A Multipurpose Computer- Controlled Scanning Photometer

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SUMMARY

The description of a mobile, multipurpose computer-controlled scanning photometer is presented. This report supersedes two earlier partial descriptions of the instrument (Kleckner, Smith and Hoch 1975; Kleckner, Michalsky and Smith 1978) and presents the instrument as it is presently configured.

The scanning, altazimuth instrument has a fairly narrow field of view (1.5° for daytime work and 2.5° for nighttime) and can point to any position within a sphere. Twelve interference filters provide the wavelength discrimination important in the aeronomical emission feature studies and the solar spectral distribution characterization program. The basic philosophy was to design the software programs to acquire a variety of solar and geophysical data which would be useful to a wide audience. The photometer design was such that most of the decision-making was incorporated in the software of the computer to allow needed or desired changes to be made readily.

ABSTRACT

This paper presents a design for a multipurpose computer-controlled scanning photometer capable of measuring optical radiation ranging in intensity from the subvisual light levels associated with night sky airglow emissions to the intense flux levels of direct sunlight. The instrument has twelve interference filters for wavelength selection, a 2.5° field of view for nighttime observations, and a 1.5° field of view for daytime observations. A photomultiplier tube is used as the low light-level detector, and a silicon-PIN photodiode serves as the insolation detector. A particular measurement sequence is programmed into the instrument and can be modified by reading a cassette tape in the field. Normal operation is fully automatic. Visits to change the data cassette tapes and to service the instrument are made every four days with extensive maintenance and calibration trips semi-annually. In addition to controlling the measurement sequence, the computer provides a means of compressing the data by a factor between two and three before recording it. The procedures used in calibrating these absolute measurements are detailed.

CONTENTS

INTRODUCTION	1
HARDWARE	2
Optical	2
Mechanical.	5
Electronic.	7
Environmental	13
CONTROL SYSTEM	15
OBSERVATIONS	17
Aeronomy.	17
Insolation.	21
Other Programs.	24
CALIBRATION.	24
Aeronomy.	25
Insolation.	27
NETWORK DESCRIPTION.	28
ACKNOWLEDGEMENTS	29
REFERENCES	30

FIGURES

1. Schematic diagram of the optical train of the photometer	3
2. Schematic diagram of the altazimuth drive system showing the principal components	6
3. The percentage variation of Si photodiode response as a function of wavelength and temperature.	10
4. Schematic diagram of the data acquisition system . . .	12
5. Photograph of the instrument showing the dome and scanning optics and the electronics assembly . . .	14
6a. The field of coverage for an assumed emission height of 150 km	19
6b. The field of coverage for an assumed emission height of 300 km	20
7. Time multiplex frame for solar measurements.	23
8. Wide-aperture calibration light source	26

TABLES

1. Filter wavelengths, bandwidths, and functions.	8
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I. INTRODUCTION

As originally conceived, the photometer described in this report was to answer a need in middle atmospheric studies for global measurements of visible emission features associated with the aurora and airglow. The desire was to eliminate the tedium of tending a photometer which repeated a sequence of all-sky scans from dusk to dawn. An improved mechanical design which avoided problems associated with cables wrapping about the rotation axis of the photometer was a further requirement.

The prototype unit was designed with an altazimuth system of mirrors that transferred parallel rays from a distant source to a conventional imaging optical train which remained stationary within the photometer. The mechanical design that allowed cableless operation of this system is described in Section II. The scan/filter sequence was wired onto the control board of the instrument. Scanning was initiated and concluded each night via a photometric threshold detector (cadmium sulfide photocell) mounted on the outside of the instrument. The photometer was housed in a fabricated aluminum cube approximately 0.76 meters on a side covered by a Plexiglas hemispherical dome with a diameter of 0.71 meters. With the exception of a few minor mechanical problems (e.g., screws loosening, air conditioners failing), the photometer functioned reliably in a harsh eastern Montana environment from September 1975 until March 1979 when it was replaced by the present-generation photometer.

