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THE HILAT VACUUM ULTRAVIOLET AURORAL IMAGER

An integral part of the requirements of the HILAT mission was to produce imagery in full daylight of the earth's auroral activity, the aurora borealis, with a selectable 30 angstrom (Å) spectral window in the vacuum ultraviolet spectrum ranging from 1100 to 2078 Å and a dynamic range from 80 to 10^5 Rayleighs.* This resulted in the design of the multimode instrument called the Auroral Ionospheric Mapper. It functioned primarily as an imager with secondary operation as a photometer at preselected wavelengths with the same spectral window or as a spectrometer scanning the full spectral range. Included with the mapper were two fixed wavelength photometers, each with a 10 Å spectral window. The design criteria and selections that are presented are related mainly to the imaging functions.

INTRODUCTION

It is of scientific interest to examine the correlation of the earth's auroral storm activity with magnetospheric effects as well as their combined effects on radio communications in the polar regions. Also, it is important to obtain data on the physical and chemical effects of energetic particle precipitation in the earth's atmosphere and to determine the relationship of observed emissions and the energy spectrum of incident particles. The Auroral Ionospheric Mapper was designed as a multimode instrument to permit an examination of those phenomena.

The aurora borealis was viewed by the mapper from the three-axis stabilized platform provided by the HILAT spacecraft that was launched in a polar, dusk-dawn orbit of approximately 830 km altitude and 82° inclination.

The imaging mode of operation produced a single pictorial swath approximately 6000 km wide, once every 101 minute orbit of the satellite. Figure 1 illustrates the orbital geometry. The imagery obtained yielded a 22.26 by 5.43 km spatial resolution at nadir. The mapper could be commanded to operate in a predetermined fixed number of spectral wavelengths with a 30 Å window in the vacuum ultraviolet spectrum.

The photometer mode of operation provided similar spectral selection except that the instrument viewed only the nadir image pixel, generating a single-element orbital swath of data. The spectrometer mode of operation also viewed only the same single-image pixel element orbital swath of data while those data were spectrally scanned over the entire vacuum ultraviolet spectral range.

The purpose of the fixed wavelength photometers was to establish a definitive relationship between established science in the near-ultraviolet and visible spectral region and the results obtained by the vacuum ultraviolet portion of the instrument.

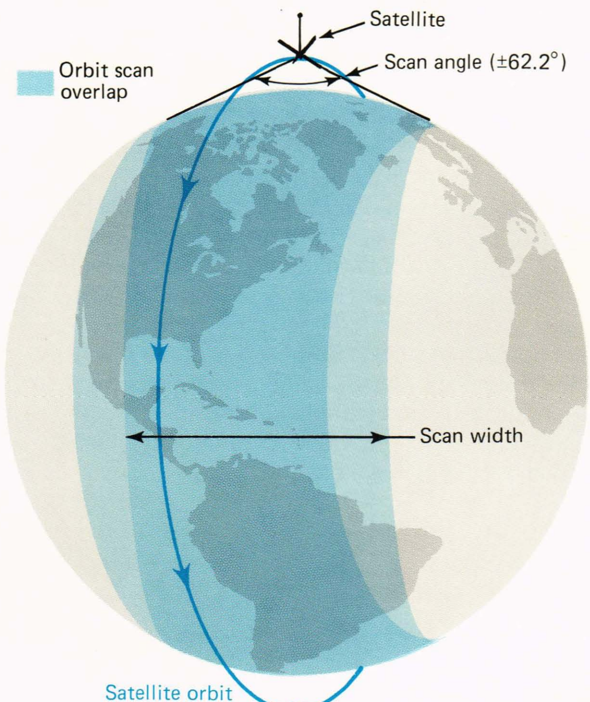

Figure 1 — Auroral Ionospheric Mapper image scan coverage.

