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OPERATION MANUAL FOR THE MULTI-WAVELENGTH ABRIDGED POLAR NEPHELOMETER

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This report is an operation manual for a multiwavelength polar nephelometer capable of measuring three angular scattering coefficients of atmospheric aerosols at five wavelengths in ultraviolet, visible and infrared spectral regions. The five wavelengths are: 0.325, 0.66, 0.95, 2.25 and 10.6 microns. The angular scattering coefficients are measured at 30°, 100°, and 140°. This portable field instrument is contained in three housings which can be located in the outdoors environment. It operates automatically from a computer based operation and recording system located in a shelter which can be at a distance of up to 100 feet away.

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1.0 GENERAL INFORMATION

1.1 Introduction

This operation manual describes the installation, operation, maintenance and troubleshooting procedures for the Abridged Polar Nephelometer. A companion report (Ref.1) on the system project should be consulted for background information on the principles of operation of the instrument and for details of the instrument design.

The purpose of a polar nephelometer is to measure the angular scattering coefficients of atmospheric aerosols for light of a given wavelength over the angular range 0 to 180 degrees, either continuously or at a large number of fixed angles. The Abridged Polar Nephelometer described in this manual measures only scattering at the angles of: 30°, 100°, 140°, but for five optical wavelengths: 0.325, 0.66, 0.95, 2.25 and 10.6 microns. The apparatus is packaged in four separate measurement modules which are, in turn, mounted in three portable environmental housings. One of these modules serves for two wavelengths (0.66 and 0.95 microns) by time-sharing the sensor instrumentation between two light sources. This dual Module 1/2 is mounted along with Module 3 (2.25 microns) in one of the housings. In order to achieve this compact arrangement, the 5 V and ± 15 VDC supplies were located in an additional environmental housing which also serves as a distribution center for the 115 VAC power for all housings.

Eash sensor has a sample volume where optical radiation from a collimated light beam is scattered from the aerosol-laden air into three detectors placed at the three angles given above. The volume for Models 1, 2, 3 and 4 is 8 mm^3 and that for Model 5 is 40 mm^3. The light beam is modulated so that it alternately illuminates the sample volume viewed by the detectors and an adjacent position blocked from their view. The modulated signal scattered from the aerosols can be distinguished by synchronous detection from the steady state signal coming from light scattered in the optical system.

Each module has a microprocessor which handles all control functions and data signal processing local to itself. All of these microprocessors are controlled by another microcomputer which serves as the system controller. The controller and the module microprocessors are connected together on a serial digital data communication system called the Hewlett-Packard Interface Loop (HP-IL). The system controller sends operation commands to the module microprocessors which, in turn, send back status information and signal data. The system controller components are described in Section 1.2.6.

1.2 Equipment Descriptions

1.2.1 Modules 1/2 and 3 General Features

Because of the time-sharing feature of Module 1/2 and since it is colocated with Module 3 in the same environmental housing, it is convenient to describe their common features at the same time. Separate sections will describe any unique aspects of the individual modules.

Figure 1.1 shows an external view of the environmental housing for these modules. The air-intake tube is seen at the right extending from the housing. Some of the latches which fasten together the two housing sections are visible near the bottom of the container. These latches pull the two sections together and compress a rubber gasket thus forming a weather-tight seal. Also visible to the left are two of the four carrying handles, which are held in the down position by springs. A view from the opposite position is shown in Figure 1.2, where the exhaust port at the rear is seen. The signal and power connectors can be seen in the bottom section.

After the cover is removed, the rectangular structure containing the detectors and sample volume for Module 1/2 can be seen in the front as in Figure 1.3. The large circular opening is the air sample duct which leads to the sample volume. The intake-pipe which penetrates the housing wall fits snuggly into this duct. The similar structure for Module 3 which can just be seen to the rear in this figure is clearly seen in Figure 1.4 which is a right side view. The light sources are on this side of the modules which can now be seen to be L-shaped structures. Figure 1.5 is a view from the left side which shows that the short arm of the L houses the signal processing electronics. The locations of the light traps for the source beam are indicated. The rear view given in Figure 1.6 shows the aspirator which pulls the air through the air duct and expels it through the exhaust pipe which penetrates the rear of the environmental housing. The electrical connectors for signal and power cables are also shown.

The detector housing and the signal processor housing covers can be readily removed for access to the detectors and the electronics. Figures 1.7 and 1.8 show Modules 1/2 and 3 in this condition from two different elevated viewing angles. The common air duct which connects the two sample volumes is also shown. Figure 1.9 provides a closer view of the signal processing electronics while Figure 1.10 shows the HP-IL converter units which interface the module microprocessors to the HP-IL signal loop.

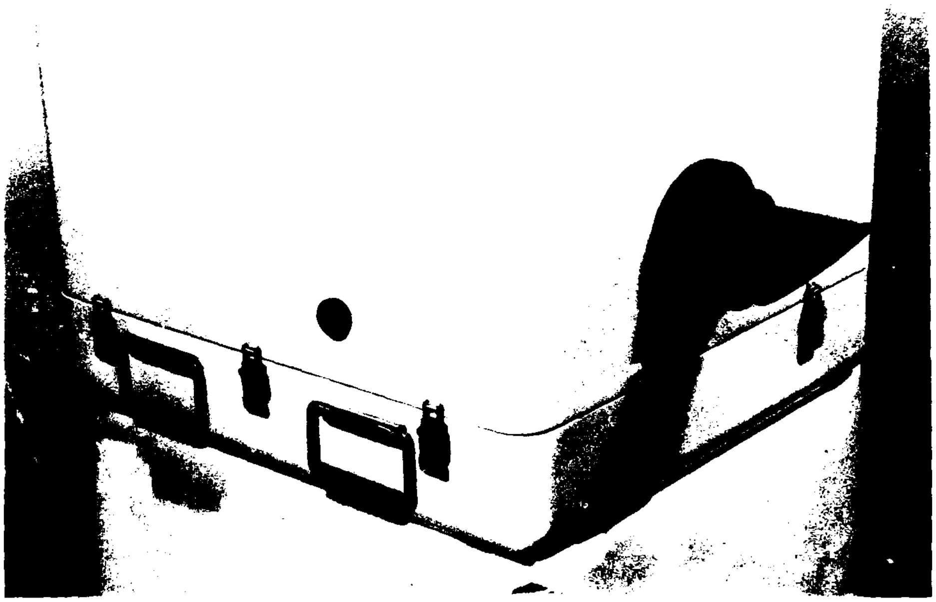

Figure 1.1 · Wavelength Modules 1, 2 and 3 with cover and air-intake tube installed.

Figure 1.2. Wavelength Modules 1, 2 and 3; rear view showing exhaust port.

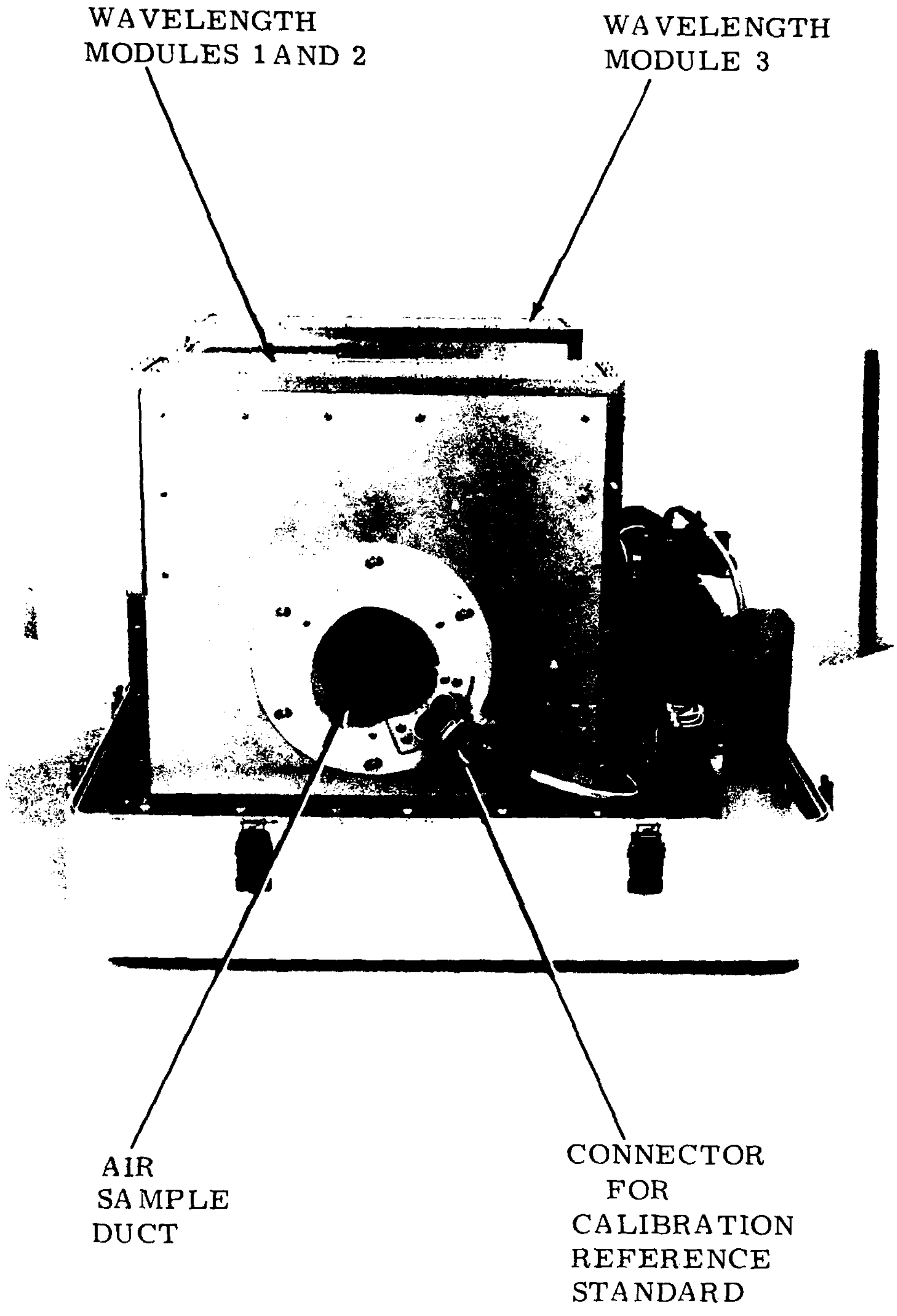

Figure 1.3. Front view of Module 1/2 and 3 after removal of environmental cover.

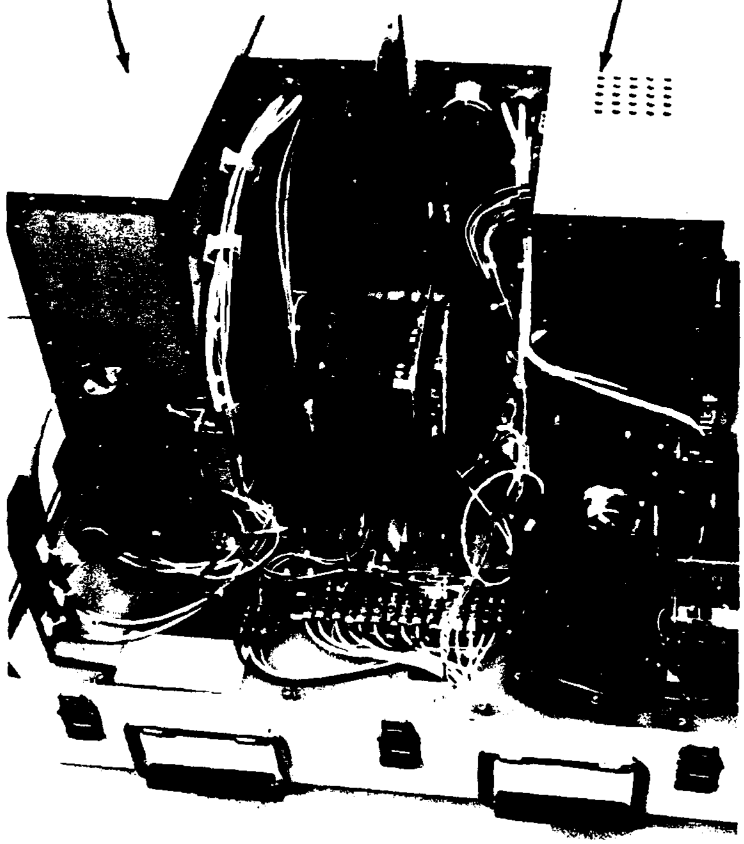

Figure 1.4. Modules 1, 2 and 3; Outer cover removed. Right Side View.

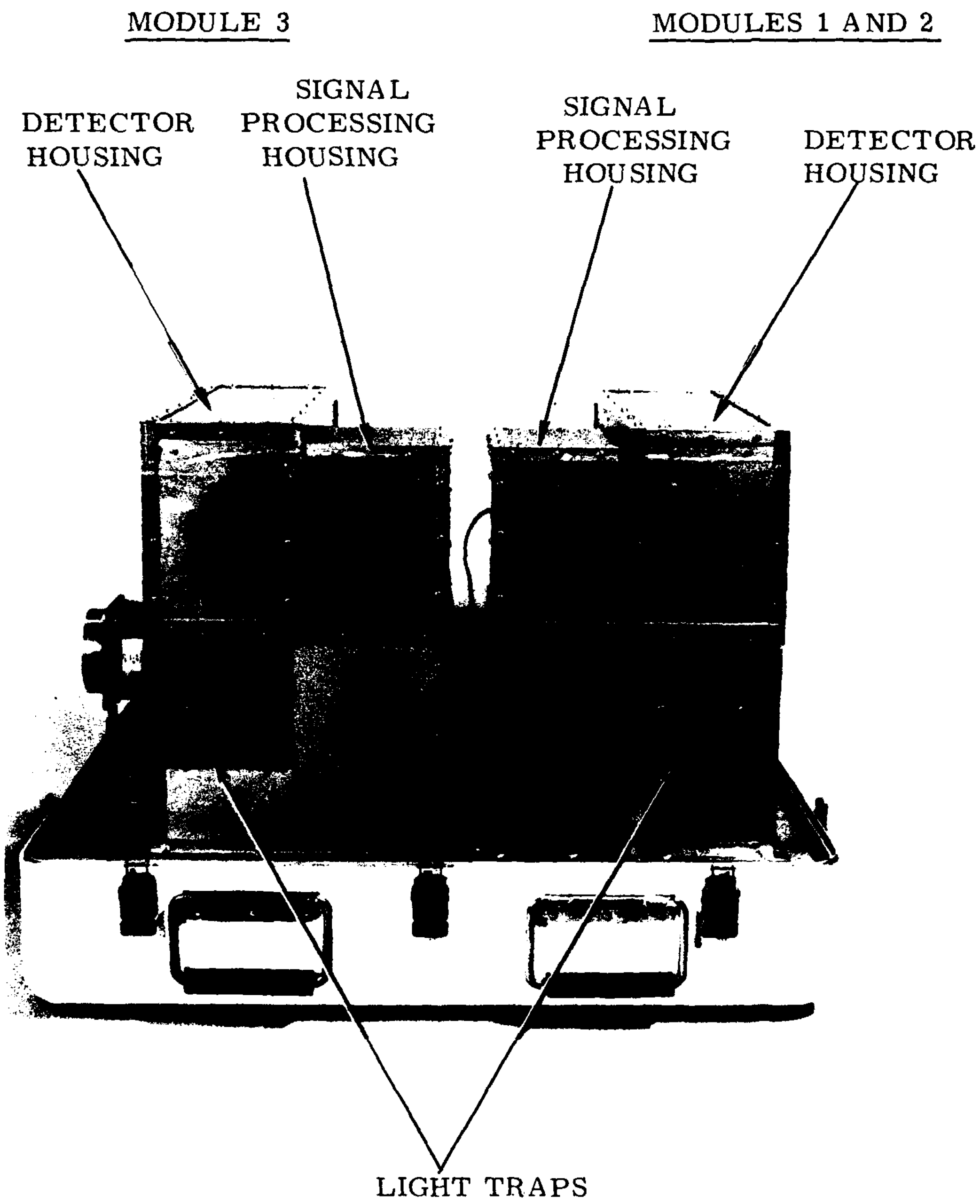

Figure 1.5 . Wavelength Modules 1, 2 and 3; locations of Detector Housings, Signal Processor Housings and Light Traps. Left Side View.

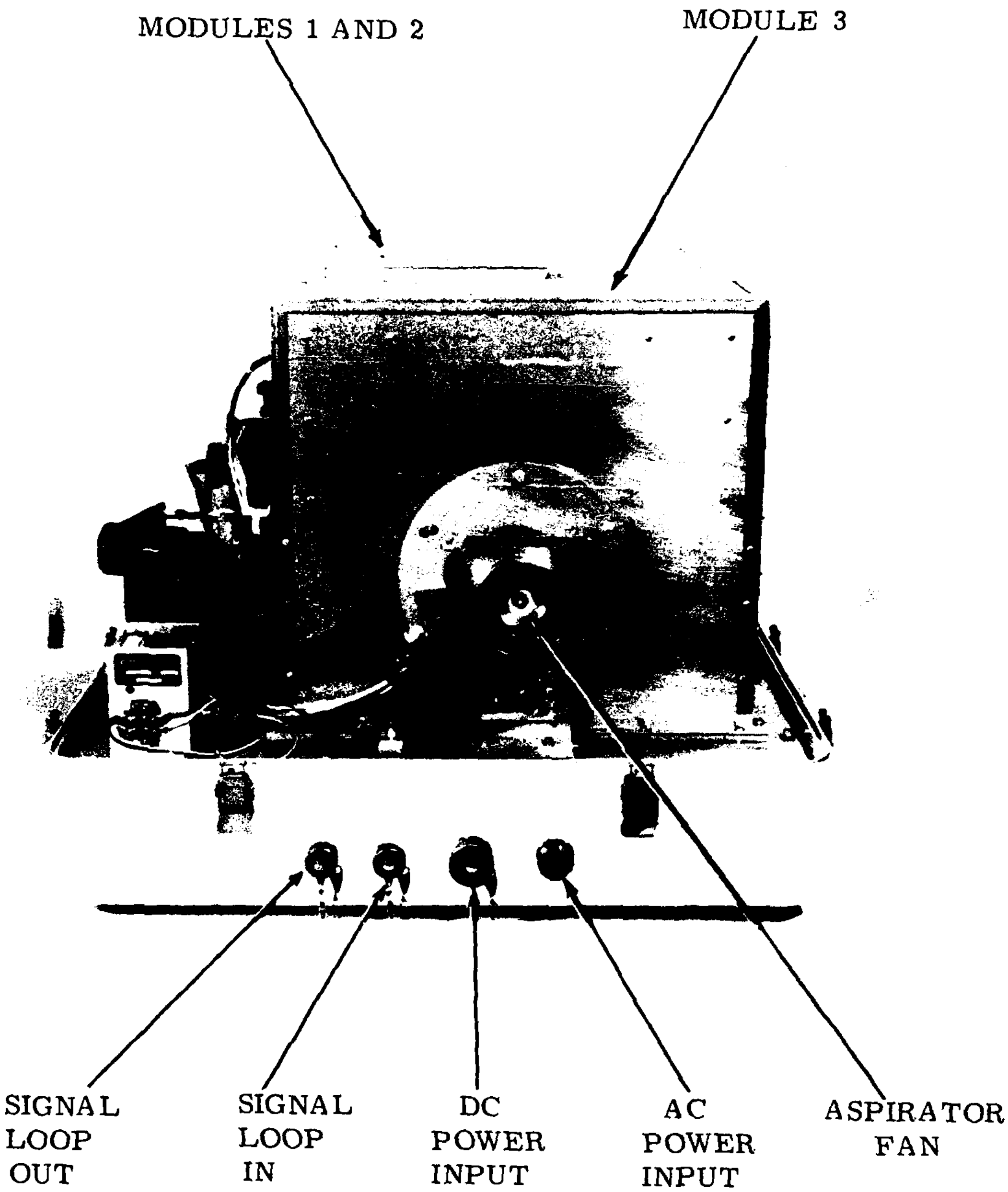

Figure 1.6 . Wavelength Modules 1, 2 and 3; locations of Power Connectors, Signal Connectors and Aspirator Fan. Rear View.

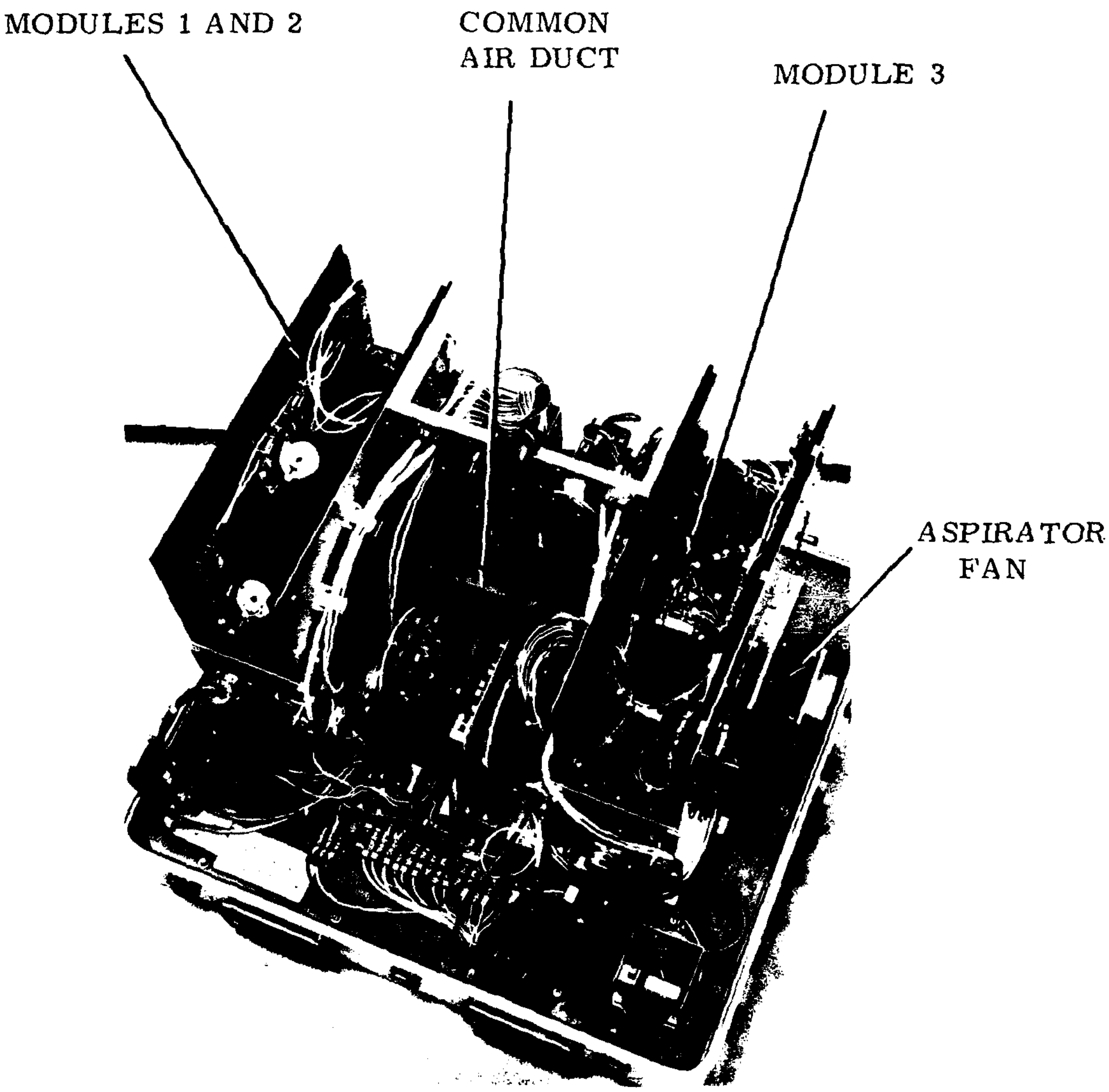

Figure 1.7 . Modules 1, 2 and 3; Locations of air duct and aspirator fan. Top view with housing covers removed.

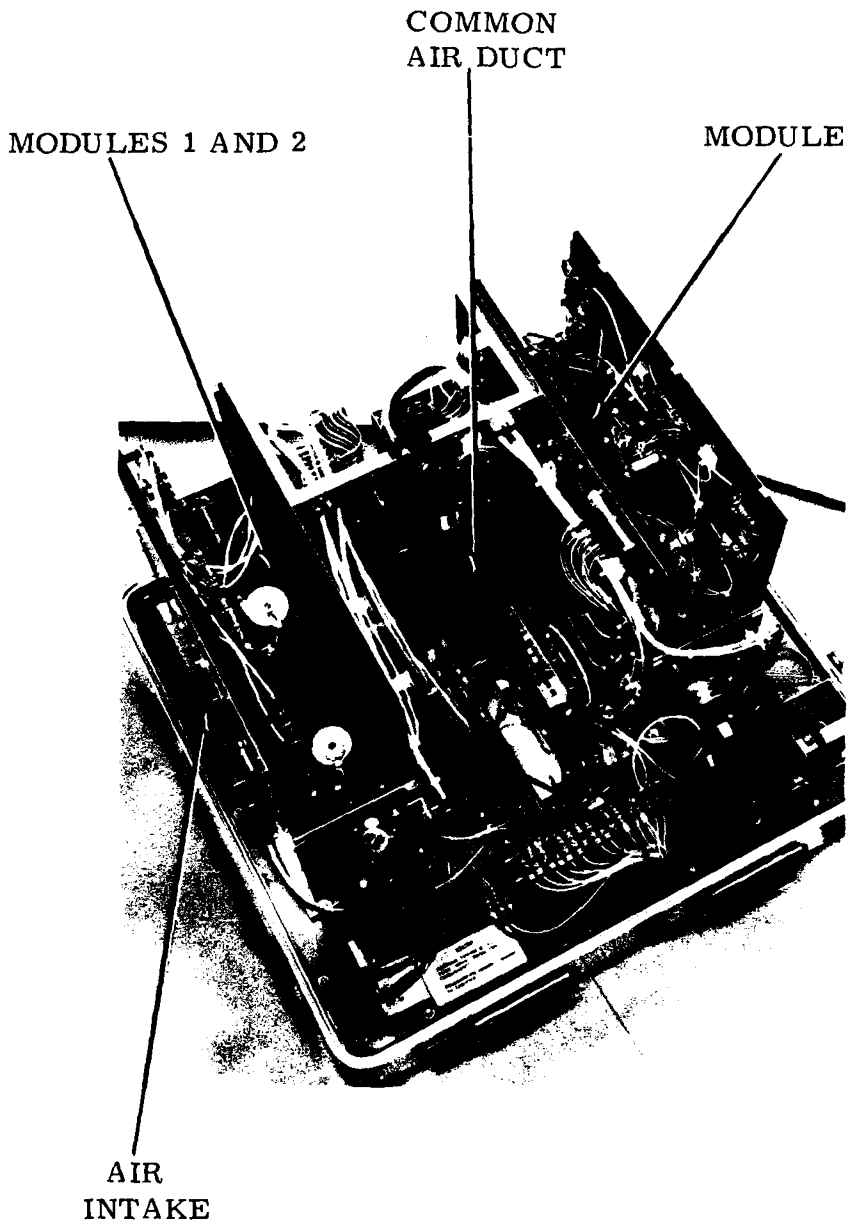

Figure 1.8. Modules 1, 2 and 3; Location of air intake and interconnecting duct work between modules. Top view with Housing Covers Removed.

