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The AIS: A Spectrograph/Imager Ensemble for Space Flight

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13. ABSTRACT *(Maximum 200 words)*
This report describes an instrument, the Arizona Imager/Spectrograph (AIS), developed for the Geophysics Laboratory by the University of Arizona for use on the space shuttle. The instrument is a combination of spectrographs and imagers intended for the study of optical emissions in the vicinity of spacecraft. It includes nine spectrographs, which cover the spectral range from 115 to 1100 nm, with spectral resolutions ranging from 0.5 nm at short wavelengths to 1.3 nm at long wavelengths, and twelve imagers which have narrow, medium, and wide fields of view and optical bandpass filters to select particular wavelengths. The images and spectra are focused onto intensified CCD's. The design of this instrument is discussed and examples of test data are presented. Keywords: Spectrographs; Imagers; Space shuttles; Space flight. (KR)

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The AIS: A Spectrograph/Imager Ensemble for Space Flight

1. INTRODUCTION

The Arizona Imager/Spectrograph (AIS) is an instrument developed for studies of aurora, airglow, and optical emissions associated with space vehicles in low earth orbit. It was designed to measure their spatial, spectral, and temporal signatures at wavelengths from the near ultraviolet, through the visible, to the near infrared. The instrument is a combination of spectrographs and imagers mounted with their optical axes coaligned to view the same object. The spectrographs and imagers incorporate both intensified charge-coupled devices (ICCDs) and bare (unintensified) charge-coupled devices (CCDs). The spectrographs and imagers constitute the sensor head and are mounted on a motor-driven scan platform that allows movement of the common pointing direction in azimuth and elevation relative to the mounting surface. Two views of the sensor head and scan platform are shown in Figure 1.

The instrument configuration described in this report was dictated by a spaceflight program to analyze shuttle glow, airglow, and aurora. Shuttle glow is a layer of optical emission on and near spacecraft surfaces. At visible wavelengths the glow extends about 20 cm from the surface. Analysis of the shuttle glow is a principal objective of the mission. The airglow and aurora are the background against which the shuttle glow will be observed. The AIS is one of the instruments that constitute the payload of the Infrared Background Signature Survey (IBSS) spacecraft which will be flown on the German-built Shuttle Pallet Satellite (SPAS) manifested for flight on STS-39 in January 1991.

Shuttle glow occurs on and near shuttle surfaces that face into the ram direction [Banks *et al.*, 1983]. The best measurements to date, primarily in the visible, show a near-continuum spectrum that peaks near 670 nm [Mende *et al.*, 1983 and Swenson *et al.*, 1985]. Few measurements have been made in the UV and IR regions of the spectrum, and they are not easily interpreted [Huffman *et al.*, 1980 and Torr and Torr, 1988]. The shuttle glow is affected by changes in altitude and by firing the thrusters [Banks *et al.*, 1980]. The intensity seems to depend on the composition and/or temperature of the surface material [Mende *et al.*, 1986]. The shuttle glow is presumed to result from chemical and excitation processes that

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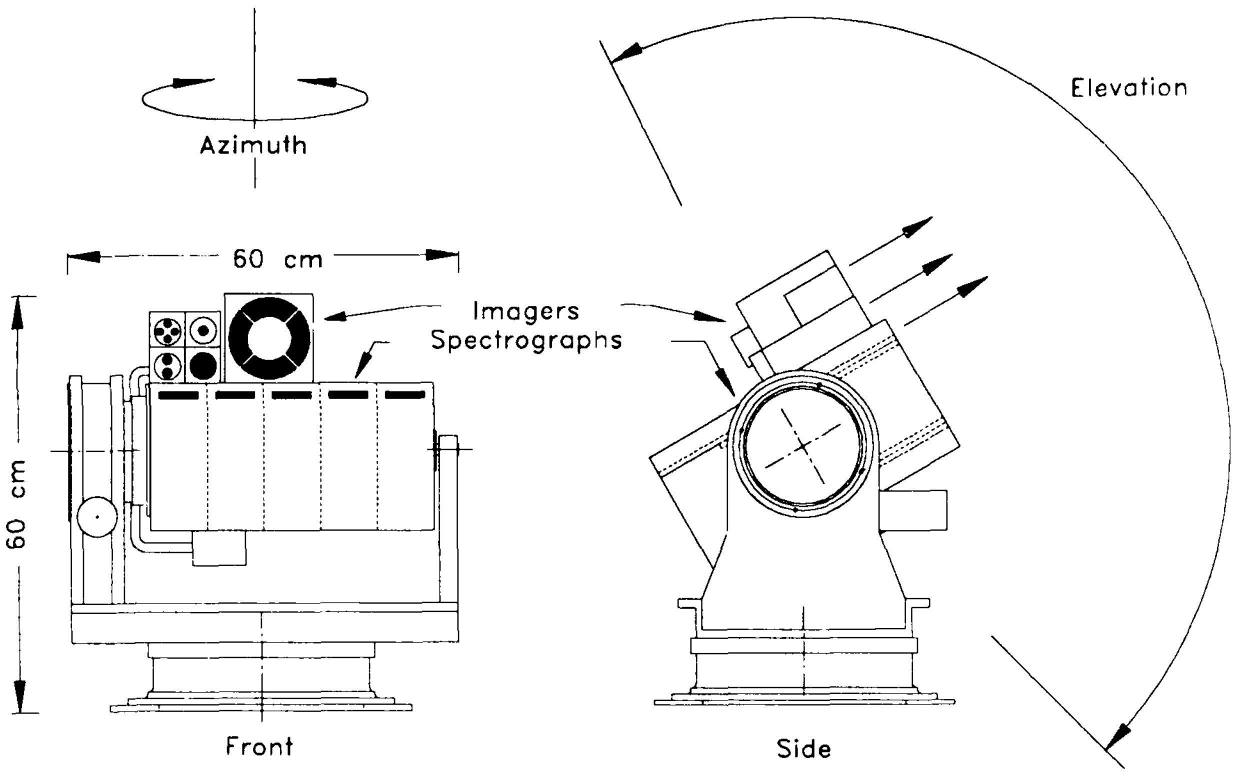

Figure 1. Sensor head and Scan Platform.

arise from the collision between the fast-moving (7.7 km/sec) shuttle with the ambient atmosphere. One objective of the IBSS mission is to identify the processes by recording images and spectra of the glow.

The present knowledge of shuttle glow was used to optimize the design of the AIS spectrographs. Complete spectral coverage from the UV to the near-IR is desired to eliminate any ambiguity that might arise from partial spectral coverage. The entire spectrum should be recorded simultaneously to observe temporal variations of the reactions that are involved. Fairly good spectral resolution is required to resolve the spectral lines that characterize various chemical processes. High sensitivity will be needed to observe weak emissions in the shuttle glow. These criteria led to a design that has nine spectrographs, to cover the spectral range from 115 nm to 1090 nm, with 0.3-nm resolution at the shortest wavelengths and 0.8-nm resolution at the longest wavelengths. Eight of the nine spectrographs use ICCDs and the ninth spectrograph has a bare CCD. All wavelengths are recorded simultaneously.

To address the problem of determining the spatial extent of glowing gas clouds, imagers fitted with interference filters are used. Since the size of emitting gas clouds may vary by several orders of magnitude, both narrow and wide-angle lenses are included. The imager section has 12 imagers with varying fields of view and spectral sensitivities.

Recent developments in ICCD and holographic technologies made it possible to design the AIS spectrographs and imagers with the spatial and spectral sensitivity required and still meet the stringent size and weight requirements of space flight [Broadfoot and Sandel, 1990]. It can be shown that the brightness of the image of the target on the detector depends only on the f-ratio of the optics. The small size of the CCD focal plane detectors allows the optics to be much smaller while still maintaining the desired f-ratio and the resulting sensitivity. The addition of image intensifiers to the CCD greatly increases the sensitivity of the instrument and makes the detectors photon-counting devices. The development of concave holographic gratings that also correct spherical and chromatic aberrations, allows the spectrographs to have fewer optical components. The holographic grating replaces the collimating lens, plane grating, and refocusing lens in a conventional spectrograph. This further reduces the size and weight of the spectrographs.

The sensor head includes all of the optics, the ICCDs, and some of the electronics for the nine spectrographs and 12 imagers It has dimensions of approximately 40 by 40 by 30 cm and weighs less than 35 kg. Figure 2 shows how the spectrographs and imagers are mounted together to form the AIS sensor head; the imager labels indicate the field of view (wide or narrow), the spectral region (UV, VIS, or IR), and the wavelength. The visible imagers have a medium field of view. The spectrographs are numbered 1 through 9 in order of decreasing wavelength. The spectral range of each spectrograph is also indicated in the figure. The nine spectrographs are contained in five optical benches which are bolted together for structural integrity. The 12 imagers are mounted on top of the spectrographs as shown in Figures 1 and 2.

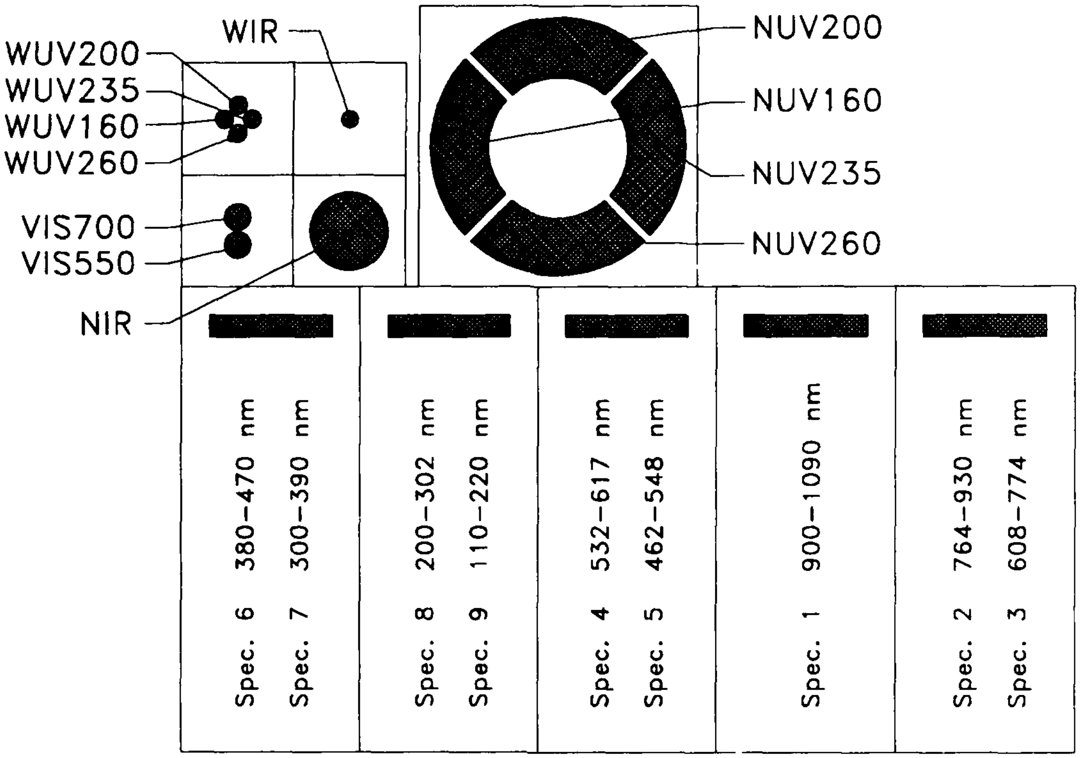

Figure 2. AIS optical sensors.

2. SPECTROGRAPHS

The spectrographs have both internal optics and foreoptics. The foreoptics focus light from the source onto the slit of the spectrograph. The internal optics disperses the light that passes through the slit and refocuses it onto the detector.

2.1 Internal Optics

The number of individual spectrographs required to cover the wavelength range from 115 nm to 1100 nm was determined by the spectral resolution required to identify chemical processes. If the performance were ideal, the transmission function would be rectangular and two samples per spectral line would adequately resolve spectral features; therefor an array of 576 optical elements, or pixels, could resolve 288 spectral lines. There is some spreading of the lines by the image intensifiers so the actual resolution is slightly degraded from the ideal case. It is still possible to resolve more than 200 spectral lines on a CCD.

The resolution requirement is not constant across the spectral range of the AIS. At the shortest wavelengths, typical glow spectra are expected to be fine-structured and require about 0.4 nm spectral resolution to separate rotational lines of molecular bands. At 0.4 nm resolution, an array of 576 pixels can cover about 100 nm. At the longest wavelengths the band systems are expected to be broader, relaxing the resolution requirements to about 1 nm. Thus in the IR, a 576 pixel array can cover more than 200 nm. The total requirements for 0.4 - 1.0 nm resolution over the spectral range of 115 to 1100 nm requires at least 4200 spectral samples to be taken. Since it is not practical to design a single spectrograph that would cover the full spectral range, a series of nine spectrographs was constructed, each with a resolution appropriate to its spectral region.

To reduce size and weight, eight of the spectrographs were mounted in pairs so that a pair of spectrographs share an optical bench, slit, and foreoptics. The spectral dispersion along the length of the CCD requires the use of all 576 pixels, but sampling along the spectrograph slit does not require the full width of 384 pixels. Two spectra are focused onto a single detector such that the spectral resolution is retained but only 192 (half of 384) samples are taken along the slit. By focussing two spectra onto each detector the detectors are used more efficiently and the size of spectrographs is reduced. The ninth spectrograph (actually spectrograph 1) occupies a full optical bench by itself. Table 1 lists the wavelength range and spectral resolution for each of the nine spectrographs, along with the photosensitive material of the detector. The grouping of the lines in the table indicates the pairing of spectrographs in the optical benches.

Table 1. Spectrograph designations, wavelengths, and resolutions. The photo-sensitive material of the detector is listed in the last column.

Spectrograph Number	Wavelength Range (nm)	Ideal Resolution (nm)	Photosensitive Material
1	900 - 1090	0.8	Si*
2	764 - 930	0.6	GaAs
3	608 - 774	0.6	
4	532 - 617	0.35	S-20
5	462 - 548	0.35	
6	382 - 468	0.35	S-20
7	300 - 386	0.35	
8	200 - 302	0.4	CsTe
9	114 - 220	0.4	

* *Unintensified*

The design of the spectrograph-optics is shown in Figures 3 and 4. Figure 3 shows a cross section of a spectrograph. The light enters at the upper left. Figure 4 shows a schematic view. The two spectrographs in an optical bench have separate gratings but share foreoptics, slit, and detector. Aberration-corrected, holographic, concave gratings, designed by American Holographics Inc., were chosen for the simplicity of the design they afford and their potential use at wavelengths from 20 to 1200 nm.

The reduced number of optical elements is evident in Figures 3 and 4. In each optical bench, the distant object is focused onto a 0.045 by 4.5 mm slit by the foreoptics. The light is both dispersed and refocused by a pair of concave holographic gratings. Two spectrally dispersed images of the slit are formed on the surface of the ICCD. The gratings are tipped slightly with respect to each other so that two consecutive spectra lie side by side on the focal plane as is shown in Figure 5. This figure shows how the two spectra are spectrally dispersed in the direction perpendicular to slit length while spatial information is retained in the direction parallel to the slit. The field of view defined by the foreoptics is 2.3° in the direction along the slit and 0.2° perpendicular to the slit. The spectrographs observe a long narrow region of the target.

The nine spectrographs are nearly identical. The distances between the grating and slit are the same for all of the optical benches. The detector is mounted perpendicular to the line from the grating center to the detector center. The remaining variables in all of the spectrographs are the grating angle and the position of the detector with respect to the grating. Each grating was designed for a specific spectrograph to cause dispersion and spectral coverage to match the size of the detector.

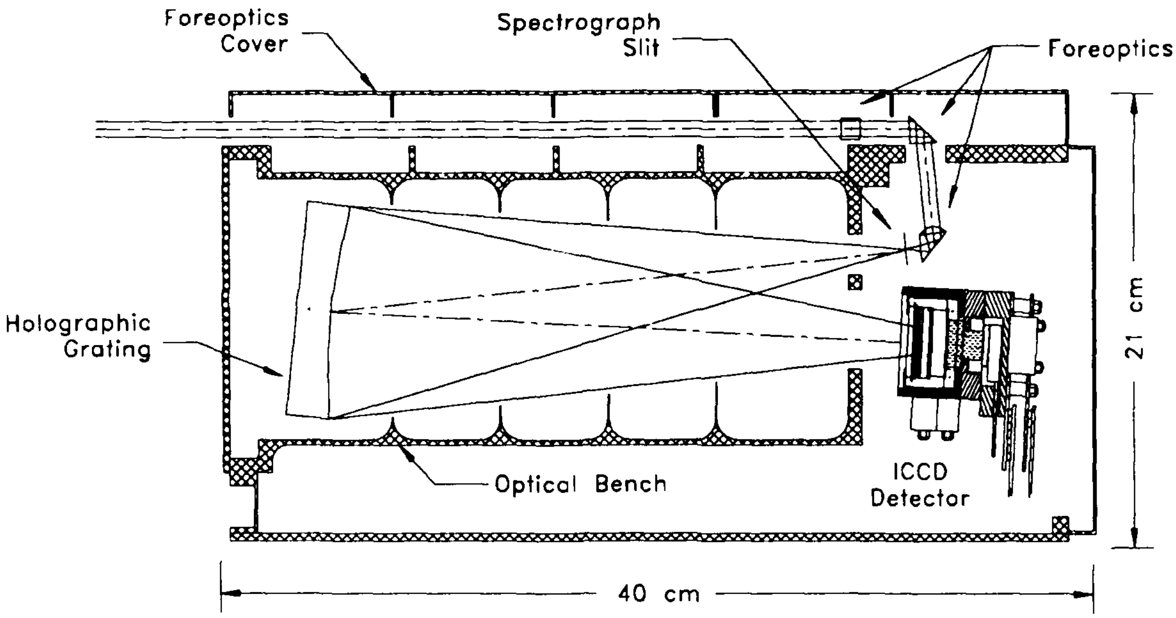

Figure 3. A cross section of a typical spectrograph optical bench.