Two circumstances led us to reconfigure the photometer. A major limitation of the first unit was its inflexibility, i.e., changing the observing routine entailed rewiring the control board within the instrument. Renewed interest in the use of the sun as an energy source led us to consider a redesign of the instrument to include daytime measurements. The second-generation photometer, which will be discussed in this paper, includes changes to accommodate both of these needs, as well as further updating.

In Section II, the hardware of the instrument is discussed, including the mechanical, optical, electronic, and environmental aspects of the instrument. In Section III, the control system for the instrument is described. In Section IV, typical observing routines for the night and day programs are discussed. Section V contains a description of the procedures used in calibrating the daytime and nighttime photometers. Finally, the instrument sites selected and rationale for their selection are presented in Section VI.

II. HARDWARE

This section describes the instrument hardware as it is presently configured. Parts and construction costs have remained relatively constant over the 4-5 years of the program due to experience gained in fabricating the units and the decreasing costs of electronic components. The photometer is, in essence, a computer-controlled altazimuth telescope with 13-cm optics. It is equipped for day and night operation with two, slightly different, sets of optics which image the objective on the two detectors used in the two programs.

A. Optical

A schematic representation of the optical train is given in figure 1. Parallel rays emitted from a distant source are transferred to the imaging optics via mirrors M1 and M2. A particular look direction is selected by positioning these two mirrors. Mirror M1 is rotated about a horizontal axis to choose a particular elevation angle, and mirrors M1 and M2 rotate together about a vertical axis to select a particular azimuth angle. The mirrors are elliptically-shaped flats with major and minor axes of 22.0 cm and 16.5 cm. They are front-surfaced with a protected silver coating which reflects over 98 percent of the light incident from 500 nm to well beyond both detector cutoffs in the near infrared (>1100 nm). Below 500 nm the reflectance is still quite high for all wavelengths covered by our filter set.

Figure 1. Schematic Diagram of the Optical Train of the Photometer.

Selection of the reflecting material was of some importance because of the polarizing properties of materials at oblique angles of incidence. Polarized radiation is not reflected equally at all angles of incidence (in our case this is not a problem since the angle of incidence is always 45°) or for all positions of the electric vector with respect to the plane defined by incident and reflected rays. This latter effect can produce a photometric signal that differs by greater than 20 percent for a highly polarized source (e.g., scattered sunlight) of constant intensity incident on an overcoated aluminum mirror. By matching the reflectances of the electric vector components parallel and perpendicular to the reflection plane, one can eliminate this problem. If a constant source is unpolarized (e.g., direct sunlight), there is no change (at the 1-percent level) in detected intensity for a light incident on aluminum or silvered mirrors.

After reflection from the two silvered mirrors, the optical path is conventional. L1 is a 12.7-cm diameter anti-reflection coated lens with a 20.3-cm focal length. Lens L2 has a 5.1-cm diameter and a focal length of -8.0 cm. It serves as a Ross zero corrector to render the rays through the interference filter, F2, nearly parallel. Lens L3 forms an image of the distant source at the 2.5° aperture A2 when assembly F1-M3 is out of the optical path, and when F1-M3 is in the optical path L3 forms a source image at the 1.5° aperture A1. L5 images the fixed virtual objective on the photocathode of the photomultiplier tube D2, and L4 images the virtual objective on the photodiode D1. These last two lenses minimize the effect of spatial inhomogeneities in the photomultiplier and photodiode responses by imaging a fixed optic on them. L1 has a large aperture to increase the throughput during nighttime observations. F1 of movable assembly F1-M3 is an iconal neutral density filter with a transmission of approximately 0.005 to attenuate direct solar radiation, and M3 is a silvered mirror that folds the optical path toward the solar detector.

B. Mechanical

The mechanical motions within the photometer are described here. This includes the scanning head, the filter wheel, and the motor-driven assembly F1-M3 (figure 1) which moves into and out of the optical path.

Figure 2 is a schematic representation of the altazimuth mount. A bi-directional stepping motor drives a dual shaft assembly which transmits power to either the upper ring gear 'A' or to both ring gears 'A' and 'B' according to the conditions of the magnetic brake and clutch. With the brake energized and the clutch free, ring gear 'A' is driven via the central shaft with ring gear 'B' clamped. This transmits power to worm gear 'C' effecting movement of mirror M1 about a horizontal axis thereby scanning in elevation angle. With the brake released and the clutch engaged, both shafts are driven simultaneously transmitting power to gears 'A' and 'B' such that the whole mount moves about a vertical axis, effecting azimuthal scanning. The azimuthal and elevation scan rates are 20° and 5° per second, respectively.

