MODEL SSP-3

Generation 2

SOLID-STATE STELLAR PHOTOMETER

TECHNICAL MANUAL FOR

THEORY OF OPERATION AND OPERATING PROCEDURES

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Figure 1-1. SSP-3 Generation 2 Solid-State Photometer.

TABLE OF CONTENTS
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LIST OF FIGURES

LIST OF TABLES

ii

SECTION 1.0

INTRODUCTION

By using an ultra-sensitive solid-state detector and integrated digital electronics, Optec has designed a unique stellar photometer enclosed in a single small package. All the electronics, including detector, electrometer amplifier, voltage-to-frequency conversion electronics, and digital display are contained in one easy-to-handle unit and powered by a rechargeable 9-volt NiCd battery. The model SSP-3 Stellar Photometer makes the concept of a "portable observatory" a reality. All that is needed to make accurate and meaningful measurements of variable stars is a telescope, chair, notebook, and the model SSP-3a photometer. Figure 1-1 shows the SSP-3 photometer coupled to a Meade 10" telescope.

Unlike most photometers used in astronomy, which employ a photomultiplier tube, the SSP-3 uses a silicon PN-photodiode detector that allows detection from the UV to the near infrared with a single detector. Other advantages of the SSP-3 include: increased safety factor since only low voltages are used (photomultiplier tube voltages can exceed 1000 volts), freedom from damage when accidentally exposed to bright lights or rough handling, exceptional linearity over a 1,000,000/1 light range, and ease of use not usually found in this level of instrumentation.

As mentioned previously, the SSP-3 photometer and a telescope are the only instruments needed for measurements of variable stars. However, to further extend the utility of this instrument, a serial output port is made available for interface to a PC or laptop computer. An interface program called SSPDATAQ is supplied with the instrument and updated versions are available from the Optec web site for no charge. This program can control all aspects of the instrument and produce data files that are compatible with RPHOT, which is a data reduction program available from Optec. Figure 1-2 shows the complete SSP-3 photometer system.

FILTERS

JOHNSON: U, B, B, R, I
WING: MA, MB, MI
CLEAR, DARK

6-POSITION FILTER SLIDER
FOR SSP-3a

2-POSITION FILTER SLIDER
FOR SSP-3

TELESCOPE ADAPTERS

2 INCH
OPTIONAL

1.25 INCH
STANDARD

DETECTOR
1mm STANDARD
.5, .75 & 2mm   OPTIONAL

SSP-3

SERIAL INTERFACE CONNECTOR

NULL MODEM CABLE

TO SERIAL PORT
OF PC COMPUTER

POWER SUPPLY
110-240 VAC 50/60 Hz INPUT
12.0 VDC AT 1.0 AMP OUTPUT

SSPDATAQ CONTROL PROGRAM
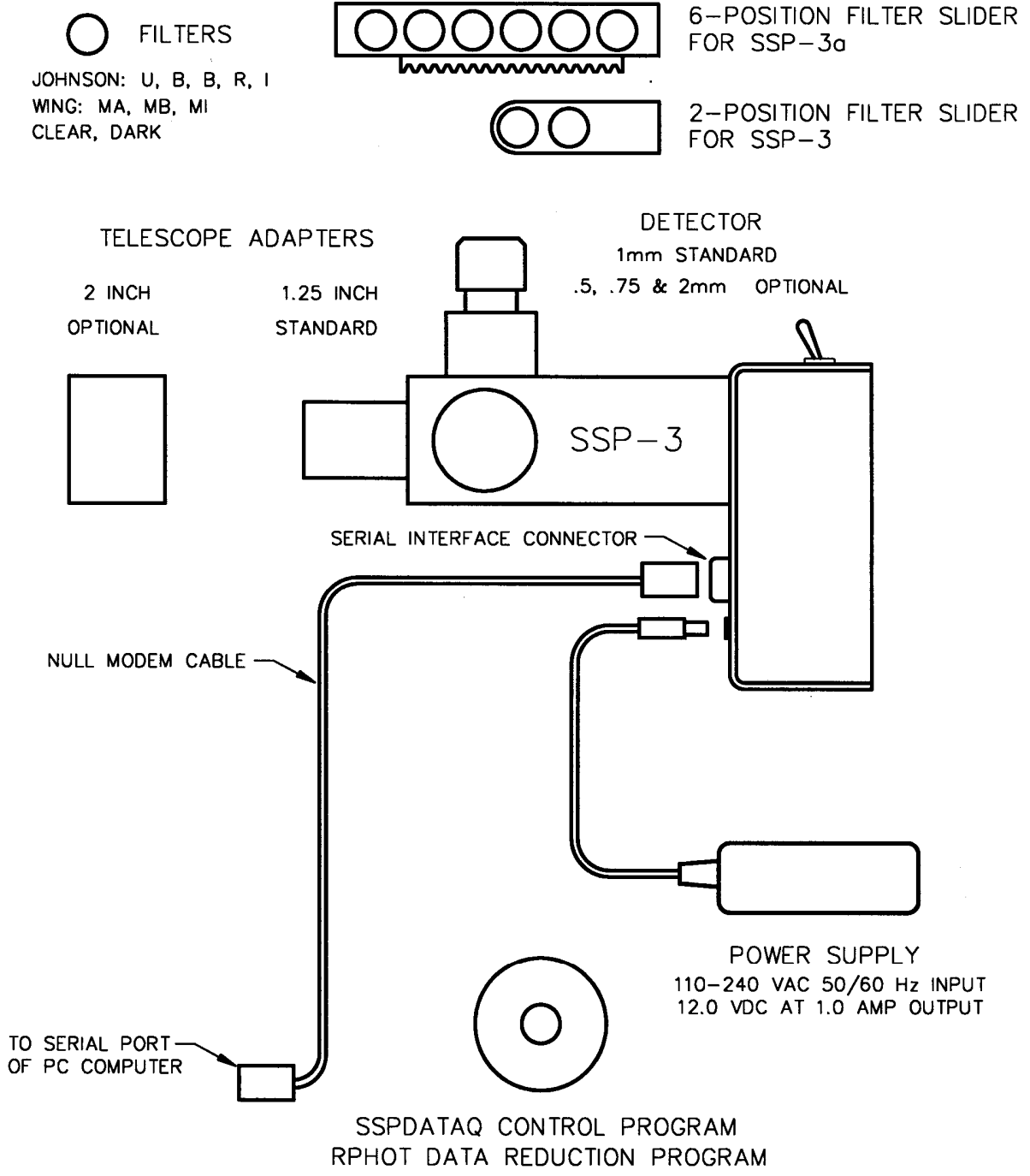RPHOT DATA REDUCTION PROGRAM

Figure 1-2. The SSP-3 Version 2 Photometer System and Accessories.