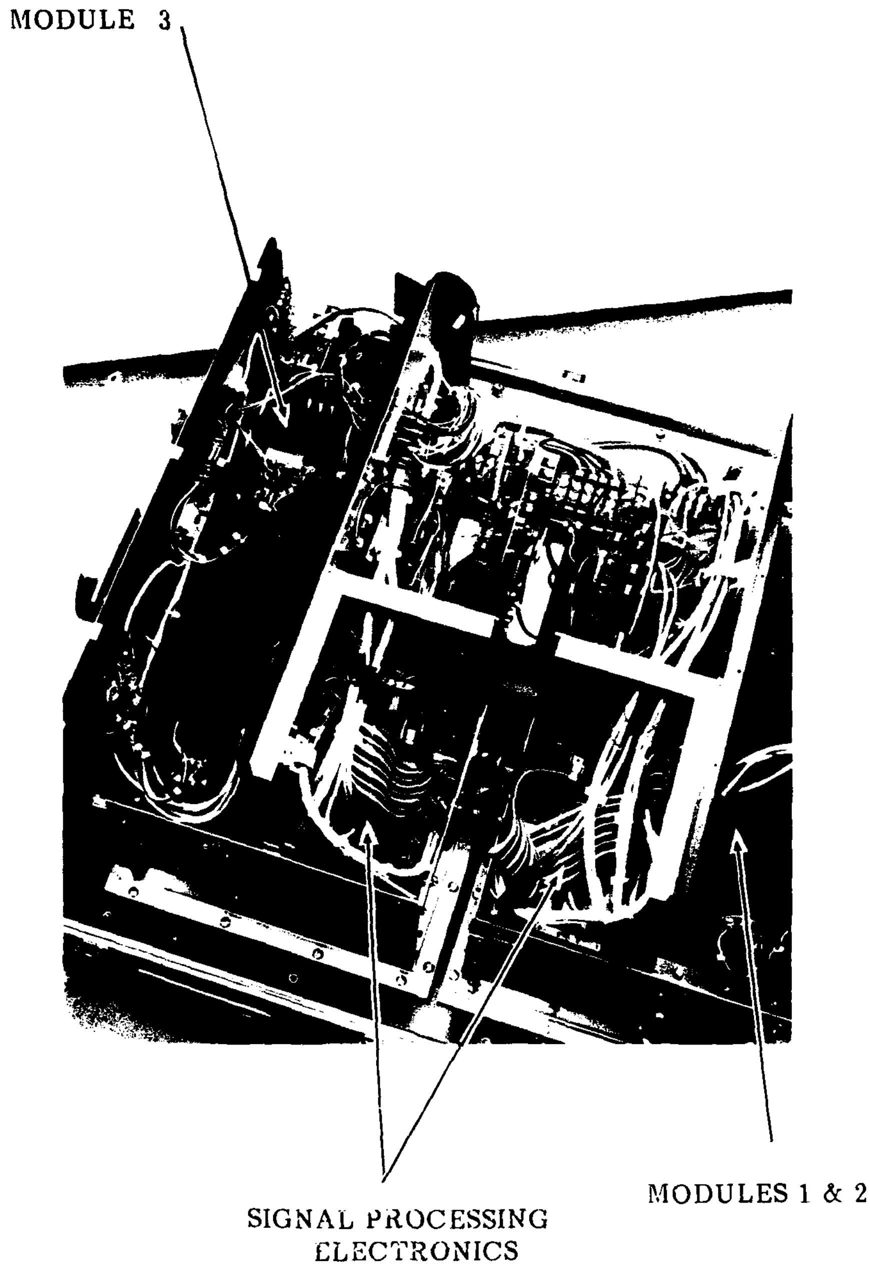

Figure 1.9. Modules 1,2 & 3; Location of signal processing electronics.
Top view wiith Housing Covers Removed.

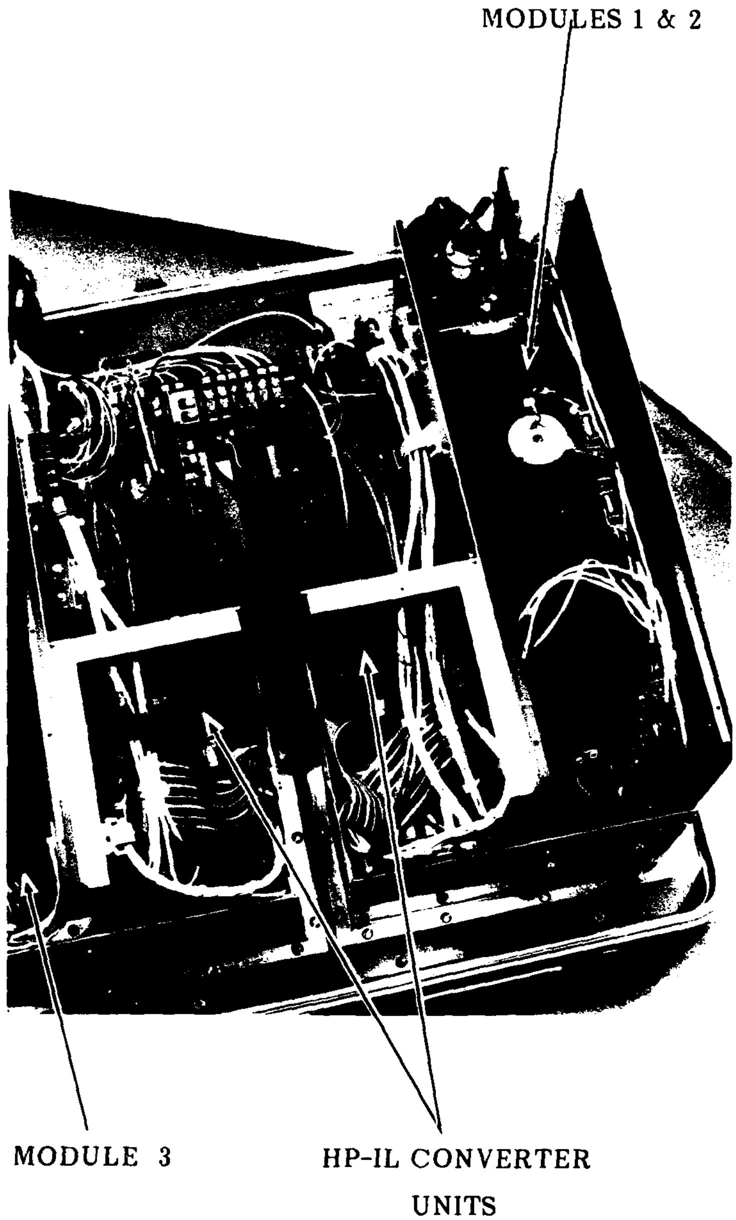

Figure 1.10 . Modules 1, 2 and 3; Locations of HP-IL converter units.
Top View Housing Covers Removed.

The main power supplies for these modules are located in a separate enclosure which also serves as the distribution point for the main 115 Vac power. Figure 1.11 shows the placement of power supplies in the opened enclosure. The Sorensen PTM 5-7 unit at the bottom supplies 5 Vdc the Thermoelectric coolers used in Module 2/3 and the Acopian A6MT 490 unit at the top supplies 6 Vdc for the tungsten lamp in the same unit. The Acopian TD-15-450 unit at the left supplies ± 15 Vdc for the general electronics in Module 1/2 and Module 3. The Acopian A5H 1700 supplies 5 Vdc for the microprocessor in both modules. An air circulating fan is provided to aid in heat dissipation.

Figure 1.12 shows the input and output connectors on this power supply enclosure. At the right is the input connector for the 115 Vac power. The first two 115 Vac output connectors supply power to Modules 1/2 and 3, and Module 5; they can be connected in any order. The third connector is specifically for Module 4 and is polarized to accept only the cable for that unit. The connector on the left is used to supply the various dc voltages to Modules 1/2 and 3.

1.2.2 Module 1/2 Features

The two transmitter pairs used as sources for the combined Module 1/2 are shown in Figure 1.13. Each transmitter is made up of a pair of optical emitting diodes with a bandpass filter. The transmitter for Module 1 operates at 0.66 microns and its filter has a square bandpass with an approximate bandwidth of ± 0.5 microns. Module 2 operates at 0.95 microns and also has a square bandpass filter with a similar bandwidth. For these two transmitters to illuminate the same sample, they are optically combined by a beam splitter which is a semi-transparent thin glass sheet. The Module 2 transmitter is mounted so that it looks directly toward the scattering chamber along a horizontal axis. The two LED sources comprising the transmitter are imaged into the scattering volume by a lens placed on that axis just outside of the chamber. The beam splitter is then placed between the first transmitter and the lens at a 45° angle so that when the Module 1 transmitter is placed on a vertical axis, its optical radiation is partially reflected into the horizontal axis where it goes through the lens and into the scattering volume. It is so located that it is imaged by the lens at the same point as the Module 2 transmitter. The transmitted beam along the vertical axis from Module 1 transmitter is allowed to fall on a silicon detector which is used as a source monitor. Figure 1.14 shows the position of this detector. When the beam splitter was placed in front of the horizontally located

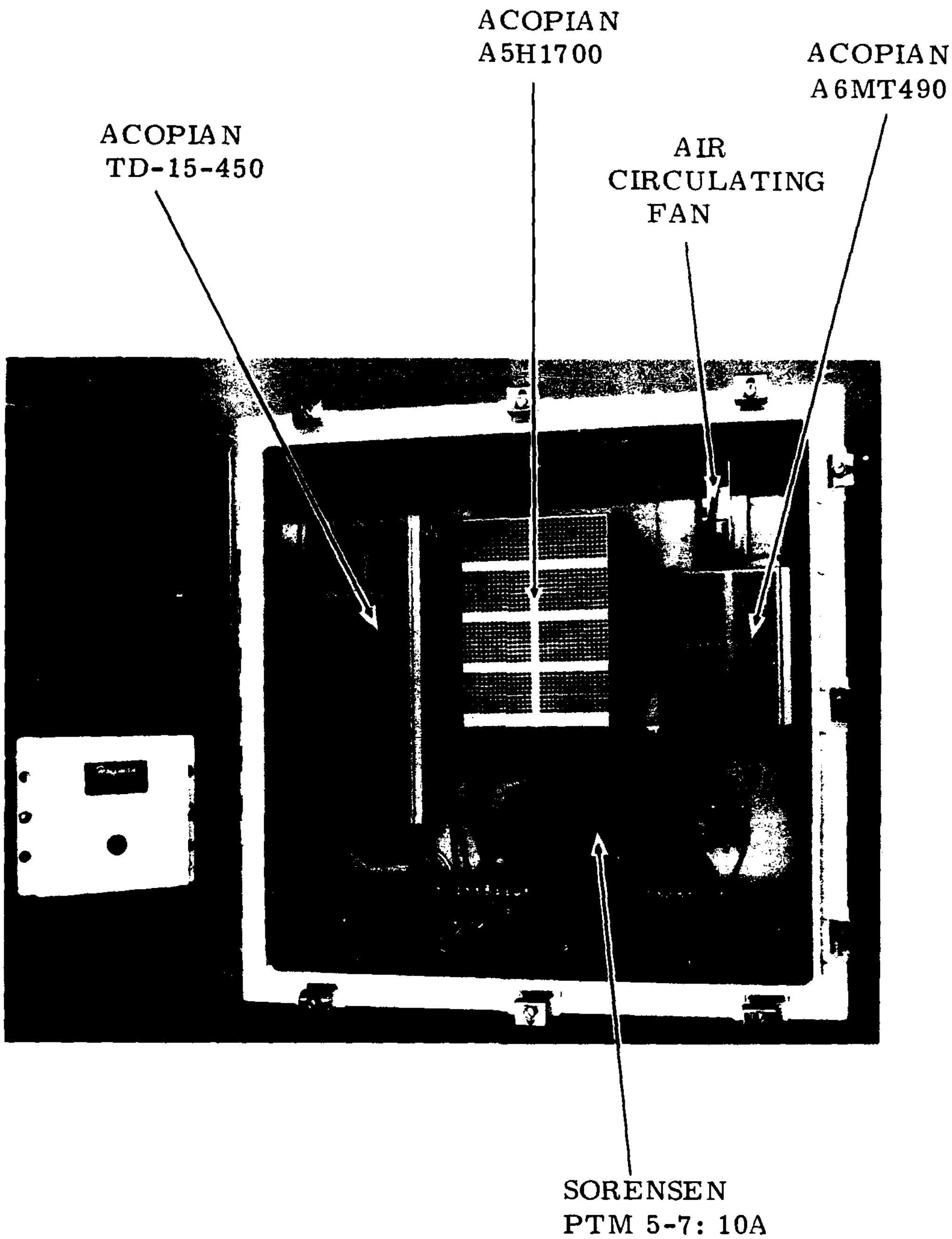

Figure 1.11. AC/DC converter model numbers for modules 1, 2 and 3 and heat dissipation electrical fan. Auxiliary Power Supply Unit.

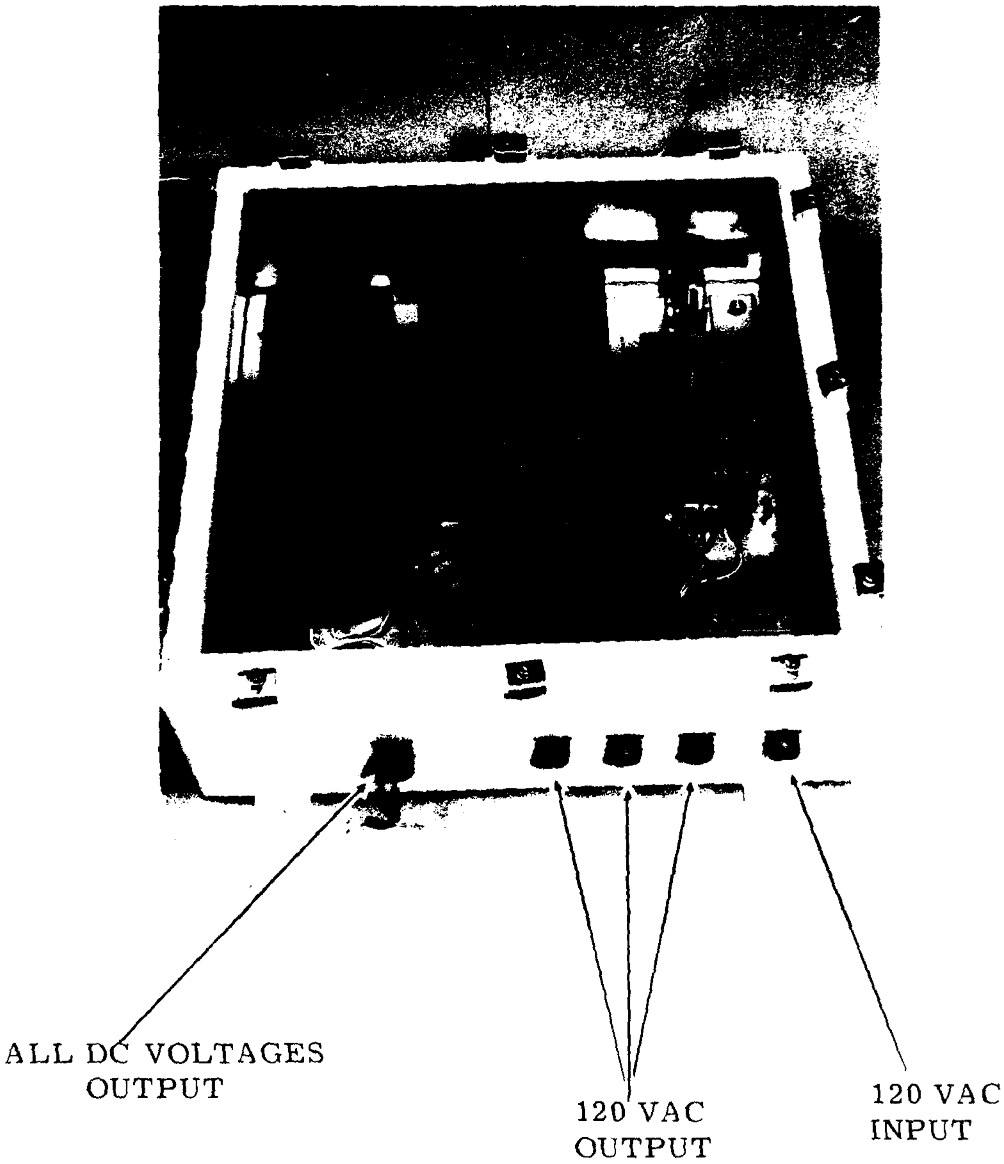

Figure 1.12. AC/DC converters for modules 1, 2 and 3.
Auxiliary Power Supply Unit.

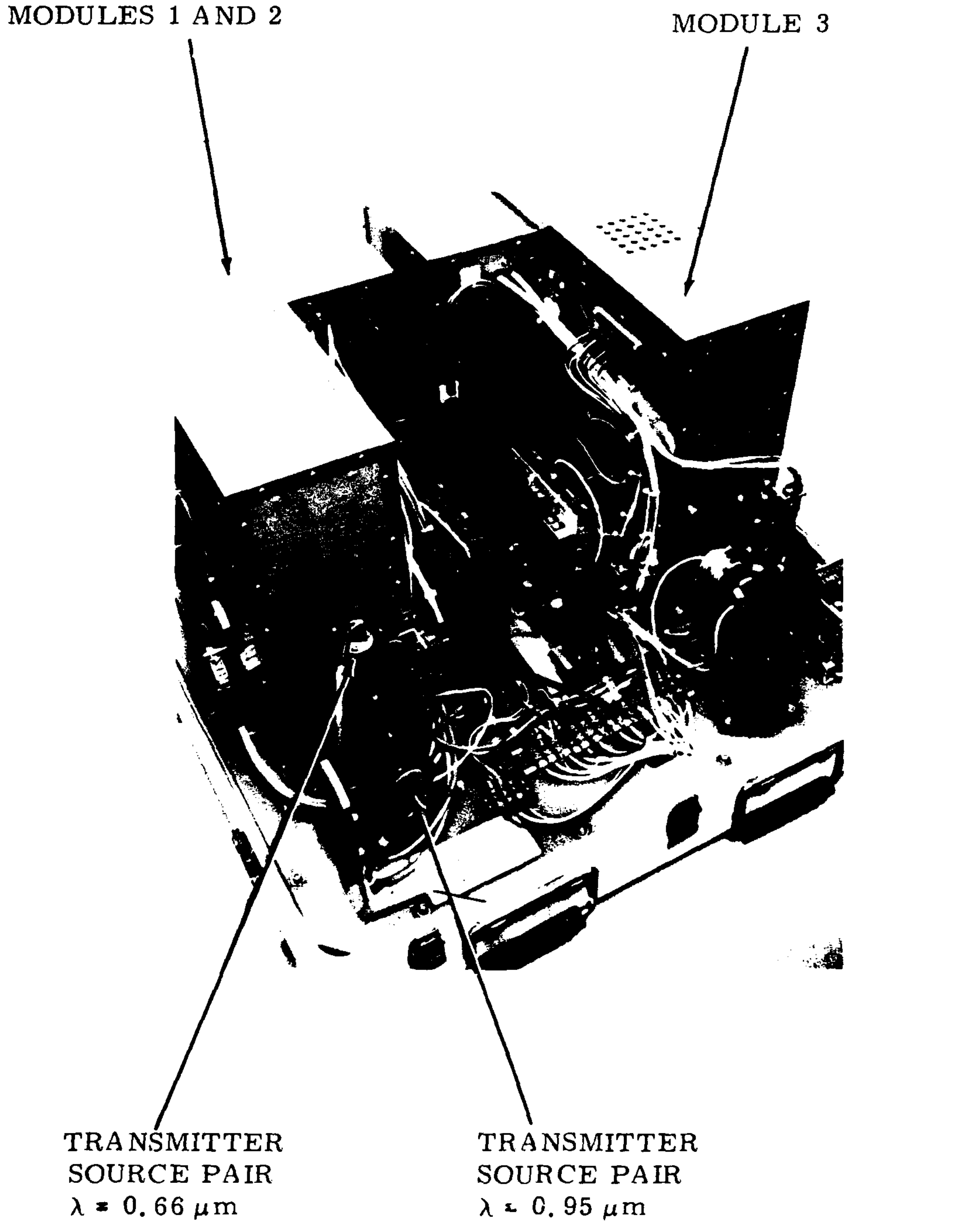

Figure 1.13. Modules 1 and 2; location of Transmitter Source Pairs. Right Side View.

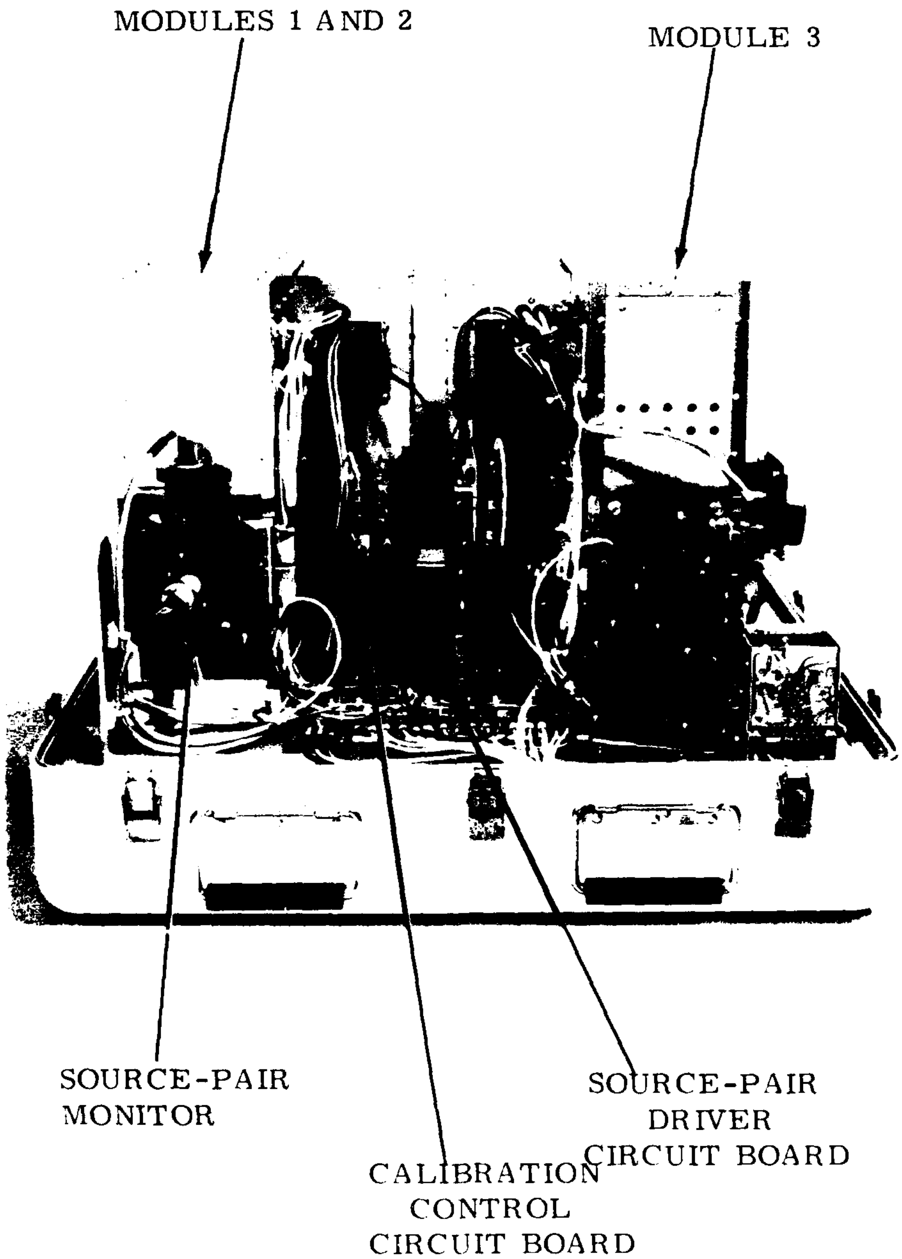

Figure 1.14. Modules 1 and 2; Location of source-pair monitor, source-pair driver circuit board and calibration control circuit board. Right Side View.

Module 2 transmitter a part of its radiation was reflected downward along the vertical axis where it also falls on the source detector. Since only one transmitter LED pair is active at a time, the single source monitor detector can serve for both. Figure 1.15 shows the circuit board containing the electronics which drive the transmitters.