Coupled to each ring gear of the drive mechanism is an optical tachometer which produces a pulse output proportional to rotation. These pulses are sampled at a 400-Hz rate and allow determination of the angular displacement in azimuth and elevation. Since the tachometers are not absolute encoding devices, a zero position must be defined for each rotation axis. For the azimuth zero, the edge of a tab attached to the rotating upper head assembly is used to trigger an optical switch. A similar arrangement, attached to the elevation assembly, serves to define the elevation zero.

A 12-position filter wheel provides wavelength discrimination for both the daytime and nighttime programs. The 5.1-cm filters are spaced equally about the periphery of the 30.5-cm diameter wheel which is driven by a bi-directional stepping motor. Tabs are

Figure 2. Schematic Diagram of the Altazimuth Drive System Showing the Principal Components.

mounted about the rim of the wheel in such a manner as to protrude and pass through a set of four equally-spaced optical switches which serve as "read" stations for filter positioning. Using "1" to indicate a tab-blocked optical switch and "0" to indicate no tab, the sequence 110111000100 is used to code filter position. The set of four optical switches interpreted as a decimal number then generates the numerical sequence (13, 11, 7, 14, 12, 8, 1, 2, 4, 9, 3, 6) as the 12-position filter wheel cycles through a revolution. A zero is generated by the "read" stations when the filters are not centered, e.g., during a filter change. The present set of filters used in all the instruments is given in Table 1. The first four are very narrow (1-2 nm FWHM) filters centered on auroral and airglow emission features and the fifth is a continuum filter for the nighttime observations. The next seven broad-band filters are selected to span the sensitivity of the photodiode used in the solar program. The narrow filters used at night are also used in some of the solar observations.

The assembly F1-M3 of figure 1 is a screw-driven carriage transported by a bi-directional motor. Positioning for day or night operation is defined by optical switches. In the day position, the optical path is through the neutral density filter F1 followed by a 90° reflection from the silvered mirror M3. At night, F1-M3 retracts. A photometric threshold detector mounted on the outside of the photometer governs the position assumed by the assembly.

C. Electronic

In the next few paragraphs, detectors used in the two photometers, signal acquisition, time-keeping, and recording are described. The minicomputer and its associated software that control these functions are discussed in Section III.

A significant problem with historical solar data is the accuracy with which much of it was taken. Detector stability

TABLE 1

Filter Wavelengths, Bandwidths, and Functions

<u>Center λ(nm)</u>	<u>FWHM(nm)</u>	<u>Use</u>
630.0	1	Night, Day
557.7	1	Night, Day
486.1	2	Night, Day
427.8	2	Night, Day
535.0	3	Night, Day
395.0	60	Day
470.0	100	Day
570.0	100	Day
680.0	120	Day
785.0	20	Day
900.0	160	Day
1010.0	30	Day

over long periods was difficult to maintain. In recent years photodiodes have proven quite suitable to this purpose. For this instrument a silicon PIN photodiode (EG&G HAV 4000) was chosen. The PIN diode has a number of characteristics which make it appropriate for this application: the response is linear to better than 1 percent over nine decades of incident light intensity; the response is constant to 0.5 percent over six months; it is physically rugged and will withstand well the effects of over-illumination. The photodiode is hermetically sealed in a package containing a high-gain FET input amplifier. Countering the positive aspects of the photodiode is the temperature dependence of the response, especially toward the long and short wavelength cutoffs. Figure 3 illustrates a typical response deviation as a function of temperature and wavelength for the type of photodiode used in the instrument (Application Note D3011C-1). By operating the diode in a zero-bias configuration, first-order variation of diode current with temperature is eliminated. To control the remaining variation shown in figure 3, the temperature is held at $20^{\circ}\pm 3^{\circ}\text{C}$ to achieve an overall stability of better than 1 percent for all but the longest wavelength filter in Table 1. A fairly constant digitization of the intensity over the range of illumination that is typically encountered in the daytime operation can be maintained by selection of one of four gains. The gain, chosen under program control, is in increments of 32 for a range of 1:32,768.