SECTION 2.0

THEORY OF OPERATION

2.1 BASIC PHYSICAL CHARACTERISTICS

Figure 2-1 shows a cross-sectional view of the SSP-3 photometer. Light enters the photometer through the 1.25-inch telescope adapter and is directed either to the focusing eyepiece or the detector by means of a flip-mirror.   The focusing eyepiece consists of a 1-inch focal length Ramsden and a reticle with a precisely scribed ring that defines the detector field of view. A green LED illuminates the reticle from the side. After a star is centered in the ring, the flip mirror is rotated to expose the detector. It is important to note that, unlike a photomultiplier system, the image of the star falls on the detector plane; a Fabry lens is not used.

To insure uniform surface response, each detector is inspected under a microscope for surface defects that could cause a signal drop if the star's image was centered upon it. Actual optical bench tests of stock units with a 0.002-inch diameter spot (equivalent to a 5 arc second stellar seeing disk with an 80 inch focal length telescope) typically show less than a 1% response variation over the surface. Since testing each unit for surface uniformity with a scanning spot is time consuming and thus expensive, only a few units of each production run are tested. The user can test the uniformity of his detector by observing the readings of a bright star on a very stable night (use the 1 scale to minimize instrument noise) in several locations around the detector. If the response varies by more than 1% within a circle measuring 0.7 times the diameter of the reticle ring, Optec will replace the detector under our warranty terms.

A two-position filter slider is mounted between the flip mirror and the detector. Any pair of filters selected by the user before delivery can be mounted in the slider. Since the slider is easily pulled out of the unit, sliders with other combinations of filters can be inserted. For most variable star work, a single slider with B and V filters is recommended to begin with.

For observations that do not require a filter such as occultation timing, asteroid rotation, and minimum timing of binary systems, the clear filter is used to insure that the proper optical distance is maintained. Without the Clear filter, the stellar image will be out of focus on the detector and the size of the blur circle would be proportional to the telescope's f/number.

FULL SCALE

EYEPIECE

RETICLE

FLIP-MIRROR

LED

FIELD APERTURE MASK

DETECTOR

ELECTROMETER

FRONT CONTROL PANEL

MAIN CIRCUIT BOARD

CONNECTOR

DETECTOR COVER WINDOW

STEPPER MOTOR (SSP-3a)

BATTERY

FILTER

SPUR GEAR (SSP-3a)

BEARING (SSP-3a)
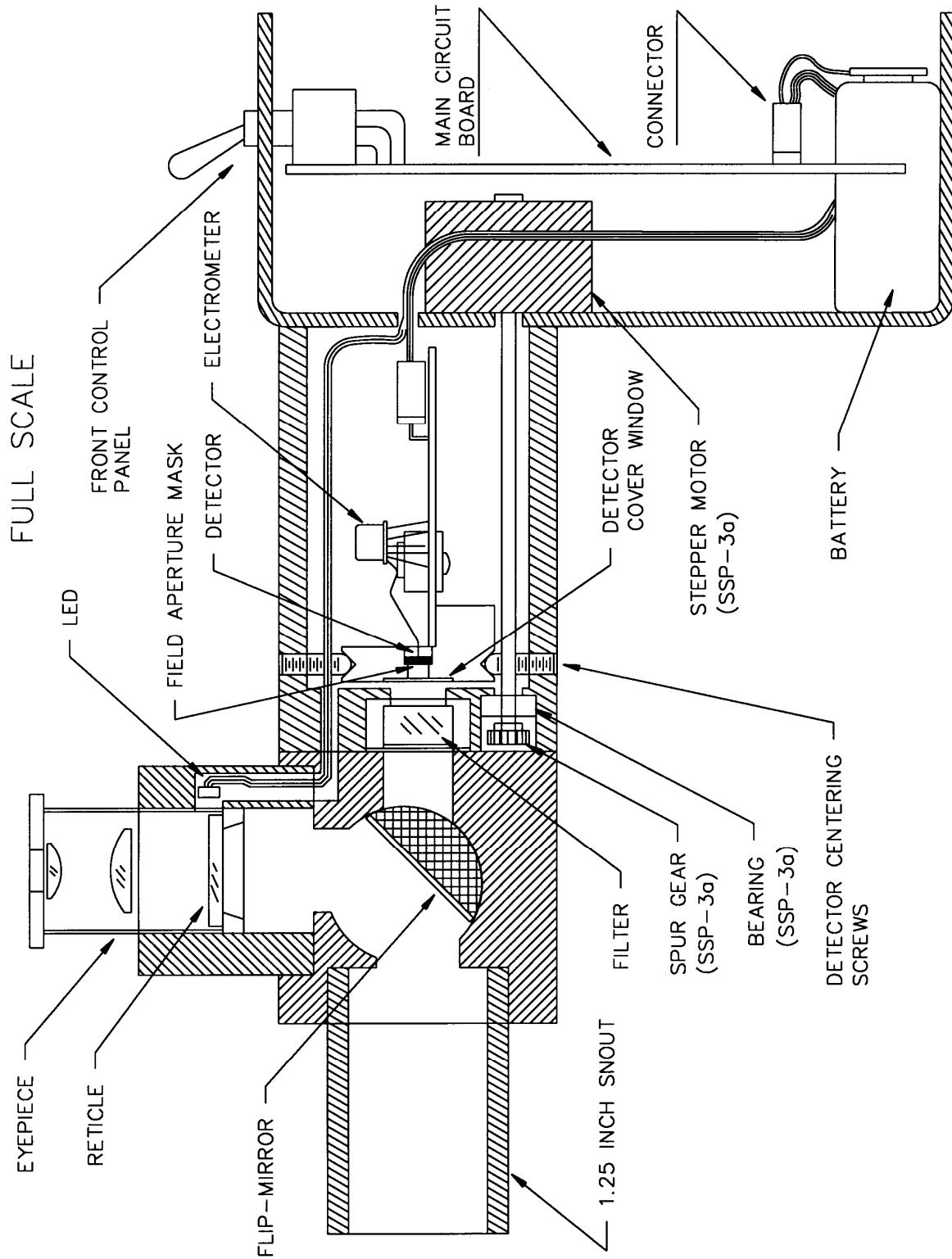
DETECTOR CENTERING SCREWS

1.25 INCH SNOUT

Figure 2-1. Cross-Sectional View of the SSP-3.