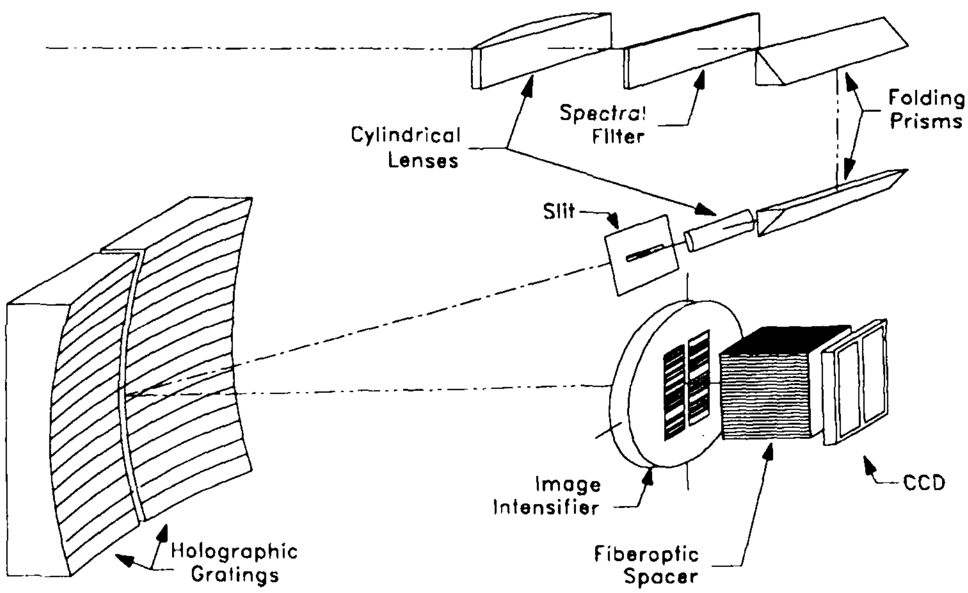

Figure 4. A schematic view of the optical bench.

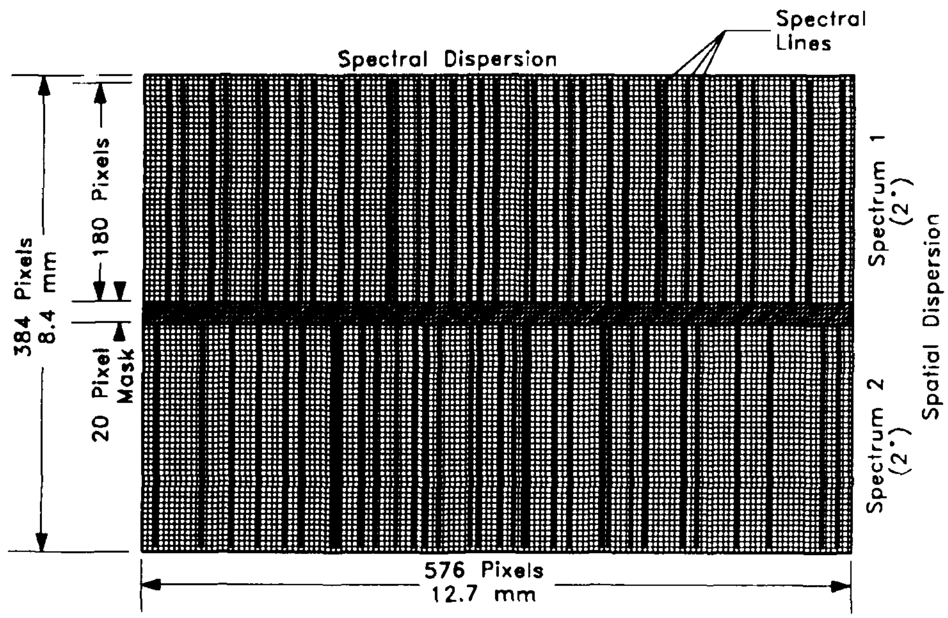

Figure 5. The image formed on the detector of the AIS spectrographs.

2.2 Spectrograph Foreoptics

The spectrograph foreoptics form an image of the object on the entrance slit and fold the optical path to reduce the size of the instrument. Two types of foreoptics are shown in Figure 6. The refractive foreoptics, shown at the left, is used in three of the five optical benches. It comprises two cylindrical lenses for focusing and a pair of prisms to fold the optical path back along the top outer edge of the optical bench. A 100 mm focal length cylindrical lens was placed 100 mm from the slit to focus in the direction of the slit. A 19 mm focal length cylindrical lens was placed 19 mm from the slit to focus in the direction perpendicular to the slit. The cross sectional area of the aperture at the first cylindrical lens is 7.2 by 30 mm and defines the field of view to be 2.3° by 0.2°. Foreoptics dimensions were chosen to assure that the full internal solid angle was filled with light, so that full sensitivity is achieved. Contamination from higher-order spectra is minimized by the design of the grating and the spectral sensitivity of the detector. Where necessary, an appropriate cut-off filter is placed in the optical path to eliminate interference by higher order spectra.

The foreoptics for the UV and near-IR spectrographs were different. In the UV case, it is impractical to maintain focus over that spectral range of 115 to 320 nm with refractive optics. Thus cylindrical mirrors were used instead of lenses, as is shown in the right half of Figure 6. This eliminated the chromatic aberration problem but considerable spherical aberration was introduced by the short-focal-length cylindrical mirrors and three reflections were required to achieve a common field of view. In the

IR case, only one spectrograph occupies an optical bench. This was done to allow a larger aperture and a larger detector area to enhance the sensitivity. The slit in this spectrograph is 8 mm long and required a 200 mm focal length lens to match the fields of view of the other spectrographs. This was accomplished by adding a negative 25 mm focal length cylindrical lens and adjusting the position of the 100 mm lens to achieve an effective 200-mm focal length for the system.

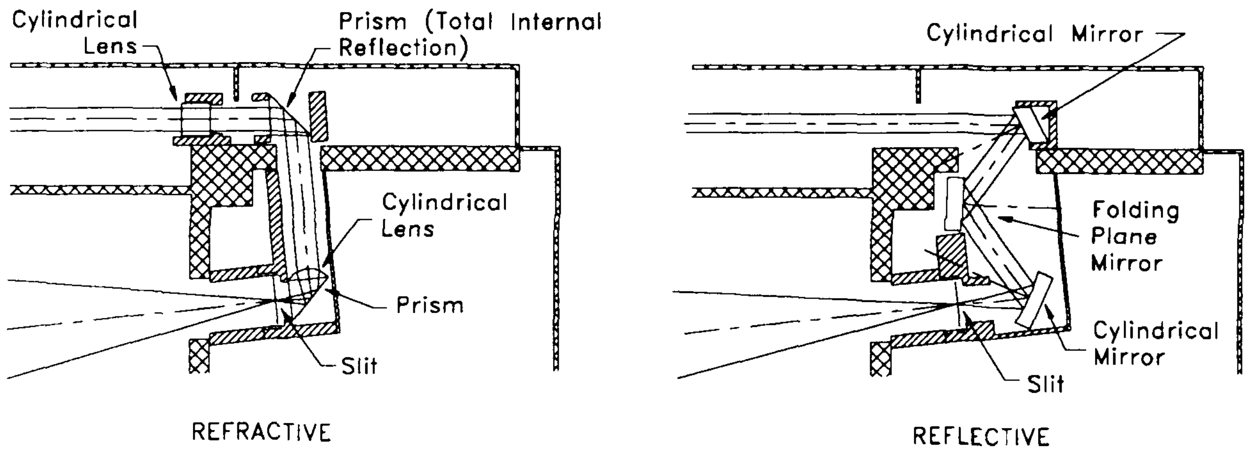

Figure 6. Spectrograph foreoptics.

3. IMAGER SYSTEMS

The 12 imagers can be placed into five categories by field of view and spectral sensitivity. There are 4 narrow-field-of-view ultraviolet (NUV) imagers, four wide-field-of-view ultraviolet (WUV) imagers, two medium-field-of-view visible (VIS) imagers, a wide-field-of-view infrared (WIR) imager, and a narrow-field-of-view infrared (NIR) imager. The wide-field-of-view imagers have 18-25° fields of view while the narrow-field-of-view imagers have 2° fields of view. Table 2 lists the fields of view, spectral responses, and photosensitive material of each of the 12 imagers. The grouping of the lines in Table 2 indicates how the imagers share image intensifiers.

The eight UV imagers have narrower bandpass filters, than do the other four imagers, to provide spectral isolation of the selected emission features. They will be used to obtain two-dimensional spatial information on the emission features observed by the spectrographs.

Table 2. AIS imager designations, spectral responses, fields of view, and photosensitive materials. The grouping of the lines in the table show how the imagers share intensifiers.

Imager Number	Imager Type	Spectral Response Peak/Halfwidth (nm)	Angular FOV Az	El	Photo-sensitive Material
1	Narrow-UV	160/25	1.8°	1.6°	CsTe
2	Narrow-UV	200/25	1.8°	1.6°	
3	Narrow-UV	235/25	1.8°	1.6°	
4	Narrow-UV	260/25	1.8°	1.6°	
5	Wide-UV	160/25	25°	21°	CsTe
6	Wide-UV	200/25	25°	21°	
7	Wide-UV	235/25	25°	21°	
8	Wide-UV	260/25	25°	21°	
9	Medium-Vis	500/200	6.0°	5.3°	S-20
10	Medium-Vis	700/200	6.0°	5.3°	
11	Wide-IR	900/400	21°	19°	Si*
12	Narrow-IR	900/400	2.3°	2.0°	Si*

* unintensified CCD

The four other imagers will obtain pointing and target-brightness information. The two visible imagers have 5° fields of view and share an imager intensifier. They will obtain broad spectral information about the gas clouds as well as star fields for post-flight pointing analysis. The two IR imagers are unintensified and are thus much less sensitive; they can observe much brighter objects without damaging the detector. They are intended to monitor target brightness (WIR) and to provide fine-pointing information (NIR).

An imager system includes the following basic components: simple lenses to focus the object onto the face of an image intensifier, an interference filter to limit the spectral response, an image intensifier to increase sensitivity, and a CCD to collect the light and transform the image into an electronic signal. The optics and intensifiers are mounted on top of the spectrographs as shown in Figures 1 and 2. Flexible fiberoptic conduits carry the images from the intensifiers down to the CCDs underneath the sensor head. The 12 images are recorded on two CCDs resulting in 6 images per CCD and 144 by 128 pixels per image. Figure 7 shows how the 12 imagers share three intensifiers and two CCDs. The CCDs are operated in a frame-transfer mode; half of the CCD is masked off, and the accumulated image on the other half is transferred quickly to the dark half, ending the exposure. Figure 8 shows how the images are placed on the two CCDs. The images on one CCD are listed first in each box and the imagers on the other CCD are listed second. The twelve imagers are distributed between the two CCDs to minimize the loss if one CCD were to fail. The details of each type of imager will be discussed below.

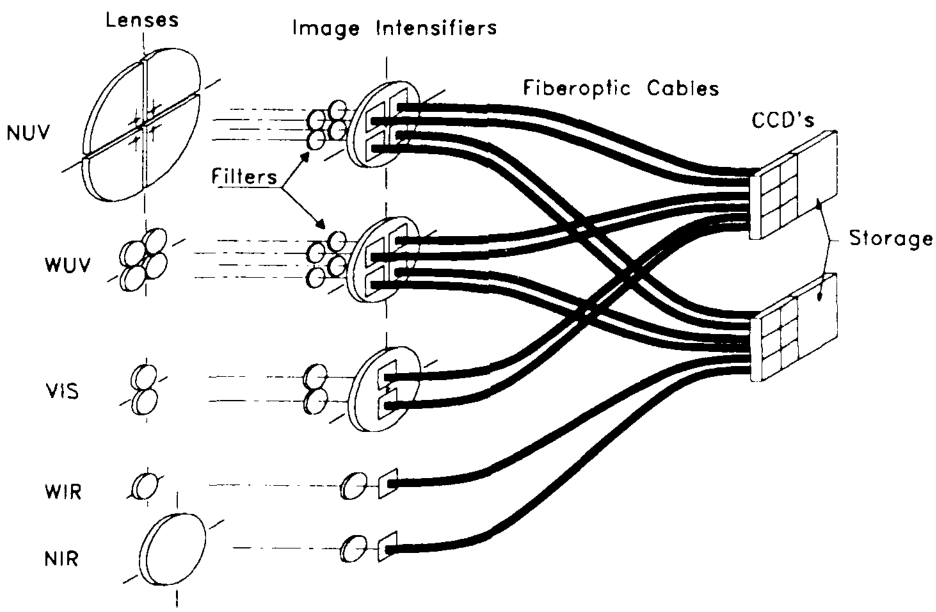

Figure 7. Scheme for sharing three image intensifiers and two CCD's among twelve imagers.

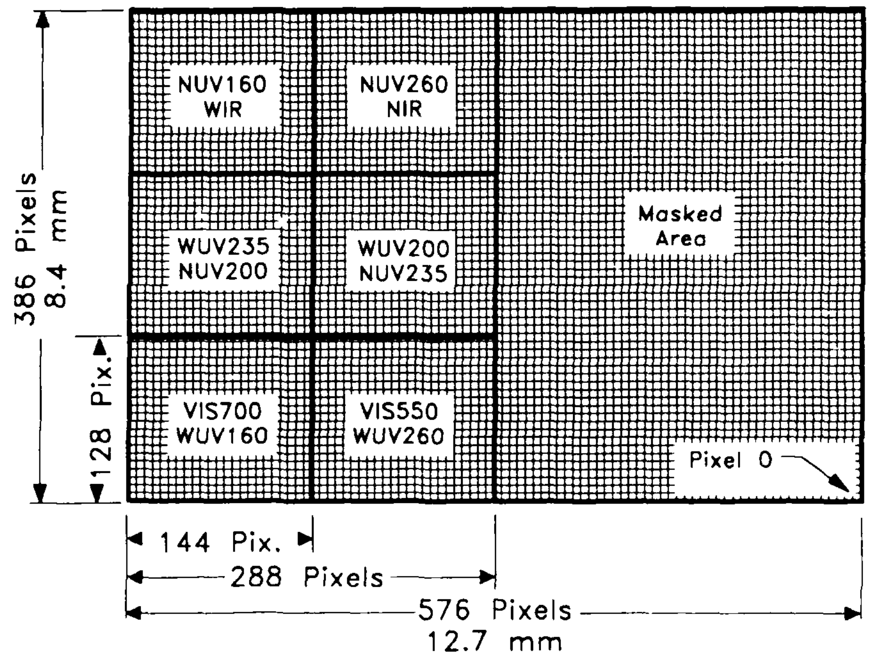

Figure 8. Arrangement of twelve imagers on two CCD's.

3.1 Infrared Imagers

The IR imagers are the simplest. They are unintensified; thus, the images are formed directly on the end of the fiberoptic conduit. Figure 9 (top) shows two views of the WIR lens, which has an 18° field of view, and (bottom) the NIR lens, which has a 2° field of view. The lens of the WIR (NIR) imager has a diameter of 5 mm (40 mm) and a focal length of 9 mm (75 mm) resulting in an f-ratio of 1.8 (1.9). Instead of interference filters, these imagers have simple cutoff filters to eliminate wavelengths shorter than 700 nm. The decrease in red sensitivity of the CCD (Si photosensitive device) provides a long wavelength cutoff at about 1100 nm. The result is a spectral range centered at 900 nm with a half-width of about 400 nm. (see Appendix A for filter curves.) These imagers will be used to monitor the target brightness and for recording pointing information.

3.2 Visible Imagers

Figure 10 shows the two visible imagers, which share a single S-20 intensifier. Each has a 9 mm diameter lens with a 35-mm focal length resulting in an f-ratio of 3.8. The imagers have 5° fields of view and are identical except for the interference filters. The interference-filter bandpasses are 550 nm and

700 nm, with 200-nm spectral half-widths. (See Appendix A for filter curves.) These two imagers are intended primarily for obtaining images of the shuttle and of star fields for use in postflight fine-pointing determinations.

3.3 Wide-Angle Ultraviolet Imagers

The WUV imagers presented some special problems. The 25° field of view required a lens with 6.8-mm focal length; however, both the intensifier window, which is 5 mm thick, and an interference filter must to fit within the 6.8-mm space. The approach chosen was uses a hemispherical lens and flat spacer, both made of MgF_2. The interference filters were deposited onto the spacer. The aperture stop was placed at the base of the hemisphere, thereby constraining the ray bundles from all acceptable angles to have common optical properties. Figure 11 shows the WUV imagers. The WUV lenses are identical, each having a 3.5-mm diameter aperture, which provides an f-ratio of nearly two. The four imagers share a single intensifier. The four interference filters have spectral bandpasses centered at 160, 200, 235, and 260 nm, with 25-nm spectral half-widths. (See Appendix A for filter curves.) These imagers are intended to provide a large-scale picture of the UV emissions.