For nighttime operation, the detector is a photomultiplier tube operated in the pulse-counting mode. The tube, an EMI 9558A, has an S-20 photocathode; consequently, it responds to wavelengths from 300-850 nm. A custom-designed magnetic lens was chosen to minimize the dark count resulting from the non-illuminated portion of the photocathode. The photomultiplier operates uncooled, but it is maintained at a fixed temperature of $20^{\circ}\pm 3^{\circ}\text{C}$. One would like to be able to detect reasonably bright auroral displays and barely detectable airglow phenomena with the same photomultiplier tube.

Figure 3. The Percentage Variation of Si Photodiode Response as a Function of Wavelength and Temperature.

To achieve this, the voltage at which the tube operates is chosen to maximize the dynamic range. A conventional pulse amplifier-discriminator amplifies the photomultiplier tube output and prevents registration of pulses of low amplitude which result from electrons originating down the dynode chain from the photocathode.

Since the photometer is operated unattended, there is concern about protection of the photomultiplier tube from over-illumination by an intense aurora or, perhaps, a brilliant lightning display. For this purpose an electro-mechanical shutter which protects the photomultiplier tube is hard-wired to two protection devices. One is the photometric threshold sensor which sends a "close-shutter" signal if the sky becomes bright enough to turn it on. The other is an overcurrent circuit, built into the photomultiplier tube circuit, which also closes the shutter should the current from the tube exceed a predetermined value.

Data acquisition from the two detectors as well as other internal sources is schematically illustrated in figure 4. An analog multiplexer selects one of eight sources as input to a 10-V/100-kHz voltage-to-frequency converter. Low sampling rates with variable integration times and a maximum nonlinearity of the voltage-to-frequency converter of ± 0.05 percent over 80 dB make this an ideal analog-to-digital conversion scheme consistent with our overall accuracy requirements. Besides the photodiode sensor, the other inputs to the analog multiplexer include, for test purposes, the photomultiplier high voltage, filter wheel temperature, outside temperature, a 5-Volt reference, a spare input, the output of a digital-to-analog converter used to check the self-consistency of the system and to provide an analog output for external monitoring devices, and a grounded input to check the stability of the electronics.

A digital multiplexer selects one of eight channels as input to a 16-bit counter. The counter is controlled by a variable time

Figure 4. Schematic Diagram of the Data Acquisition System.

base which can assume one of 16 values. The minimum integration time is 100 μ sec and the integration times increase by factors of two up to a maximum period of 3.2768 seconds. Besides the voltage-to-frequency converter, the digital multiplexer inputs include the photomultiplier tube output through the pulse amplifier-discriminator, a 10-kHz reference signal, two channels dedicated to external devices, and three spare inputs.

Instrument time is derived from the 60-kHz carrier signal broadcast by WWVB radio station of the National Bureau of Standards located at Fort Collins, Colorado. The time signal is received by an active antenna located near the instrument and the binary coded decimal signal is decoded by software to provide time of day in seconds from midnight (UTI) and day of year. During times of poor reception, interpolation is provided by a crystal clock. Recording is on magnetic cassette tapes using a commercially available tape drive (Interdata or Sycor).

D. Environmental

Housing for the photometer was carefully considered because the photometers are operated at nearly constant interior temperatures. The narrow interference filters and photomultiplier tube used for the nighttime work and the photodiode sensor used during the day are all temperature-sensitive. Figure 5 is a photograph of the photometer exterior. The standard size pickup camper unit is well-sealed, with extra insulation built in. An electric baseboard heater together with an air-conditioning unit operate on a differential thermostat which maintains the temperature at $20^{\circ}\pm 3^{\circ}\text{C}$. A square plate 90 cm on a side and 2.5-cm thick carries the optical-mechanical assembly of the photometer. This plate bolts directly beneath the transparent dome and isolates the bubble area from the rest of the housing. The space between the plate and the bubble is temperature and humidity controlled with a heater-fan unit and a desiccant tray. This warm, dry environment prevents frost or dew

Figure 5. Photograph of the Instrument Showing the Dome and Scanning Optics and the Electronics Assembly.

accumulation. The Plexiglas bubble has a uniform transmission over all wavelengths of interest and transmits more than 91 percent of normally incident radiation. The other assembly within the unit is a 2-meter rack which supports most of the electronics that control the photometer, including the minicomputer (Interdata) and the dual magnetic cassette tape transport used for program loading and data recording.