4

The detector and electrometer are rigidly mounted behind the filter slider on an X-Y adjustable V-grooved bracket. Accurate alignment of this bracket on an optical bench insures that the sensitive area of the detector matches the stellar field as defined by the reticle in the focusing eyepiece. The field diameter is determined by a mask that is placed on top of the photodiode. Sizes of 0.5, 0.75, 1.0 and 2.0 mm are available with the 1.0 mm size considered best for most telescopes with focal lengths in the range of 50 to 150 inches. See Appendix B for determination of the angular size for typical aperture/telescope combinations.

The electrometer amplifies the current from the photodiode by a factor of 5 x 10^{10} and is analogous to the operation of a photomultiplier tube. From the electrometer amplifier, the signal is then routed to the voltage-to-frequency converter for final processing into counts based on a 1 or 10 second gate time interval. The resulting count is then read from the four-digit readout on the front panel or from an external computer connected to the serial output connector.

2.2 DETECTOR THEORY

The detector used in the SSP-3 is a model S1087-01 manufactured by Hamamatsu Corporation. This unit can be classified as a planar diffusion type that offers the highest possible shunt resistance value (R_s) resulting in a very low noise current. Figure 2-2 shows the construction of this type of device and Table 2-1 lists the important physical and electrical characteristics that are used in further analysis.

When light energy greater than the band gap energy is absorbed in the P or N layers of the photodiode, electrons are excited into the conduction band. This creates what is normally called an electron-hole pair in the silicon crystal structure that makes up the photodiode. Because of the intrinsic electric field generated across the P-N junction, electron-hole pairs created in this region are pulled apart with the electrons migrating to the N side and the holes migrating to the P side. If a wire connects the P and N sides, current will flow in the wire, which is directly proportional to the light flux.

Photons of different wavelength penetrate to different depths in the photodiode before being absorbed. Blue photons are absorbed quickly near the surface of the P layer and red photons are absorbed deep in the N layer. Since recombination can occur before the electron or hole moves across the junction to its respective electrode, the probability of successful migration is strongly dependent on how near the junction the electron-hole pair is created.   The electrical term that results from this probability-wavelength relationship is called spectral response, which, more precisely, is the ratio of photocurrent in amperes to the amount of incident light power in watts at a given wavelength.   Figure 2-3 shows a plot of the spectral response for the S1087-01 photodiode.
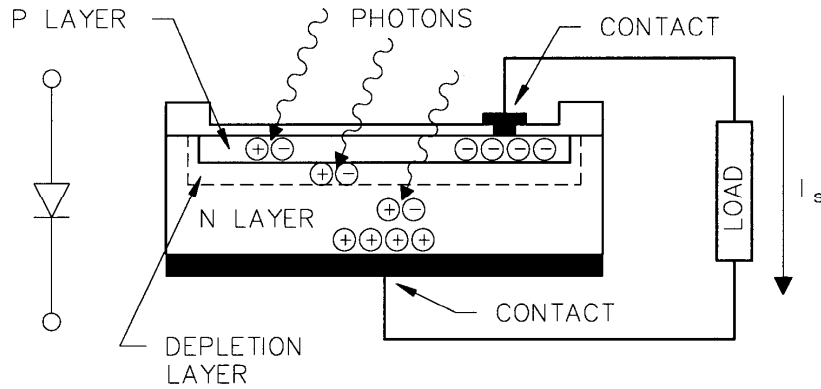
Figure 2-2. Planar Diffusion Type Silicon PN Photodiode used in the SSP-3.

Size	1.3 x 1.3
Effective Area	1.6 sq. mm
Spectral Range	300 - 1100 nm
Peak Response	0.55 A/W at 940nm
Response at 550nm	0.34 A/W
Shunt Resistance	50 G Ω typical
Noise Equivalent Power	$8\mathrm{x}10^{-16}$ W/$\sqrt{Hz}$

Table 2-1. Physical and Electrical Characteristics of the Model S1087-01

Quantum efficiency is defined as the ratio of number of incident photons to the resulting photoelectrons in the output current. Since about 75% of the incident photons are absorbed in the wavelength band from 400 to 1000nm, the S1087-01 photodiode has a Q.E. of approximately 0.75 in this band. When compared to most photomultiplier tubes, which have a Q.E. of about 0.10, the superior efficiency of the photodiode hence its output is significantly compromised by thermal noise sources in the diode and the associated amplifier. Because of these noise sources, the overall sensitivity of the SSP-3a is less than a photomultiplier photometer at some wavelengths. Only at very cold temperatures, liquid nitrogen at 77K for example, can the silicon photodiode equal and in many cases surpass the sensitivity of a photomultiplier tube due to its higher quantum efficiency.