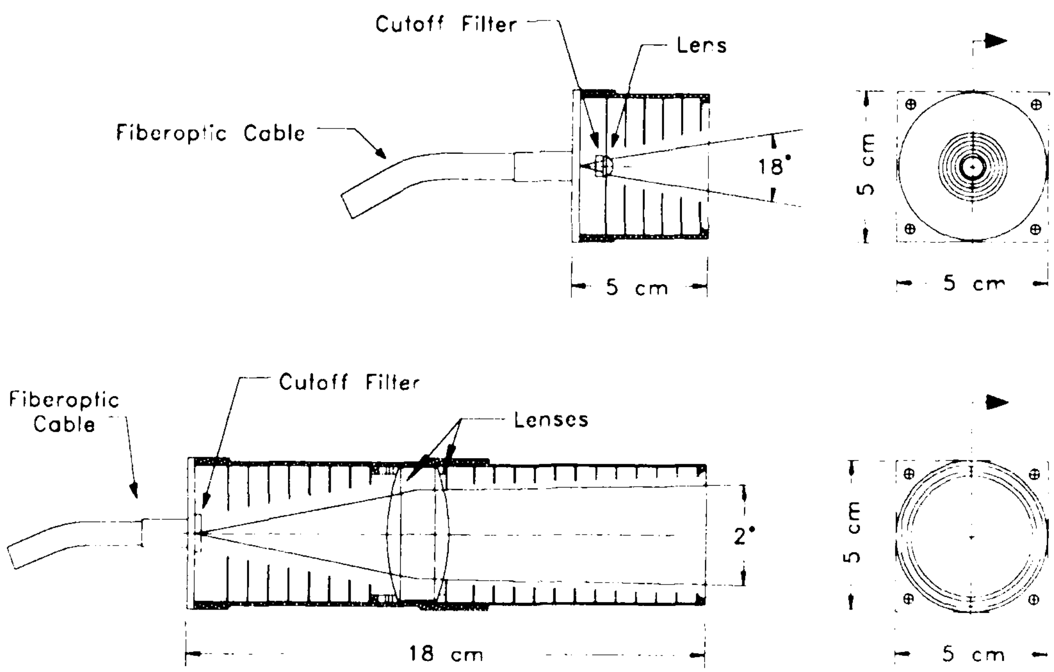

Figure 9. Wide angle and narrow angle infrared imagers.

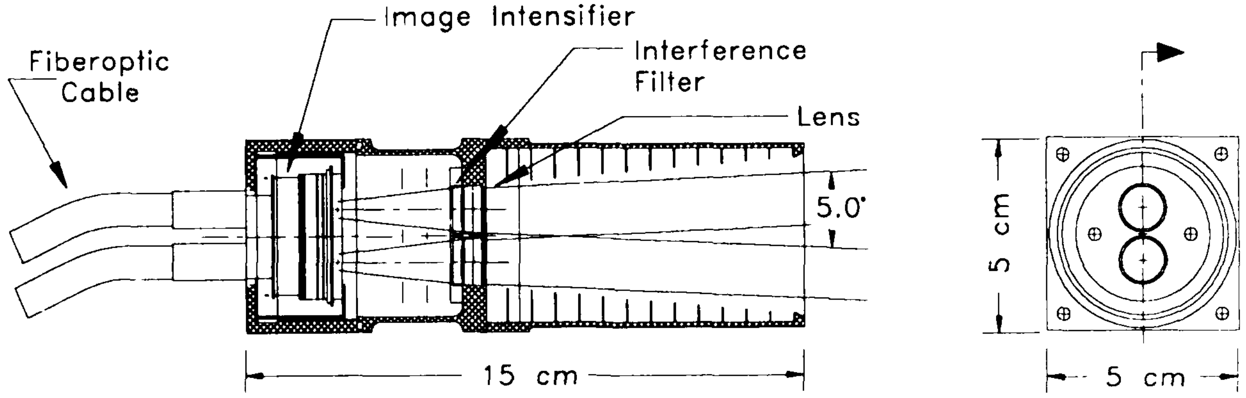

Figure 10. Two views of the visible imagers.

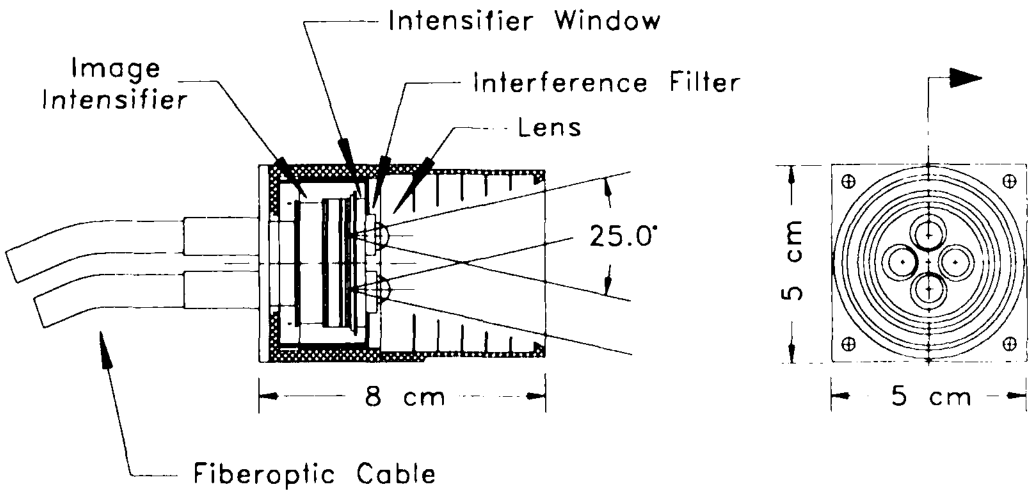

Figure 11. Two views of the 4 WUV (25° FOV) imagers. Note that the 4 imagers share a single intensifier.

3.4 Narrow-Angle Ultraviolet Imagers

The NUV imagers also presented some unique problems. The design goals included 2° field of view and maximum sensitivity, while maintaining simplicity and low weight by using a single image intensifier. Since the lenses have relatively long focal lengths, they must have a larger diameter to obtain an adequate f-ratio. A large diameter conflicts with the requirement to keep the optical axes close enough to permit sharing a single intensifier. This problem was solved by cutting a single lens into four quarters, which were separated slightly to provide four separate optical axes. A commercially available (Nye Optical Co.) Cassagrain lens coated for the UV was used. Both the primary and secondary mirrors were cut radially into four pieces, which were then remounted with a 9 mm gap as shown in Figure 12. The optical axis of each mirror set is separated by 9 mm resulting in four images on the intensifier. The original UV cassagrain lens had a focal length of 90 mm and an f-ratio of 1.1. Cutting the lens reduced the aperture of each imager to 1/4 that of the original lens and resulted in an effective f-ratio of 2.2 for each of the narrow UV imagers. The four imagers have similar filters to those in the WUV imagers. (see Appendix A for filter curves.)

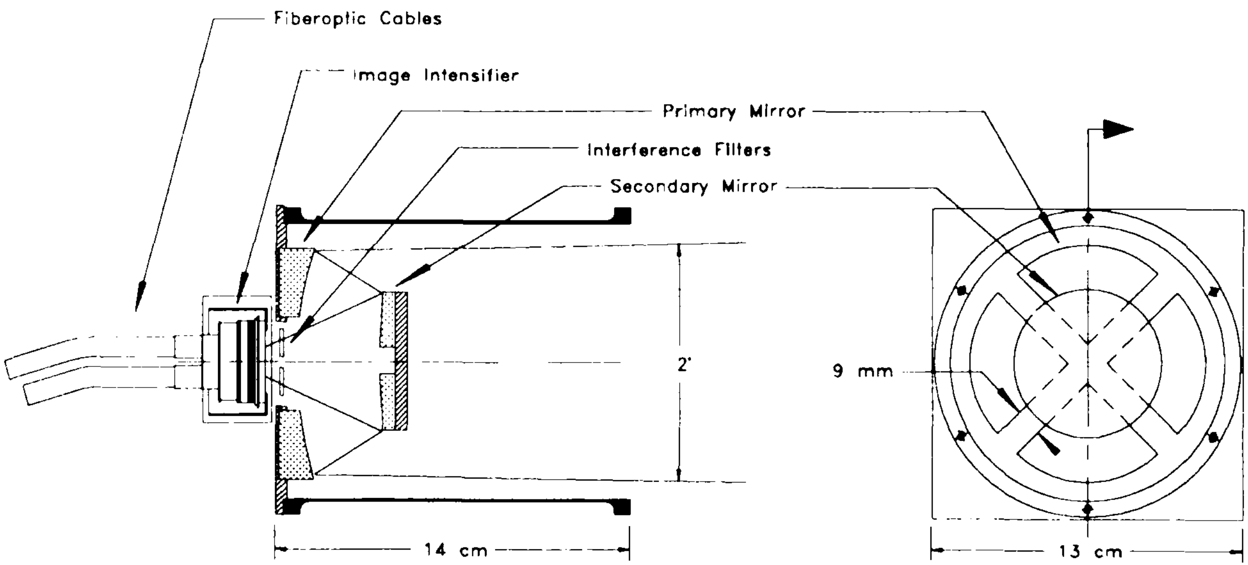

Figure 12. Two views of the four narrow-angle ultraviolet imagers.

4. INTENSIFIED CCD DETECTORS

The AIS incorporates CCD's to record the spectra and images. In the UV and visible regions of the spectrum, the signals are enhanced by proximity focused image intensifiers. In the near-IR region of the spectrum, no intensifiers were included since in the near-IR, an unintensified CCD has similar sensitivity to an intensified CCD (ICCD) with an S-1 sensitivity.

The development and application of the ICCD has been described by Broadfoot and Sandel [1986, 1990]. The ICCD lends itself well to the applications described in this report because of its dynamic range. The addition of image intensifier to a CCD results in a photon counting devices. Broadfoot and Sandel [1990] and others have described the use of the ICCD in airglow and auroral measurements.

4.1 Image Intensifiers

The seven intensifiers used in the AIS are sealed, proximity-focused image intensifiers (some from ITT Corp. and some from Varo Inc.). The intensifiers have a photocathode that detects the incoming light and a phosphor screen to regenerate the image. Between these, a series of microchannel plate electron multipliers amplify the signal to produce a much brighter image at the phosphor screen. The voltage across the microchannel plates determines the photoelectric gain of the intensifier. A single photon entering the intensifier and striking the photocathode can result in 10^4 photons emitted from the phosphor screen.

The photocathode must be at a potential of -200 volts (-800 volts for the GaAs intensifier) with respect to the front of the microchannel-plate electron-multiplier. The microchannel-plate has up to 800 volts across it to multiply the photoelectrons. A potential of 6000 volts is required to accelerate the electrons leaving the microchannel plate, about 2500 volts of which is used to penetrate an aluminum overcoat of the phosphor anode and the remaining energy is absorbed by the phosphor, which re-emits photons in the 500-700 nm region. The photo-event is spatially indexed by the microchannel plates and fiberoptic coupler to the CCD.

The spectral response of the intensifier depends on the material of the intensifier window and the material of the photocathode. Three types of photocathodes were used in order to match the spectral sensitivity of the intensifiers to the spectral region of interest. Three intensifiers with UV-sensitive CsTe photocathodes were used: one for the two UV spectrographs, one for the four WUV imagers, and one for the four NUV imagers. Three intensifiers with S-20 photocathodes were used: two for the four visible spectrographs, and one for the two VIS imagers. One intensifier with a GaAs photocathode was used for the two spectrographs between 600 and 900 nm. This intensifier is fairly new to the market and its performance under the adverse conditions of the space environment is as yet unknown. The IR spectrograph (900 to 1100 nm) and the IR imagers are unintensified.

The exposure is controlled by gating the voltage between the photocathode and microchannel plate in the intensifier. When the cathode potential is at +40 volts with respect to the front of the microchannel plate, no electrons escape the photocathode. When the photocathode is at -200 volts, photoelectrons are accelerated to the microchannel plate with enough energy to multiply on collision and begin an electron cascade multiplication process.

4.2 Fiberoptic Conduit

Both imagers and spectrographs use coherent fiberoptic bundles, called image conduits, to transfer images from the intensifier to the CCD. The spectrographs have short rigid fiberoptic blocks, while the imagers have long flexible fiberoptic cables.

The fiberoptic cables have cross-sectional dimensions of 2.8 by 3.2 mm which define the size of the image. They were constructed so that at the face of the CCD, six fiberoptic cables are merged into a single bundle with dimensions of 8.4 by 6.4 mm, which just covers half of the CCD. This merging of fiberoptic cables allows six images to be collected by one CCD. The fiberoptic cables are 60 cm long; each fiberoptic strand is about 0.004 mm in diameter resulting in about 20 strands per CCD pixel.

The spectrograph fiberoptic blocks are simpler in that each intensifier is connected directly to a single CCD. The short fiberoptic blocks, transfer the image from the phosphor to the CCD.

4.3 CCD

The CCDs used throughout the AIS, are 386 by 576 pixel, 2-dimensional arrays (model P6802 made by English Electric Valve Company). Each pixel is 0.022 mm on a side and the overall sensitive area is 12.7 by 8.4 mm. Incident photons initiate electron-hole pairs. The electrons migrate, depleting potential wells, one at each pixel of the CCD. Once the exposure is complete, the potential wells are shifted towards one corner of the CCD. The charge required to refill each potential well is measured accurately with a 12 bit analog-to-digital converter, which transforms the signal into a digital number.

The imagers use the frame-transfer mode of the CCD in which the image is quickly transferred to the masked half of the CCD, to control the exposure. The charges can be moved to the masked half of the CCD 100 times faster than they can be read out from the CCD. The transfer takes about 300 microseconds whereas the readout takes about 300 milliseconds.

The effects of temperature on ICCD's are important. It is usually necessary to cool the CCDs to reduce the effect of thermal electrons that add to the signal. At room temperature these will flow from potential wells of the CCD so fast that saturation levels will be reached in several seconds. Bright sources and high readout rates are required to operate a CCD at room temperature. The predicted brightness of the targets during the planned space mission are such that 60-second exposures will be needed. Such exposures require that the CCD temperature be no higher than 0° C. For the IBSS mission, a thermal analysis indicated that the AIS should remain below -10°C for the duration of the mission, so no active cooling was provided. Other applications of similar instruments will require that the CCD's are cooled or that newer CCD's be used that have less thermal noise at higher temperatures. The AIS design has the option of adding a cooling system that can keep the CCDs about 20 to 30°C below the ambient temperature. Cooling can be done actively with thermoelectric or circulating-refrigerant coolers or passively with radiative coolers.

5. SCAN PLATFORM AND SENSOR HEAD

The scan platform holds the sensor head so that the instruments can be pointed in nearly any direction independent of the spacecraft (see Figure 1). The Scan platform has two axes of rotation. Motion in the azimuth direction is on a pre-loaded bearing race. Motion in the elevation direction is accomplished by suspending the sensor head between two supporting structures with a bearing at one end and a bushing at the other.

The movements of the scan platform are controlled by two stepping motors, one for azimuth and one for elevation, each of which turns a worm gear. In order to maximize the number of teeth that are engaged, the worm gears are doubly tapered cone gears allowing 19 teeth to be engaged at a time. The elevation drive has a gear ratio of 120 while the azimuth drive has a gear ratio of 240. The stepping motors have 200 steps per shaft revolution and are driven at a rate of 35 rpm. The scan platform moves the sensor head in azimuth at a rate of 52° per minute with 0.0082° resolution and it moves in elevation at a rate of 105° per minute with 0.014° resolution. The sensor head can be pointed from -60° to +135° in elevation and from -175° to +175° in azimuth. The pointing position of the instruments in a given axis is determined by monitoring the number of stepping motor steps moved from a position sensitive switch at a predefined zero position. Four other switches define the positive and negative limits of motion in each axis.

6. ELECTRONICS

The AIS electronics include a computer based instrument control unit, a low-voltage power supply system, a high-voltage power supply system, a motor-drive box, and a data recorder. Figure 13 is a block diagram of the different components. Each component is a separate box and the boxes are connected by the cable harness. The boxes are designed to bolt on to a flat surface with a square bolt hole pattern spaced at 70 mm. Further details of the box dimensions can be found in the drawings in Appendix B. The following sections describe the design, operation, performance, and other characteristics of the components.

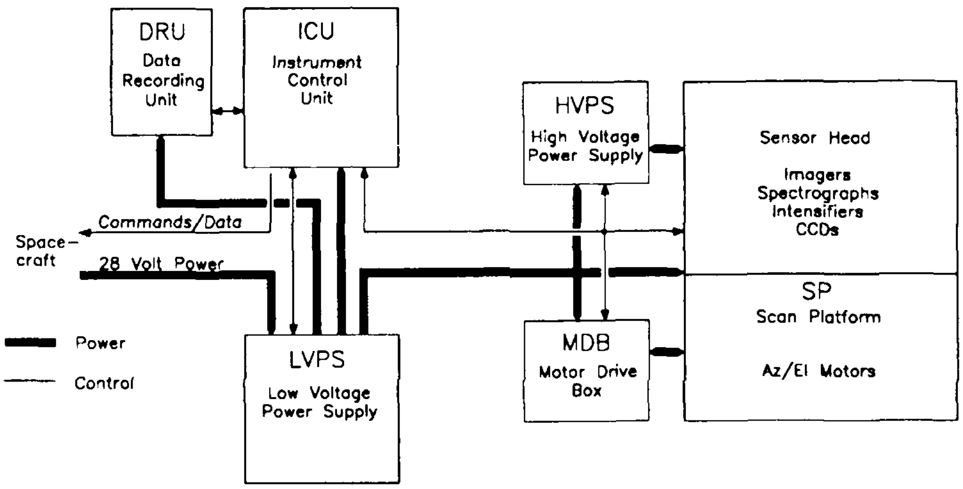

Figure 11. Block diagram of the electronics.