BASIC SYSTEM CONSIDERATIONS

The HILAT spacecraft had an orbital period of 101 minutes with a forward orbital velocity of 7.5 km/second, or a 6.6 km/second forward velocity of the satellite ground subtrack point. The orbit allowed the

*1 Rayleigh = 10^6 photons/cm^2 second.
1 angstrom = 10^{-10} meter.

mapper to provide contiguous-line-scan imaging compatible with the forward velocity of the spacecraft orbital subtrack point. This was factored into the spacecraft telemetry data format frame in a real-time system with a 0.5 second data-frame period. The period of imaging line scan was 3.0 seconds, providing for six complete telemetry data frames. The pixel size in the direction of the spacecraft orbital motion was 22.2 km and in the direction of the orbital cross plane was 5.4 km. The angular line scan in the orbit cross plane was selected to view horizon-to-horizon (124.4°) plus an overscan margin of 5° for a 134.4° total field of view, allowing for medium tolerance in the spacecraft attitude control (pointing) in roll. The fixed wavelength photometers had a total circular field of view of 2°.

Because only three commands were available from the spacecraft, the control electronics of the mapper were designed to an on-off function and two sequencer functions. By having 16 step positions on each of two sequencers, it was possible to have three major operating modes, with variances on each. The control electronics of the mapper were designed around an RCA 1802 microprocessor, which provided a high degree of flexibility. The mapper was commanded to turn on by a spacecraft timer for 25 minutes of the 101 minute orbit period while the spacecraft was over the north polar region. Instructions for the operational mode of the mapper and selection of the position function of the instrument sequencer could be transmitted to the spacecraft at any time during the orbit.

The initial dawn-dusk orbit of the spacecraft resulted in the earth's terminator being viewed during much of the instrument data-collection interval; such was the condition under which the vacuum ultraviolet imagery was provided. The fixed wavelength photometers operating at 3914 and 6300 Å could not operate in the presence of earth's albedo and were turned off automatically by individual illumination sensors. These photometer units provided data mostly during the north-polar winter solstice.

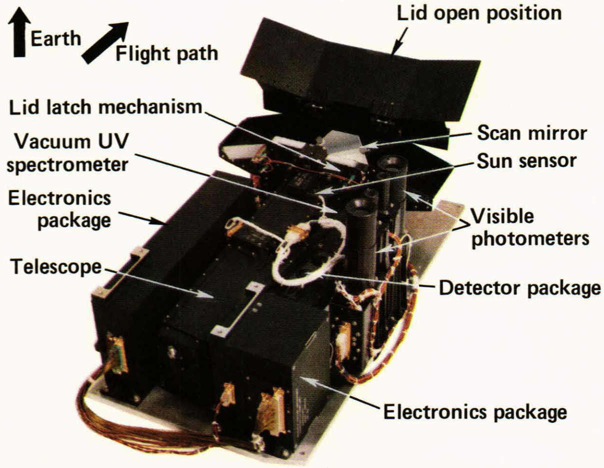

Figure 2 — The Auroral Ionospheric Mapper.

INSTRUMENT DESIGN

The postlaunch configuration of the mapper with its lid open is shown in Fig. 2. The scan mirror is shown in the nadir viewing position, which was the normal lock position for both the spectrometer and photometer modes. For the imaging mode of operation, the mirror scanned in the orbit cross plane by ±67.2° and provided an input for an off-axis parabolic-reflector telescope that focused the image on the entrance slit of the spectrometer. Figure 3 illustrates how the projection of the spectrometer entrance slit on the earth's surface is used to generate the pixel footprint over the angular range of the scan mirror. The 30 Å spectral window of the spectrometer could be scanned (in spectrometer mode) or directed to a predetermined wavelength (imaging or photometer mode) over the 1100 to 2078 Å spectral range. The spectrometer output was fed to an integrated detector package sensitive to vacuum ultraviolet located in the front of the photon counting system. A schematic of the tele-