6
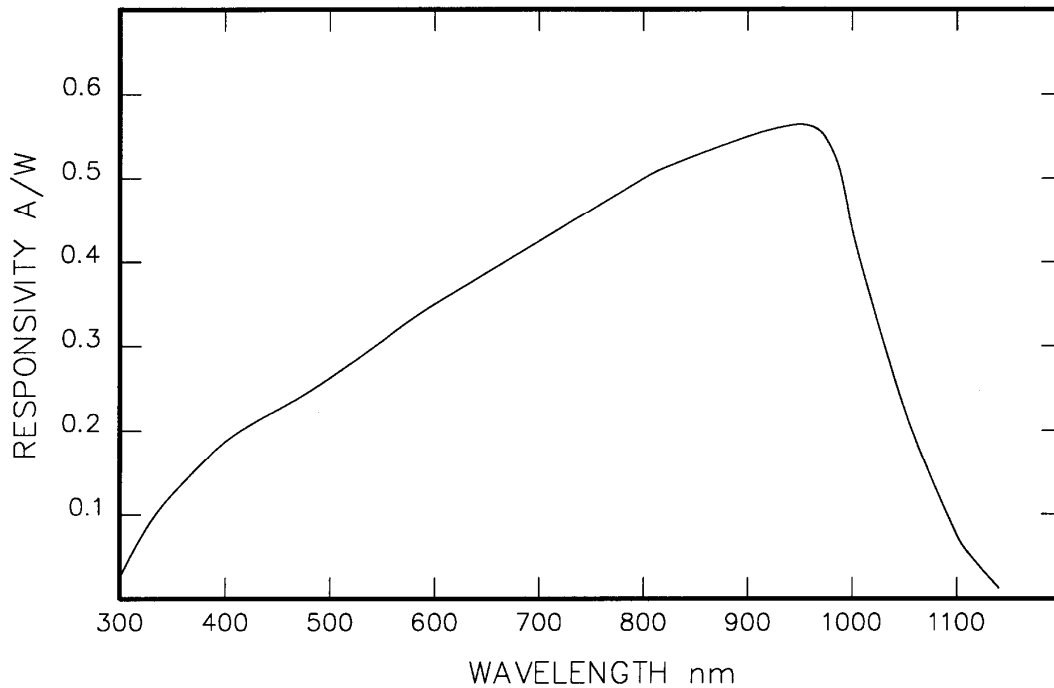
Figure 2-3. Spectral Response of the S1087-01 Photodiode Detector.

2.3 DETECTOR/ELECTROMETER DESIGN

Observing an 8th magnitude star with an 11-inch aperture telescope and SSP-3 photometer with a V filter in place will produce a photocurrent (output from the detector) of about 0.01 picoamp (1×10^{-14} A). This extremely small current must be amplified and converted to a voltage of sufficient amplitude without introducing significant amounts of current and voltage noise. Thus, the electrometer's task is as important as the detector itself. The Detector/Electrometer circuit is the heart of the SSP-3 photometer and its design is a matter of optimizing both key elements as a single working unit.

Figure 2-4 shows the basic current-to-voltage amplifier configuration used in the SSP-3. Photocurrent from the detector is balanced by an equal current in the feedback resistor, but flowing in the opposite direction so that the inverting input is kept near zero potential. The output voltage is thus:

$$E_{out} = - R_f \times I_s$$

where R_f is the feedback resistance and, in the case of the SSP-3 is equal to 50 G ohm (5×10^{10}). The photocurrent from the photodiode is I_s. In the above example observing an 8th magnitude star, the 0.01 picoamp photocurrent results in a 0.0005 V output from the amplifier.

7

$I_s = I_f$

I_f

R_f

H

I_s

DETECTOR

ELECTROMETER

$-$

$+$

E_{out}

PHOTOCURRENT

$I_s = R_h \times H$

Where R_h is the responsivity
and H is the irradiance on
the detector

OUTPUT

$E_{out} = -R_f \times I_s$
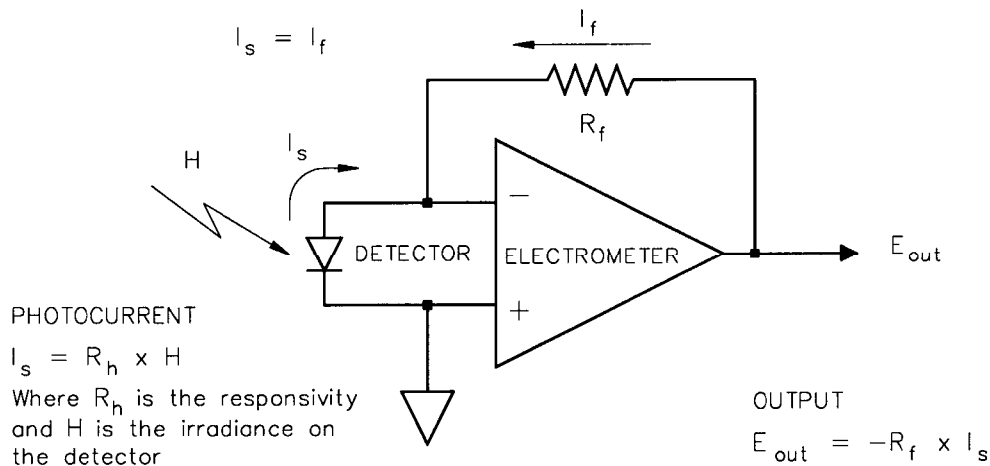
*Figure 2-4. Current-to-Voltage Amplifier Configuration Used in the
Detector/Electrometer Design.*

Of course, the gain stability of this circuit is highly dependent on the resistance stability of the feedback resistor. Fluctuations of its value due to temperature changes could cause gain errors during observations that are especially objectionable when all-sky photometry is done. The special resistor used has a temperature coefficient of 200 ppm/°C which is extremely low for a resistor of its size and rating. Thus, a 20°C drop in temperature during the night, which is not uncommon, would cause a 0.004 magnitude error in electrometer gain. Even though this error source can be safely ignored, temperature effects on the responsivity of the detector and passbands of the filters also have to be considered when extreme temperature changes do occur.

Since extremely small currents are amplified, surface leakage currents may affect the overall accuracy of the Detector/Electrometer circuit. To protect against this, the finished circuit is baked at an elevated temperature in a vacuum dessicator for several days before it is heavily coated with a silicon sealant that has a very high bulk resistance. During the cure time, which also may last several days, the finished circuit is stored in a vacuum dessicator until mounted in the SSP-3.

2.4 POWER SUPPLY

An important consideration in the design of the SSP-3 photometer was the need for a stable positive and negative power supply. It was decided that the unit should be totally portable, and should be able to run for at least five hours between charges. If this was not enough time, then the unit should be able to run on a common alkaline battery or another rechargeable battery. These objectives were all achieved using the power supply design shown in Figure 2.5.

