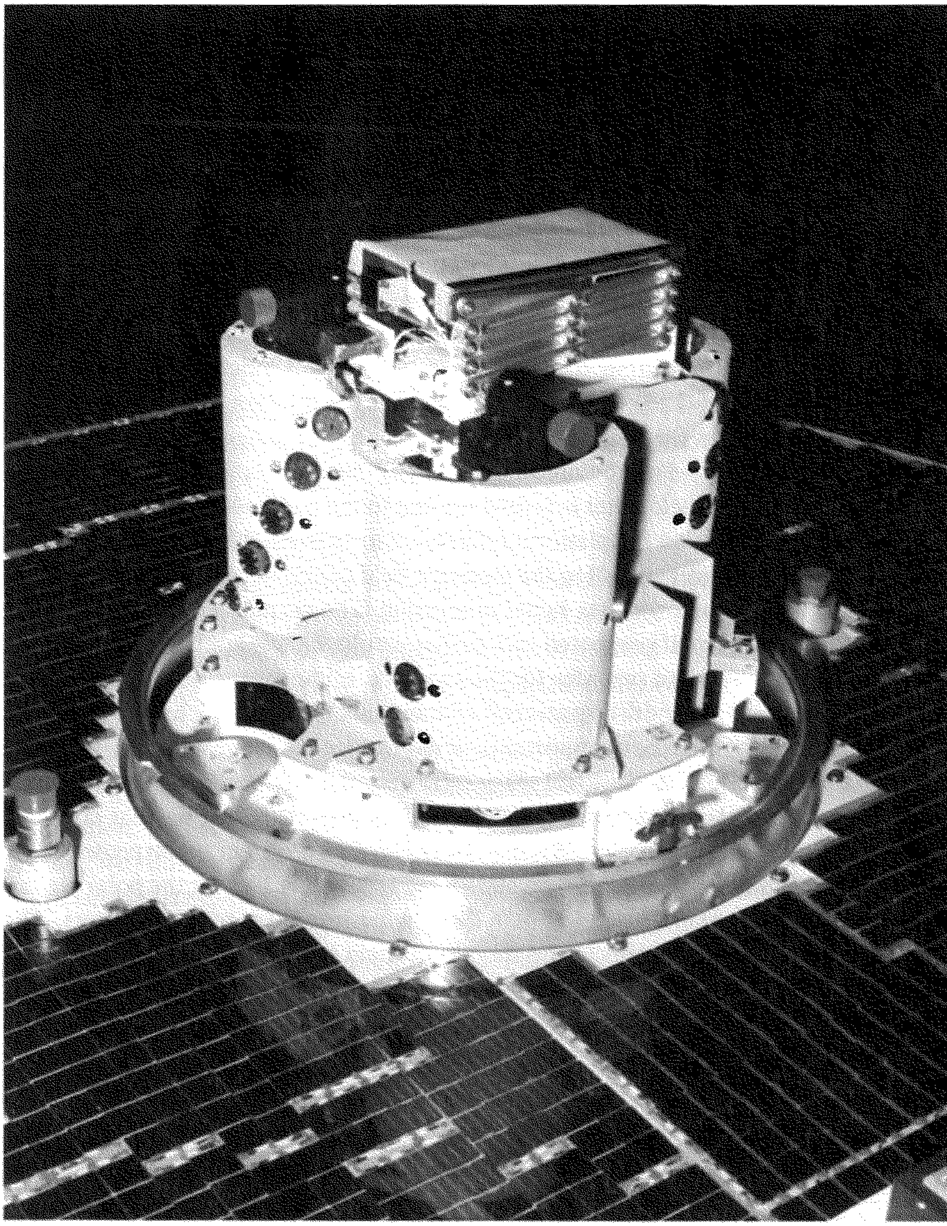

Fig. 4. Photograph of the LAPI mounted on the Dynamics Explorer-B spacecraft. The three stacks of detectors with the Geiger-Mueller tubes mounted on top are apparent. The magnetometer mast appears in its folded configuration on top of the detector stacks.

$N = [(D + 16) \times 2^{(S-2)}] + 2^{S-2}/2$ if $S > 0$. If $S = 0$ then $N = D/2$. D is the decimal value of the four least significant bits of the data word and S is the value of the four most significant bits.

2.5. Scan platform

The LAPI instrument is mounted on a single-axis scan platform at the $+Z$ end of the spacecraft [2]. The platform rotates the plane of the detector array in the geographic meridian plane. Since the geographic and geomagnetic meridian planes are roughly aligned, the detector array is always nearly parallel to the magnetic meridian plane. Typically detectors at one end of the array, which spans 180°, are aligned with the projection of the field onto the plane of the array. Out-of-plane variations of the field are accommodated by placing two detectors at each end of the array at angles $\pm 5°$ to the detector array plane. Nominally one of these end array detectors will have the magnetic field within its field-of-view.