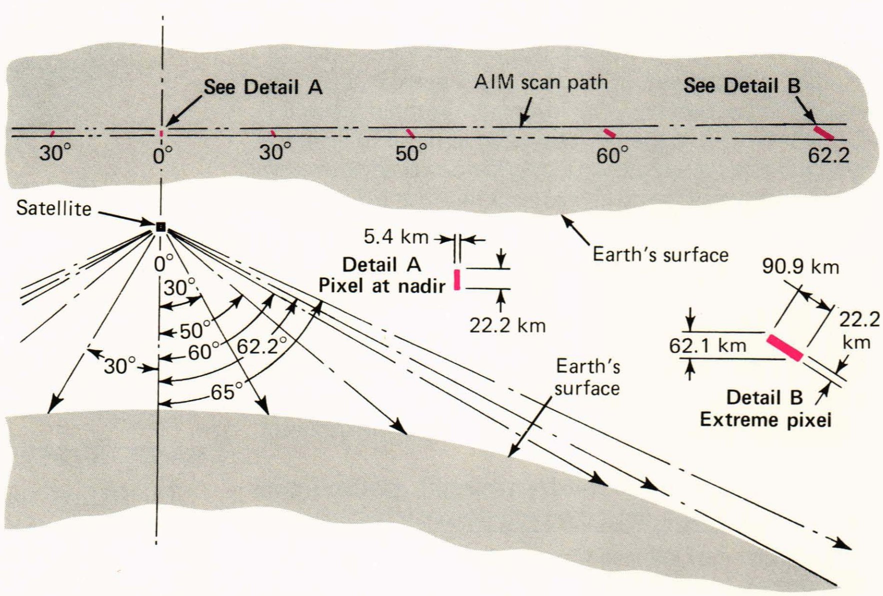

Figure 3 — Auroral Ionospheric Mapper pixel footprint projection as a function of image scan path angle.

scope/spectrometer portion of the instrument is given in Fig. 4. From Fig. 2, one can see that the basic instrument contained a sun sensor that viewed the scene via the scan mirror. Also shown in Fig. 2 are the fixed wavelength photometers with their independent illumination sensors.

The specific design characteristics for trimode operation are given in Table 1.

Table 1 — Trimode design characteristics.

Input:	100 (low-level signal) Rayleighs
Pixel size:	
	22.26 km (1.53°) orbit plane direction
	5.43 km (0.373°) cross plane direction
Line scan field of view:	134.4°
Telescope mirror size:	
	4.8 × 6.2 cm (off-axis parabola)
Telescope focal length:	22.95 cm
Telescope f-stop (effective):	*f*:3.67
Pixel dwell time:	7.03 milliseconds
Scan cycle time:	3 seconds
Image scan time:	2.36 seconds
Flyback time:	0.64 second
Wavelength scan time:	2.36 seconds (1100 to 2078 Å)
Wavelength scan step:	3.0 Å
Nadir pixel sample interval (photometer mode):	336 samples for a total of 2.36 seconds
Spectral resolution (spectrometer mode):	30 Å, from 1100 to 2078 Å
Wavelength selection:	1100 to 1868 Å (3.0 Å/step), 16 selections
Data pixels per scan:	336 (8 bits each)
Signal-to-noise ratio:	1.6 (2.56 counts/dwell time)

When the instrument is operating in the imaging mode, there are nine wavelength selections available in the spectral range.

There were six possible selections of wavelength in the spectral range given above when the mapper was operating in the photometer mode. The scan mirror was locked in the nadir position and the instrument viewed the nadir pixel at all times. The viewing time for each nadir pixel was 7 milliseconds, the same as the imaging mode.

When the mapper was operating in the spectrometer mode, a wavelength scan covering the full range between 1100 and 2078 Å was performed once per 2.36 second interval. This was the sixteenth (or last) wavelength selection. The time was the same as that for a line scan when the instrument was operating in the imaging mode. Here again, the scan mirror was locked in the nadir viewing position.

The fixed wavelength photometers were each sampled three times per image line scan for an interval of 0.8 second; each sample formed an 8 bit data word. The data words fitted into the same six telemetry data frames that contain either the imaging, photometer, or spectrometer data. The fixed wavelength photometer characteristics are summarized in Table 2.

Table 2 — Fixed wavelength photometer characteristics.