6.1 Instrument Control Unit (ICU)

The Instrument Control Unit contains the computer and most of the AIS control and interface circuitry. The computer was built by Faraday Inc. and is based on an IBM-XT bus structure and an Intel 80C88 microprocessor operating at 4 Mhz. The BIOS code is stored in non-volatile fuse-link ROMS.

The computer software runs as a stand-alone operating environment. In making a specified set of measurements, the computer will retrieve and run an experiment sequence, referred to as a template, which controls all variable parameters in the operation of the imagers and spectrographs and recording the data. The parameters include the azimuth and elevation pointing angles, exposure duration for each imager and spectrograph, gain of each intensifier, and number of pixels to be added together on each CCD. Embedded in some of the template commands are more basic elements of the control of the AIS such as turning on/off power supplies. Details of the AIS template commands are described in Appendix C.

To withstand the harshness of the orbiter launch and the space environment, the AIS uses a Eurocard connector system. There are 15 circuit cards on the ICU bus.

Computer processing unit
Boot ROM
Capacitor-backed RAM and EPROM
Summation-memory Controller
Summation memory (3 cards, 1-megabyte per card)
Digital input/output board
House keeping (2 cards)
Micro-control unit
Analog-to-digital converter
SCSI
Communication interface

The computer processing unit card holds the Faraday computer. The Faraday is commercially available computer built onto a single card and includes controlling circuitry, and 256 Kbytes of static RAM. The Faraday card is mounted on top of a Eurocard.

The boot ROM card holds the non-volatile fuse-link ROM chips that contain the BIOS-based boot program. These ROM chips are resilient to strong radiation and are designed to work in space without loss of stored information.

The RAM and EPROM card holds both the RAM chips and the EPROM chips. The executable program and templates are stored in triplicate on standard EPROMs. Triplicate storage provides a very high probability that at least one complete version will survive the mission. There are 80 kbytes of capacitor-backed RAM for storage of such data as azimuth and elevation positions, optical-disk sector, and modified templates. The capacitor can power the RAM for several days so short disruptions in the power supplied to the AIS will not require a complete reinitialization of all parameters.

The summation memory consists of three megabytes of RAM for the temporary storage of data. During an individual experiment it is desirable to have uninterrupted processing. Therefore instead of transferring each spectrum or image to the data recorder or the downlink queue, either of which may take several minutes, the data are temporarily accumulated in the summation memory. When the experiment sequence is finished, the data can be transferred to the data recorder or the downlink queue.

The digital input/output card contains the interfaces needed for the computer to control individual power converters and supplies. Items such as the data recorder, the CCDs, and the stepping motors require specific voltages at various times during an experiment. To conserve power, it is desirable to supply these only when needed, so switching of supplies is done by computer through the digital input/output board. The high voltage power supplies for the image intensifiers are also operated through this card.

The housekeeping card interprets the signals from all internal monitors of temperature and voltage at key locations: the temperatures of the CCDs, the low- and high-voltage power supplies, specific electronic chips, like the analog-to-digital converter, and the voltage levels of all internal power converters are monitored. These housekeeping data are sent continuously to the downlink queue, allowing an operator on the ground to monitor the status of the AIS.

The micro control unit (MCU) card controls the readout of the CCD. The MCU is a separate processor that can be commanded to perform simple functions such as reading part of a CCD or adding adjacent rows of pixels.

The Small Computer System Interface (SCSI) card is a standard communication device that is required to send data to the data recorder. The data recorder is an optical disk and will be used for primary data storage and is described in Section 5.5.

The communication interface card allows for the asynchronous transmission of commands to and from the spacecraft. Commands sent from the ground through the spacecraft to the AIS are stored on this card in a command queue so that the AIS computer is not necessarily interrupted. There are, however, commands that will cause the AIS to abort ongoing operations and read the next command in the queue or to abort and clear the queue. Data are sent from the AIS to the spacecraft downlink at either 800 or 2400 bits per second depending on the mission time line. These data rates are much too low to send large quantities of data to the ground; therefore the primary method of data storage is recording on an optical disk.

6.3 High-Voltage Power Supply (HVPS)

Each image intensifier requires several simultaneous voltages to accelerate and multiply the electrons. These voltages are supplied by seven power supplies, one for each intensifier. They are mounted together to form the HVPS.

The voltage supplied to an intensifier, applied in the same direction, consists of 200 volts (800 volts for the GaAs device) to accelerate photoelectrons to the microchannel-plate electron-multipliers, 800 volts across the microchannel-plates, and 6000 volts to accelerate the electrons to the phosphor anode. (about 2500 volts is required to penetrate the aluminum over-coating of phosphor anode.) The ICU controls each of the seven high voltage power supplies so all of these can be selected through the software.

6.4 Motor Drive Box (MDB)

The stepping motors that drive the rotation of the scan platform (see Section 5), are controlled by the ICU through the MDB box. The parameters such as step rate and duty cycle (on time vs. off time) are controlled by software. The MDB interprets commands from the computer and sends the appropriate pulses of current to the stepping motors.

6.5 Data Recording Unit (DRU)

The data will be stored digitally on an optical disk device that has a 200 megabyte storage capacity. The optical disk was built by OptiTech Corp. and ruggedized to military specifications by Mountain Optec corp.. The optical disk and its power converters are housed in a hermetically sealed box that maintains the internal pressure at one atmosphere.

6.6 Cables

There are hundreds of wires that run between the seven components of the AIS to carry control and data signals and power. These are teflon coated, twisted, shielded, wire pairs which terminate in shielded subminiature D-series connectors. The wires are bundled together to form a harness. The size and weight of the harness are significant as can be seen in Appendix B.

7. CALIBRATION

Calibration of the instrument is done in three stages. There will be preflight and postflight calibrations executed on the ground and an in-flight calibration executed while the instrument is in-flight. The pre-flight and post flight calibrations include measurement the following items:

1. Field of view and coalignment of imagers and spectrographs
2. Wavelength calibration and spectral line shapes of spectrographs
3. Sensitivity as a function of wavelength of imagers and spectrographs

Inflight calibration will include observation of stars of known brightness. The preflight calibration has been performed and is described in the following paragraphs.

7.1 Field of View and Alignment

This measurement was made by scanning the AIS across a calibration lamp. A bright high-pressure hydrogen lamp placed 10 m from the instrument was observable by all of the imagers and most of the spectrographs. It was positioned in the center of the NIR image. The scan platform was then moved in azimuth and elevation, repositioning the image of the lamp on the CCD array. The relationship between the position of the lamp in the image and the angular motion of the scan platform was measured. With this information it was possible to determine the degree of coalignment and the total angular fields of view of the imagers. Figure 14 shows all of the measured imager fields of view at an object distance of 1000 m referenced to the optical axis of the NIR imager. The observed offsets of the instruments are the result to small lens and mirror misalignments and will be compensated for in the analysis of the data.

The spectrograph fields of view parallel to the slit were measured by the same method. The field of view perpendicular to the slit was a little more difficult to determine since the image is spectrally dispersed in this dimension and a spectral line source was required. The variation in the brightness of a spectral line was measured as a function of scan-platform elevation angle yielding the field of view across the axis of the slit.

Figure 15 shows the spectrograph fields of view relative to the optical axis of the NIR imager. There is a systematic offset between two spectrographs within an optical bench due to spherical aberration and will be compensated for in the analysis of the data.

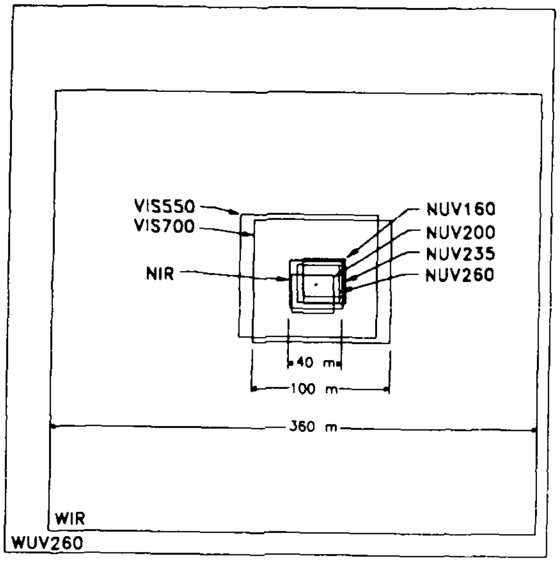

Figure 14. Fields of view of the imagers at a distance of 1000 meters.

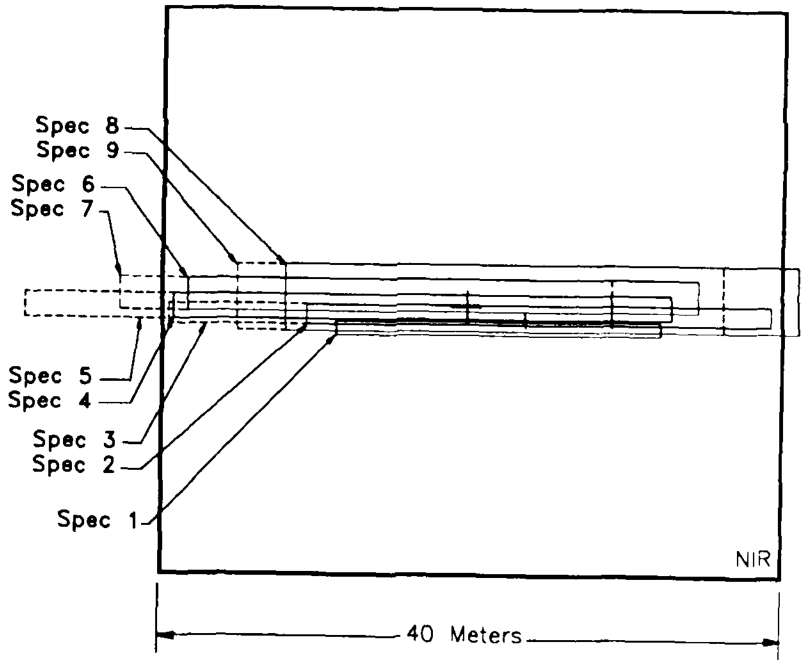

Figure 15. Spectrograph fields of view projected at 1000 m and shown relative to the NIR imager.

7.2 Wavelength calibration and Spectral Resolution

The wavelength scale for each spectrograph is approximately linear, so the position of two known spectral lines define the wavelength as a function of pixel position. Common discharge light sources such as He, H, Ar, Xe, Kr, Fe, and Ne were used for this measurement. Since numerous lines were usually present, it was possible to have several checks of the wavelength calibration for each spectrograph.

The spectral resolution was also obtained from this data. The spectral line shape and line width are governed by many variables, such as slit width, grating function, optical focus, and undersampling of the spectra by the CCD. The line shapes may vary significantly across a given spectrum. For these reasons, the best method of determining the spectral resolution and slit function is to look at the line sources and observe the line shapes. This was done with the same data as was used in the previous section.

The theoretical slit function in the image plane is a square function of width equal to that of the slit. The AIS slit is slightly more than two pixels wide (0.066 mm). The actual slit function is affected by undersampling and small misalignments in the spectrographs and is spread across 3 or 4 pixels. The final spectral resolution is slightly less than the optimum; however, further adjustments were not possible during the latter stages of hardware integration onto the spacecraft. Table 3 lists the measured wavelength range and the measured spectral resolution of each spectrograph. The spectral dispersion can be calculated from the spectral resolution and wavelength range; this value is also listed in Table 3. Also listed in the table are the quantum efficiencies of the photosensitive devices (as given by the manufacturers), the f-ratio of the foreoptics, and the sensitivity of the spectrographs (described in Section 7.4).

7.3 Spectral Sensitivity of Imagers

Ten of the 12 imagers have bandpass filters to select specific regions of the spectrum. The spectral response of the imager is the convolution of detector response and filter transmission. To determine their transmission as a function of wavelength, the filters were placed between a continuum light source and a diffusing screen. The screen was viewed with a spectrophotometer to measure brightness as a function of wavelength. The spectral response of the photocathods and CCDs were supplied by the manufacturer; in most of the imagers it varies only slightly across the pass-band of the filter.

Two of the imagers (NIR and WIR) use cutoff filters to eliminate wavelengths shorter than 780 nm. The long-wavelength cutoff results from the fall off in photometric sensitivity of the silicon of the CCD array. Spectral characteristics of the interference filters are shown in Appendix A. Curves of spectral response of the imagers are nearly the same as the filter curves shown in the appendix.

Table 3. Spectrograph parameters and calibration results.

Spectrgrph. Number	Wavelength (nm)	Measured Resolution (nm)	Dispersion (nm/pix)	Quantum Efficiency (%)	F-Ratio	Sensitivity (DN/sec for a 10 R/nm signal)
1	900 - 1090	1.3	.32	10[1]	2.9	0.019
2	764 - 930	0.9	.29	18[2]	4.1	8.1
3	608 - 774	0.9	.29	18	4.1	4.6
4	532 - 617	0.45	.15	12[3]	4.1	2.1
5	462 - 548	0.45	.15	12	4.1	3.9
6	382 - 468	0.45	.15	15[3]	4.1	0.9
7	300 - 386	0.45	.15	15	4.1	2.1
8	200 - 302	0.54	.18	6[4]	4.1	1.1
9	114 - 220	0.54	.18	5	4.1	1.1

Photocathode [1]Si (unintensified) [2]GaAs [3]S-20 [4]CsTe

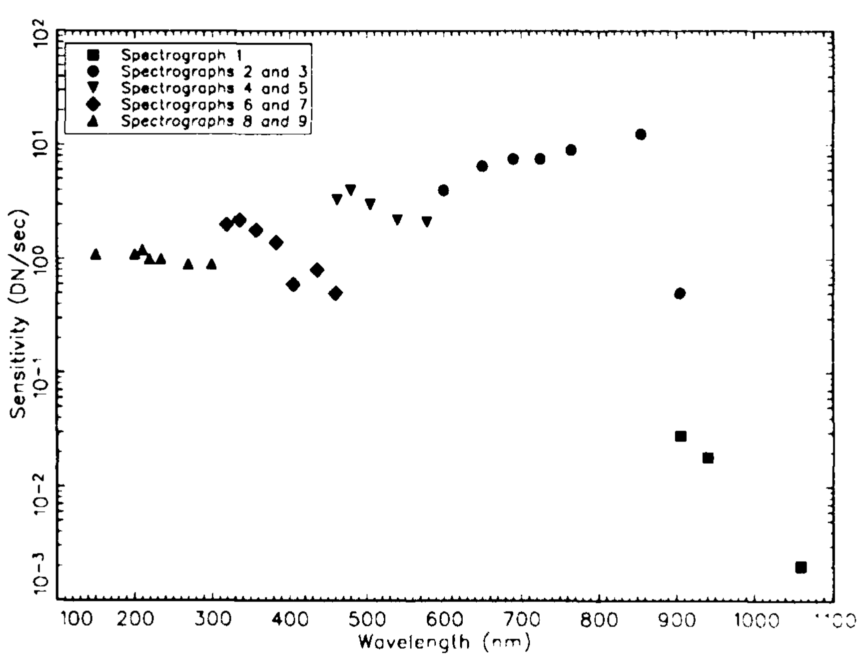

Figure 16. Spectrograph sensitivity plotted as a function of wavelength.

7.4 Photometric Calibration

The sensitivity of the spectrographs was determined using a continuum light source, a set of calibrated pass-band interference filters (calibration filters), a diffusing screen, and a calibrated detector. For each of the nine spectrographs, at least two and as many as four filters were used. The diffusing screen provided an extended source that filled the fields of view of the spectrographs. Each calibration filter was placed between the lamp and the screen; the screen was positioned so that it filled the field of view of the spectrograph. The screen brightness as a function of wave length was measured with the spectrograph; the signal at the peak transmission-wavelength of the calibration filter was determined. The procedure was repeated for several filters within the spectral sensitivity of a given spectrograph. The sensitivity of the spectrograph as a function of wavelength was calculated from these values. The results are listed in the last column of Table 3. The sensitivity is given in units of Digital Number (DN) per second for a 10 Rayleigh/nm signal. A DN is an incremental step in the output of the analog-to-digital converter. The results of the calibration are shown graphically in Figure 16. The UV and visible spectrographs are as sensitive as calculations predicted. The near-IR channel with the untested GaAs intensifier was found to be much more sensitive than the bare CCD or the S-20 intensifier between 600 and 900 nm.

The photometric sensitivity of the imagers was measured by placing the continuum screen so it filled the field of view of the imagers. The screen brightness as a function of wavelength was measured using the calibrated detector and the calibration filters. The screen brightness was then convolved with the spectral response of each imager to obtain an absolute measure of the sensitivity of the imager as a function of wavelength. Some of the parameters of the nine imagers and the results of the photometric sensitivity calibration are listed in Table 5. The sensitivity is given in DN/sec for a 10 Rayleigh/nm continuum source. The sensitivity of the 12 imagers is shown graphically in Figure 17; Each of the imagers is represented by a single point.

Final verification of the AIS concept and design involved taking a similar instrument into the field and observing the twilight and nightglow from the ground. These measurements were made with a second version of the instrument for ground-based observations, but the optical components and detectors are nearly identical to those in the AIS. An example of these measurements is given in Figure 18 and the results are very encouraging. The figure shows a nightglow spectrum in the near IR obtained by and exposure to the night sky of 180 seconds. It demonstrates how the use of ICCDs and several coaligned spectrographs permit the observation of temporal variations on a time scale of seconds instead of hours.

Table 5. Imager parameters and calibration results.