8
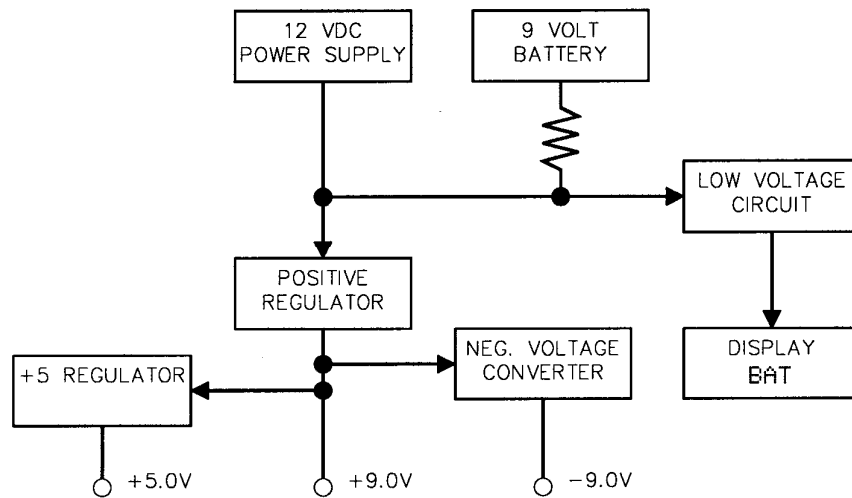
Figure 2-5. Power Supply Function Diagram.

The 12 VDC power spply delivers one of two charge rates to the battery, depending on whether the unit is on or off. If it is off, a trickle charge is applied which will fully charge the battery in approximately 15 hours. If the unit is on, enough current will be delivered to run the unit and charge the battery at the same time.   Located on the back of the unit is a 2.5 mm jack to connect the charger.

The second part of the supply consists of a 8.4 volt NiCd rechargeable battery available from General Electric (model GC9) or Gould (model GS9T). This battery can be purchased from any well-equipped hardware or department store for about $10.00. One battery is supplied with the unit when purchased.

The battery can be used alone for about 4 hours, or indefinitely with the charger attached.   In addition, a common 9-volt radio battery may be substituted if the battery is drained and there isn't time or power available for recharging it. There is also a low battery indicator on the front panel. This will light up to signal that the battery needs to be recharged or replaced before the low battery condition affects the readings.

The voltage from the battery is regulated to a constant 9.0 volts by the positive regulator. This provides a stable source for the electrometer amplifier and other electronics. Some of the analog and logic chips require a negative voltage in addition to a positive voltage source. The SSP-3 uses a negative voltage converter chip, which delivers a negative voltage at near the same amplitude as the positive input voltage from the battery and uses only a few external components.

The battery does not have sufficient power to operate the unit when the optional motorized filter slider is installed. With this option, the battery and connector are removed from the unit. Power must come from the 12 VDC power supply only.

2.5 SIGNAL PROCESSING

The voltage signal from the electrometer amplifier is processed by the voltage-to-frequency converter to a frequency that is directly proportional to the input voltage. It is extremely linear, resulting in laboratory measured correlation coefficient using a least squares regression of r=0.99995. There is an offset adjustment available with the two-button interface that allows the user to select the output count for zero input light or dark count. It is important to set this to a positive count of around five on the 1 scale with a 1-second integration time. This insures that if the electrometer amplifier drifts slightly, the dark count will still be above 0. If the offset drifts to a negative value, a reading of the dark count will show nothing on the display - the display will be dark.

Gains of 1, 10 and 100 are selectable with the SSP-3. This gain control sets the electrometer voltage that will result in a full-scale input frequency of 10K hertz. On 1, the least sensitive scale, an input of -6.6 volts corresponds to 9999 counts; however, since the highest electrometer output voltage is about -4.0 at saturation, the highest display will be around 6500 counts on this scale. Usually, only zero or first magnitude stars will saturate the electrometer. On the 10 and 100 scales, the electrometer output corresponds to -660 mv and -66 mv respectively. The user can adjust the gain, much in the same way it is done with a DC amplifier/photometer, to keep the signal reading as near as possible to full scale. By doing this, errors due to quantumization become insignificant

An integration or gate time of 1, 5 and 10 seconds is available for the SSP-3 when used in manual mode. For most observations of variable, the 10-second integration time is normally selected. The 1-second integration time is used for setup only. At the conclusion of each integration period, the display will flash briefly indicating that the count has been updated.