The housings for the silicon photodiode detectors used in Module 1/2 are shown in Figure 1.15. Each detector views the scattering volume through 1:1 imaging a lens made with two achromatic doublets. The electrical signal from each photodiode goes to an adjacent preamplifier and then to the signal processor through EMI filters in the wall of the detector housing as seen in Figure 1.16.

The processing unit is made up five electronic boards mounted in the card cage which can be seen beneath the cables in Figure 1.16. The three detector signals go first to an amplifier board and then to a combination analog multiplexer and analog-to-digital converter board. From this board, the digitized detector signals are available to the microprocessor board through the STD bus in the card cage motherboard. A timing board and an Input/Output (I/O) board complete the signal processing unit.

1.2.3 Module 3 Features

The use of an optical wavelength of 2.25 microns in Module 3 requires a different type of source and detectors than used in Model 1/2. A tungsten filament/quartz iodide lamp filtered by a 0.5 micron bandpass filter centered at 2.25 microns is a convenient source for this application. Since the source-pair concept is not feasible with a lamp, it was necessary to use a galvanometer scanner to oscillate the beam position at the scattering volume. By locating the IR bandpass filter at the entrance to the detector housing, the visible light from the tungsten lamp was available for use with the source monitor which could be a silicon photodiode. On the other hand, the signal detectors had to be cooled lead sulphide PbS. The cooling is done with 3-stage thermoelectric device. Figure 1.17 shows the arrangement of the Module 3 optical source. The mirror on the galvanometer scanner is so placed to reflect the light beam from the tungsten lamp into the detector housing entrance. A fraction of this light is then reflected from the entrance window and onto the source monitor detector. The detector configuration is designed so that the small oscillations of the mirror move the reflected light alternately on and off of the silicon photodiode producing an ac signal which can be differentiated from any steady state background signals.

The electronic circuit boards associated with the scanner and with the source monitor are mounted vertically in individual card holders on the interior side of the Module

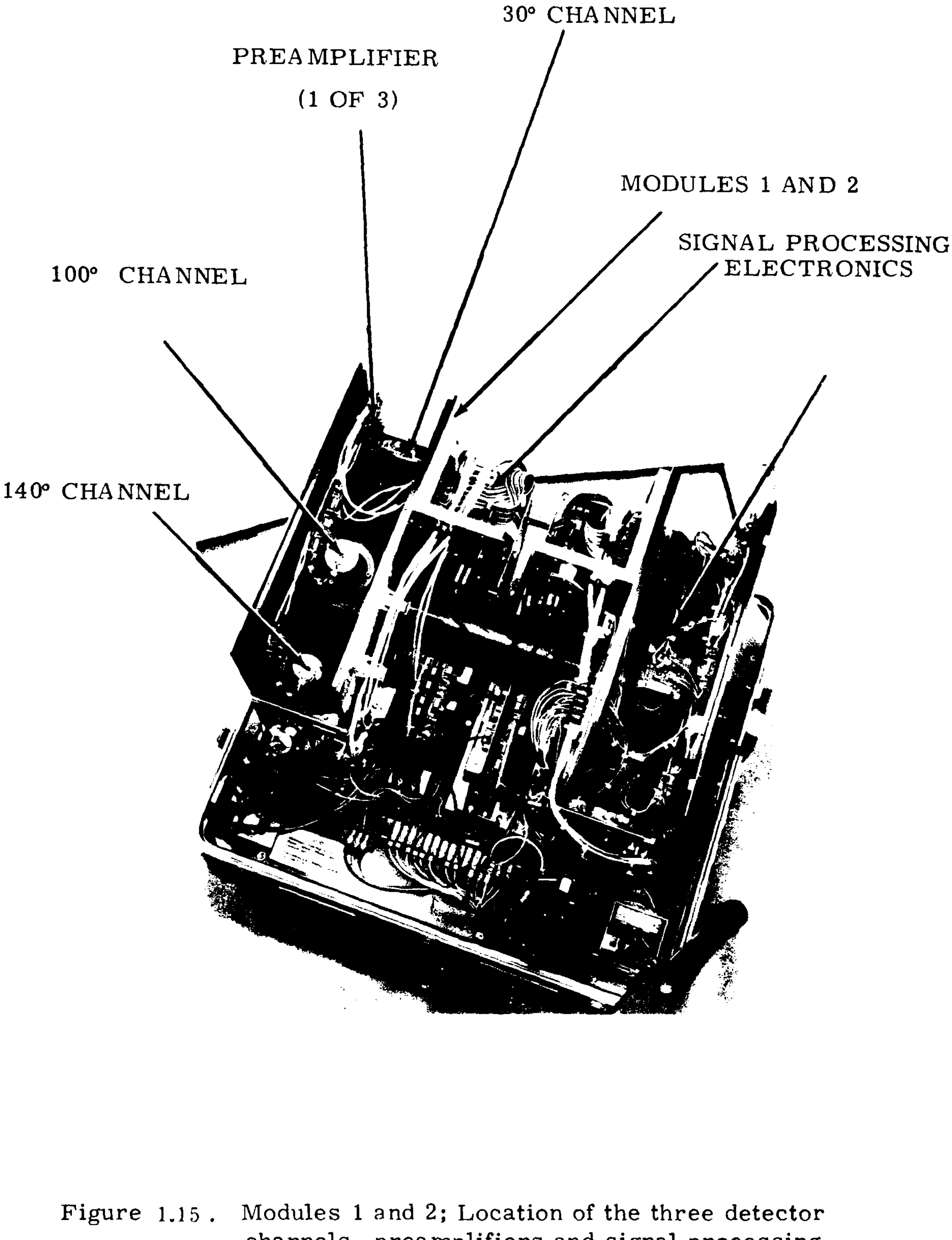

Figure 1.15. Modules 1 and 2; Location of the three detector channels, preamplifiers and signal processing electronics. Top View with Housing Covers Removed.

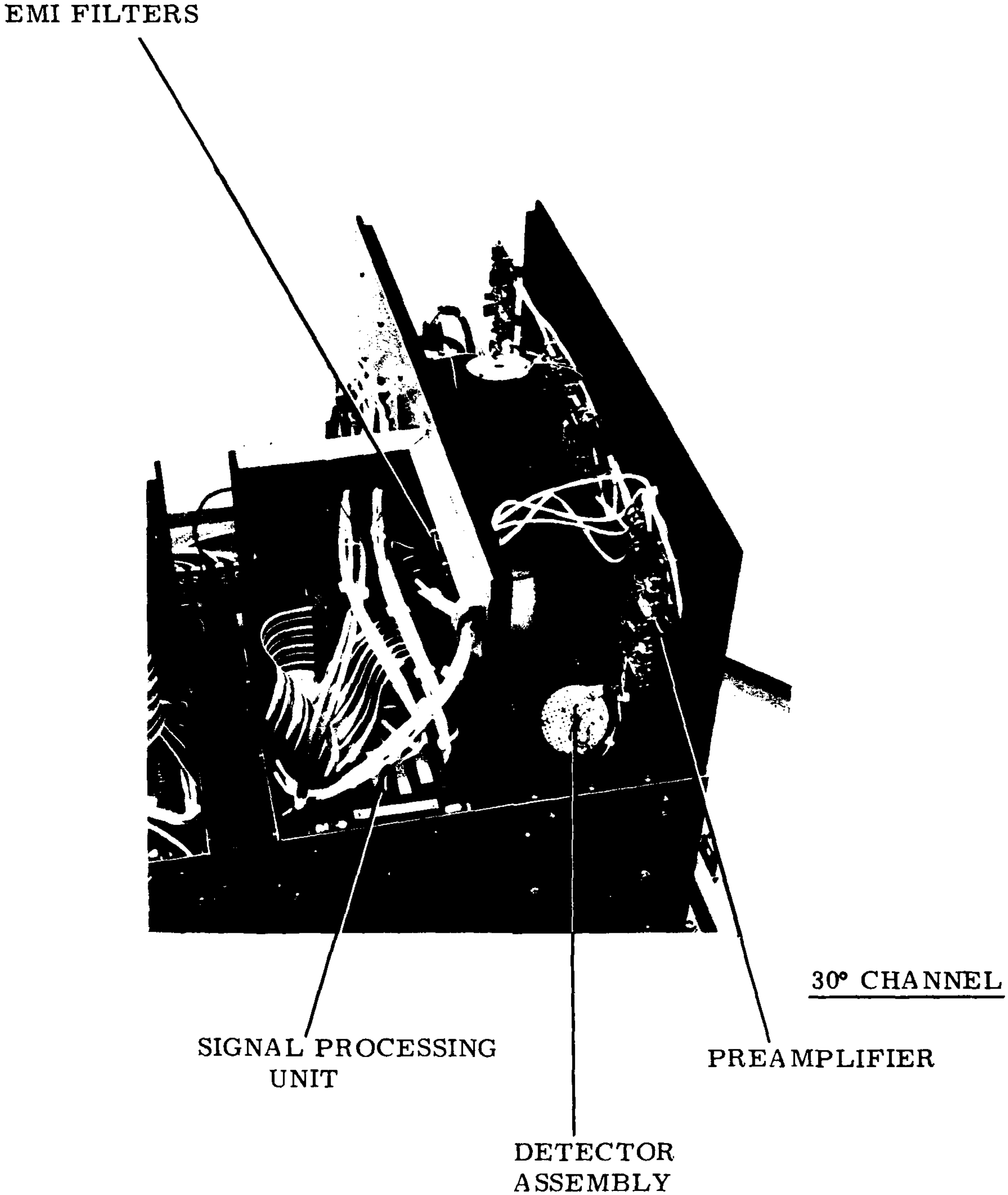

Figure 1.16. Modules 1 and 2; Locations of signal processing unit and the detector assembly and preamplifier associated with the 30° channel. Top View with Housing Covers Removed.

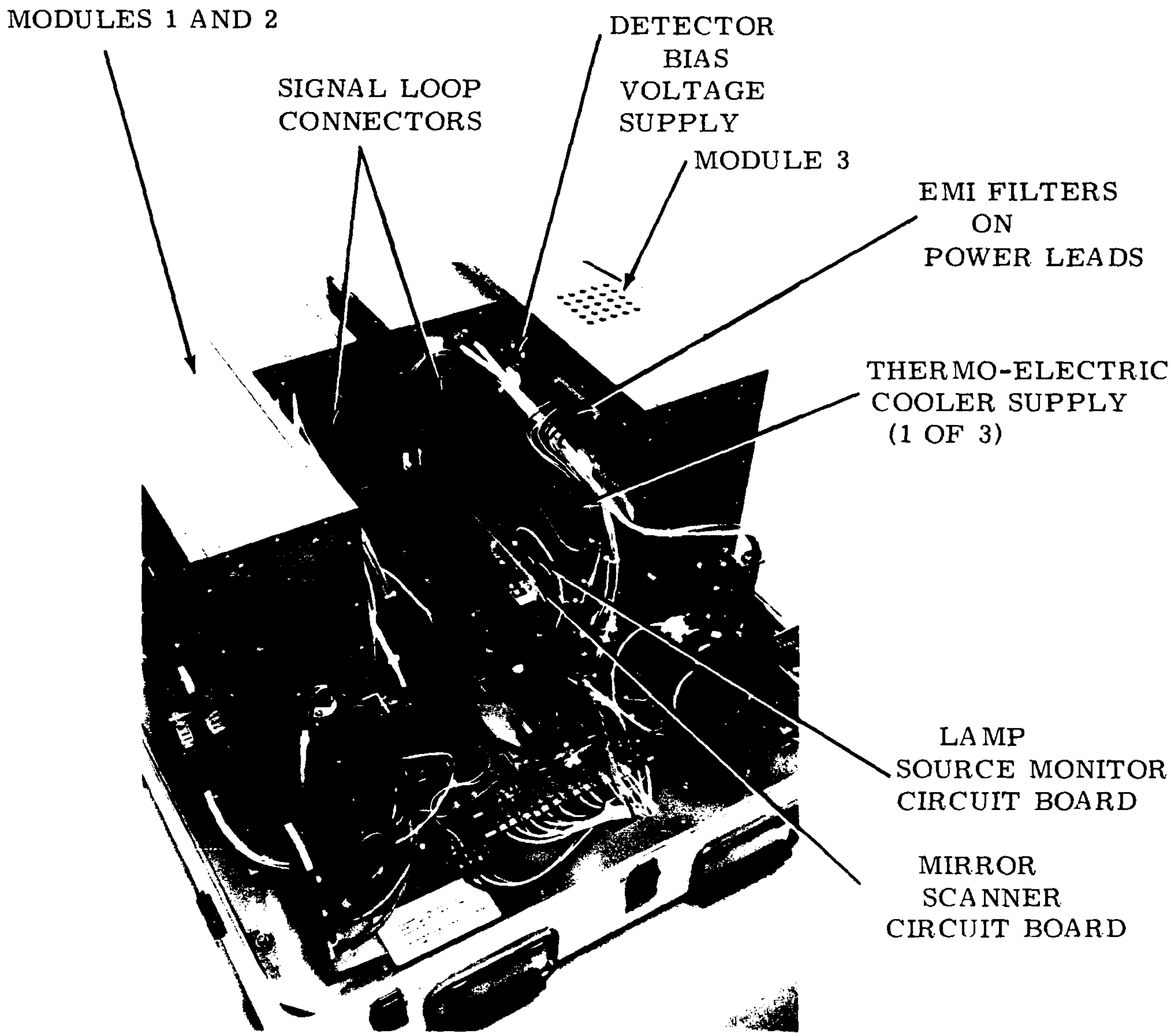

Figure 1.17. Module 3; Location of detector power supplies, circuit boards and other components. Right Side View.

3 detector housing and can also be seen in both Figure 1.17 and Figure 1.18. The galvanometer scanner body is electrically heated to stabilize it against changes in the ambient temperature. The electronic temperature controller is also shown in Figure 1.17.

The controller for the thermoelectric cooler and the bias voltage supply used with the PbS detectors are mounted on the side wall of the detector housing as seen in Figure 1.18. This power leads from the devices, enter the detector compartment through a bank of EMI filters which also can be seen in Figure 1.18. The interiors of the detector compartment and the signal processing housing are shown in Figures 1.19 and 1.20.

1.2.4 Module 4 Description

Module 4 operates at a ultraviolet wavelength of 0.325 microns using an Omnichrome HeCd laser. Only this single unit can be located in the environmental housing because of the size of the laser and its power supply. In the front view given in Figure 1.21 this module appears similar to the others. The major structural difference is seen in Figure 1.22 where the placement of the laser and its power supply is visible. The highly collimated laser beam is reflected ninety degrees by the scanner mirror and goes directly into the quartz entrance window of the detector compartment. This quartz window is tilted so that the small fraction of the beam reflected at the interface will be deflected so as to miss the scanner mirror and impinge on the entrance aperture of the beam power monitor.

Figure 1.23 is a rearward view showing further details of the laser and its controller. the galvanometer temperature controller can be seen also. In the far right corner of the unit can be seen a micro switch interlock used to interrupt the laser power when the housing cover is removed. The purpose of this protective safety feature is to prevent accidental eye exposure to the laser beam. Figure 1.24 and 1.25 are rear views of Module 4. The power supplies for the microprocessor and the signal electronics as well as the galvanometer scanner and source monitor circuit boards can be seen in the latter figure.

1.2.5 Module 5 Description

Module 5 operates at an infrared wavelength of 10.6 microns using a Hughes CO_2 laser. Even though this laser is more compact than the Module 4 Omnichrome HeCd Laser, a separate environmental enclosure was also needed to house this unit. The arrangement of the various subassemblies inside the housing is similar to that of Module 4. In

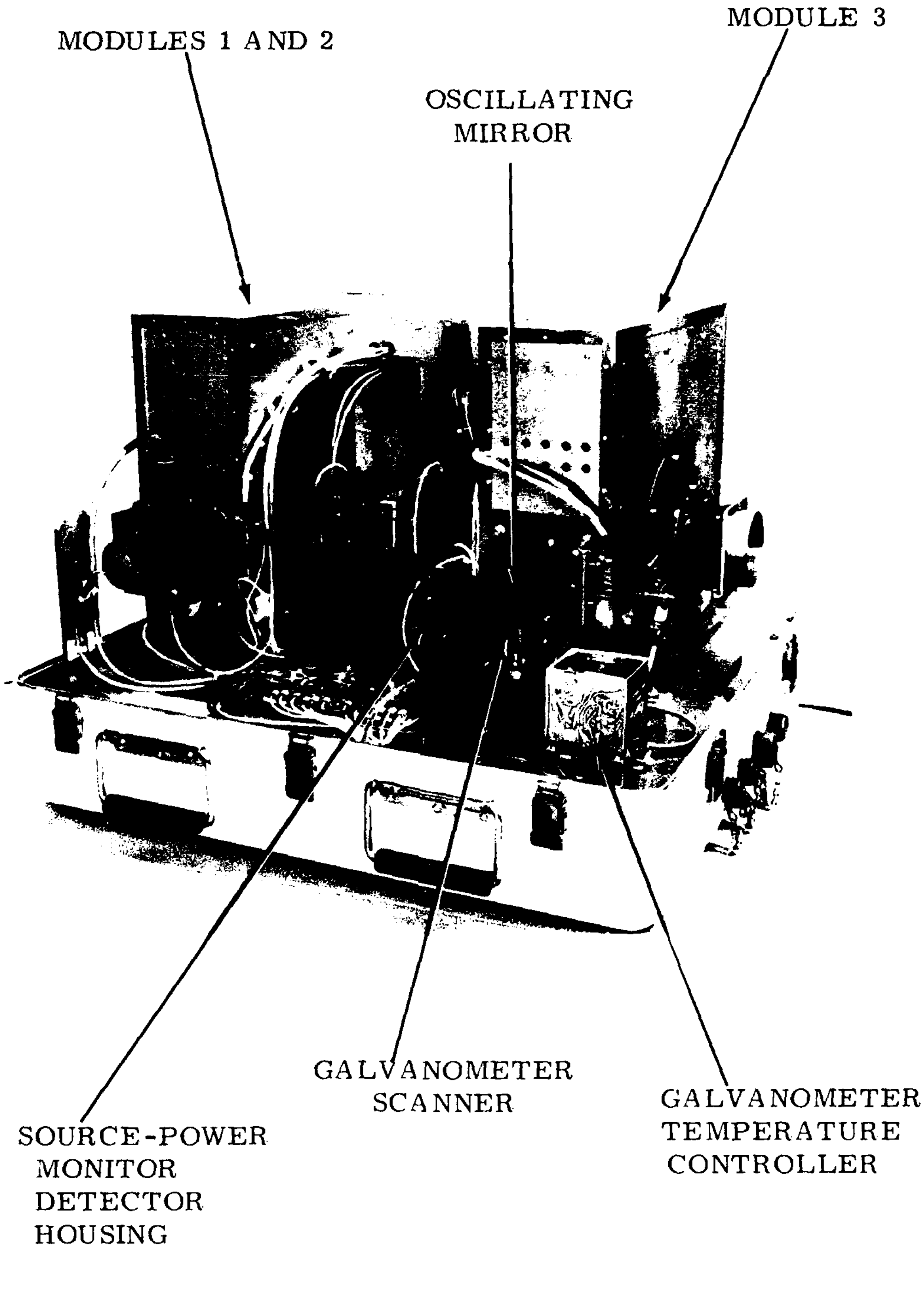

Figure 1.18. Module 3; Locations of the lamp source, source-power detector housing and components of the mirror scanner system. Right Side View.

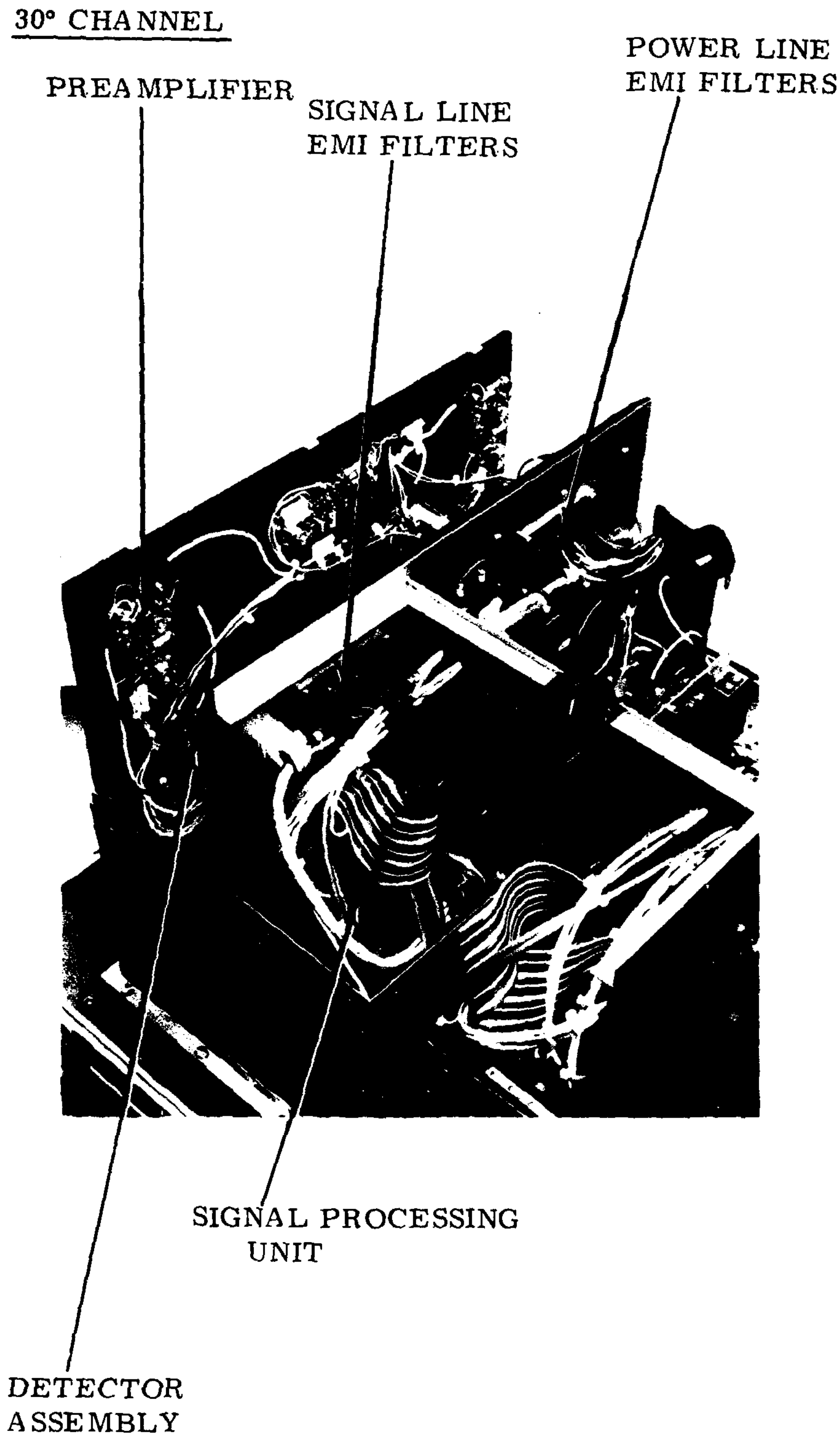

Figure 1.19. Module 3; Location of Detectors and Signal Processing Electronics.

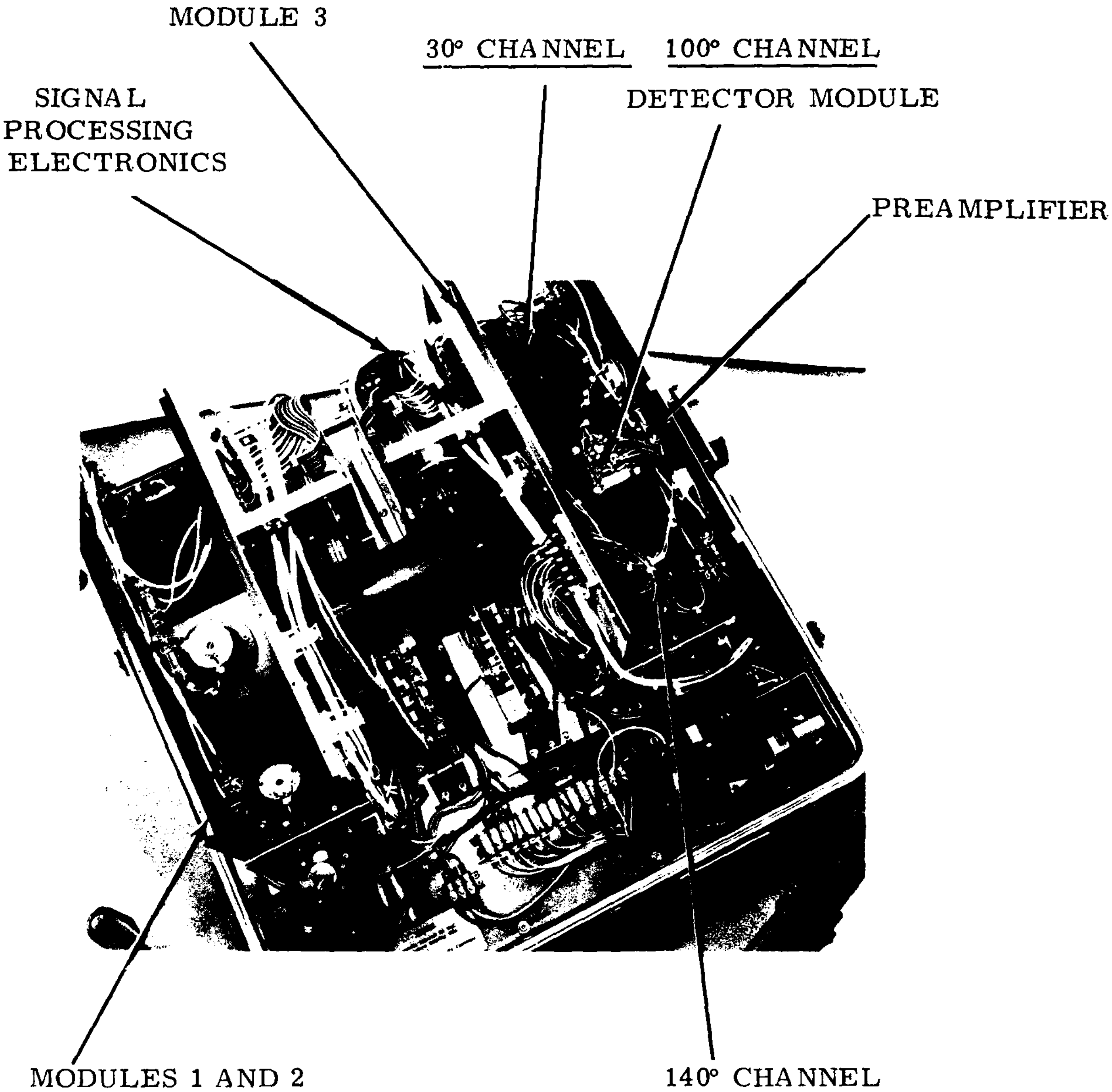

Figure 1.20. Module 3; Location of three detector channels, preamplifiers and signal processing electronics. Top View with Housing Covers Removed.