Quantity	2
Wavelength	3914 and 6300 Å
Bandpass	10 Å
Nadir viewing integration	0.8 second
Dynamic range	20 to 10^5 Rayleighs
Field of view	2° circular
Data rate	8 bits/second each

The imaging mode of operation was considered prime and produced imagery similar to a television satellite weather picture. In lieu of cloud/storm viewing, there was an auroral/storm viewing. Figure 5 illustrates an image of auroral activity with a 5 × 22 km spatial resolution as received at Kiruna, Sweden. This picture of the auroral activity was taken under daylight conditions. The day/night terminator is designated by the dotted line in the picture with dayside to the left of the dotted line. All images were produced in real time without the benefit of an on-board spacecraft record-

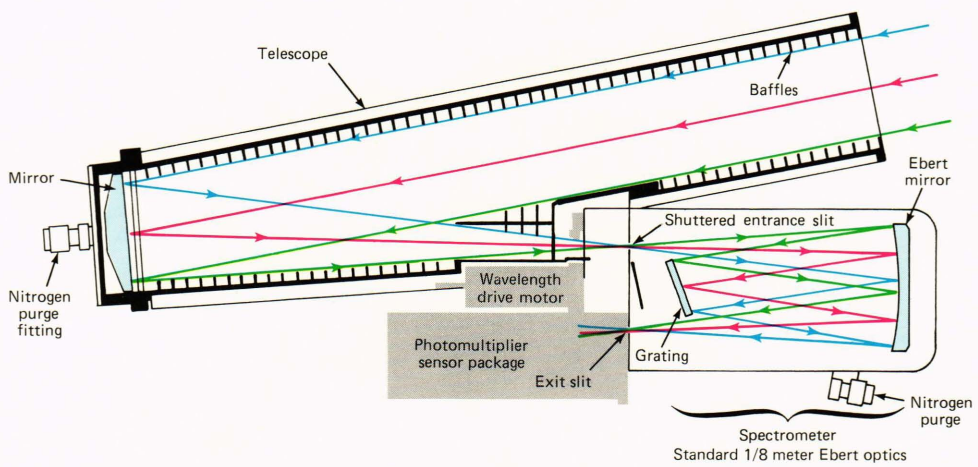

Figure 4 — Telescope-spectrometer-sensor assembly.

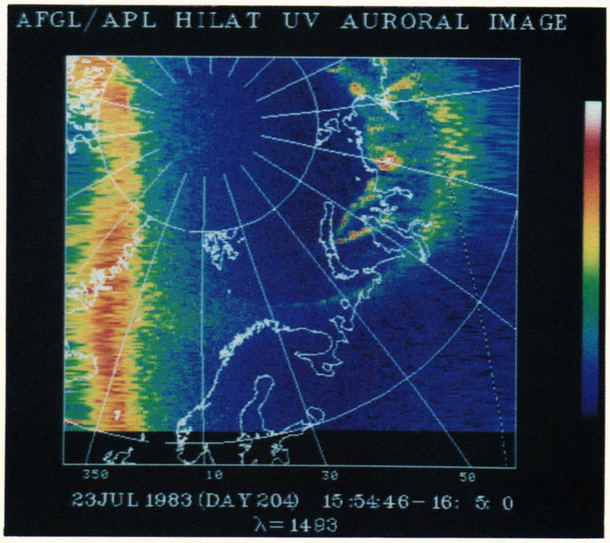

Figure 5 — Auroral image (over northern Eurasia).

er. The total inclusive instrument data rate was 992 bits per second.

OPTO-MECHANICAL

The optics of the mapper are illustrated in Fig. 4. The Ebert-Fastie spectrometer contained a mechanical shutter which was actuated periodically on command to obscure the optical input to the spectrometer and to permit a background dark count to be secured from the photomultiplier tube detector. In addition, the spectrometer was equipped with a mercury optical source to provide an optical test input to the instrument at 1849 and 1942 Å. The spectrometer contained a 3600 line diffraction grating that, in conjunction with the entrance and exit slits, yielded a 30 Å spectral resolution. The sensor at the spectrometer output was a special photomultiplier tube sensitive to ultraviolet.

The input signal to the spectrometer was from a telescope that was equipped with an intricate light shade. This telescope, an off-axis parabolic reflector, was designed to have a high throughput in the vacuum ultraviolet spectrum. When operating in the imaging mode, the field of view of the telescope spectrometer was scanned in lines by a scan mirror positioned in front of the telescope/light-shade entrance aperture.