Figure 2.6 shows a functional diagram of the signal processing circuit and Figure 2.7 shows the placement of the front panel controls.
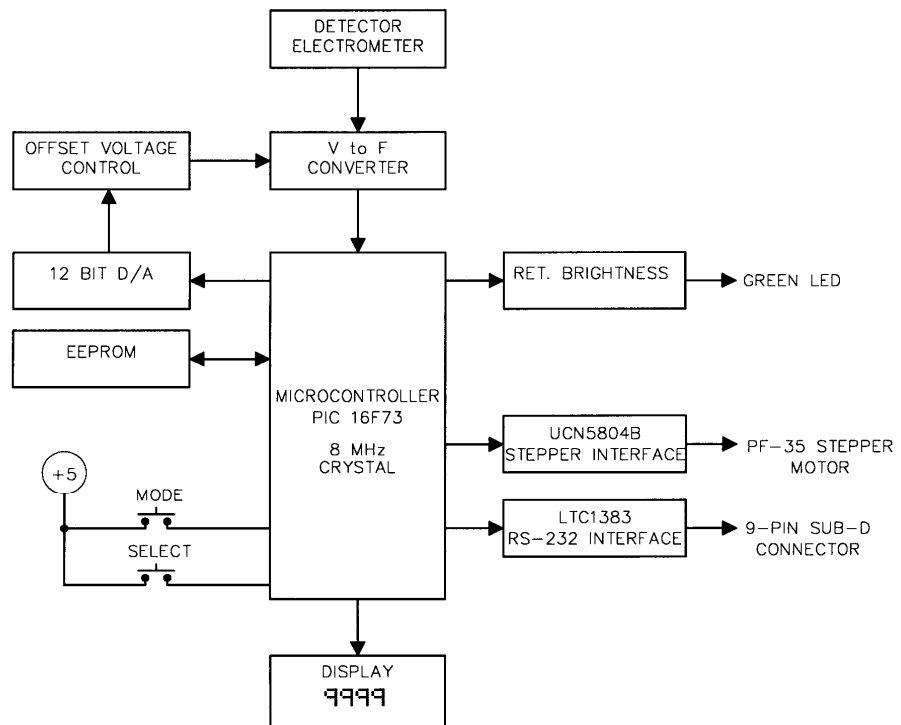
Figure 2-6. Signal Processing Circuit Function Diagram.
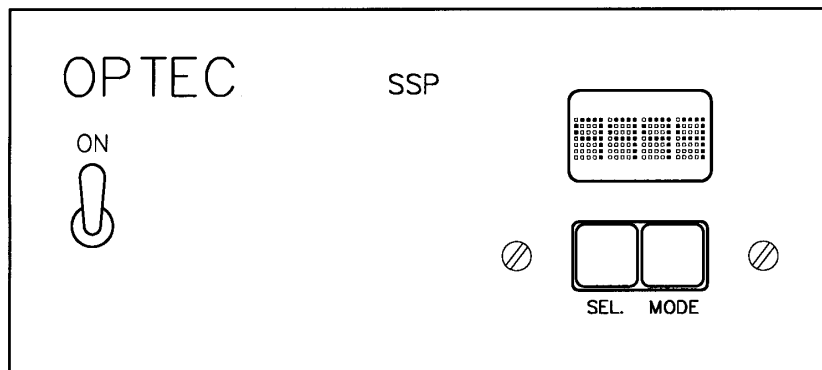
Figure 2-7. Front Control Panel.

2.6 SENSITIVITY

The sensitivity of the model SSP-3 photometer is shown in the graph of Figure 2-8. The data was determined experimentally with a Celestron 11-inch telescope at an air temperature of about 70°F. Readings with the UBVRI and Clear filters were made of the star Zeta Hercules which has a visual magnitude of 2.8 and a spectral type of G. The air mass was determined to be near 1.0. The display output is expressed in counts per second vs. magnitude using the various filters. It should be noted that these are the approximate display counts, and that accurate magnitudes should be determined using the accepted techniques of astronomical photometry,

Each line on the graph represents the approximate relationship between stellar magnitude and counts on the photometer. The B, V and I lines were too close together to show separately and so were drawn as one line for the sake of clarity. The noise counts were determined by taking the sample standard deviation of 10 consecutive readings with the mirror down, no light on the detector, and using the 1 second integration setting (10 seconds total integration time) or the 10 second integration setting (100 seconds total integration time). The noise values shown represent detector and amplifier noise only. The contributions to the noise from scintillation and changes in extinction are not indicated since they are too dependent on observing conditions. Shot noise from the sky and star are insignificant at these levels and can be ignored.

For the sake of comparison when observing dim stars, the intersection of the diagonal UBVRI and CLEAR lines and the horizontal noise lines determine at what magnitude the signal-to-noise ratio is 1 for the 10 and 100 second integration times. For example, to obtain 0.01 magnitude accuracy, a signal to noise ratio of 100 to 1 is needed. Thus, with an 11-inch telescope and 100 seconds of integration time, stars of magnitude 7.0 may be measured to 0.01 magnitude accuracy with the B, V and I filters. Similarly, stars of magnitude of 9.5 could be measured to 0.1 magnitude accuracy.
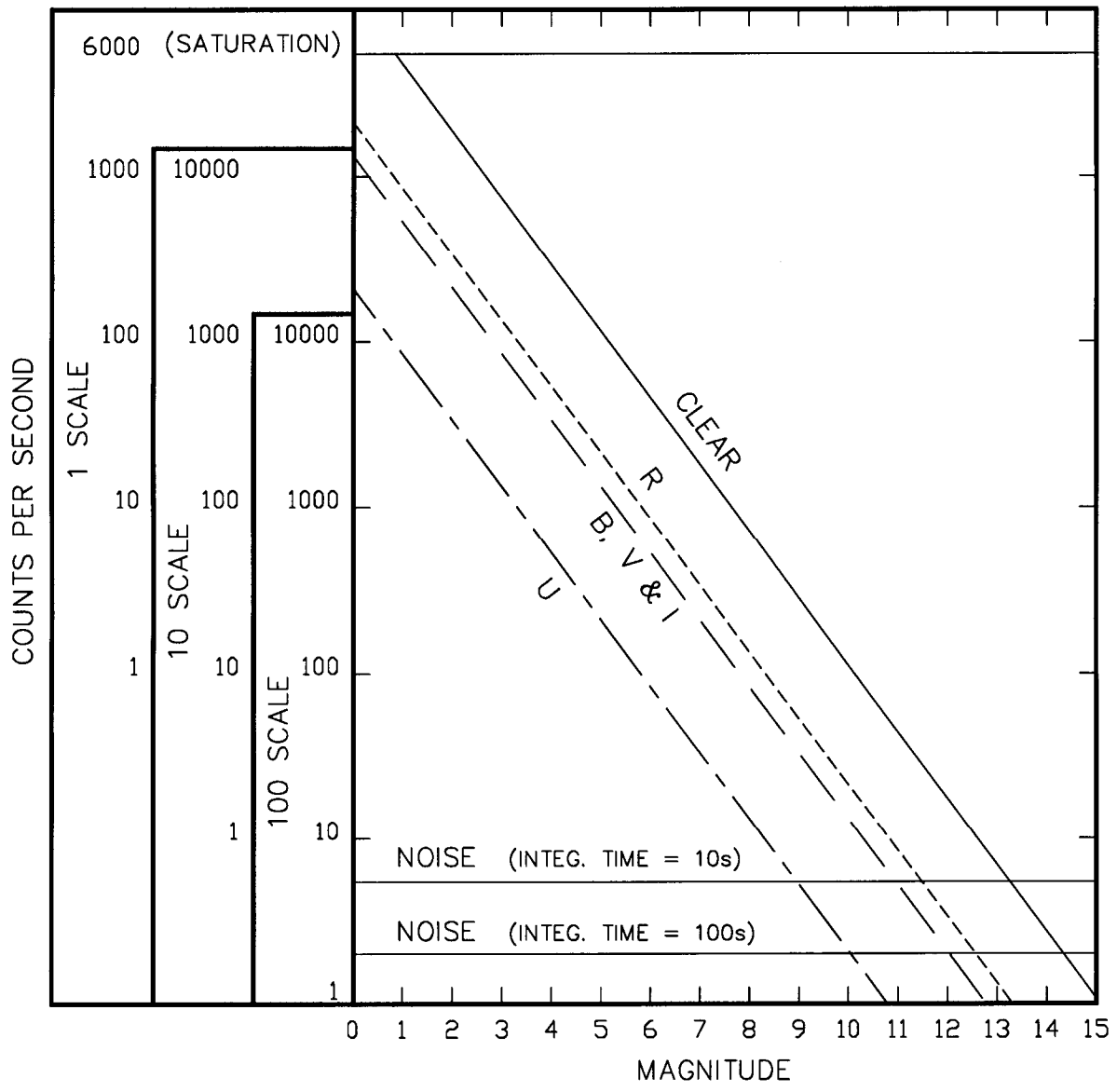
Figure 2-8. Counts per Second vs. Stellar Magnitude. These are Typical Values Obtained with an 11-Inch Aperture Telescope.