III. CONTROL SYSTEM

The control system forms the heart of the instrument and is implemented via software on a 16-bit minicomputer. An overview of the software organization, followed by a more detailed discussion of individual modules, is presented below. The hardware requirements are simple and consist of the CPU, either 32 or 16 kilobytes of core memory, two magnetic cassette tape drives, and an interface board containing the circuitry necessary to control the instrument. Power switching to actuate the motors, brake, and clutch is accomplished with solid-state relays driven by logic-level signals. Similarly, input signals reporting the status of the instrument are derived from optoelectronic sensors when possible. This reduction of moving parts has led to a high degree of reliability in the instrument.

In many ways, the software is quite similar in organization to operating systems (OS) supporting multi-tasking typically found on larger machines. The role of the OS is distributed among several software modules. The foremost of these is the scheduler (SCHED) which acts as a task manager. In the present configuration, two tasks are resident—an observing control task (OBS) and a sun position calculation task (SUN). The primary function of SCHED is to decide which task is to run at any given time and to activate that task. This process occurs every 2 msec and is driven by an external clock interrupt. The OBS task is of higher priority than the SUN task and as such has first call upon the machine resources. It frequently enters a time interval wait state, however; and during this period, the sun position calculation is performed.

OBS is the central controlling task in the machine and calls upon one of two subroutines to carry out the desired function: GEPHY, the nighttime observing program, and SOLAR, for the daytime observing program. These are described in detail in Section IV. Support for these control functions is provided by a set of small routines partitioned into three levels.

Level 1 routines are driven by hardware interrupts and execute in a non-interruptable state—i.e., once started they proceed to completion without interference. They provide the following services: 1) writing the cassette tape; 2) maintaining the pointing direction of the instrument; and 3) providing operator-machine communication via the front panel control board.

Level 2 routines are those which require regularly scheduled operations and as such provide an operating background for the control task OBS. The functions include driving the front panel display, sampling the data values from the detectors, moving the instrument head, positioning the filter wheel and day-night slide, maintaining the date and time, and providing task interval waits.

Level 3 routines carry out task scheduling, task time waits, and setup of asynchronous I/O.

The sun position calculation task, SUN, requires only the date, time, and station latitude and longitude. Parameterized representations of the equation of time and the solar declination allow a calculation of the solar right ascension and declination. These values are then transformed to azimuth and elevation values via rotation algorithms. The calculation maintains an accuracy of $\pm 0.5^\circ$.

The particular software philosophy used allows easy maintenance of the system since the structure is highly modular. In addition, since most of the machine control functions occur at a low level, changes in the operating program OBS are easily accomplished. The software has proven to be very stable. The only crashes which have

occurred over a 2-year period with nine machines are preprogrammed stops which halt the machine upon certain types of mechanical failure, beyond which continued operation would result in damage to the instrument. Updates and revisions of the software are accomplished by delivery to the field units of a cassette tape which is then loaded into each machine by the local operator.

Data acquired by the instrument are compressed before being written to magnetic tape. This affords a factor of two or more increase in running time between cassette-tape changes. Presently, a visit every four days is required to replace the cassettes. The data are recorded with an accuracy between 0.4 and 0.8 percent. Since it was desired to encode to a constant accuracy over a wide dynamic range and since successive samples of data often differ only slightly, the following encoding algorithm was used.