Figure 6 is a sketch of the scan mirror with its motor drive and optical position readout system. The scan mirror was driven by a stepper motor that rotated 4° per step or at 90 steps per revolution. Integral with the stepper motor was a gear head having a 10:1 reduction ratio, for an output motion of 0.4° per scan mirror step. It was desired to scan the viewed scene with 336 pixels with one mirror step per pixel. This resulted in a total scan angle of 134.4°.

The torque output at the stepper motor gear head was 1440 gram-centimeters for a maximum stepping rate of 600 steps per second. The total time for the mirror scan cycle was approximately 3 seconds, with 2.36 seconds for active scan and 0.64 second for mirror flyback. The motor step rate during flyback was 336 pixels per 0.64 second or an average of 525 steps per second. The motor step rate during the active scan was 336 pixels per 2.36 seconds or 142.3 steps per second. In any case, the maximum allowable motor step rate was not violated.

The angular position of the scan mirror was determined via the electro-optic readout device shown in Fig. 6. It may be observed that a multislit mask rotated with the scan mirror. This mask blocked an infrared beam except when a slit position was encountered. When the infrared beam struck a silicon

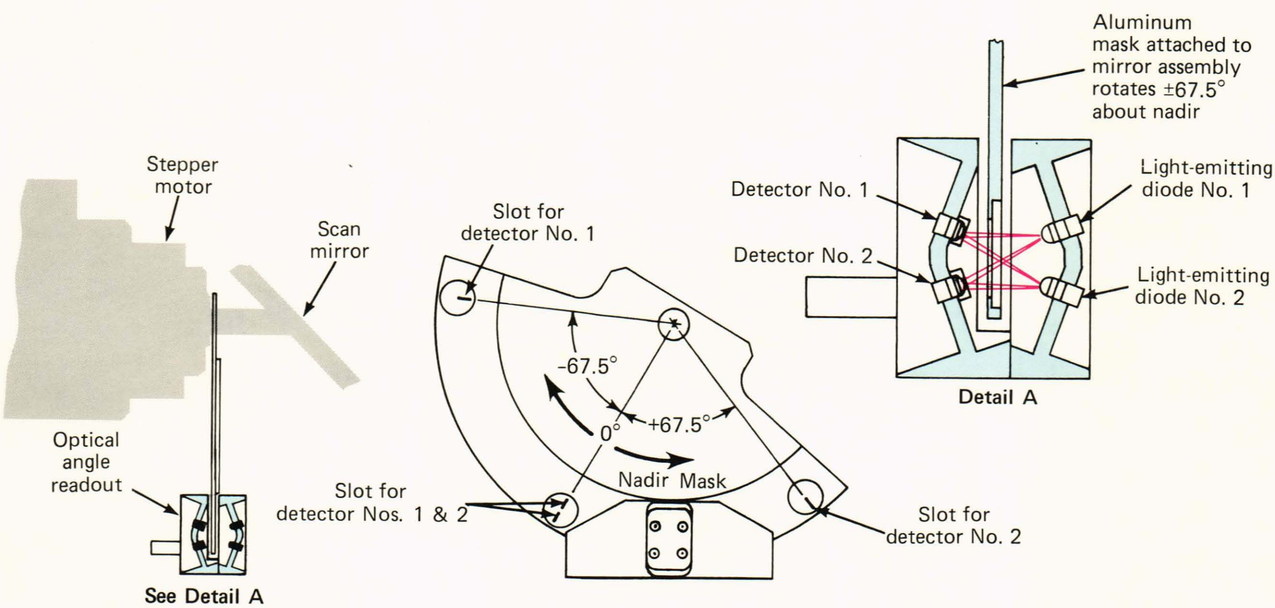

Figure 6 — AIM scan mirror angle optical readout.

diode detector, an electrical output pulse was produced. Slit positions occurred at the scan end positions and at the central nadir viewing position.

An enclosure with a spring-loaded hinged lid housed the scan mirror unit. The lid was opened after launch by redundant pyrotechnic bellows motors. All effluents generated in the activation of the bellows motors were contained in the sealed bellows units. The lid itself was equipped with microswitch sensors to indicate initial-open (release) and full-open conditions. When the lid was in the closed position during launch, the scan mirror/step motor was held captive and its activation was electrically inhibited.