Imager	Spectral Coverage FWHM (nm)	Angular Resolution (deg/pix)	Quantum Efficiency (%)	F-Ratio	Sensitivity (DN/sec for a 10 R/nm signal)
NIR	270	0.016°	10[1]	2.3	0.082
WIR	270	0.15°	10[1]	2.3	0.098
VIS550	78	0.042°	11[2]	2.6	4.0
VIS700	93	0.042°	9	2.6	2.3
NUV160	32	0.013°	5[3]	2.2	0.076
NUV200	25	0.013°	6	2.2	0.070
NUV235	20	0.013°	6	2.2	0.13
NUV260	24	0.013°	6	2.2	0.39
WUV160	30	0.17°	5[3]	2.2	0.58
WUV200	24	0.17°	6	2.2	0.55
WUV235	20	0.17°	6	2.2	0.65
WUV260	24	0.17°	6	2.2	1.6

Photocathode [1]Si (unintensified) [2]S-20 [3]CsTe

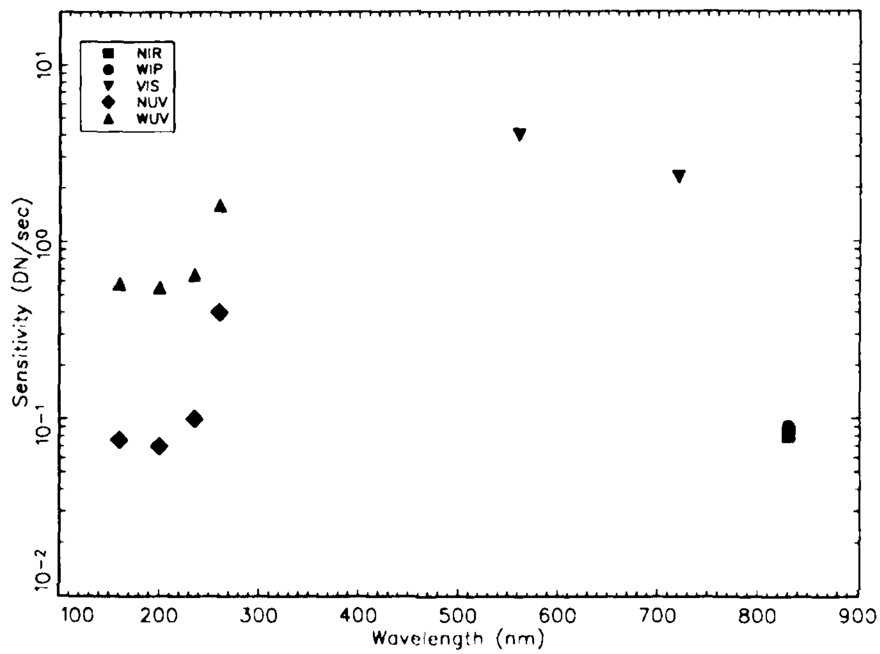

Figure 17. Imager sensitivity plotted as a function of wavelength.

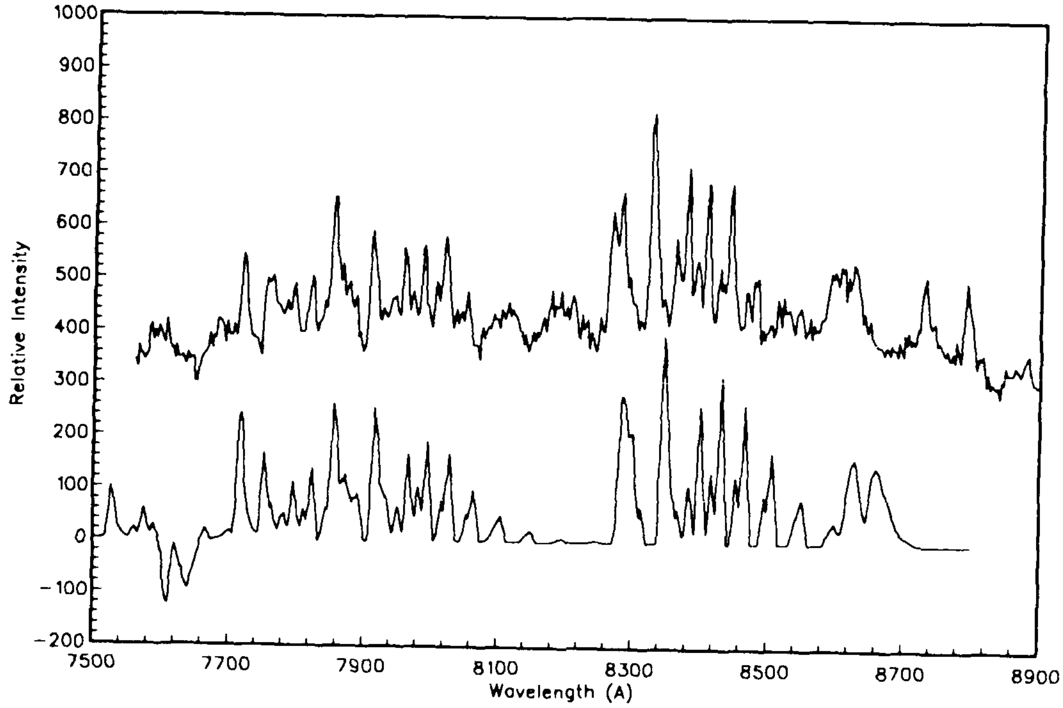

Figure 18. Nightglow data (top) showing numerous OH Meinel bands and two O_2 Atmospheric bands. A synthetic spectra (bottom) of the OH and O_2 bands is also shown.

8. INSTRUMENT OPERATION AND DATA REDUCTION

On the IBSS mission, the instrument can be commanded from either the ground or the flight deck of the Space Shuttle. To avoid sending commands to the wrong instrument, NASA has devised a command scheme in which each payload system responds only to a specific set of numbers; the AIS is assigned numbers 190 through 199. Some of the numbers represent single commands; the numbers 192 through 197 were made into a matrix so that all of the possible commands can be sent. Included in the matrix are the 16 hex numbers so that variables such as pointing angles and exposure times can also be sent to the AIS.

Figure 19 shows a flow chart of the AIS software. When power is applied, the instrument performs a bootup and health check. The status of various components are sent as a serial data string to the spacecraft for transmission to the ground. Commands are sent to the AIS through the spacecraft and are encoded as shown above. The AIS reads the commands from a command buffer, decodes it, and stores it at the bottom of a command stack. Each command is removed from the top of the command stack and executed in turn. In most cases the command will request that a specific experiment template be loaded on top of the Command Stack. The template can then be edited and then started.

A template begins by pointing the sensors in a predetermined direction and selecting which of the imagers and spectrographs will be exposed. The template controls the exposure of the different imagers and spectrographs and then records the data. The following example is a template that will be used to observe the aurora. A list of the template commands is given in Appendix C.

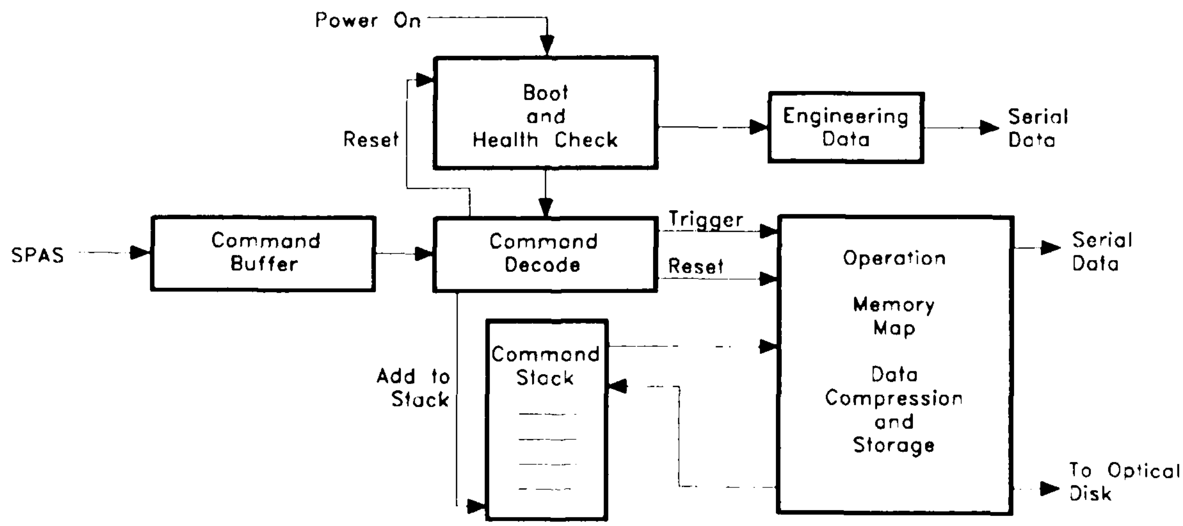

Figure 19. Flow diagram of the AIS operating system.

ln:	Command	Action
00:	expid, ELAUR	;Template, Earth Limb, Aurora, Deployed
01:	init,0.0,-5.0	;Initialize AIS to default conditions. Move -5° in elevation
02:	Select,ALL,ALL	;keep all images and all spectra
03:	set_cmpr,on	;Turn on data compression for downlinked data
04:	set_gain,SPEC2,15	;Set intensifier gain settings to maximum
05:	set_gain,SPEC3,14	
06:	set_gain,SPEC4,14	
07:	set_gain,SPEC5,14	
08:	set_gain,VIS,14	
09:	set_gain,WUV,14	
10:	set_gain.NUV,14	
11:	set_sum,IMAGERS,S2x2	;Set up imagers to sum 2 by 2
12:	set_sum,SPECTRA,S1x24	;Set up spectrographs to sum 1 by 24
13:	continuous,off	;Flush CCDs between reads
14:	flush,ALL	;flush all CCDs to clear out accumulated charge
15:	baseline	;set baseline for timing
16:	dark,SPECTRA,60.0	;Dark Spectra for 60 sec
17:	dark,IMAGERS,10.0	;Dark Images for 10 sec
18:	sync,63.0	;Wait for exposure to finish (63 seconds from baseline)
19:	wttrig	;Wait for external trigger before moving to next line
20:	fl2ush,ALL	;flush all CCDs
21:	baseline	;set baseline for timing (set timming clock to 0)
22:	expose,SPECTRA,30.0	;Expose Spectra for 30 sec (30 sec from baseline)
23:	expose,IMAGERS,10.0	;Expose Imagers for 10 sec
24:	sync,33.0	;Wait for exposure to finish
25:	downlink,none,ALL,3	;Downlink first set of spectra
26:	mov_el 1.0	;move up 1 degree elevation
27:	baseline	;set baseline for timing
28:	expose,SPECTRA,60.0	;Expose all spectrographs for 60 seconds
29:	sync,63.0	;wait until exposure is done before moving
30:	loop,26,3	;loop to line 26 three more times
31:	downlink,IR,none,4	;Downlink IR images
32:	mov_el,1.0	;Move up 1° (should be 0,0 position)
33:	flush,IMAGERS	;flush imagers
34:	baseline	;reestablish baseline for exposures
35:	expose,SPECTRA,30.0	;Expose spectrographs for 30 seconds
36:	expose,IMAGERS,10.0	;Expose Imagers for 10 sec
37:	sync,33.0	;Wait for expcsure to finish before move
38:	downlink,VIS,none,4	;Downlink visible images
39:	mov_el 1.0	;move up 1 degree in elevation
40:	baseline	;establish baseline time
41:	expose,SPECTRA,60.0	;Expose all spectrographs for 60 seconds
42:	sync,63.0	;Wait for exposure to finish
43:	loop,39,3	;loop three more times
44:	move_el,1.0	;Move up 1 degree in elevation
45:	flush,IMAGERS	;flush imagers
46:	baseline	;establish baseline time
47:	expose,SPECTRA,30.0	;expose spectrographs for 30 seconds
48:	expose,IMAGERS,10.0	;expose Imagers for 10 sec
49:	sync,33.0	;wait for exposure to finish
50:	go_el,0.0	;return to (true) bore sight
51:	set_compr,off	;Don't compress on Disk
52:	wrttape	;Write data to disk
53:	endt	;End template

The first two lines of the above template are initialization commands that define the template and move the scan platform to a predetermined orientation. The "init,0.0,-5.0" command sets some of the standard parameters and moves the scan platform to an azimuth angle of 0° and an elevation angle of -5°.

Lines 02 through 10 specify the parameters of the CCD readout and intensifiers. The "select" command specifies which imagers and which spectrographs will be exposed. The "set_gain" command sets the gain of the intensifiers. In most cases the data will be taken in darkness and the intensifier gains will be set to the maximum values.

Lines 11 and 12 specify the co-addition of pixels which governs the spatial resolution. The highest resolution requires that no pixels be summed together; however, the data will require more time to transfer from memory and more memory and disk space for storage. It should also be noted that summing several pixels together increases the sensitivity of the instrument by averaging out statistical fluctuations.

Lines 13 through 18 set up the CCDs and take a set of dark frames for calibration. The dark frames are taken with the same length exposure as subsequent data but the intensifiers are off, providing a measure of the background. The background level is sensitive to the CCD temperature and is therefore monitored frequently.

Line 19 is a command to wait for an external trigger. Many of the experiments will be correlated with other measurements or with activity aboard the Space Shuttle. The AIS can be commanded to sit and wait for a trigger command that will signal the start of an event.

Once the trigger is received the AIS can begin any sequence of exposures and movements. Typically, a set of images will be taken followed by a series of spectra, repeated several times at different exposures to be sure of getting the best exposure. The template shown above exposes the imagers for 10 seconds and the spectrographs for 30 and 60 seconds. Spectrographs require longer exposures than the imagers since the spectral dispersion is so much greater.

Data are stored in the 3-megabyte buffer until the end of a set of measurements. Portions or all of the data can be sent to either the data recorder or the downlink queue. Usually the complete data set is recorded by the data recorder and a few images and spectra will be sent to the ground so that the performance of the AIS can be monitored. In the template above, the first set of exposures are sent to the downlink queue while the subsequent exposures are being taken.

The low bandwidth and restrictive nature of the communication link requires that much of the data be compressed before being sent to the ground. Some data will be compressed for storage on the data recorder as well. The uncompressed data from a single exposure of all the imagers and spectrographs will nearly fill the 3 Mbytes of RAM. Note that the 7 CCD's have 1.5 million pixels, which, at two bytes per pixel could produce 3 megabytes of data. In order to store significant amounts of data, two reduction schemes will be used; 1) adjacent pixels within an image for a along a spectrograph slit can be summed,

2) the digital data can be compressed by approximating a 12-bit value by an eight-bit value.

Pixel summing can be done either by adding electrical charges before analog-to-digital conversion of by adding digital values stored in memory. In the spectrographs, summing is normally done only along the slit thereby retaining full spectral resolution. In the imagers, pixels are normally summed in groups of 2 by 2, 3 by 3, or 4 by 4, depending on experiment requirements. Summing more pixels not only reduces the data volume but increases sensitivity as well.

The compression of digital data uses a quasi-logarithmic scale that retains the five most significant bits of the original value and adds a four-bit code to indicate where the truncation occurred. Of the five retained its, the most significant bit is always a one, so it need not be recorded; each datum therefore requires a single 8-bit byte. The compression algorithm is as follows:

Data Compression

Step 1. If the original value is less than 32, store the eight least significant bits and end. (Bits 0-3 contain the true value, and bits 4-7, which are all zero, are taken as the code.) Otherwise proceed to step 2.

Step 2. Set the code to 2? and proceed to step 3.

Step 3. If the value is less than 32, store the least significant four bits as bits 0-3 and the code as bits 4-7 of the output byte, and end. Otherwise divide it by two (shift right one bit), increment the code by 1, and repeat step 3.

Once the data have been removed from RAM the instrument can turn off its internal power supplies and return to an idle state until the next experiment is initiated. In the idle state it continues to send information and engineering data to the downlink queue.

9. SUMMARY

The AIS is a unique combination of spectrographs and imagers designed to measure the entire spectrum from 115 to 1100 nm with sufficient spectral resolution to resolve rotational lines in most vibrational bands. The coaligned imagers will provide spatial images of a few prominent spectral features at selected wavelengths. Since it is a staring rather than scanning instrument, all of the spectra and images are obtained simultaneously, and short lived or rapidly changing events.

The use of CCDs and ICCDs provide a large dynamic range and sensitivity to record individual photons. The small size of the focal plane permits miniaturizing the optics and results in small size and low weight. The use of concave holographic gratings eliminates a number of optical elements for an even smaller size and lower weight. Finally the sharing of CCDs among several imagers or spectrographs results in a further reduction in size and weight.

Although it was designed for specific scientific objectives (that is, the study of shuttle glow), its versatility allows the AIS to be used for numerous other experiments such as studies of airglow or aurora. Small changes, such as modifications to foreoptics and the replacement of interference filters, could allow the design to be used in any number of applications.

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Appendix A:
AIS Interference Filter Curves

The following figures show the percentage of light transmitted through each filter plotted as a function of wavelength. There are six curves plotted for six types of imagers (see Figures A1 through A6). There are 4 UV filters which are used in both the Narrow field-of-view UV imagers and the Wide field-of-view UV imagers. Figures A1 through A4 show the transmission curves for the filters in the 4 NUV imagers. The WUV imagers have very similar filters. There are also two filters for the two VIS imagers (see Figures A5 and A6). The infrared imagers have cutoff filters that eliminate light with wavelengths less than 780 nm. The limit of sensitivity toward the red is determined by the falloff in detector sensitivity to long wavelength light at 1050 nm. The resulting sensitivity of the IR imagers is plotted in Figure A7. The curves plotted in Figures A1 through A7 are combined in Figure A8.