A single-axis flux gate magnetometer mounted on a 17-inch deployable boom (Figure 4) on the top of the LAPI instrument controls the rotation of the platform. The magnetometer axis is in the geographic meridian plane. The magnetometer is operated as a nulling device; i.e., the magnetometer commands the scan platform to rotate in such a direction that the magnetometer is turned normal to the component of the field in the plane. In this configuration the platform reference axis is parallel (or anti-parallel if the control system is so commanded) to the magnetic field component in the array plane to the accuracy of the magnetometer signal processing. The output of the magnetometer is digitized in the CEP and compared to a digital word which is controlled by a minor mode command. This word provides for the zero level of the magnetometer and can be adjusted for magnetometer drift, spacecraft contamination fields (which were measured before launch and found to be unimportant), or to produce offset angles for the reference line from the magnetic field. This will allow different orientations of the non-uniformly spaced detectors in the array to the magnetic field to provide higher angular coverage over various pitch angle domains. Accuracies of the entire system are expected to be about 2° in the minimum magnetic field region and better than 1° over the polar region. These uncertainties are much smaller than the angular responses of the detectors. The angle of the scan platform shaft to the spacecraft main body is telemetered every two seconds to a resolution of 0.36°.

2.6. Operation mode control

The LAPI has considerable operational flexibility to allow it to satisfy the scientific goals of high angular, temporal and spatial resolution. The operational modes are established by command received by four registers (see Figure 1). These registers use continuous power to allow stored commands when the LAPI is turned off.

One command controls PPS and HVPS operations. Each PPS can be commanded to start on any of 63 voltage levels, skip 0, 1, 3, 7, 15, or 31 levels, dwell on any level, and step at rates from 1 to 64 steps s^{-1}. Each HVPS can be commanded to one of two levels. A second command controls the selection of data channels sampled by the spacecraft data handling system. Since 32 minor frame telemetry words (at a 16 minor frame s^{-1} rate) are assigned to the 30 CEM outputs from LAPI (the Geiger-Mueller tube counting rates are sampled in subcommutated words), a subset of the detector outputs must be selected to obtain the nominal 32 point energy spectrum each second. Additional supercommutation of a detector output in one minor frame provides even higher time resolution.

A third command allows input current monitoring of all power supplies. The monitoring level and location are sent to the 4 s subcom. Additional bits of the command are used to change a variable gain voltmeter to automatically cycle through voltage monitoring points, such as each PPS step level or to monitor a chosen voltage. The monitor level and location are sent to the 4 s subcom.

3. Calibration

A completely automated calibration system was constructed for the Dynamics Explorer plasma instruments due to the large number (30) of analyzers for the LAPI and the High Altitude Plasma Instrument [3] to be calibrated. Separate vacuum systems were used for the analyzer and CEM gain calibrations.

3.1. Analyzer calibration

An oil-free, high vacuum system was constructed for the analyzer calibration, which was carried out at pressures in the 10^{-7} torr range. The vacuum systems employed molecular sieved rotary and turbo molecular pumps for initial roughing. High vacuum was achieved and maintained by cryogenic pumps. Mass spectral measurements were made to verify cleanliness in the system.

Geometric factor calibrations were achieved by the use of electrons for both the electron and ion analyzers. All voltage polarities were reversed on the ion side during calibration. Earlier proton calibration of an ion channel indicated the results to be equal except for differences in CEM energy dependent detection efficiency. Efficiency differences were corrected by use of CEM efficiency vs energy calibration data.

Due to earlier experiences with hot filament sources (drifts, small beam size, etc.), a different approach was taken in electron generation. Photoelectrons were generated from a gold target by ultraviolet photons. Photons were supplied by a temperature-stabilized commercial mercury-argon lamp. This lamp generated an almost pure ($> 99\%$) flux of 2563 Å photons. The photons were collimated with a 46 cm collimator and allowed to impinge upon a 400 Å gold film on the vacuum side of a 3.8 cm thick, 2.5 cm diam quartz window. The resulting cold ($\leq$ few tenths eV) photoelectrons were then linearly accelerated between the negatively biased photocathode and a grounded, high transparency (80%) screen anode. A highly uniform, large diameter and time stable beam of monoenergetic electrons was produced by this 'photo' electron gun. A computer-controlled high resolution 30 kV high voltage source was used to vary the electron energy.

A goniometer system was constructed to synthesize an omnidirectional beam from the monodirectional electron source. The goniometer had two translational and two angular degrees of freedom which were under interactive software control.