During operation in the spectrometer mode, with the mapper continuously viewing nadir, the spectrometer grating was scanned over its full spectral range via a smaller stepper motor. Each step produced a 3 Å change in the spectral position of the 30 Å wide window over the 1100 to 2078 Å range for a total of 326 steps. This stepper motor, unlike the scan-mirror stepper motor, ran in one direction only. A spring-loaded cam system was used with the spectrometer grating to produce a 2.3 second wavelength scan and a 0.7 second flyback interval, which resulted in a total wavelength scan cycle of 3 seconds, providing the required compatibility with data produced in both the imaging and photometer modes. Figure 7 illustrates typical in-orbit spectrometer scan data as taken by the mapper and received by Navy Station 502 at APL.

ELECTRO-OPTICS

In keeping with simplicity and reliability, the design of the mapper utilized spectrometer hardware that had been proved in space and rocket flight. The physical size of the scan mirror and of the telescope aperture was driven by an acceptable signal-to-noise or photon count at the photomultiplier tube detector for a given minimum optical input level. It must be remembered that the 0.125-meter Ebert-Fastie spectrometer was an *f*:4.3 system that should be matched by the input telescope. An off-axis parabola had been selected for this application because it would provide good signal throughput, adequate angular resolution, and rugged integrated baffle design (see Fig. 4). The telescope focal length required to match the system operational orbit parameters and the spectrometer entrance slit dimensions of 1.5 millimeter wide × 6.16 millimeter high was 22.95 cm. The telescope mirror aperture was a rectangle measuring 4.8 × 6.2 cm, resulting in an equivalent *f*:3.7 system. The size of the scan mirror (10.2 × 13.3 cm) was dictated by the telescope mirror, the instantaneous field of view, and the total scan angle; moreover, the sun-sensor field of view was also projected by this mirror. The scene pixel footprint projection of the spectrometer entrance slit is shown in Fig. 3.

The detector section of the mapper was an EMR type 510G-09-13 photomultiplier tube which had a cesium iodide photocathode deposited onto a magnesium fluoride window. The tube had a secondary emission amplification of 10^6. In the spectral region of interest, the quantum efficiency of the sensor was 10% or better. The sensor was of metal/ceramic highly ruggedized construction.

The three operating modes of the mapper were driven by the imaging mode; it is the 7.03 millisecond pixel dwell time that became significant. The detection signal-to-noise ratio or signal count per pixel dwell time for the given aperture telescope was dominated by the statistical shot noise since the sensor dark count was about one count per 20 seconds. A signal-to-noise ratio of 1 was achieved when there was an equivalent optical input of 80 Rayleighs.

ELECTRONICS DESIGN

Two electronics packages were included in the design of the mapper: the spectrometer electronics package, which was the drive unit for the spectrometer and the integrated detector, and the controller electronics package, which functioned as the main mapper control unit. Figure 8 shows that the controller interfaced with all functional parts of the instrument as well as with the host satellite.

The spectrometer-electronics package received logic timing and command signals as well as power from the mapper controller, which, in turn, drove the integrated detector, the spectrometer grating motor and dark shutter, the mercury test lamp, and the solar sensor.

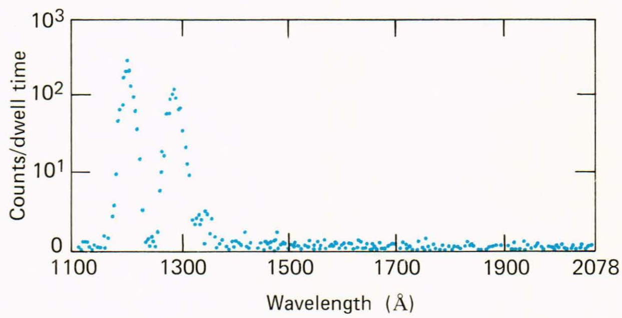

Figure 7 — Auroral Ionospheric Mapper spectrometer scan.