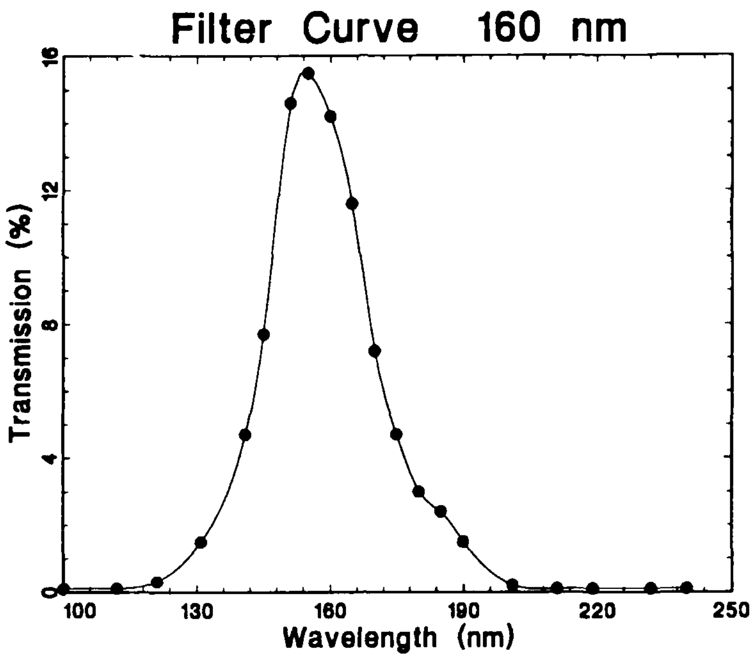


Figure A1. Interference filter transmission function for the NUV160 and WUV160 imagers. Percent transmission is plotted as a function of wavelength.

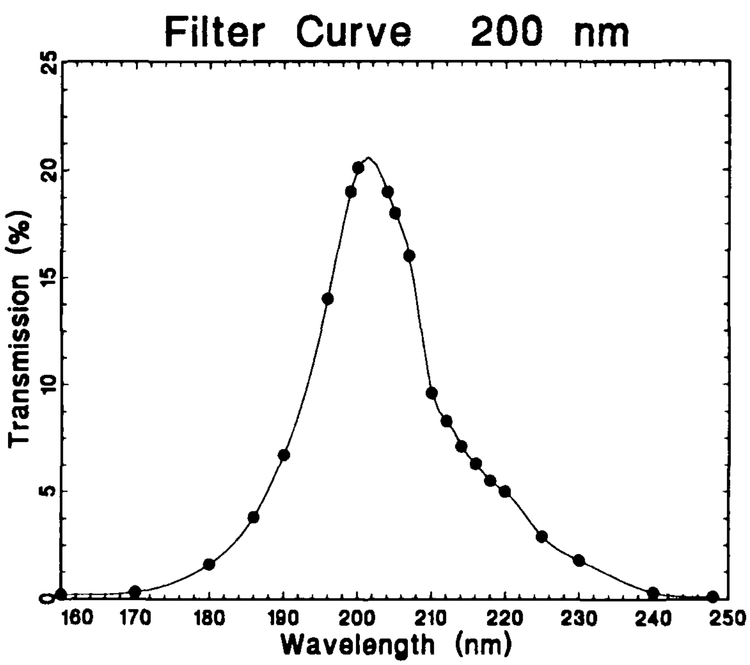


Figure A2. Interference filter transmission function for the NUV200 and WUV200 imagers. Percent transmission is plotted as a function of wavelength.

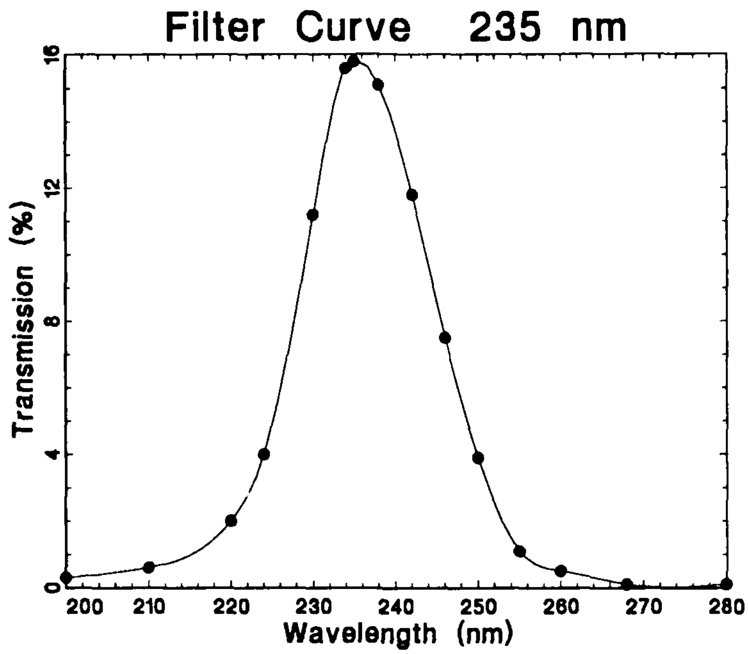


Figure A3. Interference filter transmission function for the NUV235 and WUV235 imagers. Percent transmission is plotted as a function of wavelength.

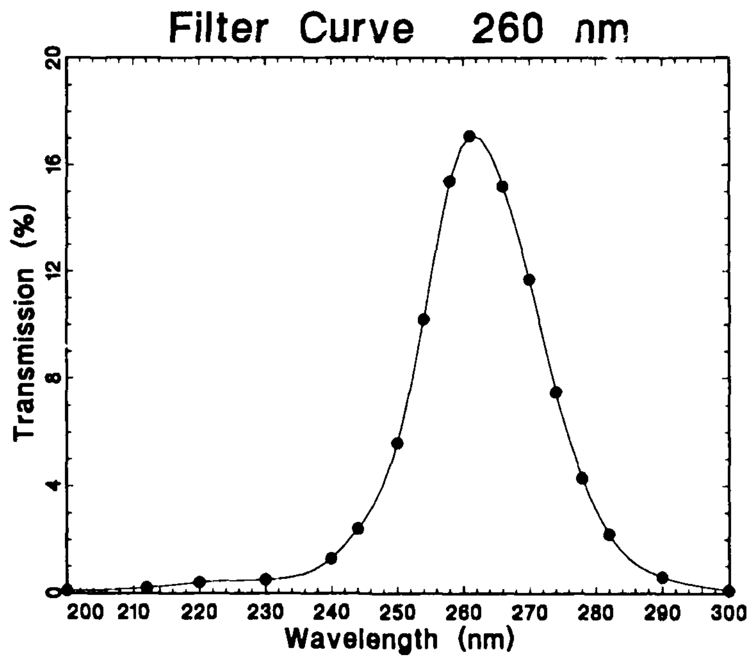


Figure A4. Interference filter transmission function for the NUV260 and WUV260 imagers. Percent transmission is plotted as a function of wavelength.

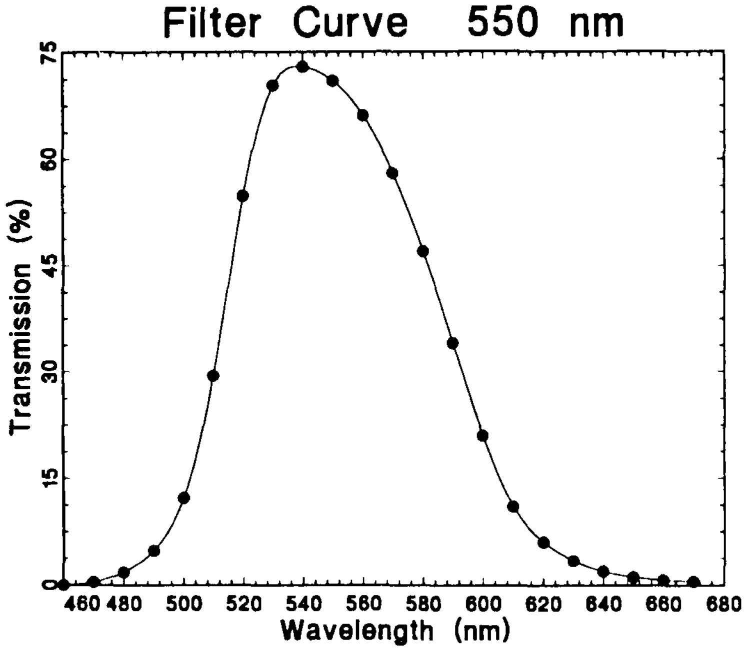


Figure A5. Interference filter transmission function for the VIS550 imager. Percent transmission is plotted as a function of wavelength.

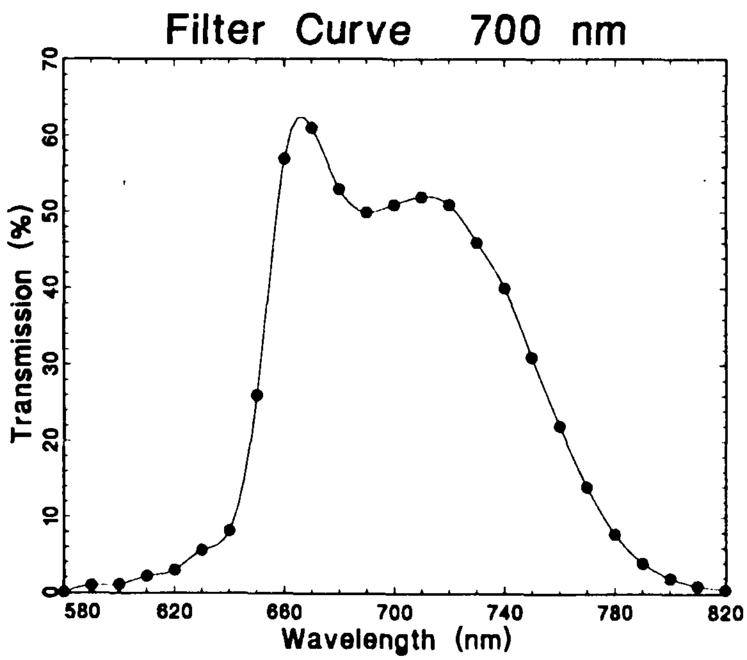


Figure A6. Interference filter transmission function for the VIS700 imager. Percent transmission is plotted as a function of wavelength.

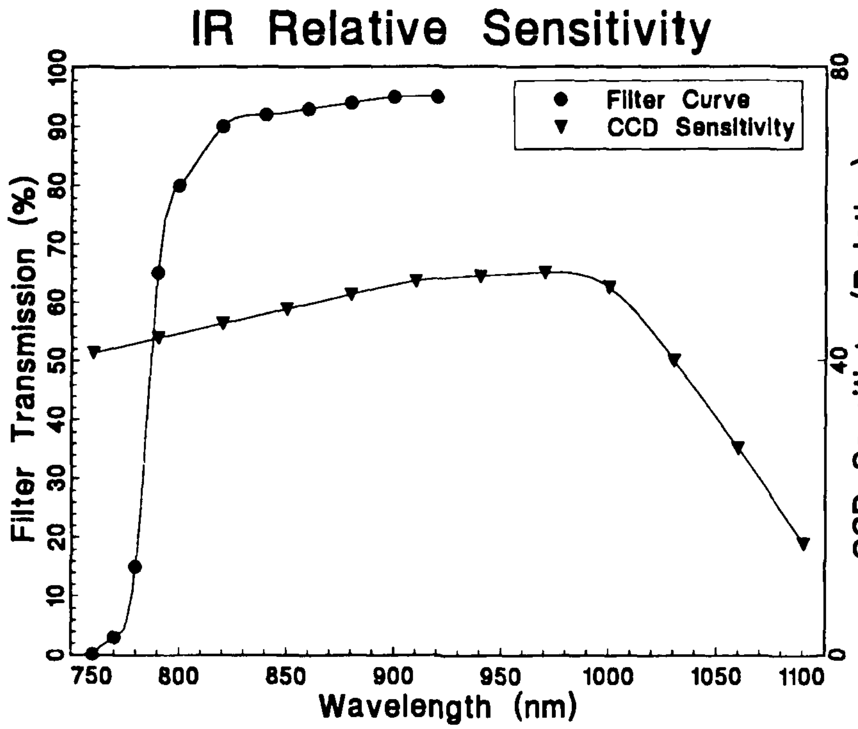


Figure A7. The NIR and WIR imagers have cut-off filters to define the short wavelength limit and the sensitivity of the Si faceplate of the CCD limits the long wavelength sensitivity. The two curves are plotted together.

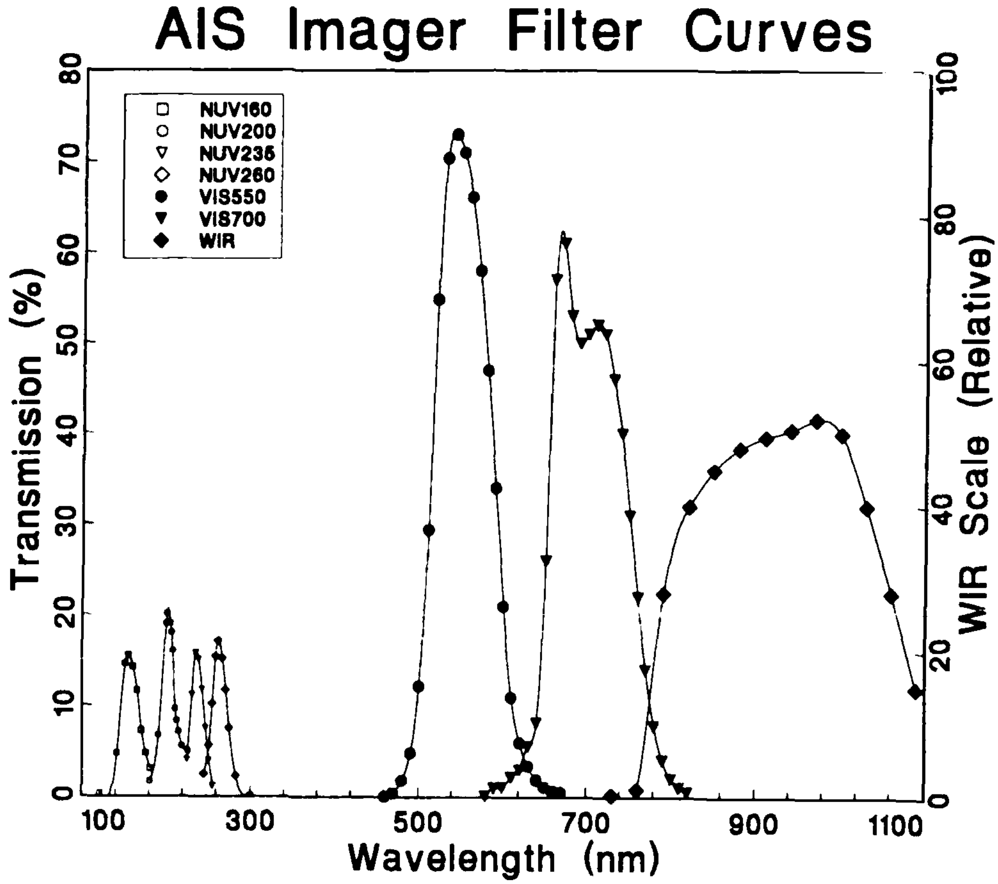


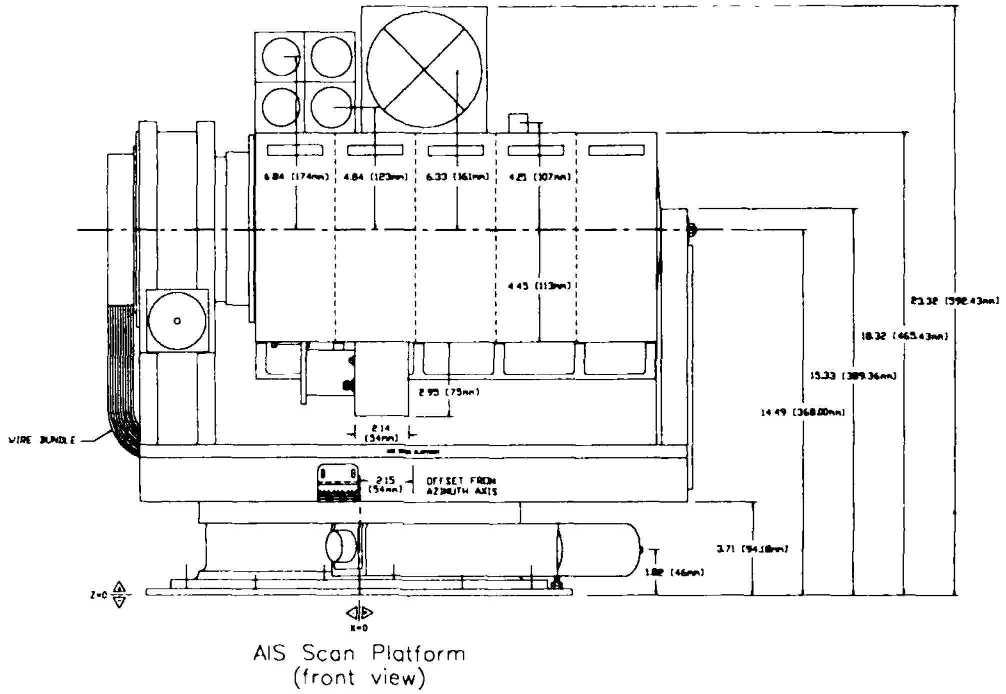
Figure A8. This figure includes all of the curves plotted in Figures A1 through A7. Note that the WIR curve is plotted in arbitrary units.