The algorithm successively left-shifts the 16-bit data value until the most significant bit is set. The shift count is added to the integration period used to acquire the value (see Section II) and a pseudo-period derived. The gain/pseudo-period byte is then compared with the previous value and is recorded only if a change occurred. The most significant byte of the data value is then recorded; this value lies between 128 and 255. To avoid oscillation at the decision point, an alternate scaling may be chosen. If the mantissa is scaled at $3/2$ of its value, then the mid-range of the scaled mantissa will not intersect the mid-range of the unscaled mantissa. Thus when a gain/period byte change is required, the scaling which gives a mid-range value is chosen until another gain/period byte change is required.

IV. OBSERVATIONS

A. Aeronomy

The nighttime observing program is designed to obtain all-sky coverage of airglow emissions [OI] 557.7 nm and [OI] 630.0 nm, auroral emissions [OI] 557.7 nm, [OI] 630.0 nm, N_2^+ 427.8 nm, and

H β 486.1 nm and the continuum at 535.0 nm. Five interference filters (Table 1) are used to select these wavelengths. The luminosity threshold varies from 2 Rayleighs (R) for units not located in the auroral zone to 10 R for units located in the auroral zone. The field of view is 2.5° for all units.

The observing technique consists of scanning the night sky in a series of almucantars at elevations 10°, 15°, 20°, 30°, and 50° for emission filters, and 10°, 26°, 42°, 58°, and 74° for the continuum filter. The geometrical circle of coverage depends on the altitude of the emission. For example, at 300 km, the 10° elevation scan has a radius of approximately 1150 km or 10° of geographic distance. For a 150-km emission altitude, the 10° elevation scan has a circle of coverage radius of approximately 650 km or 6° of geographic distance. Figure 6a illustrates the extent of the all-sky coverage obtained from the present eight locations of MASP units for 150-km altitude emissions and figure 6b for 300-km altitudes. The emission filter elevation scans were selected such that when constructing all-sky circle maps from the five elevation scans for an emission altitude of 300 km, the five concentric projection circles are approximately equidistant.

The number of samples taken at each elevation scan depends on the elevation of that scan and the auroral activity. With a field of view of 2.5°, an average integration period of 0.1 seconds, and a scanning rate of 20° per sec, the maximum sample rate used is one sample per 3° (120 samples per scan) in the 10° and 15° elevation scans. Allowing for the cosine effect of the sky solid angle covered for the other elevation scans, the maximum sample rates used are 90 samples per scan for elevation scans at 20° and 30°, and 60 samples per scan for the elevation scan at 50°. If the control program determines from the previous 630.0-nm all-sky scan that the auroral activity is low, the sample rates for the line emission filters all decrease by a factor of two. The sample rates for the

10° ELEVATION SCANS: 150 Km ALTITUDE

Figure 6a. The Field of Coverage for an Assumed Emission Height of 150 km.

10° ELEVATION SCANS: 300 Km ALTITUDE

Figure 6b. The Field of Coverage for an Assumed Emission Height of 300 km.

continuum filter are always 120, 90, 72, 45, and 24 samples per scan for azimuth scans at elevations of 10° , 26° , 42° , 58° , and 74° , respectively.

One all-sky survey, which includes five almucantar scans plus zenith and dark-current measurements, takes 124 seconds. One set of 5-filter surveys takes 620 seconds. If it is determined from the previous 630.0-nm all-sky survey that the auroral activity is low, a set of 5-filter surveys is started on the hour and at every 20-minute increment from the hour. If the auroral activity is determined to be high, a set of 5-filter surveys is started on the hour and at every 12-minute increment from the hour. Sample data, unit identification, status information, date, and times are stored in memory until the storage reaches a pre-set number of bytes and then the buffer is written on the magnetic cassette tape and reset. Each cassette record, for active auroral periods, includes approximately two all-sky surveys.

The nighttime program runs whenever the solar elevation is depressed greater than 15° below the horizon and the date is not within two days of full moon. During full-moon periods no nighttime data are acquired.

B. Insolation

In the daytime measurements program, an attempt was made to design the operating routine to accommodate as many potential users of the data collected as possible. The direct solar data should be useful to central receiver power production facilities, to photovoltaic and photobiological conversion programs, and to radiative transfer theorists and climate modelers interested in the attenuation of solar radiation by atmospheric aerosols and water vapor. The diffuse radiation measurements should be especially helpful to those interested in the radiation transport properties of clouds, to aerosol physicists and chemists, and to low-temperature solar

collector designers and architects. The next few paragraphs outline the basic routine employed at all photometer sites.