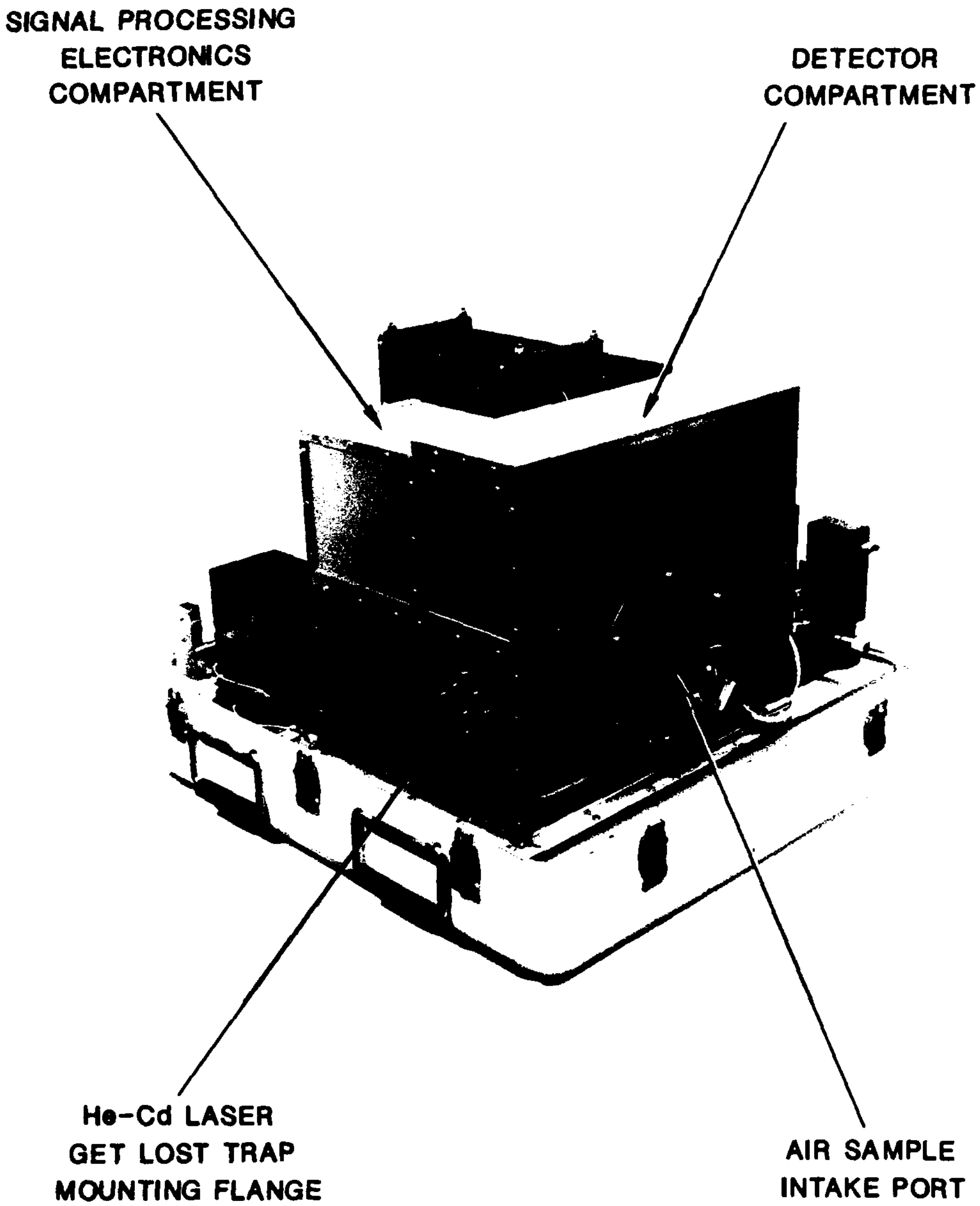

Figure 1.21. MODULE 4 ; LOCATIONS OF THE DETECTOR AND SIGNAL PROCESSING ELECTRONICS COMPARTMENTS AND THE He-Cd LASER GET LOST TRAP.

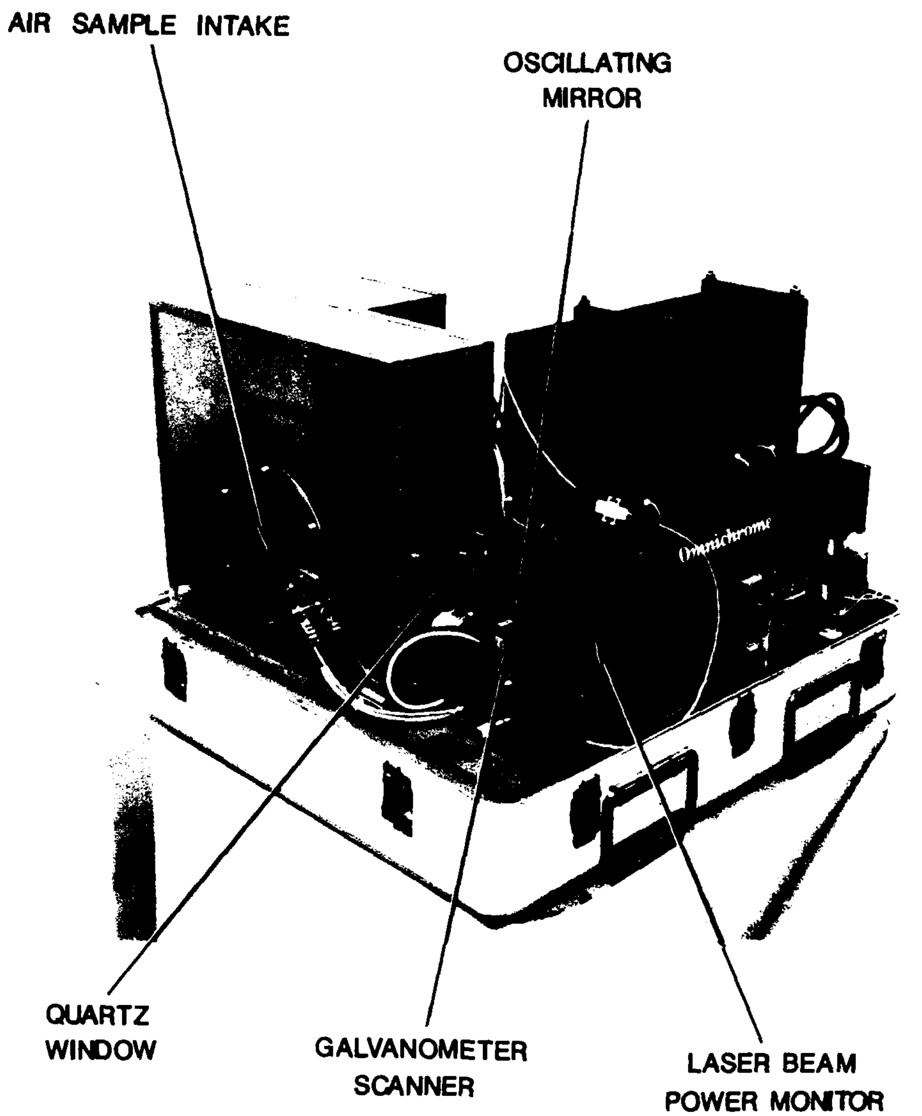

Figure 1.22. **MODULE 4 ; LOCATIONS OF AIR SAMPLE INTAKE AND LASER BEAM HANDLING COMPONENTS.**

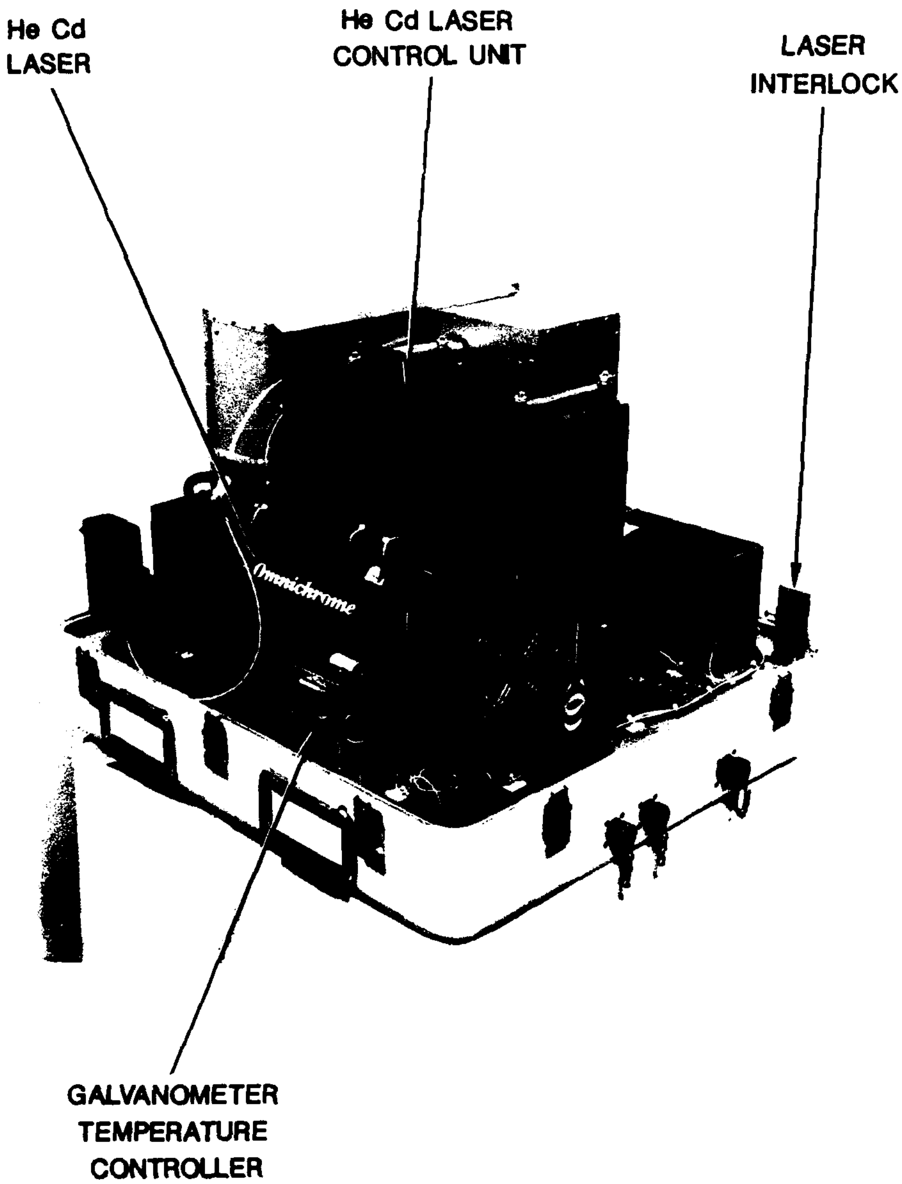

Figure 1.23. **MODULE 4 ; LOCATIONS OF THE He–Cd LASER, LASER POWER SUPPLY, LASER INTERLOCK, AND GALVANOMETER TEMPERATURE CONTROLLER REAR VIEW.**

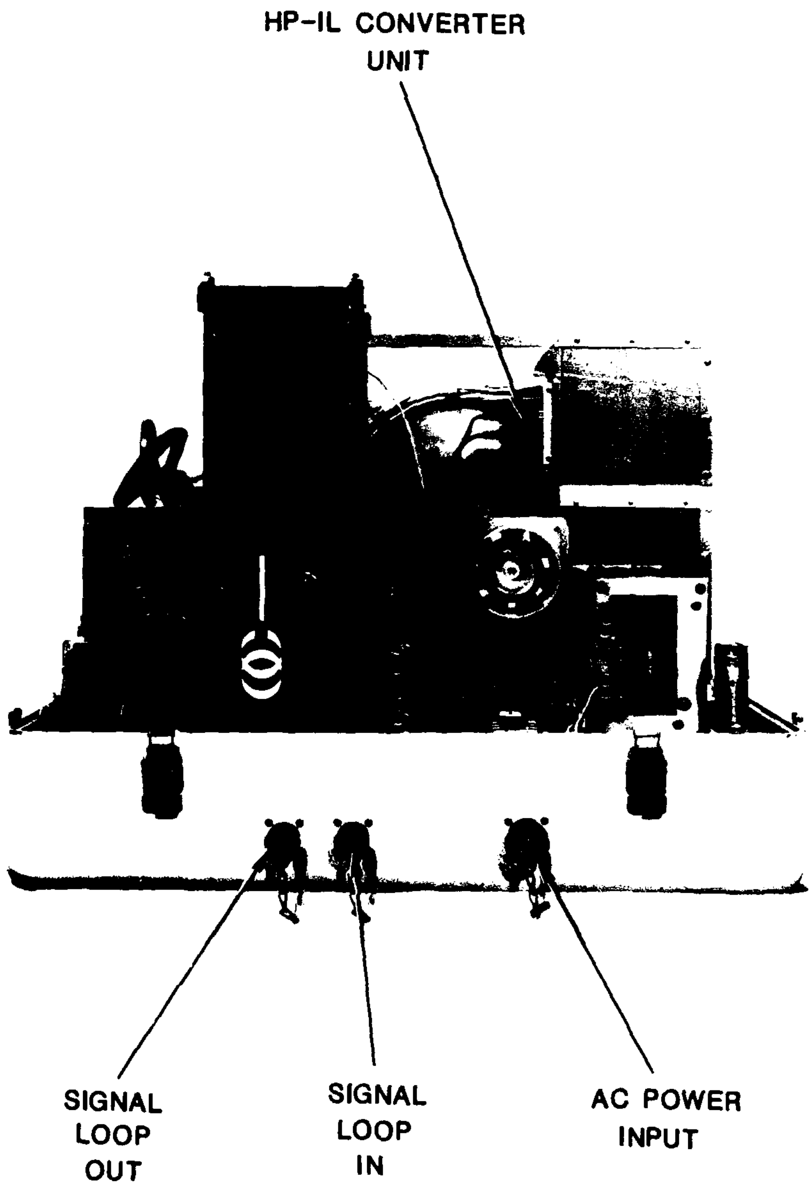

Figure 1. 24. **MODULE 4 ; LOCATIONS OF SIGNAL AND POWER CONNECTORS AND THE HP-IL CONVERTER UNIT REAR VIEW.**

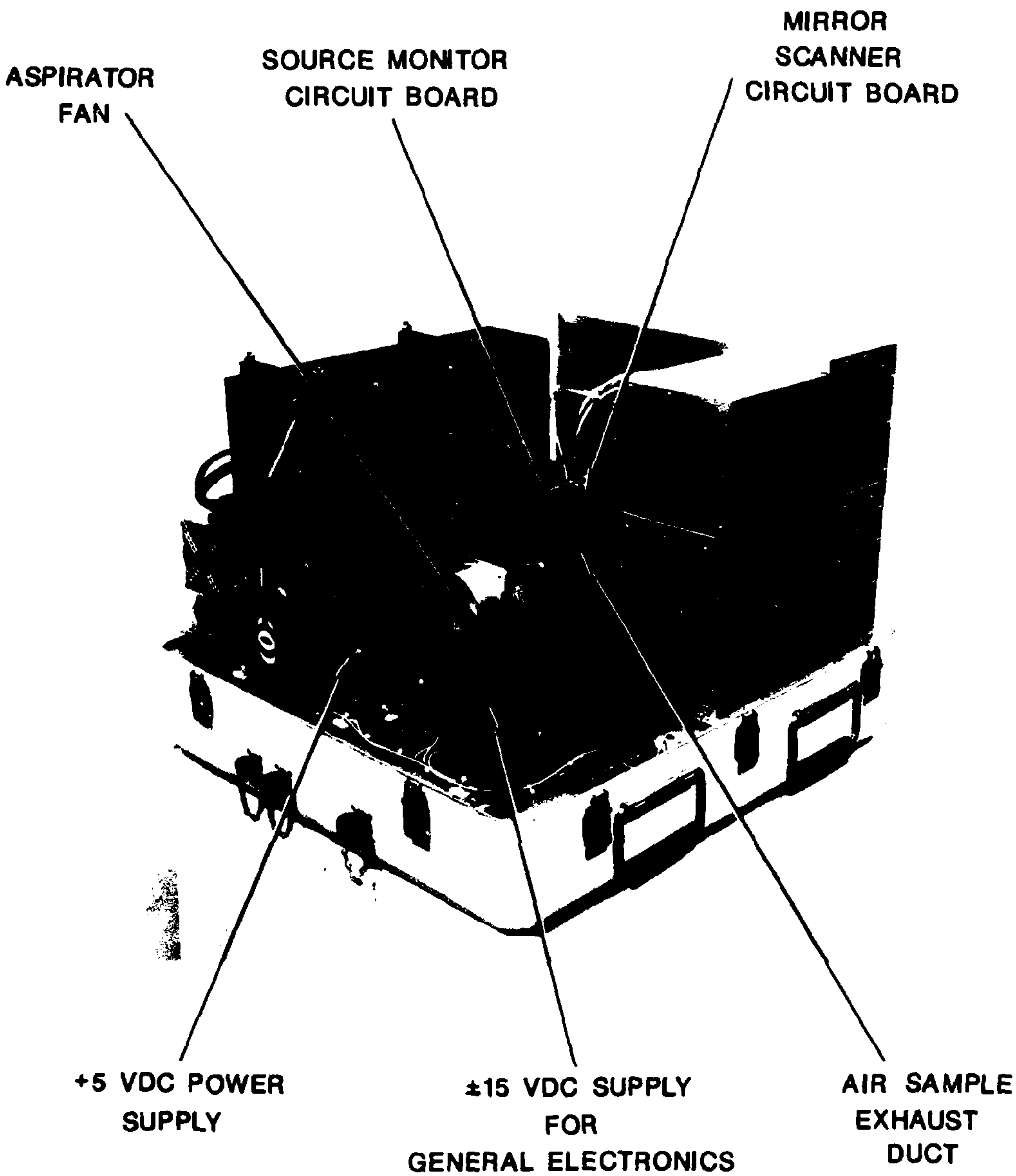

Figure 1.25. **LOCATIONS OF ASPIRATOR FAN,INTERCONNECTING AIR SAMPLE DUCT, AC/DC CONVERTERS,AND SEVERAL ELECTRONIC CONTROLS MODULE 4 REAR VIEW.**

particular, the laser is located so that the optical beam follows the same path as described in Section 1.2.4. After exiting the laser, the beam takes a 90° turn at the scanning mirror and then enters the module housing through a germanium window. The beam reflected backward from the entrance window goes to the beam power monitor. The same uncooled pyroelectric detector is needed for the signal detectors and the beam power monitor detector.

External front and rear views of Module 5 environmental housing are shown in Figures 1.26 and 1.27. With the cover removed, Figure 1.28 shows the CO_2 laser, the detector compartment and the signal processor housing. Figure 1.29 shows details of the path of the laser beam from the exit aperture of the laser to the mirror mounted on the galvanometer scanner and to the entrance window. The beam power window is shown in the position to receive the reflected beam from the entrance window. The air intake to the sample volume is seen to the left of the photograph. Figure 1.30 shows the air duct on the rear of the sample volume which connects to the aspirator fan. The rear view in Figure 1.31 shows the signal and power connectors and also the laser control. panel. The meter on this panel measures the discharge current in the laser at approximately 6 ma. Finally, Figure 1.32 shows the locations of the power supplies, the galvanometer temperature controller, the source monitor circuit board, and the mirror scanner circuit board.

1.2.6 System Controller Components

Figure 1.33 shows the four components of the System Controller: (1) an HP-87 Computer, (2) an HP82901M Dual Disk Driver, (3) an HP82905B Data Matrix Printer, and (4) a Hayes Chronograph. Also shown is the cable transition box which allows the HP-IL cables to be connected to coaxial cables carrying the digital communications to the remotely located housings. The three Hewlett Packard units are interconnected by HP-IB cables while the chronograph is connected to the computer by an RS-232 cable.

1.2.7 Sample Volume Assembly

The scattering of the source beam by the aerosols in the air sample going through the Module takes place in the sample volume assembly. This unit, which is common to all modules, serves first as a section of the air duct which goes through the housing. Second, it contains apertures for the source beam to pass through and exit to the beam dump and for the scattered light to exit to the three detectors at the scattering angles

Figure 1.26. Wavelength Module 5 with cover and air-intake tube installed.

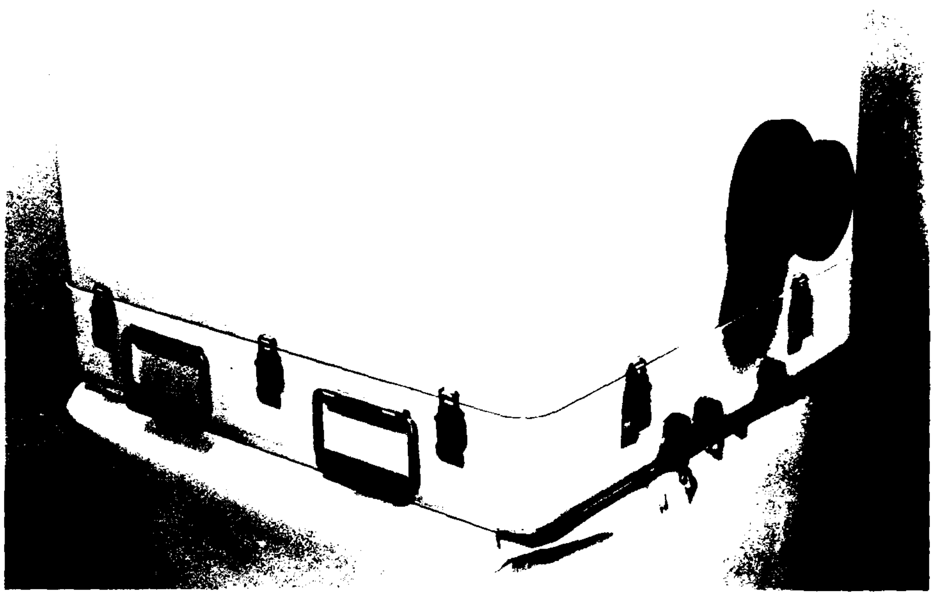

Figure 1.27. Wavelength Module 5; Rear view showing exhaust port.

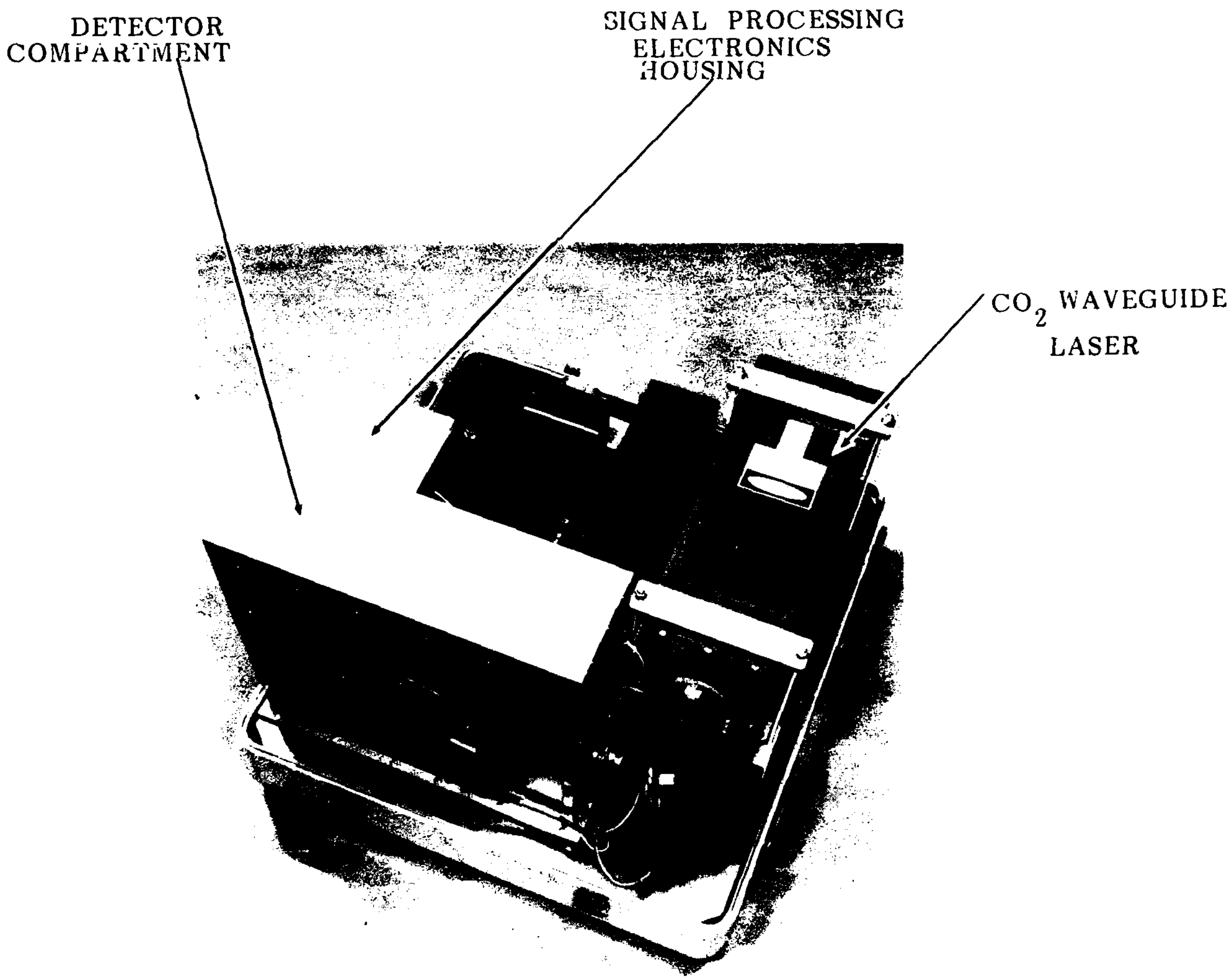

Figure 1.28. Module 5; Cover removed showing locations of the CO_2 laser, detector housing and housing for the signal processing detector Top View.