13

SECTION 3.0

OPERATING PROCEDURE

3.1 CHECK-OUT LIST

Remove the filter slider and clean filters, only if necessary, with a cotton swab dipped in alcohol or lens cleaning fluid. Do NOT rub hard.

Before taking readings, turn the photometer on and allow at least 10 minutes warm-up time at observatory temperature.

After warm-up, observe that the count with the mirror down (no light on detector) is within the range of 3 to 7 with Gain and Integration set at 1 and 1 second accordingly. If reading is not within this range, adjust the offset as described in section 3.3.

With the U, B and V filters, the common low wattage red lights found in most observatories which provide low level illumination will not affect the reading if some precautions are taken to shield the telescope optics from direct illumination. The R and I filters, on the other hand, allow more than 100 times more light energy from red light to irradiate the detector. Even interior observatory surfaces that are illuminated by the red light and near the front of the telescope will affect the reading. Before taking important readings with the R and I filters, it is recommended that the user experiment with the illumination in his observatory to gauge the effect it has on the count obtained from the SSP-3.

3.2 USING THE PHOTOMETER

With the mirror down, site the star or sky region in the center of the reticle. After confirming that the telescope is tracking properly, carefully flip the mirror up and record the readings.

To change gain and/or integration time, hold the MODE key down until the GAIN is displayed. Pressing the MODE again will show the next option on the menu, which is INTG (integration time in seconds). The other MODE selections after this are OFF (offset adjustment) and RET (reticle lamp brightness). Pressing the SELECT key will allow the user to change the value for GAIN, INTEG, OFF and RET. When the selection is made using the SELECT key press the MODE key and you will see the word DONE displayed. At that point other menu selections can be selected using the MODE key. The last item is RUN which allows the user to exit the selection menu and return to the operating program. When RUN is selected and the menu routine is exited, the display will remain blank until a reading is completed. It takes a little getting use to,

but with practice, the selections can be made very rapidly. There is no way any harm can be done to the instrument by making an improper selection.

The possible selections for GAIN are 1, 10 and 100. The possible selections for INTG are 1, 5 and 10 seconds.

IMPORTANTà In order to enter the serial program loop and use the instrument with SSPDATAQ, it is necessary that PC be selected for INTG.

To take a star or sky brightness measurement, three consecutive readings of 10 seconds integration time (integration set for 10 seconds) each are normally taken. Always ignore the first reading since the mirror can never be flipped up exactly at the beginning of a new 10-second cycle. After seeing the first count displayed, record the next three.

After the reading sequence is completed, return the mirror to the viewing position and confirm that the star is still centered properly in the reticle. Normally, if the star is within a circle of 0.35 radius of the scribed ring center, more than 99% of the star's light has been collected by the detector. This rule of thumb does depend on seeing quality.

At this point, the user has successfully completed making a reading and is referred to other sources of information about stellar photometry.

3.3 CALIBRATION, ADJUSTMENTS, AND BATTERY MAINTENANCE

For precise determination of stellar magnitude, the filters used in the SSP-3 must be calibrated with standard stars. The procedure for doing this is beyond the scope of this manual and the user is referred to the IAPPP and AAVSO organizations and standard texts on photometry. Simple determination of filter correction factors can be made by using a close pair of stars with a wide color temperature difference. This method is used by many users and is recommended for novice users.

The reticle and detector are critically aligned at the factory and the user should make no adjustment. If the eyepiece is removed from its mount it may be necessary to realign the detector, a procedure that will probably have to be done at Optec. If dust on the reticle is troublesome, remove it by blowing air (canned air for camera cleaning is suggested) through the 1.25-inch snout.

If the reticle ring needs to be adjusted in brightness, enter the menu selection by pressing and holding down the MODE key. When GAIN is seen on the display press the MODE key again until RET is displayed. Press the SELECT key and you will see the current brightness setting. The default setting is MED (medium brightness). Press the MODE key to select another brightness. After selecting another brightness setting or if the user wishes to keep the current

setting, press the SELECT key and DONE will be displayed. The user now has the option to pick another menu selection. The RUN selection will return the user to the operating program.

A 9V NiCd radio battery is used to power the unit and is located on the bottom side of the main circuit board. This battery should last for many hundreds of cycles if properly used.

The suggested procedure is to plug in the charger for a period of 12 to 18 hours to fully charge the battery and then use the photometer for a night's observation powered only by the battery. When the battery is nearly discharged, the BAT indicator on the front panel will turn on. At that time, a fresh battery should be installed or the charger plugged in to complete the observation.