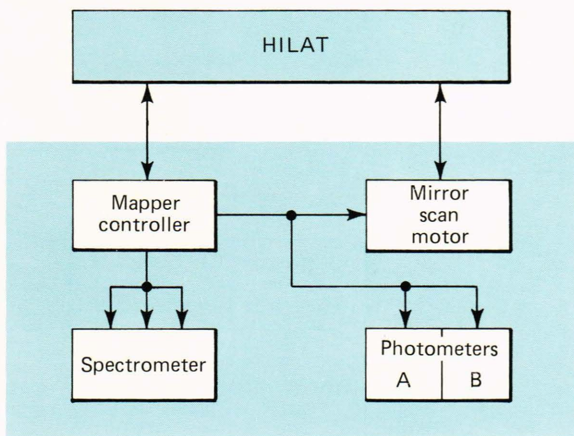

Figure 8 — Auroral Ionospheric Mapper block diagram.

The spectrometer electronics contained a digital accumulator circuit that counted the output pulses from the integrated detector. The accumulator circuit then yielded a compressed 8 bit count, of which the most significant three bits represented an exponent and the least significant five bits represented a mantissa. The net accumulator count was given by

$$\text{count} = (\text{mantissa} \times 2^{\text{exp}}) + 2^5(2^{\text{exp}} - 1).$$

The accumulator covered a range of 0 to 8159 counts before it reached capacity; it included a prescalar option for dividing by 10 that could be selected by ground command.

The spectrometer diffraction grating was driven by a stepper motor, which either held the grating at a fixed wavelength position or continuously scanned in wavelength, depending on the Auroral Ionospheric Mapper mode of operation. The grating motor can be commanded to operate in a mode called 3× power, which increases the drive current through the motor windings. This was a backup mode that could be used to free the motor if it became frozen in place because of extreme temperature.

With the mapper in the electronic calibration mode, the dark shutter was closed once per orbit for a 6 second period. During the last 3 seconds of this period, an electronic test signal was injected into the integrated detector, which provided a dark count measurement and a test of the accumulator circuitry.

In the optical calibration mode, the mercury test lamp was commanded on for 1 minute, once per orbit. It provided a simple test of the responsiveness of the integrated detector and the setting of the spectrometer wavelength.

The solar sensor circuitry protected the photomultiplier tube by inhibiting the high-voltage power supply in the integrated detector.

As the main control unit for the instrument, the controller generated all timing signals, drove the mirror scan motor, monitored the operation of the spectrometer system and fixed wavelength photometers, and provided the data, command, and power interface with the satellite.

The electronics for the controller were based on the RCA 1802 microprocessor (see Fig. 9). Complementary metal oxide semiconductor logic was used throughout to keep power consumption low. The microprocessor controlled the operation of the instrument through the transfer of data to and from input/output ports in the peripheral circuitry.

The controller could vary both the step period of the mirror scan motor and the direction of scan. The position indicator circuit was used to synchronize mirror position with scan timing.

Accumulators for the two fixed wavelength photometer packages were contained in the controller. These accumulators were similar to the one used in the spectrometer electronics, but prescalars were always used because the dwell times were longer. The 3914 Å photometer utilized a ÷256 prescalar; the 6300 Å photometer used a ÷32 prescalar. Each photometer package contained a solar sensor circuit that would inhibit power to the integrated detector if solar intensity exceeded a threshold level.

The instrument data stored in random access memory were output to the serial data interface for proper insertion into the satellite telemetry frame. A synchronous, serial data interface was used with 496 bits output every data frame (0.5 second).

The command sequencers consisted of two 4 bit counters that could be incremented by ground command. The A sequencer set the instrument operating mode; the B sequencer selected the backup function. The various sequencer states are listed in Table 3. The sequencer logic was continuously powered so that ground commands could be stored and acknowledged even when the instrument was not in operation.