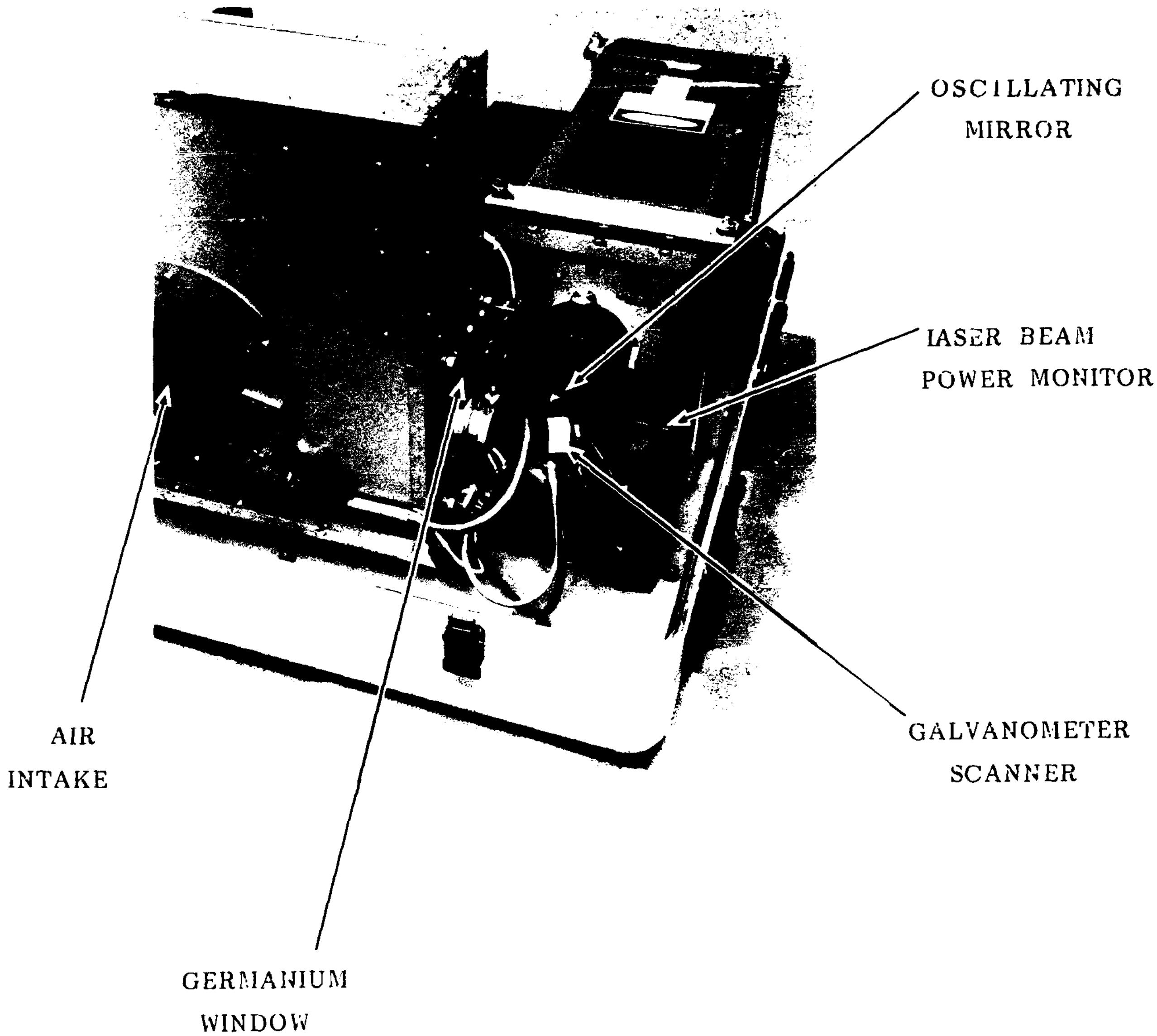

Figure 1.29. Module 5; Locations of air intake and laser beam handling components. Front View.

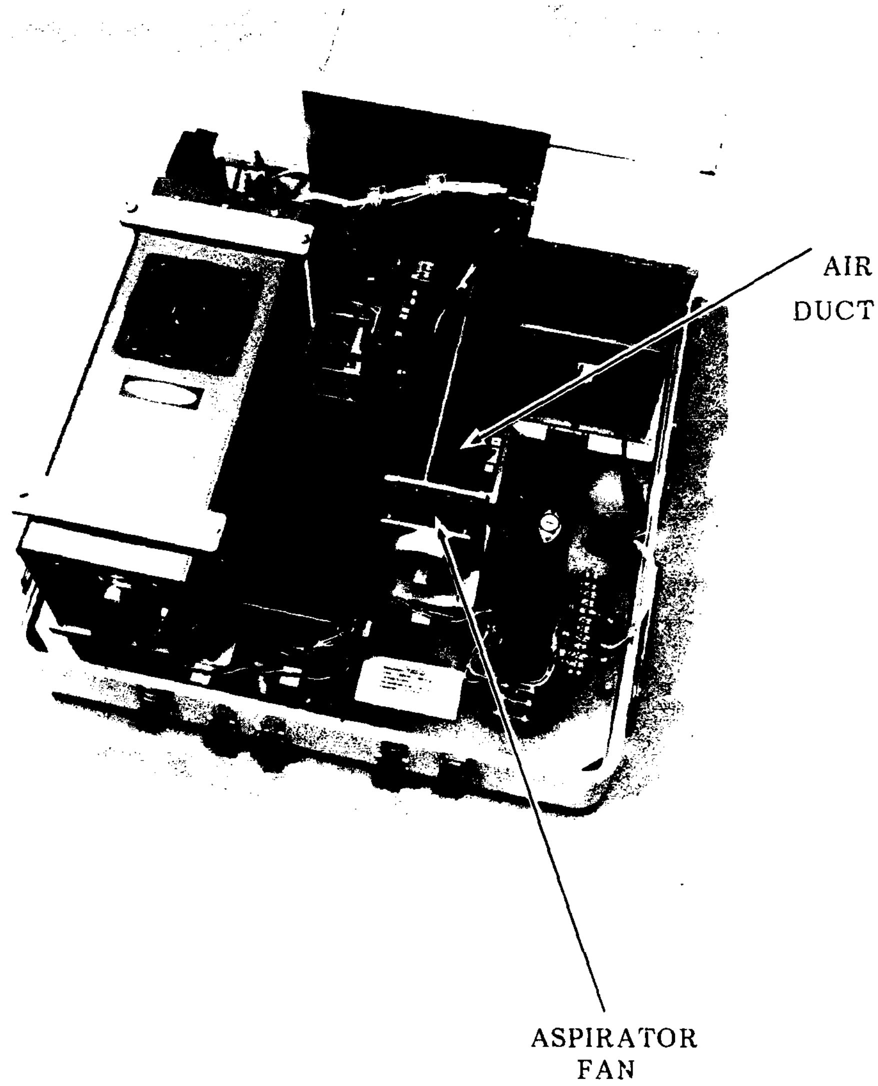

Figure 1.30. Module 5; Location of aspirator fan and interconnecting air duct. Top View.

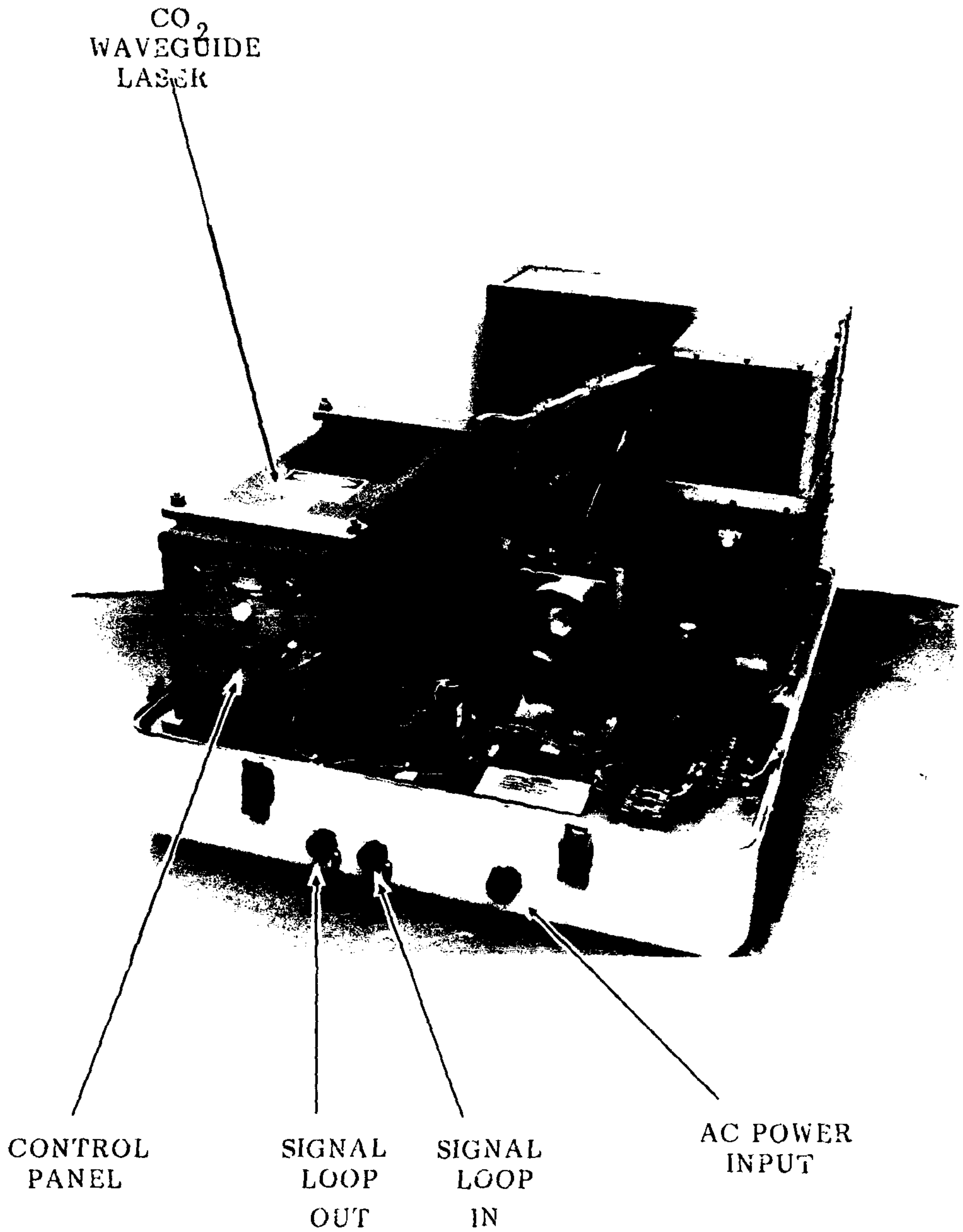

Figure 1.31. Module 5; Location of signal and power connectors and the control panel of the CO_2 laser. Rear View.

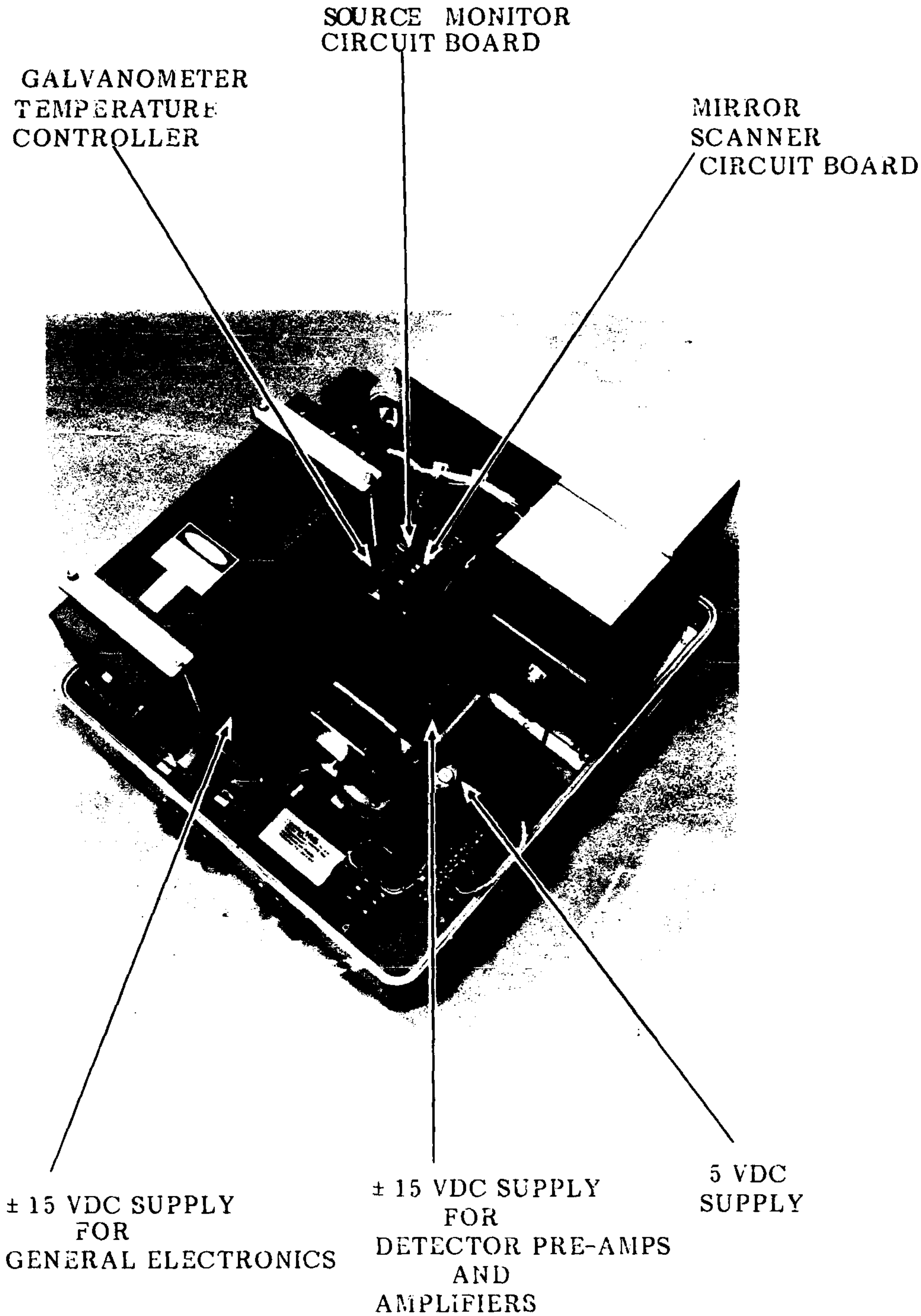

Figure 1.32. Module 5; Location of AC/DC converters and several electronic controls. Top View.

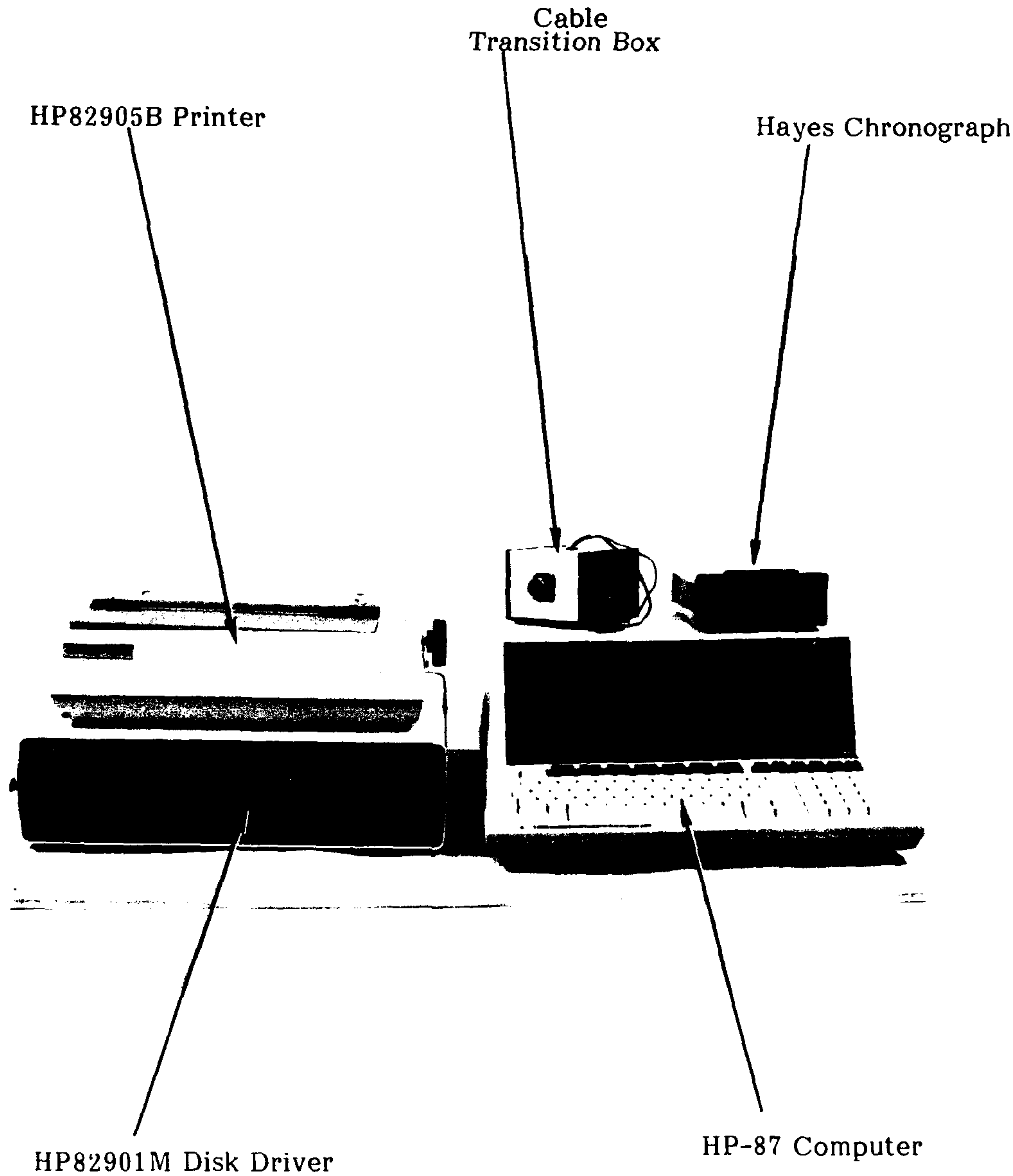

Figure 1.33. Control & Recording Section of the Polar Nephelometer.

of 30°, 100°, and 140°. Also it contains baffles used to help reduce extraneous scattered light not arising directly from the scattering volume. Finally, it contains a movable scatterer which can be inserted into the source beam by command from the system controller and serves as a reference standard. Figures 1.34, 1.35 and 1.36 show the front, side and rear views of the sample volume assembly in order to illustrate these features.

Figure 1.34 shows a front view of the sample volume assembly which can slide from the Module housing after five screws are removed from the front circular front plate. Air flow is into the plane of the illustration. The source beam enters at the right and exits at the left. The calibration reference scatterer is the small sphere mounted on a thin rod which can be seen in silhouette. That assembly is raised and lowered by a linear motion stepper motor which is connected to a control cable through the connector assembly mounted to the front plate. The side view in Figure 1.35 shows the apertures through which the source beam passes. The calibration reference sphere is again seen in silhouette. The rear view in Figure 1.36 shows the system of metal fins which serve both as light baffles and as a support for the short cylinder which defines the scattering volume.

The calibration reference scatterer provides a method of checking that any module is operating properly and that the signal level has not changed significantly from the last reference check. The scatterer normally is in its retracted position, but can be inserted in the sample volume using the Calibration command provided in the operating program (see Section 3.0 and Appendix A).

When the small sphere is in its calibration position, optical radiation is scattered into all three channels producing signals which are displayed on the computer CRT and can be printed on the matrix printer, if desired. The presence of signals on all channels verifies that the system is operating. Comparison of their value with previously recorded values will show any change in sensitivity.

1.2.8 Filter Wheel Assembly

A three-position filter wheel driven by a rotary stepper motor is placed behind the entrance aperture on each Module. One position is completely open and is used when taking data. A second position is completely blocked and is used to check the no-signal or zero reading of the detector electronics. The third position is used when taking readings from the calibration reference sphere and contains an optical attenuator which reduces

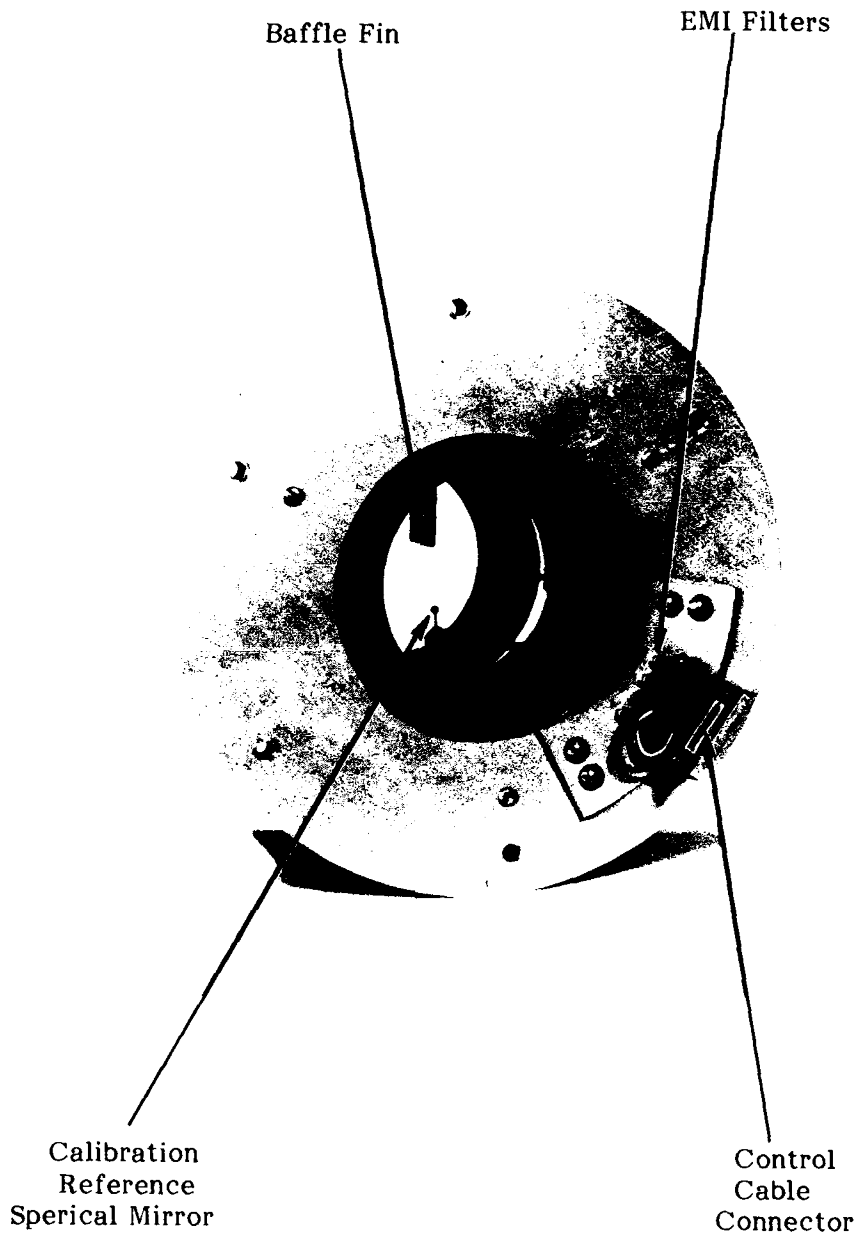

Figure 1.34. Sample volume assembly; front view.

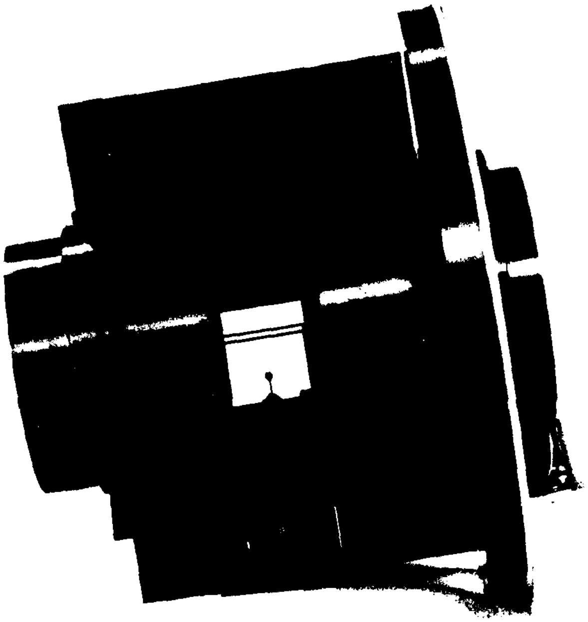

Figure 1.35. Sample volume assembly; side view.