Appendix B
AIS Dimensions

Table 5 shows the weights and sizes of each of the six components of the AIS. The weight of the cables is also given. Figures B1 through B18 show the six components as viewed from three different angles. The dimsensions given in the figures are in inches [mm].

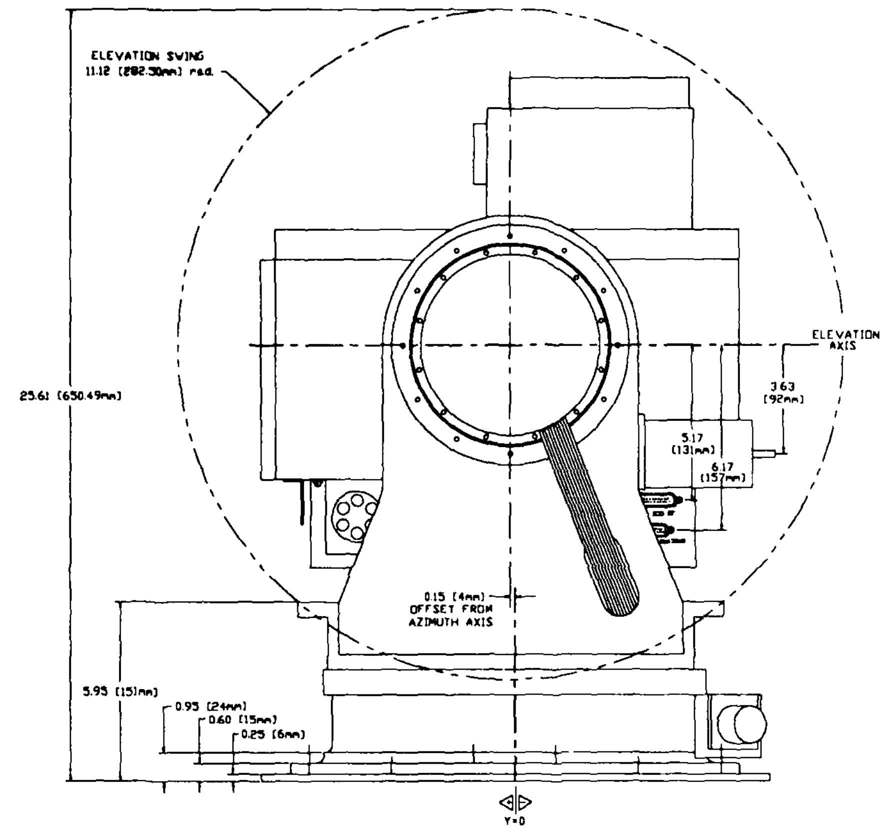
Table 3. Weights and dimensions of the boxes that comprise the AIS

AIS Component	Weight (kg)	Dimensions H × X × Y (cm)
SP	75	60 × 36 × 40
ICU	10	23 × 36 × 33
LVPS	8	10.5 × 35 × 26
HVPS	8	10 × 30 × 23
DRU	15	20 × 25 × 50
MDB	1	5.2 × 18 × 9.4
Cables	7	n/a



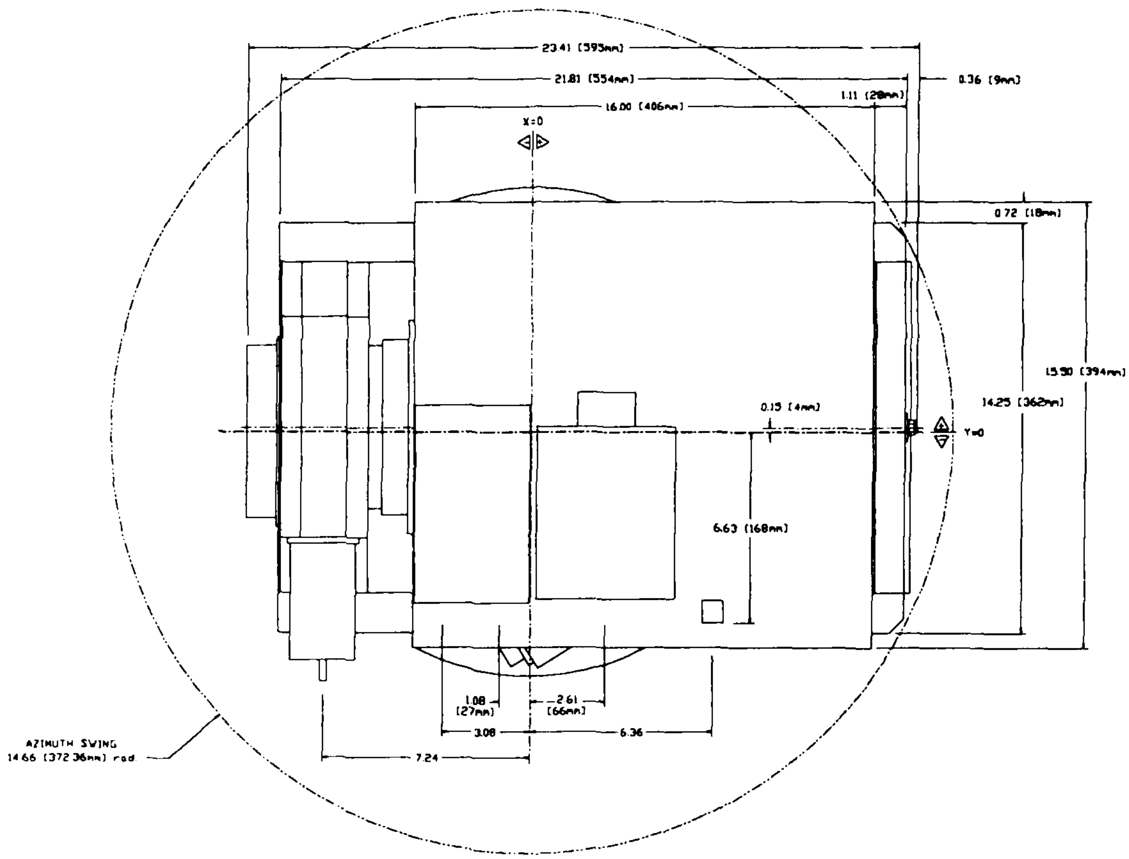
WIRE BUNDLE
OFFSET FROM AZIMUTH AXIS
AIS Scan Platform
(front view)

Figure B1



AIS Scan Platform
(side view)

Figure B2



AIS Scan Platform
(top view)

Figure B3

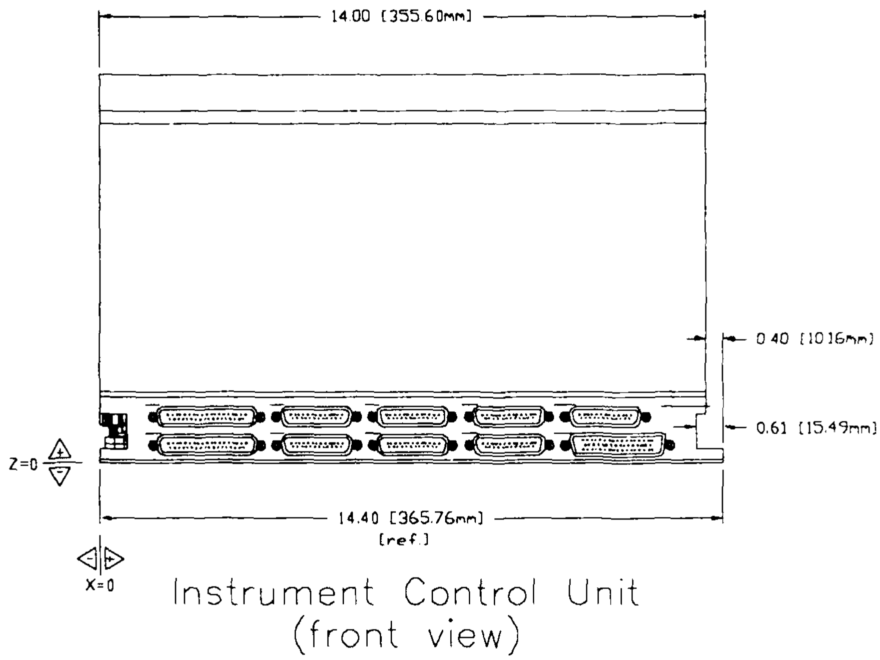


Figure B4

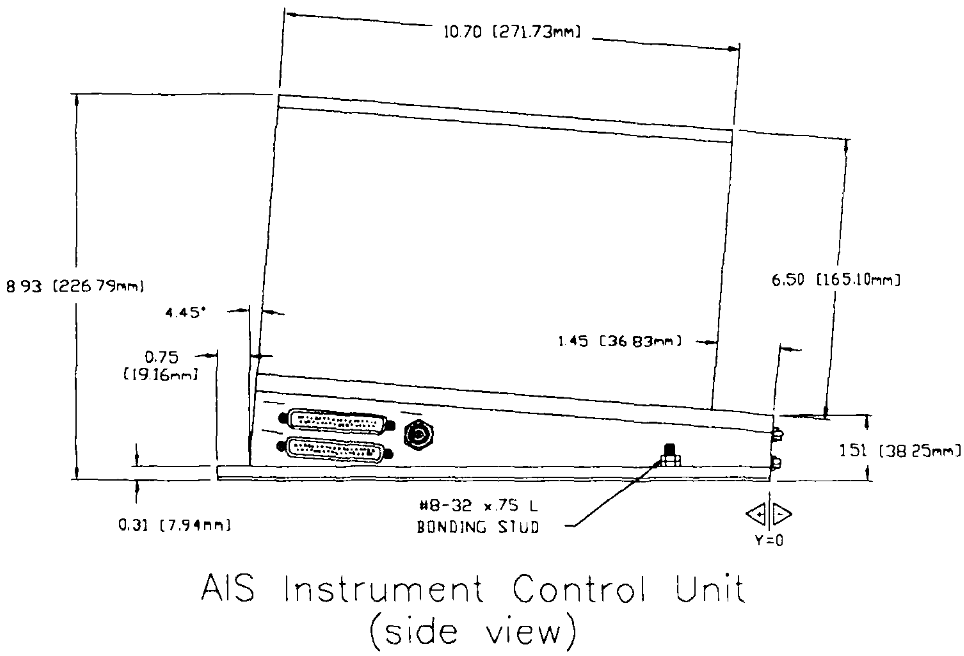


Figure B5

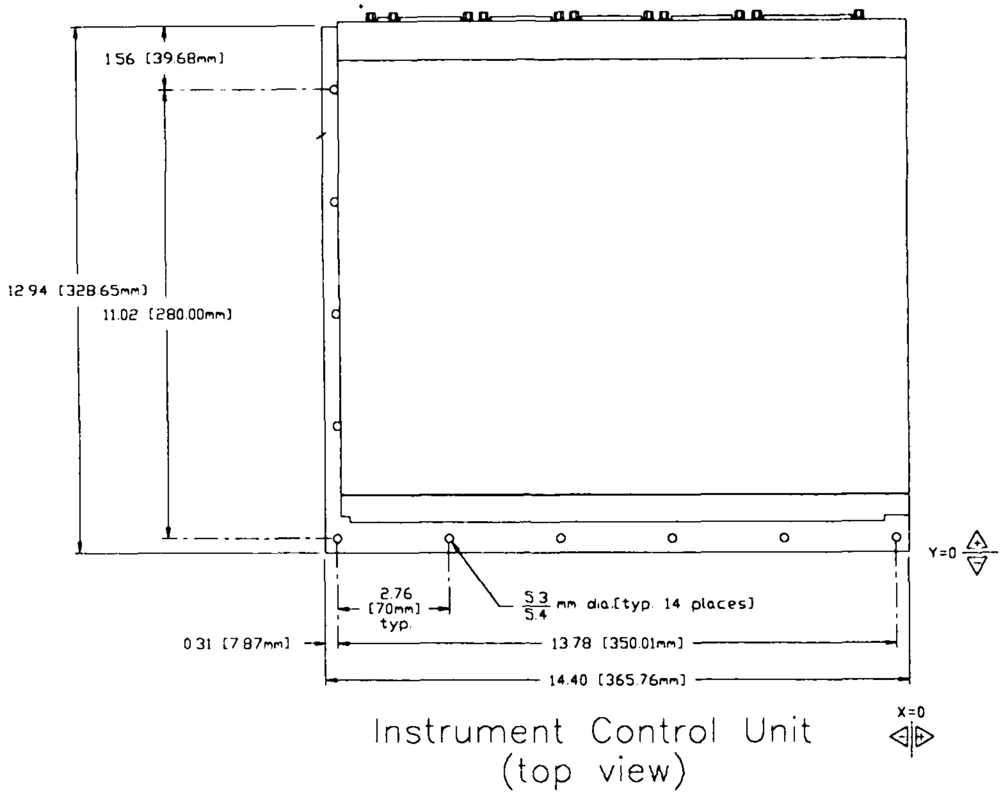


Figure B6.

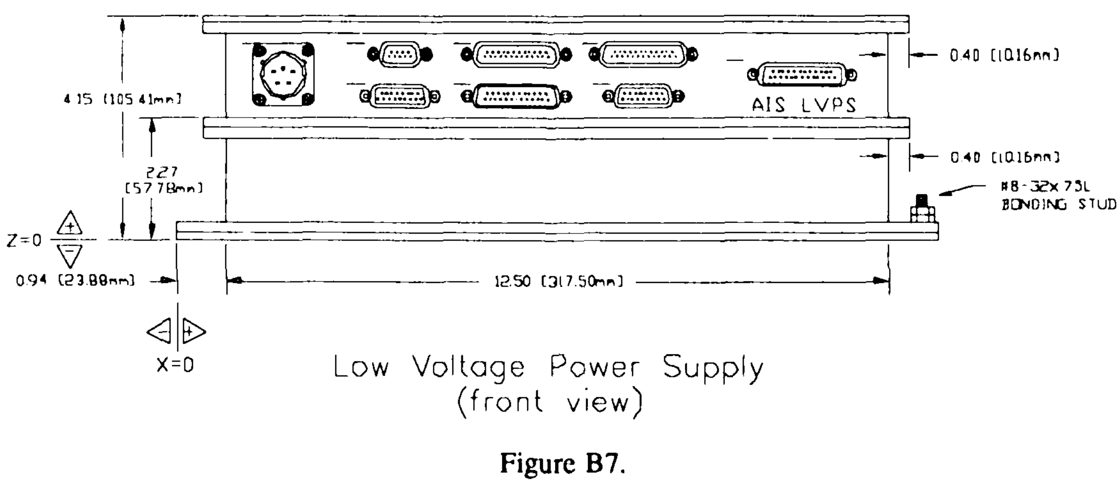


Figure B7.

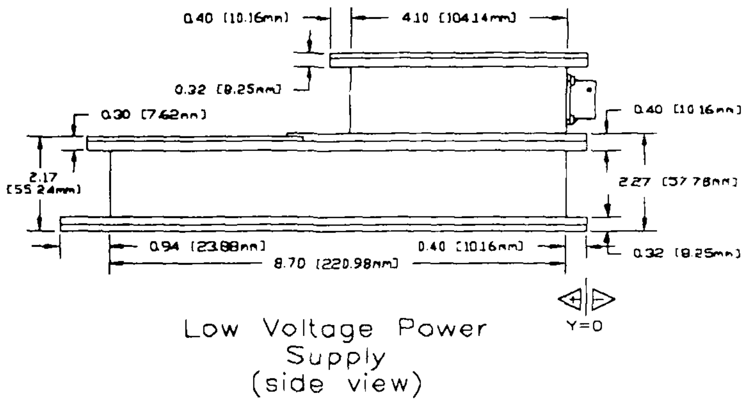


Figure B8.

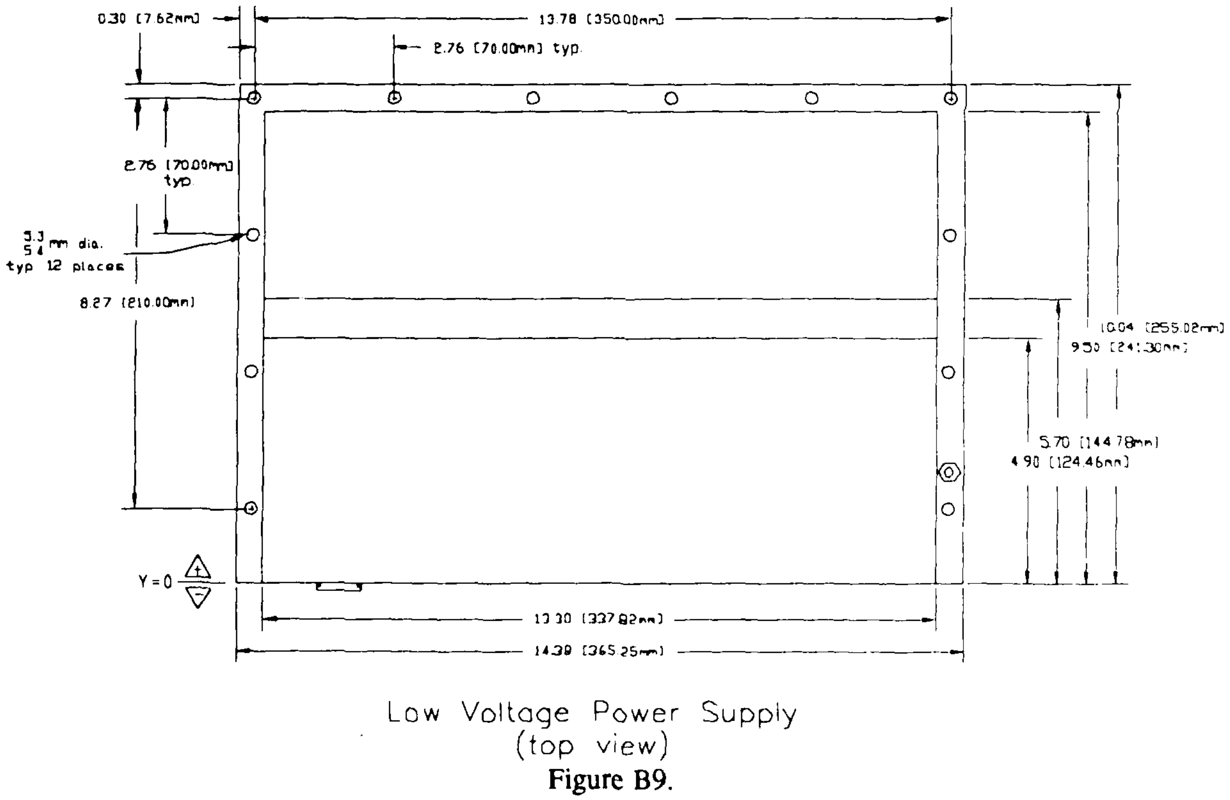


Figure B9.