Figure 7 illustrates the sequence of measurements that begins at sunrise and is repeated every 30 minutes until sunset. Every 5-minute time slice begins with a direct measurement of the sun. The straightforward procedure of pointing directly at the sun cannot be confidently employed. The sun's position is calculated once per minute to an accuracy of $\pm 0.5^\circ$. The pointing accuracy of the instrument is $\pm 0.3^\circ$. The largest error in pointing by dead reckoning, however, ordinarily occurs in the alignment of the instrument. In principle, it may be aligned to within 0.5° but only after a great deal of painstaking effort. In view of these considerations, one cannot be certain that the sun is entirely within the 1.5° field-of-view aperture at all times. To make the direct measurement then, a sun-centered raster scan is made. This scan has dimensions 5° in azimuth by 3° in elevation with samples taken every 0.5° in azimuth and every 0.3° in elevation, generating 110 samples of which only the largest is retained along with its location in the scan. The scan is repeated for each of the seven solar filters during the first part of each 5-minute time slice, except during the first and fourth time slices of the 30-minute sequence when there is sufficient time to sample all 12 filters. During the second 5-minute time slice of the 30-minute sequence, a solar almucantar scan is performed in each of the solar filters. A solar almucantar scan is a revolution in azimuth at the solar elevation. The first sample is taken 5° in azimuth from the sun with subsequent sampling every 5° to 180° from the sun. The third and fourth time slices sample in a similar manner except the scanning is in elevation starting 5° above the sun and continuing to the opposite horizon. Two scans are required because the elevation scan rate is one-fourth that of the azimuth. The fifth and sixth scans sample the diffuse sky roughly every 10° . The scans are almucantars at every 10° of elevation. The azimuth spacing of the samples is scaled as the sine

Figure 7. Time Multiplex Frame for Solar Measurements.

of the elevation angle. A broad red filter scan in the sixth time slice follows a broad blue filter scan in the fifth time slice.

The control program writes a variable length record in an attempt to efficiently record the data, i.e., minimize the ratio of inter-record gap to total record length. It provides for power/fail recovery, and it writes an identifiable record at day's end. At night, it takes samples, after the F1-M3 assembly of figure 1 is removed, to determine the number of counts due to the offset voltage on the photodiode, i.e., dark count.

C. Other Programs

The idea of allowing most of the decision-making to be incorporated within the software allows new observational requirements and requests to be handled rather easily. One program, which has proved very useful, is a utility program used to check the operation of the unit, to calibrate the unit, and to run special experiments using the routine scan patterns of the instrument.

Two recent examples illustrate the ease with which new experiments may be implemented. A request was received to study the diffusion properties of a "charge" of ionized material released from a rocket in the ionosphere. The program to accomplish this was a hybrid version of software that already existed for the routine nighttime monitoring and the utility program described above and, consequently, required only a few days to code and debug. Another request involved the measurement of diffuse data sampled over the hemisphere in five broad filters as input to an architectural model employing sunlight for interior lighting. This required less than an afternoon to implement. Not all future requirements will be this straightforward, but most will be able to build on the extensive software that already exists.

V. CALIBRATION

All of the current programs using the mobile automatic scanning photometer require that the photometer make absolute measurements.

Outlines of the methods employed in calibrating the two detectors are given below.

A. Aeronomy

A wide-aperture standard light obtains its primary calibration via a transfer comparison against a Carbon 14 activated phosphor light source as described by Smith and Alexander (1963). It has also been intercompared with the University of Michigan's and the University of Alaska's calibrated lamp sources in order to establish a coordinated network of standard sources. The MASP unit is calibrated by positioning the standard lamp directly in front of the scanning head such that the source fills the field of view. A calibration program, run on the MASP central processor, records alternately the photometer tube output and the output of the lamp sensor (described later) for the solar and aeronomy filters. The accuracy of the absolute calibration is approximately 20 percent.