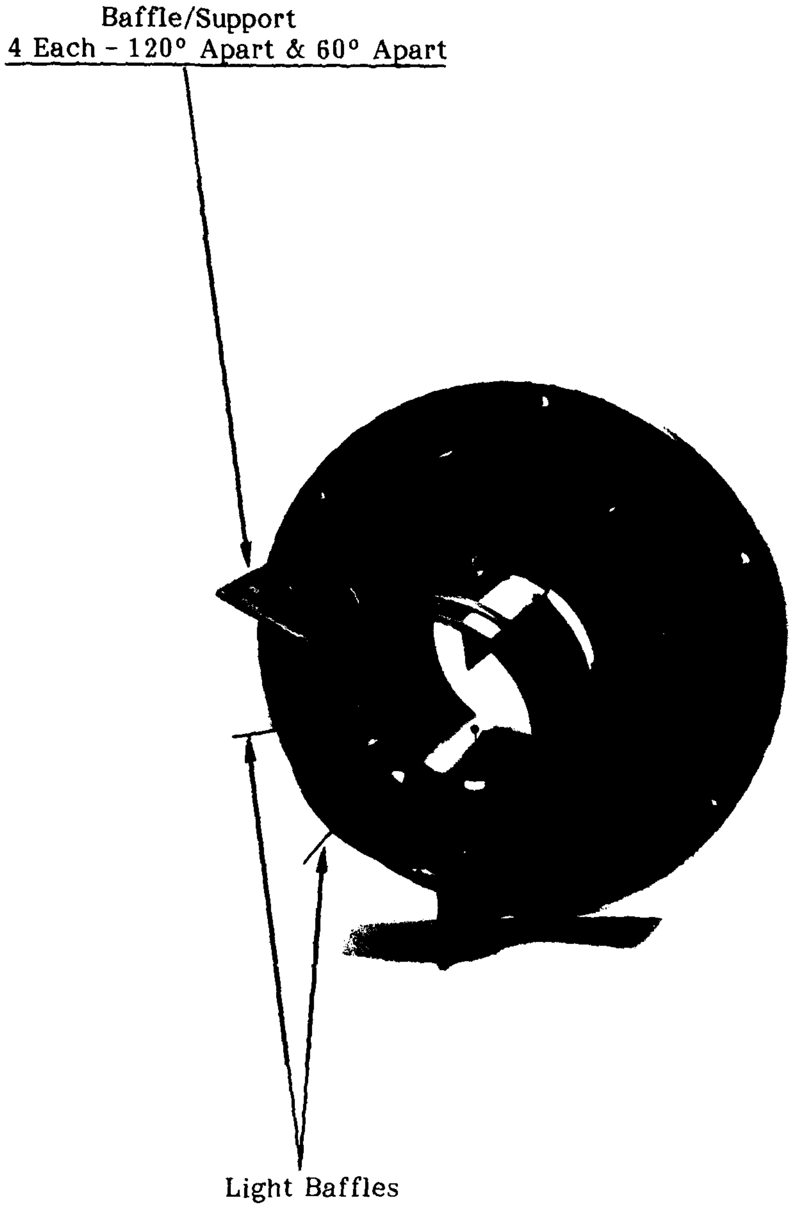

Figure 1.36. Sample volume assembly; rear view.

the otherwise strong signal to a weaker level which can be handled by the electronics. The filter wheel is driven to any of these three positions by an assembly language subroutine in the on-board microprocessor. The microprocessor drives the wheel by sending stepping pulses to the motor until the wheel position sensors indicate that the desired position has been reached. Figure 1.37 is a rear view of the filter wheel assembly showing the wheel which is made from a large gear and is driven by a small gear mounted on the motor shaft. The motor is on the other side of the plate. The position sensors are activated by two small reflective studs located on the wheel periphery. In Figure 1.37, they can be seen in the upper left quadrant of the wheel.

Figure 1.38 is a front view of this assembly showing the entrance window surrounded by the stepper motor and the connectors to the motor and to the wheel position sensors.

1.2.9 Light Traps

After the source beam leaves the sample volume, it goes into a cavity (called variously a light trap or beam dump) whose purpose is to prevent any light from scattering or reflecting by any path back into the detectors. Figure 1.39 shows the form of the trap used on Module 1/2 and Module 3. It is a wedge of absorbing black glass. Figure 1.40 shows the style of trap used on Module 5 and also on Module 4. The narrow laser beams are successively reflected into the apex of the two inclined glass surfaces. The angle is such that the reflections can never turn around and come out of the trap.

1.2.10 Air Duct System Accessories

Figure 1.40 shows some accessory attachments to the air duct system used in operating and calibrating the APN. The first item on the left is the air intake tube which is inserted through the environmental housing and into the sample volume assembly when the system is being operated. To the front of this tube is the shipping and storage cap used to seal the intake opening in the environmental housing cover when the instrument is not taking data or during shipping. To the right and rear of this cap is the short exhaust pipe section that functions both as an exhaust port and a sealing cap. The open exhaust slot can be seen in this figure. Rotation of the circular end plate closes the slot thereby sealing the exhaust pipe. This pipe fits snugly into the aspirator fan housing.

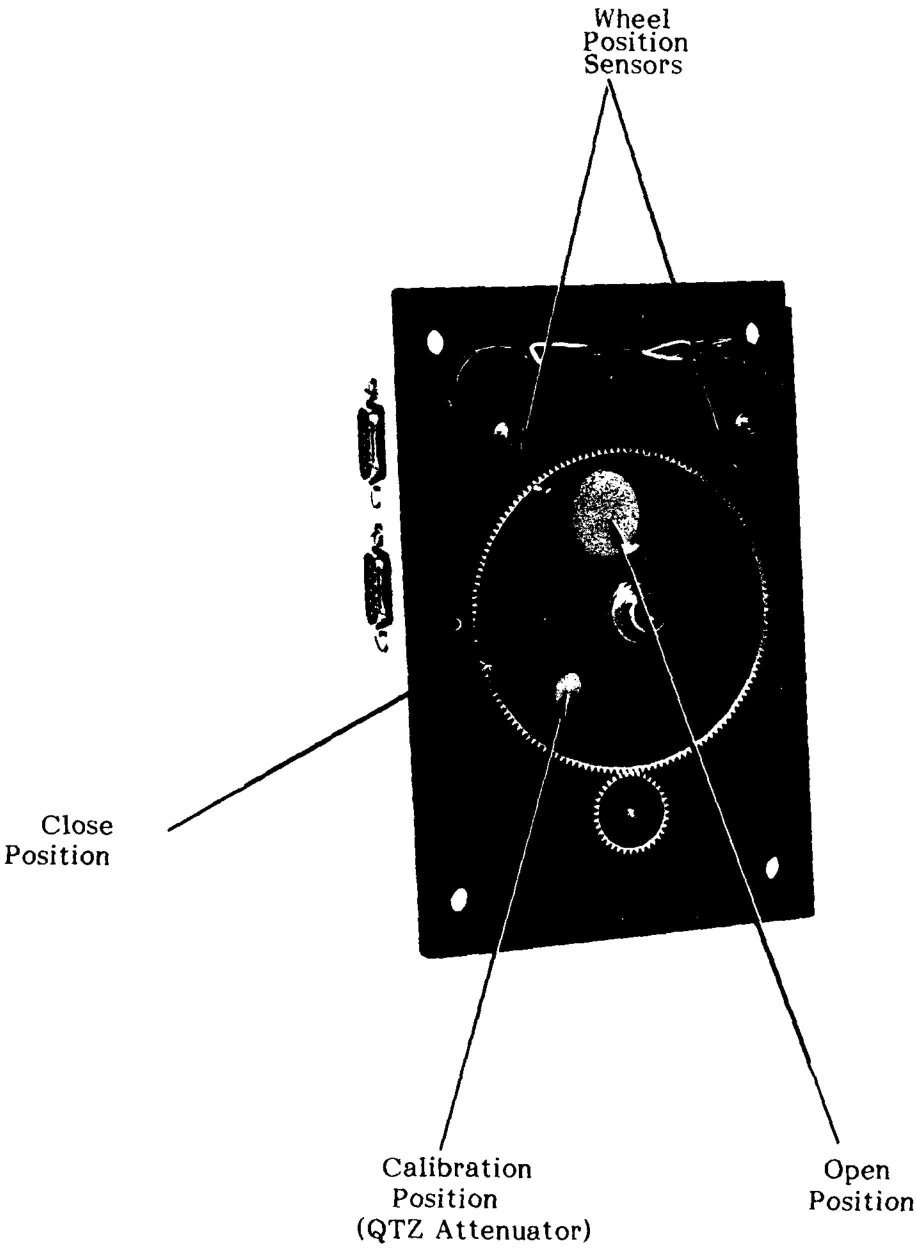

Figure 1.37. Filter wheel; rear view.

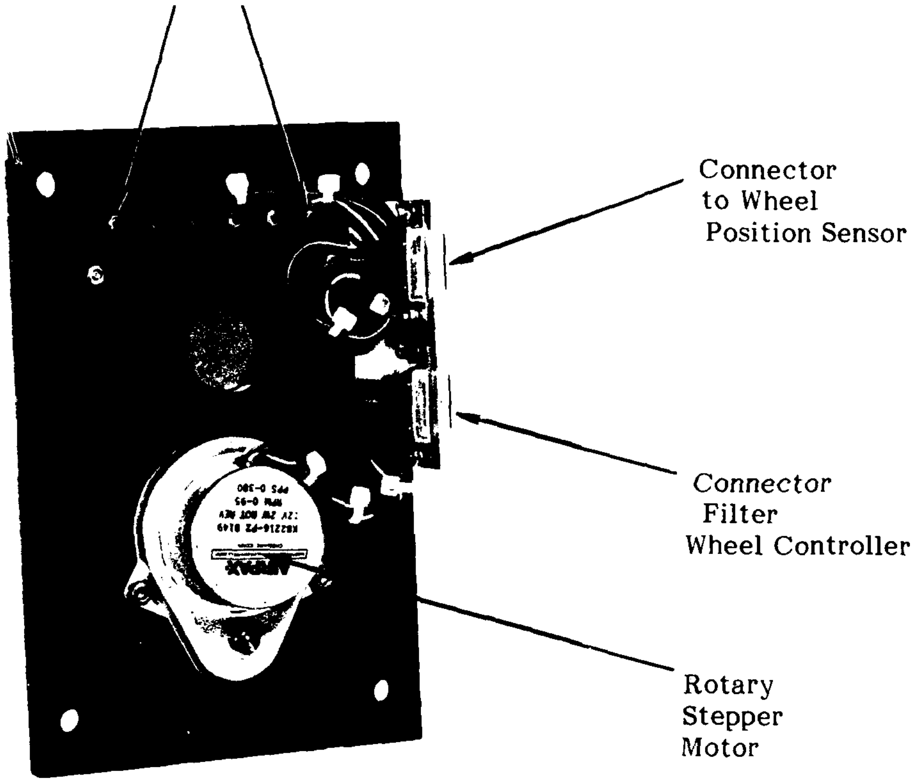

Figure 1.38. Filter wheel; front view.

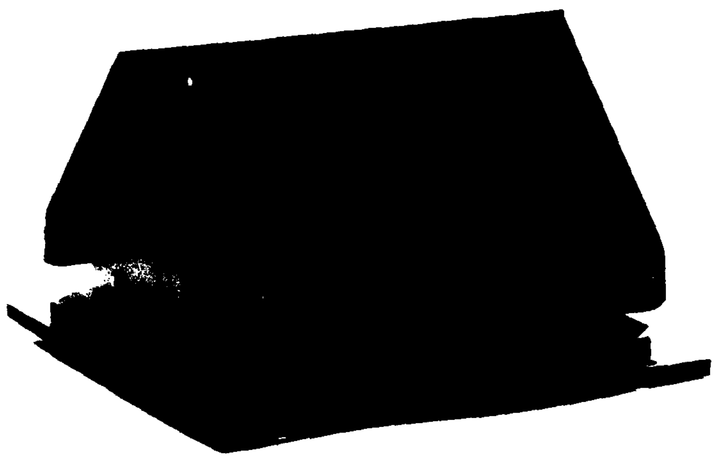

Figure 1.39. Wedge section of light trap; Modules 1 and 2 and Module 3.

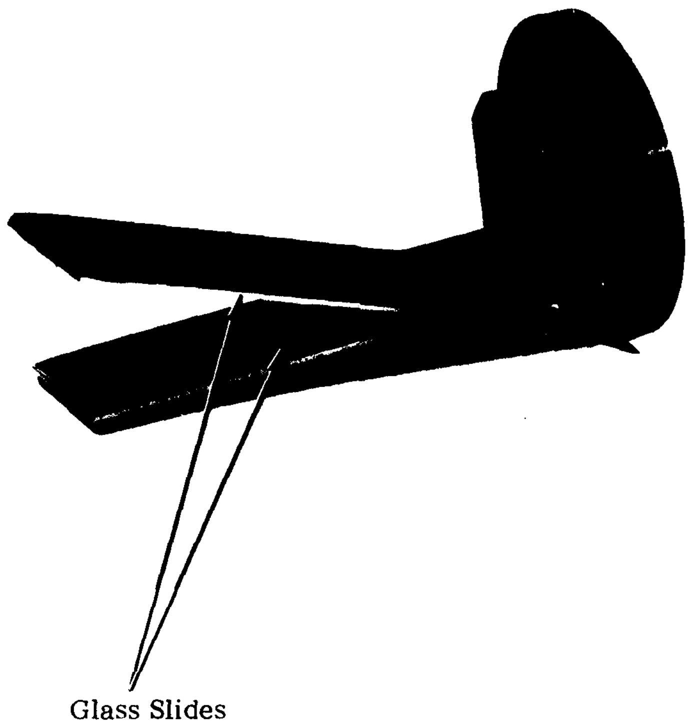

Figure 1.40. Laser beam dump; Module 5.

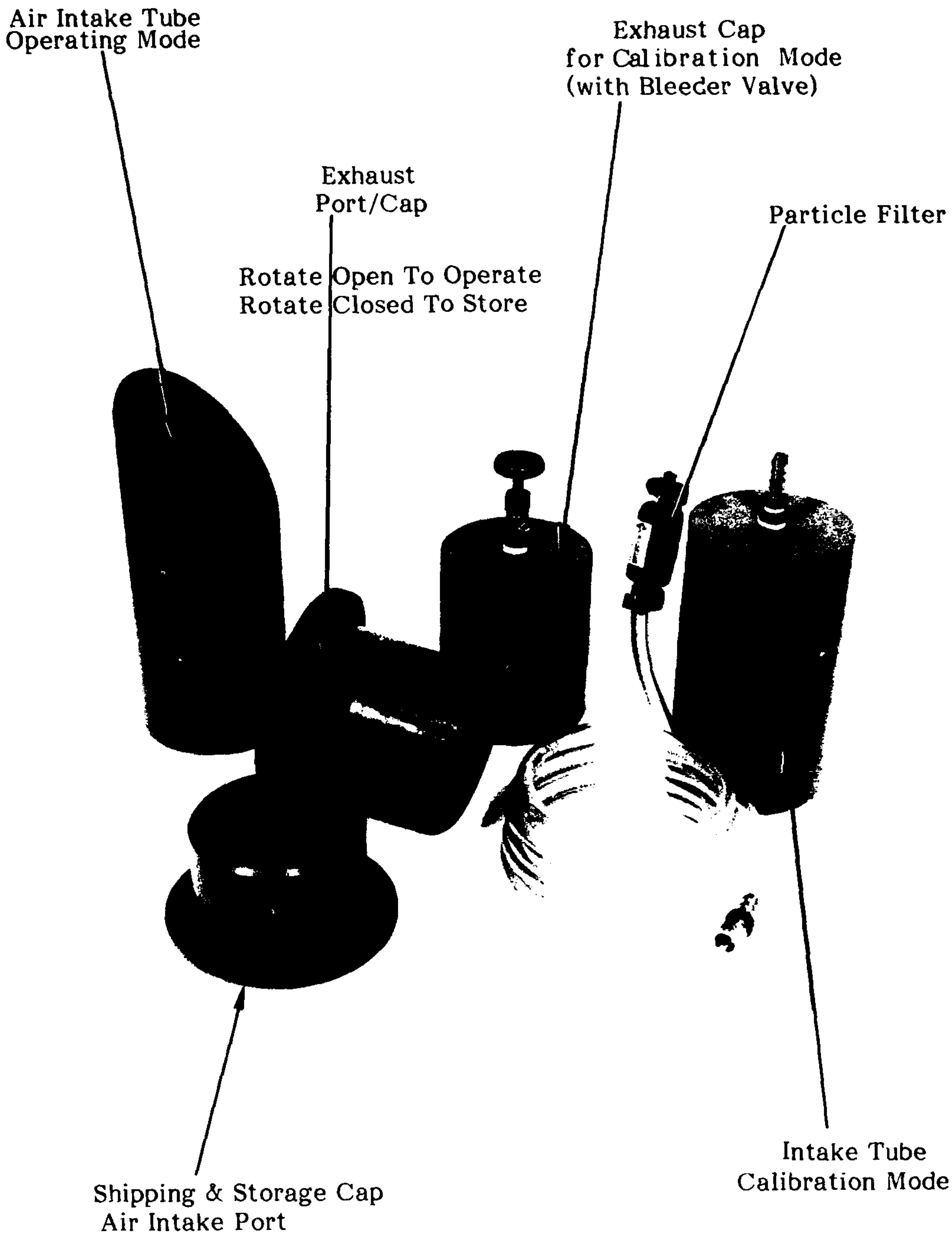

Figure 1.41 Air duct system accessories.

The remaining two tubes are used to introduce Freon into Module 1/2 for calibration. The intake and exhaust tubes are removed and replaced by the corresponding calibration tubes. The calibration exhaust cap is equipped with a bleeder valve to help control the gas flow. The intake tube is equipped with plastic tubing having a fitting which connects directly to disposable commercial Freon refrigerant tanks. An in-line particle filter is inserted in the tubing to remove particles which are found in those tanks. Figure 1.42 shows the Freon system installed.

An additional accessory is an air filter system capable of filtering particles of 0.1 micron diameter and larger. Figure 1.43 shows the air filter system attached to Module 5. An industrial grade separate-less HEPA filter with a minimum efficiency of 99.97% at 0.3 microns is connected to the intake port by flexible aluminum tubing. A blower fan mounted on the input side of the filter forces the air through the filter and through the instrument. The filter system is periodically connected to the modules to measure the residual stray light signal level when no aerosols are present in the sample volumes.

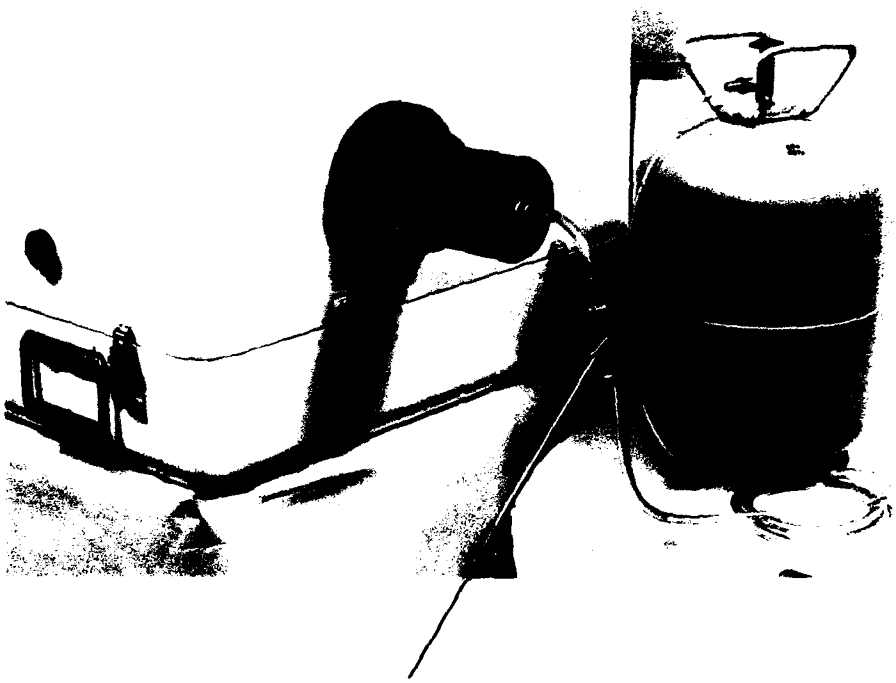

Figure 1.42. Wavelength Modules 1, 2 and 3; techniques for introduction of Freon during calibration.

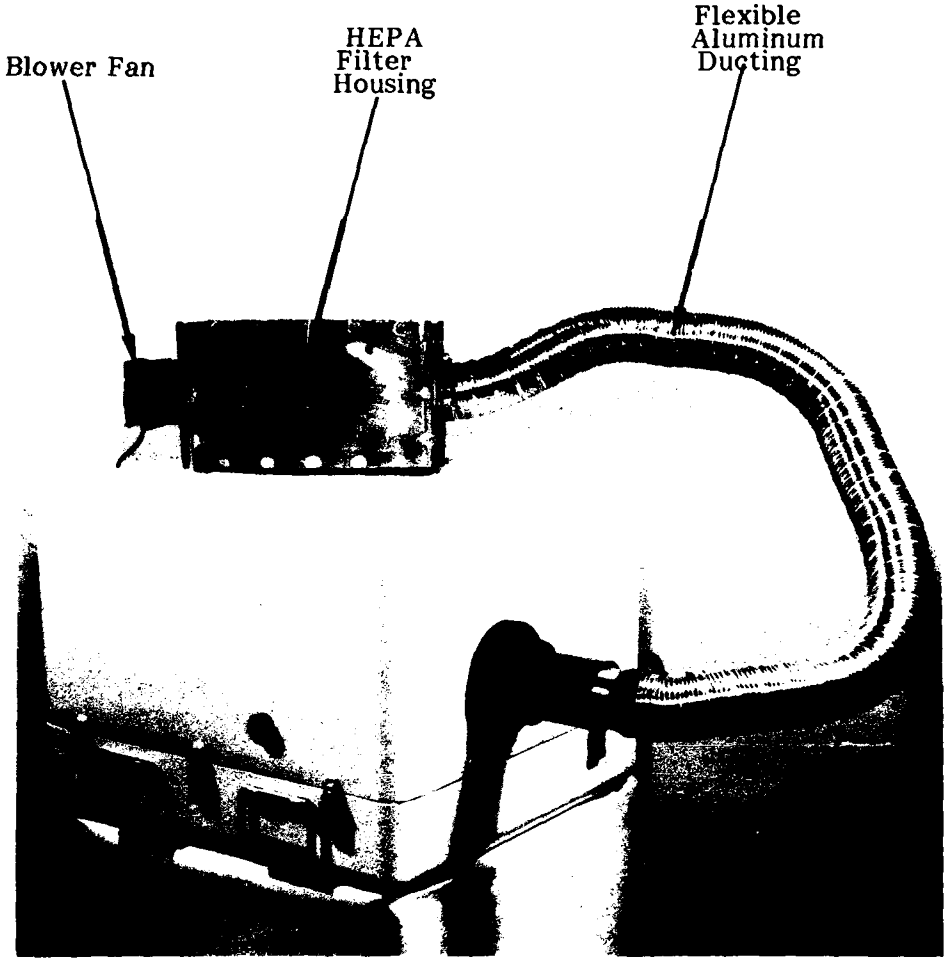

Figure 1.43. Wavelength Module 5; technique for introducting filtered air to establish zero readings of detector channels.

2.0 PREPARATION FOR USE AND RESHIPMENT

2.1 General

The Abridged Polar Nephelometer was specially designed for all season field operations including rain and snow conditions. Because the interior components are ruggedly mounted and the equipment housing can be easily sealed against the ambient environment, very little special preparation is needed for shipment. Conversely, since the equipment components are fully assembled, the entire system can be rapidly set-up and taken-down at any site where 115 VAC power is available.

2.2 Unpacking and Inspection

Unpack the system components from any protective containers which may have been used for shipping to the operating location. All environmental housings should be opened by removing their covers and inspected to verify that the internal components are undamaged and in their proper locations. In particular, all electrical terminals and connections should be checked for tightness. Finally, before the covers are replaced, the power switch on the aspiration fan in each of the three system modules should be set in the ON position. The covers can now be replaced and the installation begun.

2.3 System Installation

The installation of the APN consists of three phases: (1) siting and mounting the instrument modules, (2) locating and connecting the system controller/computer components and (3) connecting power and signal cables between the system controller and the remotely located instrument modules. The signal cables are twinax coaxial cables and care should be exercised to avoid any kinks while laying and covering them. Installation for laboratory operation follows the same general procedure, but can be appropriately abbreviated.

The instrument modules should be located in a clear area away from anthropogenic disturbances, facing the prevailing wind and several feet above the ground. It is desirable, but not necessary, to shade the instrument housings from direct solar irradiation. A suitable raised platform can be readily constructed using pipes. The power supply housing can be placed on the ground under the stand, but not more distant than allowed by the 25 ft. long interconnecting cables.

After the instrument modules have been situated, intake nozzles should be inserted in the front of the housings and the extent slots in the exit tubes should be opened. When calibrations are to be done, the appropriate fittings for introducing Freon or filtered air should be inserted in place of the normal intake nozzles and exit tubes.

The system controller comprises the following Hewlett-Packard components: an HP-87 computer, an HP82905B matrix printer, and an HP82901M dual flexible disk drive. Date and time are obtained from a Hayes Stack Chronograph which is connected to the HP-87 through an RS-232 serial port. All four of these components are powered from 115 VAC. Each of the Hewlett-Packard components has an ON/OFF switch. The Hayes instrument is powered through a small 13.5 VAC power pack which plugs directly into a 115 VAC socket.