An HP 9825 computer was used for process control and analysis. During the data acquisition phase the computer controlled, from inner to outer loop, the electron energy, polar angle, azimuthal angle, deflection voltage, CEM voltage, X position, and Y position. Each data sample acquired was recorded on disk and logged with the above listed variables for later sorting and averaging. Special-purpose, interactive, graphics oriented software was created to set up the calibration cycle, monitor data acquisition, and log the data. Aproximately 10 000 samples were taken in the calibration of each analyzer. Additional software was developed for analysis of the data to calculate the energy resolution, angular resolution and deflection sensitivity. A complete cycle of data logging and data reduction required approximately 12 h.

3.2. Absolute calibration

Absolute calibration was accomplished in a piecewise fashion. The geometric factor of the collimators was calculated analytically with high precision. The calibration data provided a relative, energy-angle dependent transfer function. An absolute transfer function was obtained by taking the ratio of the relative energy-angle transfer function through the complete analyzer system to one obtained by placing the same channeltron directly behind the collimator. This process eliminated the CEM efficiency in geometric factor determination. The absolute transfer function was then multiplied by the collimator geometric factor to obtain an absolute energy-angle dependent geometric factor. The CEM efficiency is factored in when the data are converted to geophysical units.

This piecewise process resulted in a very accurate calibration of the electrostatic analyzers because of the source stability and the ratioing process. The overall error was thus dominated by counting statistics.

3.3. Channeltron calibration

Each CEM was tested and selected for stability. Stability was defined as having reached a stable gain of $> 1 \times 10^8$ between 5×10^9 and 1×10^{10} total counts. All CEM's were manufactured from the same glass lot and were almost identical in tested characteristics.

A separate cryogenic bell jar system was used for CEM calibration. Pressures during calibration were in the 10^{-8} torr range. Complete tests of gain and resolution at two counting rates were carried out on random samples. At 5×10^3 counts s^{-1}, the gains were 1 to 2×10^8 and the FWHM resolution varied from 25 to 50%. At 1×10^6 counts s^{-1}, the gains were $\sim 5 \times 10^7$ with resolutions from 50 to 100%. Output vs input count rate tests of the CEM-amplifier combination indicated linear response to ~ 1 to 2 megapulses s^{-1} with a rollover frequency of the amplifier being ~ 6 megapulses s^{-1}. Thus corrected rates of > 10 megapulses s^{-1} are possible.

4. Data Formats and Analysis

LAPI data processing and analysis will be accomplished on the project Science Data Processing System (SDPS) [4]. Investigators access a central computer at the Goddard Space Flight Center via advanced graphics terminals. Three types of processing are planned for the LAPI data. The first type, the Summary Plots [4], will contain one electron and one ion sensor output plotted in an energy-time grey scale spectrogram.

Each spectrogram will contain 10 minutes of data with the output appearing on microfiche.

The LAPI specific processing will be performed either by interactive processing or batch processing. Under interactive processing the system is designed to give the investigator the flexibility to examine the LAPI data en masse via rough plots of decommutated telemetry data and in detail via plots of geophysical unit data, and to store such data at different stages of processing. Batch processing is accomplished in a production manner by the operators of the SDPS on the basis of time periods identified by scanning the Summary Plots for interesting events or from various solar-terrestrial indices. The final products of either type of processing are Mission Analysis Files, a public data base accessible by all investigators associated with the program.

Data in intermediate files or the final Mission Analysis Files may be displayed on the graphics terminals or routed to a micrographics unit for microform production. Several types of standard displays will be available:

(1) differential number flux vs energy at all angles samples;
(2) velocity space density vs energy or velocity at angles sampled;
(3) velocity space density vs angle parameterized by energy (velocity);
(4) isodensity contours of velocity space density;
(5) grey scale spectrograms with energy-time and angle-time coordinates.

Detailed science analysis will be performed interactively with the Mission Analysis File data base. Access to data sets from other instruments on both spacecraft will provide the data base for interpretations leading to the fulfillment of the objectives.

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References

1. Heikkila, W. J., Smith, J. B., Tarstrup, J., and Winningham, J. D.: *Rev. Sci. Instrum.* **41**, 1393 (1970).
2. Hoffman, R. A., Hogan, G. D., and Maehl, R. C.: *Space Sci. Instrum.* **5**, 349 (1981) (this issue).
3. Burch, J. L., Winningham, J. D., Blevins, V. A., Eaker, N., Gibson, W. C., and Hoffman, R. A.: *Space Sci. Instrum.* **5**, 455 (1981) (this issue).
4. Smith, Paul H., Freeman, Clyde H., and Hoffman, R. A.: *Space Sci. Instrum.* **5**, 561 (1981) (this issue).