Figure 8 illustrates the important features of the wide-aperture standard lamp which consists of two diffusing cavities. The first small cavity houses a GE 3026 halogen cycle miniature lamp, L1, which is driven by a constant-current power supply. The lamp is positioned within the cavity such that the first baffle, B1, shields the aperture, A1, from direct illumination. Thus the light must be scattered at least once from the flat white interior of the cavity before exiting the aperture. A Schott #FG-4 filter, F1, is placed just ahead of the aperture in order to increase the apparent color temperature of the light source.

The second cavity is a standard aluminum instrument case measuring 45 cm x 60 cm x 50 cm deep, the interior of which has been painted flat white. A second baffle, B2, is placed so as to shield the first diffuser, DF1, from direct illumination from the aperture. A second smaller diffuser, DF2, is placed after the first one which serves as the exit pupil of the instrument. The diffusing disks are 0.3-cm thick, milk-white Plexiglas which has proven to be comparable to opal glass in its diffusing properties.

Figure 8. Wide-Aperture Calibration Light Source.

The lid of the case houses the two power supplies—one for the lamp previously described and a smaller power supply for the optical sensor, D1, whose function is to monitor the light output reflected from the second baffle. The lamp power supply is a constant-current design and in practice maintains the lamp output constant to better than 1 percent. The optical sensor consists of a silicon PIN photodiode (RCA 30808) and a high-gain LM308AN op amp, the output of which is supplied to the multiplexer input of the MASP central processing unit for data recording.

B. Insolation

In order to achieve an absolute calibration of the solar photometer, an active cavity radiometer (ACR) is used (Radiometrics Corporation). The ACR has proven a reliable instrument for the absolute measurement of solar radiation. This type of instrument was responsible for defining the 2.2-percent error in the International Pyheliometric Scale. This absolute pyrhelimeter is described by Willson (1973) and is essentially a light-absorbing cavity wound with a resistance heater and a resistance thermometer. Absolute power measurements are made by heating the cavity to a given temperature with and without radiation incident on the cavity. The difference in power requirements is the absolute value of the incident radiation, aside from a calibration constant near 1.

The mobile photometer is calibrated on clear, cirrus-free days as close to solar noon as possible. Each sun-looking reading of the ACR is sandwiched between two dark readings of the ACR. Since the ACR has a 2-second time constant, approximately 30 seconds is allowed to elapse before 12 consecutive readings, one-half second apart, are made. By averaging the 12 readings, we arrive at a more accurate value of the power levels. Each ACR measurement is immediately followed by a photometer measurement of the solar flux through the same filter. There is an approximate delay of 45 seconds between measurements on the two instruments. By measuring

near noon when the solar elevation changes little and by making measurements with as little delay as possible, a calibration accuracy of 1 percent or better is obtained on the high-throughput filters. The measurement for any particular filter is repeated several times and then averaged to arrive at a calibration factor for each filter.

There was some concern that the changing incident spectral distribution of the sun as the airmass increased would necessitate an airmass-dependent calibration. The effect would be strongest in the blue-ultraviolet region of the spectrum where the strong λ^{-4} Rayleigh scattering extinction coefficient is most pronounced. An airmass-dependency study in the broad blue filter was made to check this effect. No statistically significant change over five airmasses was detected.

VI. NETWORK DESCRIPTION

Three funding agencies have contributed to the development of the photometers, each with different requirements for their program. Three of the units were funded to provide aeronomical observations during the International Magnetospheric Study; two of the units were funded to take site-specific solar data; and the five remaining units were to provide both daytime and nighttime measurements. These considerations account for the geographical distribution of mobile automatic scanning photometers given in figure 6.

There were north-south and east-west chains of photometers. The north-south chain included Fort Providence (Northwest Territories, Canada), Leduc (Alberta, Canada), Hinsdale (Montana), Boulder (Colorado), and Albuquerque (New Mexico). The east-west chain included Richland (Washington), Hinsdale (Montana), Iron Mountain (Michigan), and Albany (New York). There were eight stations rather than ten because two units were retained for special-purpose use, e.g., nonroutine experiments or non-network filters. This geographic arrangement existed for more than two years and is now being revamped due to programmatic changes.

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