The printer and disk drive are connected via HB-IB cables to the built-in HP-IB (Hewlett-Packard Interface Bus, a parallel data bus) in the HP-87 computer. The connectors on these special cables can be stacked, thus allowing multiple inputs to a single port. In addition, the cables can be daisy-chained from instrument permitting flexibility in placement of the components.

The chronograph is connected on the HP-87 through an HP92939A Serial Interface which is the Hewlett-Packard implementation of the RS-232 data communications protocol. This interface is inserted into any one of the 4 I/O slots on the backplane of the computer. The connector on the built-in cable with the interface, does not mate directly with the connector on the back of the chronograph. To make this connection a 2½ ft. gender changer/null modem cable is inserted between the chronograph and the HP-Serial Interface cable. In addition, the null modem behavior is created by modifying the internal connections in the cable in order to conform to the data sending and receiving directions on the HP cable. This modification consists of interchanging the wires on pins 2 and 3 of one connector of the gender change.

2.4 System Interconnection

The electrical interconnection diagram for the APN is shown in Figure 2.1. The 115 VAC single phase power for the remotely located instrument modules should originate at a switched source located near the system controller. A cable of approximately 100 feet length is provided and has a connector which mates with a connector on the power supply enclosure. The connection on the source end of the cable will vary with the facilities available at each installation. The auxiliary power supply enclosure distributes both DC power (± 15 V and 5 V) and AC power (115 V) to the housing containing Module 1, 2 and 3 and only AC power to the Module 4 and Module 5 housings. The power

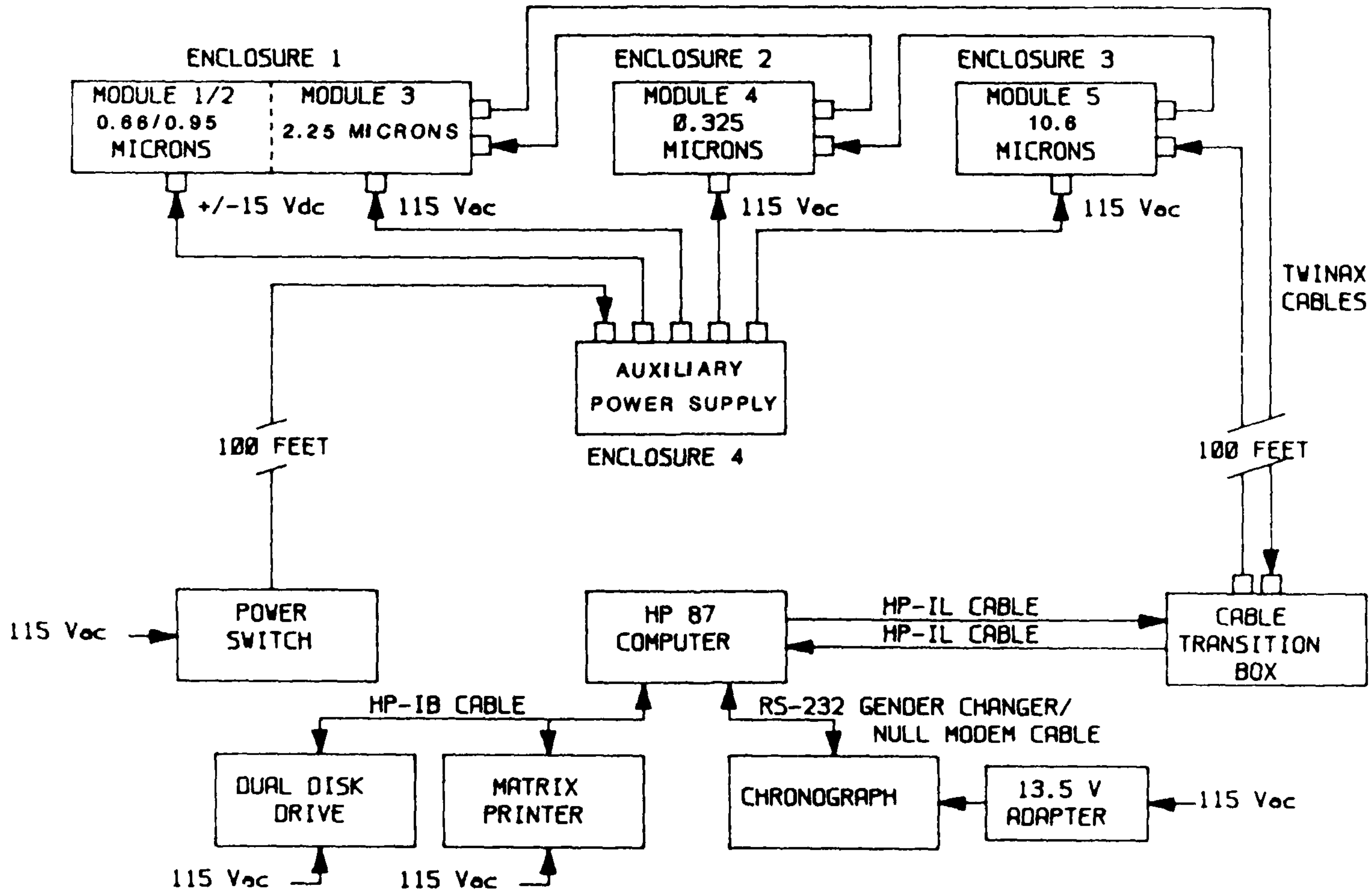

Figure 2.1. Electrical Interconnection Diagram for Abridged Polar Nephelometer System.

interconnections are made with four 25 ft. cables - one for the DC power and three for the AC power. The AC cables, for Modules 1, 2, 3 and Module 5 have identical connections and are interchangeble while the AC cable for Module 4 is polarized differently. In addition, the DC cable has unique connectors. When either Module 4 or Module 5 is being operated alone, the power supply housing can be bypassed and the 100 ft. AC power cable can be directly connected to the input connector.

The digital signals which are passed in both directions between the system controller and the individual microprocessors in each Module are carried on the Hewlett-Packard Interface Loop (HP-IL). The (HP-IL) is a low power signal communication system which can be used to interconnect various computers and peripherals. A specially designed HP cable system is normally used for interconnecting components. Since this cable is not suitable either for long distance transmissions or exposure to the outside environment, two 100 ft. lengths of twinax cables are provided to extend the signal loop from the system controller to the instrument modules. A special transmission box is provided to interconnect the twinax and HP-IL cable from the HP-IL interface which is located in one of the I/O slots on the HP-87. Each instrument modules has a pair of twinax connectors which accept the input and output ends of the signal cable loop. A transition from twinax back to HP-IL cable is made inside the enclosure. Two additional 25 ft. sections of twinax are provided to make the loop connection between the three housings. The HP-IL connections can be made in any feasible order since the controller software is capable of cataloging the name and position of all peripherals on the loop.

At this point, the installation is complete and the instrument system is ready for operation.

2.5 Packing and Shipping

De-installation of the APN system follows the installation steps in reverse. First, the system power and signal cables are disconnected and stowed. The long lengths (25 ft. to 100 ft.) should be coiled and then tied or taped securely. The remaining cables should be boxed with other small components.

The three environmental housings are prepared for shipping by removing the open intake nozzle and replacing it with the closed capping tube and by closing the exit pipe. If these units are to be shipped by commercial carrier, they should be enclosed in a wooden box using heavy plastic foam padding for shock protection. If transported by user operated truck, similar protection against shock should be used only with some shielding against weather (say tarpaulin covers as a minimum).

The computer control system is de-installed by removing the interconnecting cables between the computer, the disk drive, the printer and the chronograph. The computer is prepared for shipping by removing the ROM drawn, the Serial I/O interface, and the HP-IL Interface from the slots at the rear of the computer. These three units should be packed in small cardboard boxes. The computer, disk drive and printer should be packed in sturdy cardboard boxes, preferably the manufacturer's shipping box. Cardboard inserts should be placed in both slots of the Dual Disk Drive to protect the drive heads. The Hayes chronograph and the units removed from the computer can be packed in a suitable box.

The remaining components do not require any special handling and can be packed as desired.

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3.0 OPERATING PROCEDURE

After the system installation is completed, the Abridged Polar Nephelometer is ready to be operated using the HP-87 Computer as the system controller. The first step is to apply 110 VAC power to the System Controller components and to the APN system. The configuration of the APN is given in Figure 3.1. The Controller components are the HP-87 Computer, the Matrix Printer, the Dual Disk Mass Storage and the Hayes Chronograph. The computer printer, and Mass Storage have individual ON/OFF switches while the Chronograph is powered through a 15V/13.5 VDC adapter. The APN is powered when 115 VAC is applied to its power cable. The only required sequence is to turn on the Printer and Mass Storage before the Computer. Also, the APN must be ON before the operating program is started. The second step is to load the operations program into the computer and start the program. This program is stored on a 5¼" diskette with the name "APN_OP" which is a mnemonic code for Abridged Polar Nephelometer Operation (A copy of this BASIC program is given in Appendix A). The diskette is inserted into DRIVE 0 (left hand drive) of the Mass Storage Unit. The program is loaded into the computer memory by typing LOAD "APN_OP" and pressing the key <END LINE>. The red light on the drive can be observed to see when the loading is complete. The loaded program is started by pressing the key <RUN>. Further operating instructions are generated by the program and displayed on the computer CRT screen. Setting-up the program requires that the operator supply information and make various choices. While the procedure is straightforward, the following brief description will be helpful for a first time user.

The first input data request is for various constants used in calculating the angular scattering coefficients from the detector outputs. The electrical zero is needed for the power source monitor and for each of the three signal detectors, while the Optical zeros and the calibration constants are only needed for the three single detectors. This set of data is requested for each module which is present on the HP-IL loop.

The electrical zero is the digital reading from a detector when no radiant power is incident on it. It is essentially the electrical noise in the preamplifier input circuit. The values for the channel detectors in a module are obtained by closing off the optical entrance to the scattering chamber with the filter wheel in its blocked position. The optical zero is the digital reading from a channel detector when radiant power is incident on the scattering chamber, but all aerosols have been removed from the incoming by

Table 3.1. General Configuration of the APN Sensor Modules.

Module	Wave length, Microns	Source	Source Monitor	Signal Detector	Beam Modulator
1	0.66	Dual LED	Si Photodet.	Si	Electronic
2	0.95	Dual IRED	Si Photodet.	Si	Electronic
3	2.25	Tungsten + Filter	Si Photodet.	PbS(Cooled)	Scanning Mirror
4	0.325	Helium/ Cadmium	Si Photodet.	Photo-multi-plier	Scanning Mirror
5	10.6	CO_2	Pyroelectric	Pyro-electric	Scanning Mirror

the HEPA filter. The calibration constant is the proportionality factor that converts the arbitrary digital reading from each detector channel into the angular scattering coefficient with units of Km^{-1} sr^{-1}. The values of these constants are determined by introducing a known scatterer into the various modules.

The next group of input requests asks for the parameters which control the operation of the system. First, the operator is asked to select the number of data values to be averaged for the final reading from the following list: 6, 8, 10, 12, 14, 15, 16, 18, 20. Next, if the dual Module 1/2 is active, the operator is asked to select the time sharing duty cycle from a list of values which depends on the number of data values selected in the previous request. These lists have been prepared so that the number of data values in each fraction of the duty cycle will be commensurate with the total number of data values. Finally, a value for the time interval between readings of the individual samples must be entered by the operator. In this case, the operator's choice is limited by a lower bound of 40 seconds and an upper bound of 80 seconds. In combination with the minimum of 6 and the maximum of 20 for the number of data values in the list given above, the minimum value of the time interval for a complete data taking cycle is 4 minutes and the maximum value is 24 minutes. Typically, a value of 15 data values is used with a 60 second time interval to get a 15 minute data cycle. A cycle of this length ensures that a representative sample of aerosol will be obtained. After these inputs have been made, they are printed along with the date and time as a heading for the subsequent data records.

Finally, the operator is asked to select one of the three operation commands which each Module can accept. These commands are: C (Calibration), Z (Zero), and O (Operation). The C command instructs the microprocessor in a Module to insert a small spherical metallic scatterer into the center of the scattering volumes and to rotate the filter wheel so that an attenuating filter is placed on the source beam path. This configuration produces a reference signal in each channel that can be used to verify that each channel in the system is responding and that its output value corresponds to the previously recorded reference value. The Z command causes the scatterer to be retracted if it is the inserted position and the filter wheel to turn to the position which blocks off the source beam. This configuration is used to determine the electrical zero defined above. The O command sets the apparatus to its normal configuration for measuring aerosol scattering. This configuration is also used when determining the optical zero by introducing filtered air into the Module.

Table 3.2. Typical Output Data Format for Abridged Polar Nephelometer.

Time	Module No.	Power Monitor	Chan 1	Chan 2	Chan 3
2:49:35	1	394	2.228E+001	-2.430E+001	1.525E+001
2:49:35	3	573	2.771E+002	1.112E+002	3.310E+001
2:49:35	4	11	-3.083E+000	5.000E+000	9.633E+000
2:49:35	5	776	5.650E+000	2.750E+000	8.667E-001
2:50:34	2	953	1.335E+001	-1.117E+002	-2.322E+001
2:50:34	3	573	2.367E+002	1.250E+002	4.950E+001
2:50:34	4	27	6.567E+000	1.747E+001	1.450E+001
2:50:34	5	747	1.110E+001	1.683E+000	1.550E+000
2:51:34	2	954	7.800E+000	-1.135E+002	-1.940E+001
2:51:34	3	572	3.001E+002	6.747E+001	4.500E+000
2:51:34	4	33	1.785E+001	2.225E+001	1.815E+001
2:51:34	5	761	9.283E+000	2.917E+000	1.383E+000
2:52:35	1	395	2.025E+001	-1.443E+001	5.100E+000
2:52:35	3	572	2.623E+002	9.112E+001	5.592E+001
2:52:35	4	32	1.807E+001	2.273E+001	1.567E+001
2:52:35	5	764	7.000E+000	4.967E+000	-1.167E-001
2:53:34	2	956	9.683E+000	-1.277E+002	-2.002E+001
2:53:34	3	572	2.474E+002	5.100E+001	3.445E+001
2:53:34	4	32	1.645E+001	2.015E+001	1.248E+001
2:53:34	5	769	9.133E+000	2.500E+000	1.250E+000
2:54:34	2	954	2.325E+001	-1.170E+002	-2.352E+001
2:54:34	3	571	2.716E+002	8.270E+001	2.122E+001
2:54:34	4	32	1.310E+001	1.712E+001	1.020E+001
2:54:34	5	763	1.107E+001	-5.833E-001	4.483E+000

Time	Module No.	Power Monitor	Average Channel 1	Std. Dev. Channel 1	Average Channel 2	Std. Dev. Channel 2	Average Channel 3	Std. Dev. Channel 3
2:54:34	1	395	2.1267E+001	7.19E-001	-1.9367E+001	3.49E+000	1.0175E+001	3.59E+000
2:54:34	2	954	1.3521E+001	2.98E+000	-1.1746E+002	3.09E+000	-2.1538E+001	9.23E-001
2:54:34	3	572	2.6586E+002	8.39E+000	8.8081E+001	1.02E+001	3.3114E+001	6.97E+000
2:54:34	4	28	1.1492E+001	3.11E+000	1.7453E+001	2.43E+000	1.3439E+001	1.23E+000
2:54:34	5	763	8.8722E+000	8.15E-001	2.3722E+000	6.75E-001	1.5694E+000	5.76E-001

After the chosen command has been executed, the microprocessor in the Module sends back an acknowledgment word which repeats the command that was sent and includes a status indicator which shows whether the command was properly executed. This word consists of four characters as follows: Character (1) - Module Number, Character (2) - Command Sent, Character (3) - X (No Meaning), Character (4) - a decimal digit (zero means command executed correctly, non-zero signifiers error in execution). Three non-zero digits are used to identify errors: 1 - Bad message received over HP-IL communication loop, 2- Filter wheel positioning error, and (3) Scatterer positioning error. If errors appear in the acknowledgment word, the operator must take action to stop the operation and correct the fault.

The system then begins its program of data collection as determined by the operator's input. For each data sample, the readings from the power monitor and the three detectors are displayed on the computer CRT and printed out for each module. When the number of sample readings reaches the value selected by the operator, the averages and their standard deviations will be calculated by the computer and displayed and printed.

Table 3.2 shows a typical example of data output. In this example, Modules 1/2, 3 and 5 were being operated at 60 sec sample intervals with 10 samples in an average. Modules 1/2 were operated with a 40/60 duty cycle. The six columns of the data samples are from left to right: (1) Time, (2) Module Number, (3) Power Monitor, (4) Channel 1, (5) Channel 2, and (6) Channel 3. The average of the ten samples follows the data group with a single line separation. The column identification is the same as described above except that the Channel 1/2 and 3 readings are followed by their standard deviation. No standard deviation is calculated for the power monitor.

For convenience, the operational procedure described above is summarized into the series of steps which are given in Table 3.3.

Table 3.3. Summary of Procedure for Operation of the Abridged Polar Nephelometer (APN).

1. Place all modules to be used at selected site. Connect all signal and power cables to modules. (Note: All cable connectors are polarized.)

2. Connect main power cable to 115 VAC 60 Hz commercial power source.

3. Switch on computer and peripherals in the following sequence:

   (a) Printer (HP Model 82905B, S/N 2134J11625).

   (b) Flexible Disc Drive (HP Model 82901M, S/N 2101A14928).

   (c) Computer Terminal (HP Model 87, S/N 2206A56972).

   (d) Digital Clock (Hayes Chronograph S/N 021104934).

4. Insert Floppy Disc containing program "APN_OP" Version 2.3 into Disc Drive 0.

5. Load Program "APN_OP" from disc into computer by typing the instruction LOAD "APN_OP" and pressing <END LINE> key.

6. After allowing an interval of one to two minutes for loading, the program can be started by pressing the <RUN> KEY at which time the power light on the computer will be blinking on and off. Shortly thereafter, the computer will address the clock for the current time. This action can be seen by a flickering of the LED's which display hours, minutes and seconds.

7. After another one to two minute interval, the following instructions will appear on the CRT screen:

PRESS T TO TYPE CAL. CONSTS

PRESS D TO READ DISK CAL. CONSTS

PRESS SPACE FOR INITIALIZATION CONSTS

The operator must select one of these alternatives and continue with the corresponding step 8A, 8B or 8C below.

8A. To type in the calibration constants, press T followed by <END LINE>. The operator then types in the values for electrical zeros, optical zeros and calibration constants as requested by the screen display. After these have been entered, the following displays on the screen must be answered.

STORE CONSTS ON DISK (Y/N)?

(Type Y or N, then <END LINE>)

SELECT NUMBER OF VALUES IN AVERAGE FROM FOLLOWING LIST:

6, 8, 12, 14, 15, 16, 18, 20

(Type in 15, then <END LINE>)

ENTER READING TIME INTERVAL IN SECONDS (>40-<80)

Type in 60, then <END LINE>)

Table 3.3. Summary of Procedure for Operation of the Abridged Polar Nephelometer (APN). (Continued)

STORE DATA ON DISK (Y/N)?

(Type Y or N, then <END LINE>)

ENTER MODULE [M] COMMAND C, Z, O

(Type command C, Z or O for the module whose number appears in place of the symbol [M] shown above, then <END LINE>. This display will repeat for each module being used.)

12B. Do not press D. This choice is not currently implemented.

12C. When SPACE BAR is pressed, the program uses the previously set of calibration constants and requests operating values as in 12A beginning with the request to "SELECT NUMBER OF VALUES IN AVERAGE FROM FOLLOWING LIST:"

[NOTE: The command C, Z and O produce the following actions: C - the test subject is inserted in the scattering volume and the attenuator is rotated into the source beam path. Z - the test object is removed if present and the blocking filter wheel position is rotated into the beam path. O - the test object is removed if present and the open filter wheel position is rotated into the beam path.]

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4.0 THEORY OF OPERATION

The basic concept of this polar nephelometer is that the presence of aerosols in the scattering volume will scatter light from the source beam of wavelength λ into a detector at an angle θ and produce an output voltage signal which is linear with the angular scattering coefficient $\beta\ (\theta, \lambda)$. The form of the transfer equation is

$$V = [\text{const}]\ \beta\,(\theta, \lambda) + V_o$$

where V_o is an offset voltage produced mostly by scattered light. This offset voltage is determined by reading the voltage values for each channel in each module when filtered air is flowing through the system. Since the HEPA filter removes all aerosol particles, the voltage from each channel detector originates with light scattered from the optical system and the scattering chamber. This equation is then solved for the angular scattering coefficient to give

$$\beta = (\theta, \lambda) = K\,(\theta, \lambda)\,(V - V\,o)$$

when $K\,(\theta, \lambda)$ is the calibration constant for a given polar angle θ and wavelength λ. The calibration constants must be determined by separate measurements of the output voltages when a known scatterer is introduced into the system. Since the APN uses 5 wavelength modules and 3 scattering angles for each module, there is a total of 15 calibration constants and 15 offset voltages.

In the operating program described in Section 3 and given in Appendix A, this equation has been rewritten as

$$B(C, M) = \left(\frac{VN\,(C,M)}{TI} - VE(C,M) - VZS(C, M1)\right)*\ BCK(C,M)$$

where C = channel index, 1 to 3

M = module index, 1 to 5

VN (C,M) = signal voltage from channel C of Module M

TI = time interval between readings, seconds

VE (C,M) = predetermined electrical zero voltage from channel C of Module M

VZS (C,M) = predetermined optical zero voltage from channel C of Module M (measured by introducing filtered air)

BCK(C,M) = calibration constant for channel C of module M

The calibration constants for Modules 1, 2 and 4 can be determined by using Freon 12 and Freon 22 as calibrating gases since their angular scattering coefficients have been measured. But neither of these gases produce a measurable signal at the 2.25 and 10.6 micron wavelengths. While tentative constants have been measured for these latter wavelengths using cigarette and cigar smoke, much more calibration work has to be done on these modules.

5.0 MAINTENANCE AND TROUBLESHOOTING

5.1 Maintenance

The Abridged Polar Nephelometer System requires no specific maintenance for any components. The insertion and removal of the intake and exhaust tubes and sealing caps described in Section 1.2.10 will be made easier if silicone stopcock grease is occasionally applied to the O-rings to be found in the flanges on the environmental housing covers.

5.2 Troubleshooting

This guide to troubleshooting the APN will only provide a general procedure which can aid in isolating faults to major sections or components. The logic of fault isolation or location used here is similar to that followed in any electronic troubleshooting. The usual indication of trouble will be the loss of a normal operating signal. The action taken is to start at either end of the signal chain and successively examine the input or output of each module or component in order until the point where the signal disappears is discovered. The faulty unit is then replaced or repaired. Since signal chain in the APN is partly optical and partly electronic, the existence of the optical beam must often be checked as part of the troubleshooting procedure. The electronic signal chain is partly analog circuitry and partly digital circuitry. The analog circuits are mostly of striaghtforward design and can be checked with normal oscilloscope and voltmeter techniques. The digital circuits can be checked with diagnostic software to locate board level faults.

The first step in fault isolation is to establish whether the fault lies in the analog system or the digital system. The digital system consists of the HP-87 computer, the HP-IL loop and the individual microprocessors in each module. The HP-87 has its own internal diagnostics which display fault messages on the CRT screen. The messages and their meanings are listed in the HP-87 instruction manual. Some diagnostic programs for the I/O ports are listed in the instruction manual for the particular device.

HP-IL faults usually appear as TIME OUT errors. The first check is to verify continuity of the loop itself. Next the loop should be closed on itself with no devices present to verify that the port is operable. Then, one device at a time should be added to the loop until the fault reappears. The presence of power at the IL converter should then be verified. The converter itself can be checked by substitution of another converter. The placement of the HP-IL converter on the side of the Signal Processor Housing can be seen in Figure 1.10. After removing the housing cover, a spare converter can be substituted by disconnecting the ribbon cable and releasing the clamp holding the unit in the side wall of the housing. A program to examine the contents of the interval registers in the IL converter is given in the HP-IL Interface Owner's Manual (HP82938A). If all checks out OK to this point, the fault has been isolated to one of the on-board microprocessors. Board substitution will be useful at this point. Following the above outlined steps will usually isolate digital faults. Component replacement is the corrective action.

Troubleshooting the analog system begins at the optical source by verifying the presence of the optical source. A different test is used for each module. Module 1/2 is the most difficult to test because the sources are not directly accessible, nor are they readily visible to the eye. The simplest indicator is the Kodak IR fluorescent card. This card can be obtained from:

Kodak Apparatus Div.
901 Elmgrove Rd.
Rochester, NY 14650
(716) 726-7543

The card will glow with an orange color when exposed to the beam. It must be pre-excited with a UV or fluorescent lamp. The Module 3 tungsten lamp is immediately visible when operating. The beam from the HeCd laser produces visible as well as UV light and the presence of that beam can be verified by inserting a piece of white paper in the beam. **CAUTION: Do not look directly into the beam.** The presence of the beam from the 10.6 micron CO_2 laser can also be verified by inserting a piece of paper into the beam which will burn a hole in the paper when present. **CAUTION: Do not look directly into the beam or let it fall on your skin.**

If the sources are present, the next test is to create a scattering signal either by raising the calibration reference sphere or by introducing smoke or vapor into the scattering volume. At this point, the search should be directed to the electrical signals produced by the detectors. Use of an oscilloscope as a signal probe is appropriate at this point. In this way the signal can be traced up to the analog-to-digital converter board. The procedures, thus outlined, are capable of isolating most of the signal faults in this instrument.