An analog-to-digital converter was provided to allow the mapper controller to monitor the 16 analog housekeeping signals, which provided an indication of the health of the instrument. Signals that were monitored included power-bus voltage and current, motor

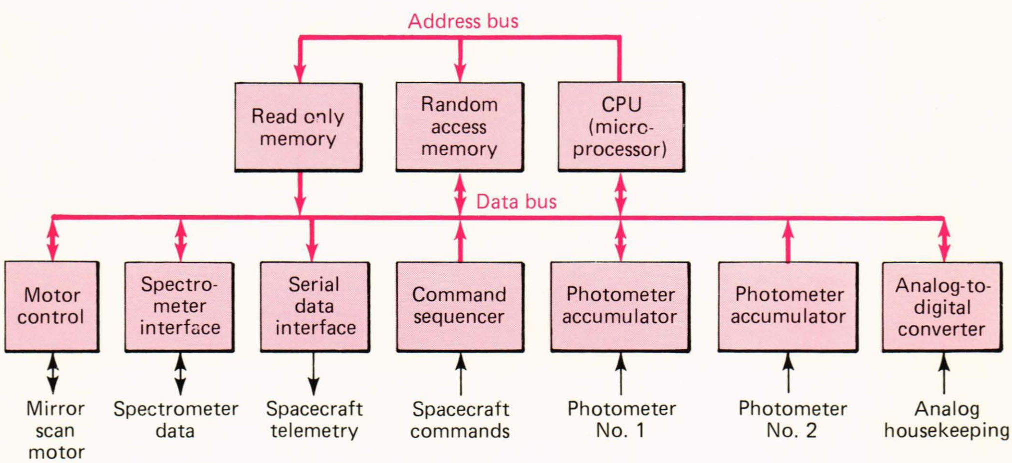

Figure 9 — The Auroral Ionospheric Mapper controller/processor.

Table 3 — Command sequencer steps.

Sequencer A			*Sequencer B*	
Position	*Function*		*Position*	*Function*
0	Imaging	at 1216 Å	0	Normal operation
1	Imaging	at 1304 Å	1	Electronic calibration
2	Imaging	at 1356 Å	2	1 and 11 combined
3	Imaging	at 1414 Å	3	Optical calibration
4	Imaging	at 1454 Å	4	1 and 9 combined
5	Imaging	at 1493 Å	5	3× power to grating motor
6	Imaging	at 1594 Å	6	3 and 7 combined
7	Imaging	at 1670 Å	7	Extra scan motor winding
8	Imaging	at 1750 Å	8	Normal operation
9	Photometer	at 1304 Å	9	Sun sensor override
10	Photometer	at 1356 Å	10	3 and 9 combined
11	Photometer	at 1414 Å	11	Data prescalar
12	Photometer	at 1493 Å	12	1 and 7 combined
13	Photometer	at 1554 Å	13	7 and 9 combined
14	Photometer	at 1670 Å	14	9 and 11 combined
15	Spectrometer:	Scan 1100 through 2078Å	15	7 and 11 combined

Note: Any combination of sequencer A and sequencer B is obtainable.

currents, package temperatures, and solar-sensor output currents.

The operation of the mapper was based on a 3 second line-scan cycle, during which a preprogrammed sequence of events occurred. When the instrument power was turned on, the controller determined the mode of operation from the sequencer values. An initialization sequence followed, during which the scan mirror and wavelength grating were driven to their correct position and the beginning of the line-scan cycle was aligned to the satellite start-of-frame pulse.

Following the initialization sequence, the 3-second line-scan cycle was repeated until instrument power was turned off by a timer in the spacecraft. As the mirror stepped over the scan part of the cycle, covering 134.4° in 2.36 seconds, 336 data pixels were collected from the spectrometer accumulator, one pixel per motor step. During this scan, three data pixels were saved from each of the fixed wavelength photometers. Wavelength position, status data, and analog housekeeping data were also sampled during each line period.

At the end of the scan part of the cycle, the mirror direction was reversed and the mirror was stepped back to its start position to begin the next scan cycle. The step rate was ramped up to four times the normal scan rate over the first seven steps of this flyback region and then ramped back to the scan rate at the end of the flyback region.

One complete line of data was buffered before it was output to the satellite telemetry system. Six satellite data-frame periods were required to read out one line of data (372 bytes). Included in a line of data were 336 ultraviolet data pixels, 6 photometer data pixels, 16 analog housekeeping parameters, and 14 digital status parameters.

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