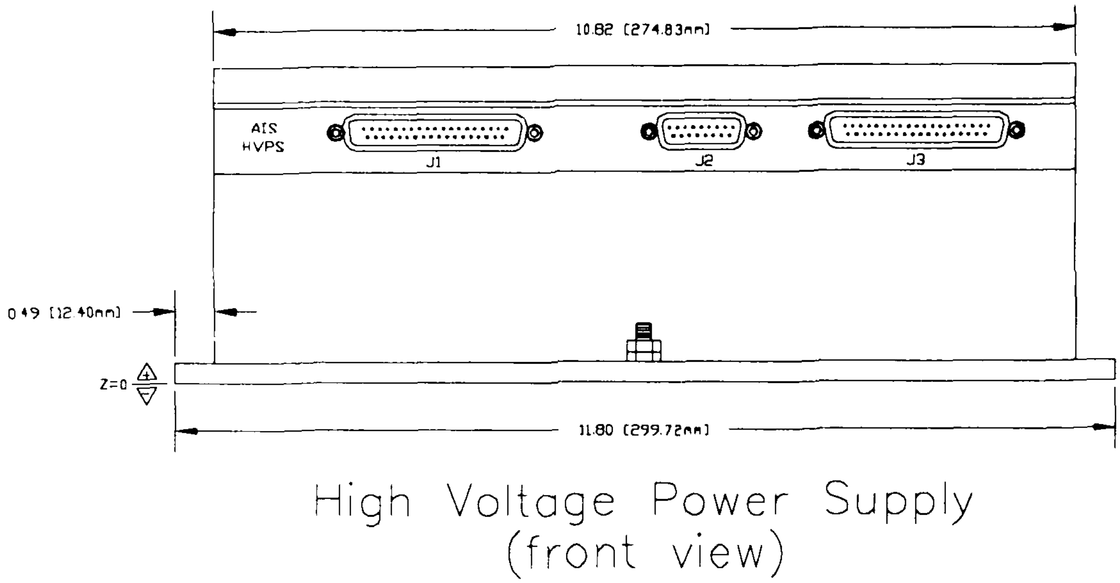


Figure B10.

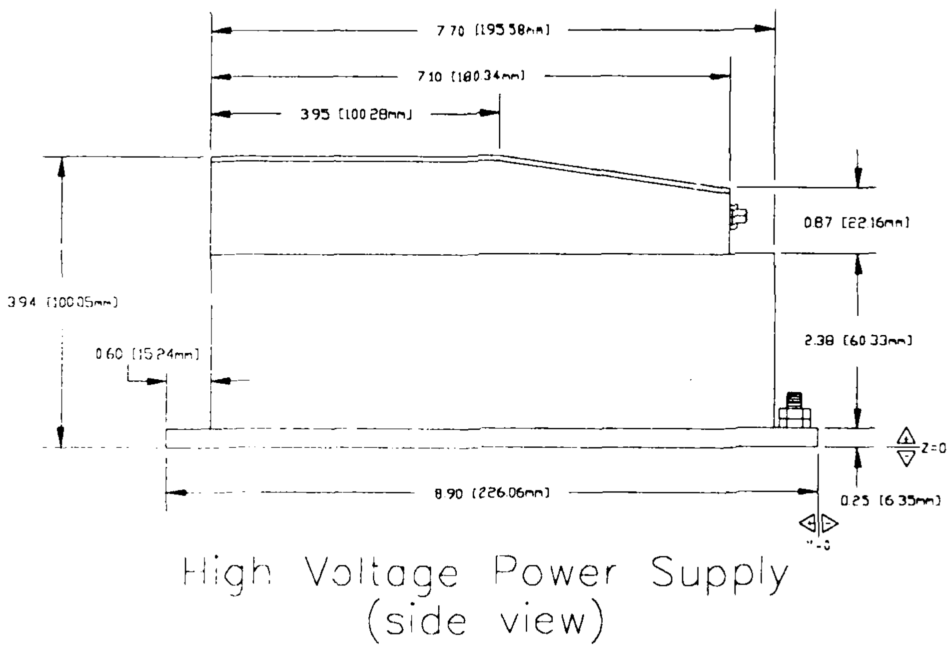


Figure B11.

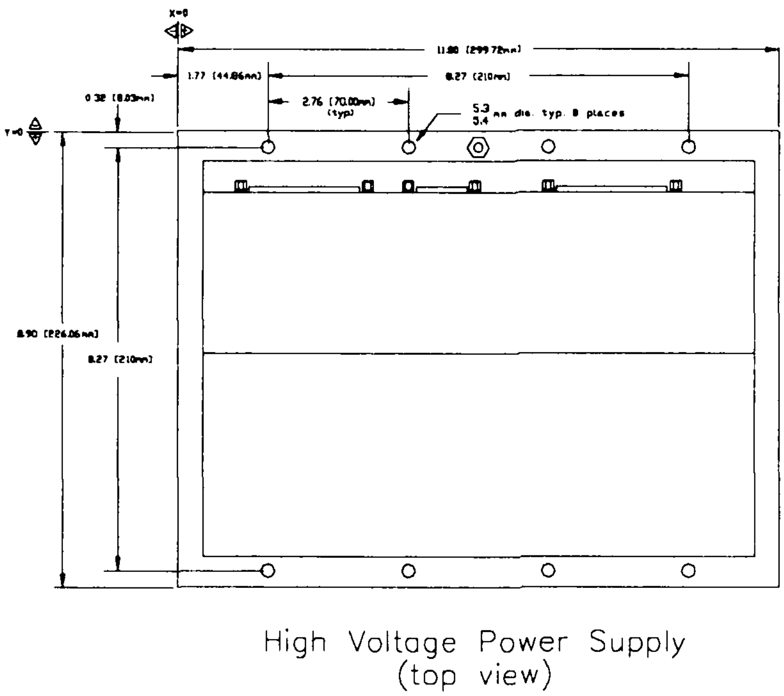


Figure B12.

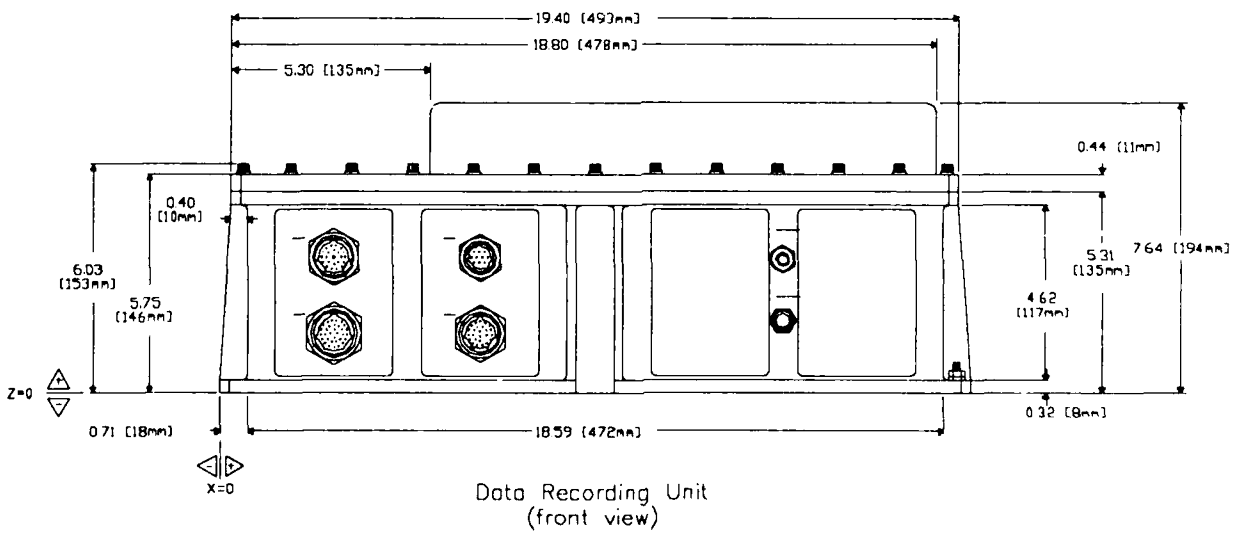
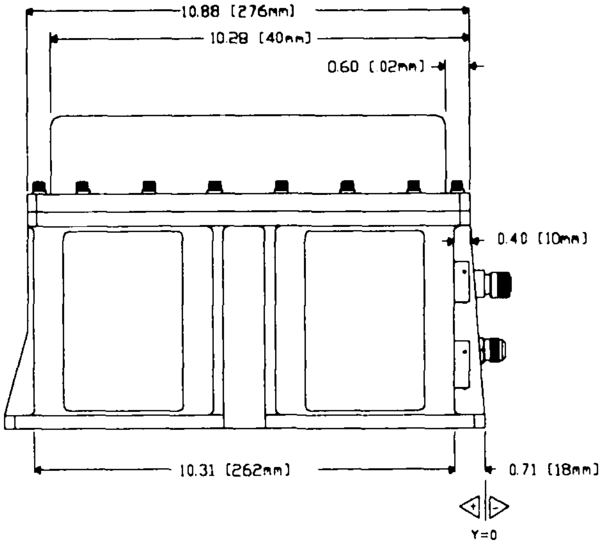
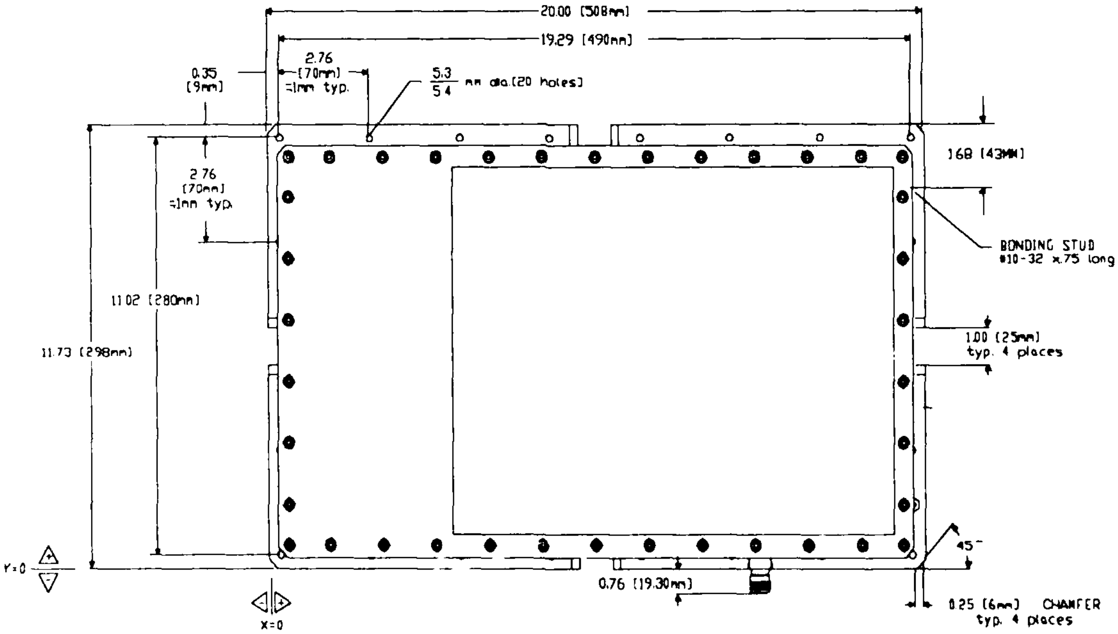


Figure B13.



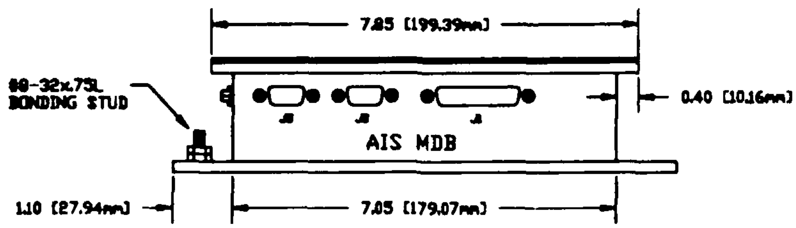
Data Recording Unit
(side view)

Figure B14.



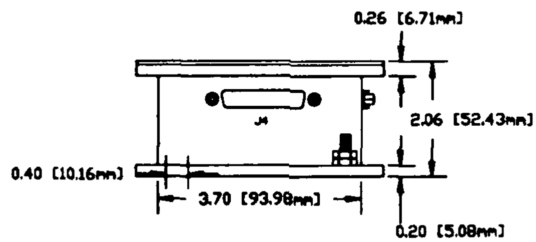
Data Recording Unit
(top view)

Figure B15.



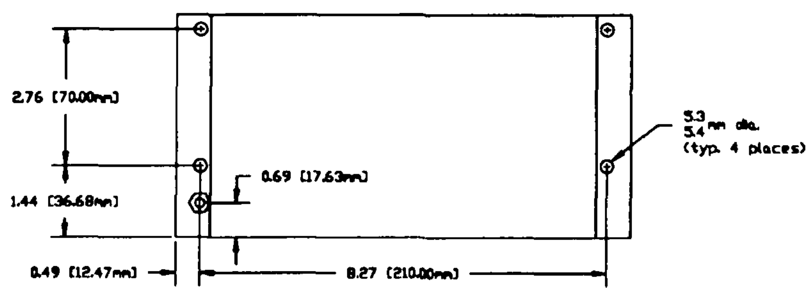
Motor Drive Box
(Front View)

Figure B16.



Motor Drive Box
(Side View)

Figure B17.



Motor Drive Box
(Top View)

Figure B18.

Appendix C
Software Commands

The AIS runs under a unique operating system. The following is a list of AIS commands that can be compiled to form templates. This list is not a complete set of the AIS commands but it does include the commands which are used to create templates. The commands not listed are only for diagnostics and trouble shooting.

Initialization:

EXPID,name		Experiment identification.
INIT,azpos,elpos		Initialize to default.
azpos,elpos	=-1,-1	don't move
	= 0,0	coalign

Template Control:

LOOP,line,ntimes	Loop to line "line" "ntimes" times
MODIFY,line,num,val	Modify parameter no. "num" on line "line" by adding "val" to present value.
SET_PARAM,line,num,val	Set parameter no. "num" on line "line" to "val".

Exposure Control:

SELECT,imagers,specs	Select "imagers" and "specs" where "imagers" is a list of the imagers (i.e. VIS,NUV,WUV) and "Specs" is a list of spectrographs (i.e. SPEC1,SPEC2). Either or both can be ALL indicating all of the imagers or all of the spectrographs.
SET-SUM,ccds,stype	Set the pixel summation to a specific summation pattern. The parameter "ccds" can be IMAGERS, SPECTRA, or CCD0-CCD6. The parameter "stype" can be s1x1, s2x2, s4x4, s1x8, s1x12, s1x16, or s1x192.
BASELINE	Establish a baseline time from which all timed values shall be timed.
CONTINUOUS,on/off	Set flush flag to flush before each exposure (off) or not to (on).
SET_CMPR,on/off	Set data compression
SET_GAIN,hv,level	Set intensifier number "hv" to a gain setting of "level"
GATE,hv,on/off	Manually turn intensifier no. "hv" on or off.

Taking Exposures:

FLUSH,ccds	Remove accumulated charge from CCD "ccds".
EXPOSE,ccds,time	Expose "ccds" for "time" seconds where "ccds" is the same as in SET_SUM.
DARK,ccds,time	Expose "ccds" for "time" seconds where "ccds" is the same as in SET_SUM. In this case leave the intensifiers off.

Scan Platform Movement:

MOVE_AZ,deg	Move "deg" degrees in azimuth
MOVE_EL,deg	Move "deg" degrees in elevation
GO_AZ,deg	Go to azimuth angle "deg"
GO-EL,deg	Go to elevation angle "deg"

Data Handling:

DOWNLINK,imsps,dset	Send data from "imsps" imager or spectrograph and "dset" data set where... imsps is WIR, NIR, BOTH_IR, VIS, VIS700, VIS750, WUV, NUV, SPECT1-SPECT9 and dset is 0 for last data set, or 1 for first, 2 for second , etc.
SPECT192	Sum spectrograph data to 1x192 (off chip)
WRTTAPE	Send all data to the optical disk

Miscellaneous:

SYNC,time	Wait until "time" seconds have passed since the last BASELINE command.
WTTRIG	Wait until a trigger command is received
ENDT	End template

Note: There are numerous commands which control the basic AIS components. They are not used in the scientific templates and are thus, not listed here.

* U. S. GOVERNMENT PRINTING OFFICE: 1990--700-000/20017