REFERENCES

VENDORS MANUALS

HP-87 Operating and BASIC Programming Manual
HP-85 I/O Programming Guide
Introduction to the HP-87
HP82905B Printer Owner's Manual
HP82938A HP-IL Interface Owner's Manual
HP82939A Serial Interface Installation and Theory of Operation Manual
HP82937A HP-IB Installation and Theory of Operation Manual
HP82940A GPIO Installation and Theory of Operation Manual
HAYE STACK Chronograph Owner's Manual

APPENDIX A

OPERATING PROGRAMS

```
100 ! APN_OP VER.2.3 27 JUNE 86 MPS
110 COLD_START:
120 PRINTER IS 701,72
130 PRINT CHR$ (27)&"&l1L"
140 DIM VE(3,5),VZ(3,5),VN(3,5),VZS(3,5),BCK(3,5),RESP$[128]
150 DIM B(3,5),BS(3,5),BSS(3,5),BMN(3,5),STD(3,5),MODL(5)
160 DIM MAR0(3,25),MAR1(3,25),MAR2(3,25),MAR3(3,25),MAR4(3,25)
170 DIM MAR5(3,25),SC(20),CD(12),MON$(12),D(5),K(5),NN(5),NNN(2),ND(5)
180 ! Initialize variables
190 FALSE=0 @ TRUE=NOT FALSE @ DC,NDEV,NNN(1),NNN(2)=0 @ MM=1
194 DSKFLG=FALSE @ FILMAX=112 @ RECMAX=100000 @ NSW=0
200 FOR J=0 TO 5 @ D(J),K(J),NN(J)=0 @ NEXT J
210 FOR J=0 TO 5
220  FOR I=0 TO 3
230   VE(I,J),VZ(I,J),VN(I,J),VZS(I,J)=0 @ BCK(I,J)=1
240  NEXT I
250 NEXT J
260 DATA 3,0,4,0,5,0,4,0,7,5,4,0,6,0,5
270 FOR I=6 TO 20 @ READ SC(I)@ NEXT I
280 ! Get time from Hayes Chronograph
290 RESET 10 @ OUTPUT 10 ;"ATLS" @ ENTER 10 ; X$@ OUTPUT 10 ;"ATVT:"
300 ENTER 10 ; X$@ OUTPUT 10 ;"ATVD/" @ ENTER 10 ; X$@ OUTPUT 10 ;"ATRD"

310 ENTER 10 ; DT$@ OUTPUT 10 ;"ATRT" @ ENTER 10 ; THA$
320 THA$=THA$[1,9]
330 H=VAL (THA$[1,2]) @ MI=VAL (THA$[4,5]) @ S=VAL (THA$[7,8])
335  IF THA$[9,9]="P" THEN H=H+12
340 T=(H*60+MI)*60+S
350 DATA JAN,FEB,MAR,APR,MAY,JUN,JUL,AUG,SEP,OCT,NOV,DEC
360 DATA 0,31,59,90,120,151,181,212,243,273,304,334,365
370 FOR I=1 TO 12 @ READ MON$(I)@ NEXT I
380 FOR I=0 TO 12 @ READ CD(I)@ NEXT I
390 RESTORE 350
400 YR=VAL (DT$[1,2]) @ MN=VAL (DT$[4,5]) @ DY=VAL (DT$[7,8])
410 JD=YR*1000+CD(MN-1)+DY
420 SETTIME T,JD
430  SET TIMEOUT 9;30000 @ ON TIMEOUT 9 GOTO WARN_TOUT
440 ! Device catalog
450 FOR I=1 TO 5 @ MODL(I)=0 @ NEXT I
460  RESET 9 @ WAIT 500 @ CLEAR 9
470  STATUS 9,7 ; NDEV
480 IF NDEV=0 THEN DISP "No device on loop" @ GOTO COLD_START
490 WAIT 20000
500 FOR I=1 TO NDEV
510  SEND 9 ; UNL UNT LISTEN I MTA
520  ! SET HP82166 REGISTERS
```

```
530  CONTROL 9,2 ; 4,160 ! DDL 0
540  CONTROL 9,2 ; 5,0 ! RFC
550  OUTPUT 9 USING "#,B" ; 0,16,218,5,0,0,0,0,0,0,0,13,10,13,10
560  CS$="D" @ GOSUB CMDRESP
570  MODL(HTD (RESP$[1,1]))=I
580 NEXT I
590 ! Set calculation constants
600 GOSUB CONSTS
605 ON X GOTO TYPE ,DISK ,WARM_START
610 DISK: GOSUB RPARAM  @ GOTO WARM_START
620 TYPE: FOR M=1 TO 5
630 IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN 710
640 IF M>2 AND MODL(M)=0 THEN 710
650  DISP "Enter Module ";M;"Electrical Zero for Monitor & Channels 1,2,
3"
660  INPUT VE(0,M),VE(1,M),VE(2,M),VE(3,M)
670  DISP "Enter Module ";M;"Optical Zeros for Channels 1,2,3,"
680 INPUT VZS(1,M),VZS(2,M),VZS(3,M)
690  DISP "Enter Module ";M;"Calibration Constants for Channels 1,2,3,"
700  INPUT BCK(1,M),BCK(2,M),BCK(3,M)
710 NEXT M
712 DISP "STORE CONSTS ON DISK(Y/N)?" @ INPUT ANS$
714 IF ANS$="Y" OR ANS$="y" THEN GOSUB WPARAM
720 WARM_START:
730 IF MM=2 THEN MODL(1)=MODL(2) @ MODL(2)=0 @ MM=1
735 FOR J=0 TO 5 @ D(J),K(J),NN(J)=0 @ NEXT J
740 FOR J=0 TO 5
750  FOR I=0 TO 3
760   B(I,J),BS(I,J),BSS(I,J),BMN(I,J),STD(I,J)=0
770  NEXT I
780 NEXT J
790 FOR J=0 TO 25
800  FOR I=0 TO 3
810   MAR0(I,J),MAR1(I,J),MAR2(I,J),MAR3(I,J),MAR4(I,J),MAR5(I,J)=0
820  NEXT I
830 NEXT J
840 ! Set program parameters
850 DISP "Select number of values in average from following list:"
860 DISP "6,8,10,12,14,15,16,18,20"
870 INPUT N
880 FOR M=1 TO 2
890 IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN SW_CNT=1 @ GOTO 990 ELSE SW_
CNT=0
900 NEXT M
910 DISP "Select Module 1 Duty Cycle from following list:"
920 FOR I=0 TO SC(N) @ DISP I/SC(N);"  ";@ NEXT I
930 INPUT DC
940 IF DC=0 OR DC=1 THEN NSW=0 ELSE NSW=SC(N)
950 IF DC=.5 THEN MM=1
960 IF DC=0 THEN NN(1)=0 @ NN(2)=N @ MM=2 @ MODL(2)=MODL(1) @ MODL(1)=0
@ GOTO 990
970 IF DC=1 THEN NN(1)=N @ NN(2)=0 @ MM=1 @ GOTO 990
980 NN(1)=INT (DC*SC(N)+.1) @ NN(2)=SC(N)-NN(1) @ NNN(1)=NN(1)-1 @ NNN(2
)=NN(2)-1
990 ND(1)=INT (N*DC+.1) @ ND(2)=N-ND(1)
1000 FOR M=3 TO 5
1010  IF MODL(M)#0 THEN NN(M)=N @ ND(M)=N
1020 NEXT M
1030 NMAX=0 @ X,Y=0
1040 FOR I=1 TO 5 @ Y=MAX (X,NN(I)) @ IF Y>X THEN X=Y @ NMAX=I
```

```
1050 NEXT I
1060 DISP "Enter reading time interval in seconds (>40 - <80)"
1070 INPUT TI@ TT=TI*1000
1080 MAFLG=FALSE ! DISP "Moving average ? (Y or N)";@ INPUT ANS$
1090 ! IF ANS$="Y" OR ANS$="y" THEN MAFLG=TRUE ELSE MAFLG=FALSE
1100 ! Output preface
1110 PRINT TAB (12);"ABRIDGED POLAR NEPHELOMETER CONSTANTS AND SETTINGS"

1120 OUTPUT 10 ;"ATRT" @ ENTER 10 ; THA$
1130 PRINT TAB (24);DT$;TAB (56);THA$
1140 PRINT
1150 DISP "Electrical Zeros:" @ PRINT "Electrical Zeros:"
1160 DISP "MODULE     MONITOR         CHAN1       CHAN2       CHAN3"
1170 PRINT "MODULE     MONITOR         CHAN1       CHAN2       CHAN3"
1180 FOR M=1 TO 5
1190  IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN 1240
1200  IF M>2 AND MODL(M)=0 THEN 1240
1210  DISP USING 1230 ; M,VE(0,M),VE(1,M),VE(2,M),VE(3,M)
1220  PRINT USING 1230 ; M,VE(0,M),VE(1,M),VE(2,M),VE(3,M)
1230  IMAGE 2X,2D,4X,4(2X,MD.DDDE)
1240 NEXT M
1250 PRINT
1260 DISP "Optical Zeros:" @ PRINT "Optical Zeros:"
1270 DISP "MODU"_E                     CHAN1       CHAN2       CHAN3"
1280 PRINT "MODULE                     CHAN1       CHAN2       CHAN3"
1290 FOR M=1 TO 5
1300  IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN 1350
1310  IF M>2 AND MODL(M)=0 THEN 1350
1320   DISP USING 1340 ; M,VZS(1,M),VZS(2,M),VZS(3,M)
1330  PRINT USING 1340 ; M,VZS(1,M),VZS(2,M),VZS(3,M)
1340  IMAGE 2X,2D,10X,3(2X,MD.DDDE)
1350 NEXT M
1360 PRINT
1370  DISP "Calibration Constants:"
1380 PRINT "Calibration Constants:"
1390  DISP "MODULE                     CHAN1       CHAN2       CHAN3"
1400 PRINT "MODULE                     CHAN1       CHAN2       CHAN3"
1410 FOR M=1 TO 5
1420  IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN 1470
1430  IF M>2 AND MODL(M)=0 THEN 1470
1440   DISP USING 1460 ; M,BCK(1,M),BCK(2,M),BCK(3,M)
1450  PRINT USING 1460 ; M,BCK(1,M),BCK(2,M),BCK(3,M)
1460  IMAGE 2X,2D,10X,3(2X,MD.DDDE)
1470 NEXT M
1480 PRINT
1490  DISP N;"   ";TI;" second values in average"
1500 PRINT N;"   ";TI;" second values in average"
1505 IF MODL(1)=0 AND MODL(2)=0 THEN 1530
1510  DISP "Module 1 Duty Cycle: ";DC
1520 PRINT "Module 1 Duty cycle: ";DC
1530 FOR I=1 TO 4 @ PRINT @ NEXT I
1532 DISP "STORE DATA ON DISK(Y/N)?"
1534 INPUT ANS$
1536 IF ANS$="Y" OR ANS$="y" THEN DSKFLG=TRUE ELSE DSKFLG=FALSE
1538 IF DSKFLG THEN GOSUB OPEN
1540 ! MU_PROC COMMANDS
1550  FOR M=1 TO 5
1560   IF MODL(M)=0 THEN 1590
1570   DISP "Enter Module ";M;"Command: C,Z,O"
1580   INPUT CS$@ PRINT M,CS$ @ I=MODL(M) @ GOSUB COMD
```

```
1590  NEXT M @ WAIT 10000
1600 I=MODL(1) @ CS$="DW1S4" @ IF I#0 THEN GOSUB CMDRESP
1610 I=MODL(2) @ CS$="DW2S4" @ IF I#0 THEN GOSUB CMDRESP
1620 FOR M=1 TO 5 @ IF MODL(M)=0 THEN 1650
1630 I=MODL(M) @ CS$="D" @ GOSUB CMDRESP
1640 PRINT RESP$[1,4] @ DISP RESP$[1,4] @ IF VAL (RESP$[4,4])#0 THEN BEE
P
1650 NEXT M
1660 ON KEY# 1 GOTO SRPAUSE
1670 ON TIMER# 1,TT GOSUB COLL_DATA
1680 GOTO 1680
1690 ! Timeout warning
1700 WARN_TOUT: DISP "Timeout on HP-IL Loop" @ BEEP
1710 DISP "Press CONT key to restart" @ PAUSE @ GOTO COLD_START
1720 ! KEY# 1 Halt/Pause
1730 SRPAUSE: OFF TIMER# 1 @ IF DSKFLG THEN GOSUB CLOSE
1740 BEEP @ DISP "Press CONT key to restart" @ PAUSE @ PRINT CHR$ (12) @
 GOTO WARM_START
1750 !
1760 !
1770 ! Read data from modules
1780 READ_DATA: FOR M=1 TO 5
1790 IF MODL(M)=0 THEN GOTO 1930
1800 I=MODL(M) @ CS$="D" @ GOSUB CMDRESP
1810 T=TIME  @ VN(0,M)=HTD (RESP$[5,8])-VE(0,M)
1820 VN(1,M)=HTD (RESP$[9,12])*256+HTD (RESP$[13,14])
1830 VN(2,M)=HTD (RESP$[15,18])*256+HTD (RESP$[19,20])
1840 VN(3,M)=HTD (RESP$[21,24])*256+HTD (RESP$[25,26])
1850 IF M>2 THEN 1930
1860 IF DC=0 OR DC=1 THEN 1930
1870 IF SW_CNT#NNN(MM) THEN SW_CNT=SW_CNT+1 @ GOTO 1930
1880 IF MM=1 THEN MODL(2)=MODL(1) @ MODL(1)=0 @ MM=2 @ GOTO 1900
1890 IF MM=2 THEN MODL(1)=MODL(2) @ MODL(2)=0 @ MM=1 @ GOTO 1900
1900 SW_CNT=0 @ M=2
1910 CS$="DW"&VAL$ (MM) @ GOSUB CMDRESP
1920 CS$="D" @ GOSUB CMDRESP
1930 NEXT M
1940 RETURN
1950 ! Data collection
1960 COLL_DATA: GOSUB READ_DATA
1970 FOR M=1 TO 5
1980 IF M<3 AND MODL(M)#0 AND NSW=0 THEN 2030
1990 IF M<3 AND MODL(M)#0 AND SW_CNT=0 THEN 2070
2000 IF M<3 AND MODL(M)=0 AND SW_CNT>0 THEN 2070
2010 IF M<3 AND MODL(M)=0 AND NSW=0 THEN 2070
2020 IF M>2 AND MODL(M)=0 THEN 2070
2030  B(0,M)=VN(0,M)-VE(0,M)
2040  FOR C=1 TO 3
2050   B(C,M)=(VN(C,M)/TI-VE(C,M)-VZS(C,M))*BCK(C,M)
2060  NEXT C
2070 NEXT M
2080 ! Make calculations
2090 FOR M=1 TO 5
2100 IF M<3 AND MODL(M)#0 AND NSW=0 THEN 2150
2110 IF M<3 AND MODL(M)#0 AND SW_CNT=0 THEN 2350
2120 IF M<3 AND MODL(M)=0 AND SW_CNT>0 THEN 2350
2130 IF M<3 AND MODL(M)=0 AND NSW=0 THEN 2350
2140  IF M>2 AND MODL(M)=0 THEN 2350
2150  IF D(M)<ND(M) THEN D(M)=D(M)+1
2160  K(M)=K(M)+1 @ IF K(M)>ND(M) THEN K(M)=1
```

```
2170  FOR C=0 TO 3
2180   IF M=1 THEN BARR=MAR1(C,K(M))
2190   IF M=2 THEN BARR=MAR2(C,K(M))
2200   IF M=3 THEN BARR=MAR3(C,K(M))
2210   IF M=4 THEN BARR=MAR4(C,K(M))
2220   IF M=5 THEN BARR=MAR5(C,K(M))
2230   BS(C,M)=BS(C,M)-BARR+B(C,M)
2240   BSS(C,M)=BSS(C,M)-BARR*BARR+B(C,M)*B(C,M)
2250   IF M=1 THEN MAR1(C,K(M))=B(C,M)
2260   IF M=2 THEN MAR2(C,K(M))=B(C,M)
2270   IF M=3 THEN MAR3(C,K(M))=B(C,M)
2280   IF M=4 THEN MAR4(C,K(M))=B(C,M)
2290   IF M=5 THEN MAR5(C,K(M))=B(C,M)
2300   BMN(C,M)=BS(C,M)/D(M)
2310   VAR(C,M)=(BSS(C,M)/D(M)-BMN(C,M)*BMN(C,M))/D(M)
2320 VAR(C,M)=ABS (VAR(C,M))
2330   STD(C,M)=SQR (VAR(C,M))
2340  NEXT C
2350 NEXT M
2360 H=T DIV 3600 @ L=T-H*3600 @ MI=L DIV 60 @ S=L-MI*60
2370 ! Print data
2380  ! Print current values
2390 FOR M=1 TO 5
2400 IF M<3 AND MODL(M)#0 AND NSW=0 THEN 2450
2410 IF M<3 AND MODL(M)#0 AND SW_CNT=0 THEN 2480
2420 IF M<3 AND MODL(M)=0 AND SW_CNT>0 THEN 2480
2430 IF M<3 AND MODL(M)=0 AND NSW=0 THEN 2480
2440 IF M>2 AND MODL(M)=0 THEN 2480
2450  DISP USING 2470 ; H,MI,S,M,B(0,M),B(1,M),B(2,M),B(3,M)
2460 PRINT USING 2470 ; H,MI,S,M,B(0,M),B(1,M),B(2,M),B(3,M)
2470 IMAGE 2D,":",2Z,":",2Z,X,2D,2X,4D,3(X,MD.DDDE)
2480 NEXT M
2490 ! Print averaged values
2500 IF NOT MAFLG AND K(NMAX)#NN(NMAX) THEN 2610
2510 DISP @ PRINT
2520 FOR M=1 TO 5
2530 IF M<3 AND MODL(1)=0 AND MODL(2)=0 THEN 2590
2540 IF M<3 AND MODL(M)=0 AND NSW=0 THEN 2590
2550  IF M>2 AND MODL(M)=0 THEN 2590
2560  DISP USING 2580 ; H,MI,S,M,BMN(0,M),BMN(1,M),STD(1,M),BMN(2,M),STD
(2,M),BMN(3,M),STD(3,M)
2570  PRINT USING 2580 ; H,MI,S,M,BMN(0,M),BMN(1,M),STD(1,M),BMN(2,M),ST
D(2,M),BMN(3,M),STD(3,M)
2580  IMAGE 2D,":",2Z,":",2Z,X,2D,2X,4D,3(X,MD.DDDDE,2X,D.DDE)
2585 IF DSKFLG THEN GOSUB RITEDISK
2590 NEXT M
2600 DISP @ PRINT
2610 RETURN
2620 END
2630 ! Command/response subroutine
2640  CMDRESP: SEND 9 ; UNL UNT LISTEN I MTA
2650  OUTPUT 9 USING "K" : CS$
2660  SEND 9 ; UNL UNT MLA TALK I
2670  ENTER 9 ; RESP$
2680  RETURN
2690 ! Command subroutine
2700  COMD: SEND 9 ; UNL UNT LISTEN I MTA
2710  OUTPUT 9 USING "K" ; CS$
2720  SEND 9 ; UNL UNT
2730  RETURN
```

```
2740 END
2800 CONSTS:
2810 DISP "PRESS T TO TYPE CAL.CONSTS"
2820 DISP "PRESS D TO READ DISK CAL.CONSTS"
2830 DISP "PRESS SPACE FOR INITIALIZATION CONSTS"
2840 INPUT ANS$
2850 IF ANS$="T" OR ANS$="t" THEN X=1
2860 IF ANS$="D" OR ANS$="d" THEN X=2
2870 IF ANS$#"T" AND ANS$#"t" AND ANS$#"D" AND ANS$#"d" THEN X=3
2880 RETURN
2890 WPARAM: PAFLG=TRUE
2910 ASSIGN# 2 TO  "PARAM1:D701"
2920 PRINT# 2,1 ; DATE ,TIME
2930 ASSIGN# 2 TO  *
2940 GOTO ROUTINE
2950 RPARAM: PAFLG=FALSE
2960 ROUTINE:
2980 ASSIGN# 2 TO  "PARAM2:D701"
2990 IF PAFLG THEN PRINT# 2 ; VE(,) ELSE READ# 2 ; VE(,)
2995 ASSIGN# 2 TO  *
3010 ASSIGN# 2 TO  "PARAM3:D701"
3020 IF PAFLG THEN PRINT# 2 ; VZS(,) ELSE READ# 2 ; VZS(,)
3030 ASSIGN# 2 TO  *
3050 ASSIGN# 2 TO  "PARAM4:D701"
3060 IF PAFLG THEN PRINT# 2 ; BCK(,) ELSE READ# 2 ; BCK(,)
3070 ASSIGN# 2 TO  *
3080 RETURN
3090 OPEN:
3100 ASSIGN# 1 TO  "DSKDAT:D701"
3110 READ# 1,1 ; NFILE,NREC
3120 GOSUB TEST
3130 IF MODL(1)=0 AND MODL(2)=0 THEN NADEV=NDEV
3140 IF (MODL(1)#0 OR MODL(2)#0) AND (DC=0 OR DC=1) THEN NADEV=NDEV
3150 IF (MODL(1)#0 OR MODL(2)#0) AND (DC#0 AND DC#1) THEN NADEV=NDEV+1
3160 T=TIME  @ H=T DIV 3600 @ L=T-H*3600 @ MI=L DIV 60
3170 NAME$=VAL$ (JD)&VAL$ (H)&VAL$ (MI)&":D701"
3180 CREATE NAME$,2*NADEV+1,88
3190 ASSIGN# 3 TO  NAME$
3200 GOSUB HEADER
3210 RETURN
3220 TEST:
3230 IF NFILE>= FILMAX OR NREC>= RECMAX THEN DISP "DISK FULL" @ DSKFLG=F
ALSE
3240 DISP "REMAINING FILES: ";FILMAX-NFILE;"  REMAINING RECORDS: ";RECMA
X-NREC
3250 PRINT @ PRINT "REMAINING FILES: ";FILMAX-NFILE;"  REMAINING RECORDS
: ";RECMAX-NREC @ PRINT
3260 FILCTR=NFILE @ RECIND=0
3270 RETURN
3280 HEADER: RECIND=RECIND+1
3290 PRINT# 3,RECIND ; MODL(1),MODL(2),MODL(3),MODL(4),MODL(5),DC,TI,N,0
,0,0
3300 FOR L=1 TO 5
3310 IF L<3 AND MODL(1)=0 AND MODL(2)=0 THEN 3360
3320 IF L<3 AND MODL(L)=0 AND NSW=0 THEN 3360
3330 IF L>2 AND MODL(L)=0 THEN 3360
3340 RECIND=RECIND+1
3350 PRINT# 3,RECIND ; L,VE(0,L),VE(1,L),VE(2,L),VE(3,L),VZS(1,L),VZS(2,
L),VZS(3,L),BCK(1,L),BCK(2,L),BCK(3,L)
3360 NEXT L
```

```
3365 RETURN
3370 CLOSE:
3380 FILCTR=FILCTR+1 @ NFILE=FILCTR @ NREC=NREC+RECIND
3390 PRINT# 1,1 ; NFILE,NREC
3400 ASSIGN# 1 TO  *
3410 ASSIGN# 3 TO  *
3420 DISP @ DISP "FILE NO.: ";NAME$;" NO.OF RECORDS IN FILE: ";RECIND
3430 PRINT @ PRINT "FILE NO.: ";NAME$;" NO.OF RECORDS IN FILE: ";RECIND
@ PRINT
3440 IF NFILE<FILMAX THEN RETURN
3450 DISP "DISK FULL" @ DSKFLG=FALSE @ RETURN
3460 RITEDISK:
3470 RECIND=RECIND+1
3480 PRINT# 3,RECIND ; H,MI,S,M,BMN(0,M),BMN(1,M),STD(1,M),BMN(2,M),STD(
2,M),BMN(3,M),STD(3,M)
3490 IF RECIND>= 2*NADEV+1 THEN GOSUB CLOSE  @ GOSUB OPEN
3500 RETURN
```

```
10 ! APNDINIT VER 1.2 25 JUNE MPS
20 ! DISK INITIALIZATION FOR POLAR NEPHELOMETER
30 ! DATA DISKS
40 !
50 !
60 !
70 !
80 !
90 !
100 BEGIN: DISP "INSERT DISK IN DRIVE 1, PRESS ANY KEY-ENDLINE"
110 KEY$=""
120 LOOP: INPUT KEY$@ IF KEY$="" THEN LOOP
130 DISP "ENTER VOLUME LABEL (<= 6 CHARS)"
140 INPUT VLABL$
150 DISP "WAIT 2 MINUTES"
160 INITIALIZE VLABL$,":D701"
170 CREATE "DSKDAT:D701",1,16
180 ASSIGN# 1 TO  "DSKDAT:D701"
190 PRINT# 1,1 ; 0,0
200 ASSIGN# 1 TO  *
210 DIM VE(3,5),VZS(3,5),BCK(3,5)
220 FOR J=0 TO 5
230   FOR I=0 TO 3
240     VE(I,J),VZS(I,J)=0 @ BCK(I,J)=1
250   NEXT I
260 NEXT J
270 CREATE "PARAM1:D701",1,16
280 ASSIGN# 2 TO  "PARAM1:D701"
290 PRINT# 2,1 ; 0,0
300 ASSIGN# 2 TO  *
310 CREATE "PARAM2:D701",20,8
320 ASSIGN# 2 TO  "PARAM2:D701"
330 PRINT# 2 ; VE(,)
340 ASSIGN# 2 TO  *
350 CREATE "PARAM3:D701",20,8
360 ASSIGN# 2 TO  "PARAM3:D701"
370 PRINT# 2 ; VZS(,)
380 ASSIGN# 2 TO  *
390 CREATE "PARAM4:D701",20,8
400 ASSIGN# 2 TO  "PARAM4:D701"
410 PRINT# 2 ; BCK(,)
420 ASSIGN# 2 TO  *
430 DISP "DISK INITIALIZED"
440 WAIT 2000
450 A$=""
460 DISP "INITIALIZE ANOTHER DISK(Y/N)?" @ INPUT A$
470 IF A$ <> "Y" OR A$ <> "y" THEN DISP "FINISHED" @ END
480 GOTO BEGIN
490 END
```