A fully charged battery should give about 4 to 5 hours of operating time. Maximum battery life is obtained by using the battery through a full charge and discharge cycle. Alternately, a regular 9V radio battery may be substituted for the NiCd battery to give longer operating time. An alkaline battery has about 5 times the capacity of a NiCd battery, thus 25 hours of total operating time can be expected.

IMPORTANT**à** Make sure the photometer is turned off before the charger is plugged in or a new battery installed.

Offset is adjusted at Optec and should not have to be changed. However, if the instrument is used in an extremely cold or hot climate, the offset may have to be adjusted. Do this adjustment in a dimly lit room with the flip mirror in the down position. Wait at least 10 minutes for the electronics to stabilize. Enter the menu selections by pressing and holding down the MODE key until GAIN is seen on the display. First, select a GAIN of 10 and INTG of 1 before proceeding with the offset adjustment. Press the MODE key repeatedly until OFF is seen on the display. Press the SELECT to show the current offset value. After a couple of seconds, a + and – symbols will appear on the display. To raise the offset, press the key under the + symbol and to lower the offset press the key under the – symbol. If the user delays more than a few seconds to make an adjustment, the display will show DONE and the program will return to the menu selection routine. After pressing the + or – key for making an adjustment, the display will immediately show the new offset which should change by about 3 or 4 counts. The + and – symbol will again be displayed allowing the user another option to adjust the offset. Keep adjusting the offset until a value around 50 is obtained. At that point, stop and wait for the DONE to be displayed. Exit the menu selection routine after the desired INTG and GAIN values are selected.

SECTION 4.0

TROUBLE-SHOOTING GUIDE

The following common problems and solutions have been collected over the years from our customers and our attempts to solve their instrument problems. Before calling us, read through these and relevant sections of this manual to see if an easy solution exists for your errant photometer.

1) **Unit has been turned on and left to warm up for the proper time but a display of 0000 is seen unless light is incident on the detector.**

   Adjust the offset to read 5 with the Gain and Integration time set to 1.

2) **The dark count (no light on the detector) appears to drift with time and temperature beyond what you have been accustomed to.**

   This could be a serious problem if the drift is due to a break in the moisture seal protecting the detector/electrometer assembly. The unit should always be kept in a dry and warm environment when not used. Place the unit in a sealed container with about 4 ounces of activated desiccant for a period of 48 hours. If desiccant is not available, use a 100 watt spot light placed about 2 feet from the unit for a similar length of time. Allow the unit to come to ambient temperature before measuring the drift. If the problem does not disappear or reduce to acceptable levels, it will have to be returned to Optec for repair.

3) **The unit seems to drift and give erratic readings with the I and R filters but appears to work OK with the B and V filters.**

   Read Section 3.1 again. In addition to observatory or nearby incandescent light causing problems, high cirrus clouds not visible with the naked eye or an active aurora can cause havoc in the far red and infrared portions of the spectrum and be invisible in the visible portion.

4) **The unit appears to give much higher than expected counts every once in a while.**

   If the unit is powered by the AC driven power supply, any surge in the power line may cause an increase in the number of counts for the integration interval. Refrigerator compressors, dome motors, and telescope position servos could easily be the cause of this problem. The best solution is to use the unit with the battery alone. If observations longer that 4-5 hours need to be done, use a regular 9 volt alkaline radio battery instead of the NiCd battery. This type of battery will power the unit for about 25 hours. Vibration and strong radio signals may also be the cause of the problem.

   In the case of the SSP-3a which must use the external power supply, plug the power supply into a power strip that has surge protection with EMI/RFI filtering. This product should be available at any computer or electronics store.

5) **The night appears clear but the star count is diminishing with time faster than expected due to changing extinction conditions.**

A common problem especially with Celestron and Meade telescopes is that a nearly invisible film of condensed water will develop on the corrector plate or main mirror during the night if the dew point is high enough. Usually this fog film can only be seen when a strong light is projected down the front of the telescope and the optics carefully inspected. A hair dryer is the only cure. "Dew-zappers", low wattage heaters designed to fit over the front cell, are now commonly available to avoid this condensation problem.

6) **As the star approaches the edge of the detector the count begins to fall but it looks as if the star is still completely within the ring as seen in the eyepiece.**

The stellar light profile (energy vs. radius from the center of the star) is much larger than what is seen. On a good night a seeing disk could appear to be about 2 arc second in diameter. However, to capture over 99% of the energy a detector diameter (field aperture) of over 20 arc seconds is needed. A hazy night or a night with much greater turbulence could increase the stellar profile many more times. Thus, care must be taken to keep the star from drifting near the edge of the detector since some of the incident energy will be lost.

SECTION 5.0

SPECIFICATIONS

DETECTOR
Type   Silicon PN-photodiode

NEP 8×10^{-16} W/$\sqrt{Hz}$ (typical)

Detector Size — 1.3mm square (2.4mm square optional)
Spectral Range (5% points) — 300 to 1100 nm
Shunt Resistance — 50 G Ω (typical)
Surface Uniformity — <1%

ELECTROMETER
Type — Current-to-Voltage
Bias Current — .15 pA Max.
Offset Voltage — <.25 mV
Open Loop Gain — 100000 V/V Min.
Closed Loop Gain (Rf) — 5×10^{10}
Input Voltage Noise — 4 μV(p-p) (.1 to 10Hz)
Input Current Noise — .003 pAAAA(.1 to 10Hz)
Maximum Output Voltage — 6 V

A/D CONVERTER
Type — Voltage-to-Frequency
Full Scale Frequency — 10 Khz
Full Scale Input Voltages — -66 mV (100 SCALE)
-660 mV(10 SCALE)
-6.6 V (1 SCALE)
Linearity — <0.3%
Offset — <.5mV (adjustable to 0)

CONTROLLER/DISPLAY
Microcontroller — 16F73 from Microchip
Oscillator — 8.0000 MHz
Timer Accuracy — +/-25ppm at 25°C
Display — 4-character 5x7 matrix
Character Height/Color — .11 inch - Red

POWER SUPPLY
Battery — 9 volt NiCd (Type GE GC9 or Gould GS9T)
Operating Time — 4 hours at 65°F
3 hours at 20°F
Capacity — 100 mA hours
Recharge Time — 12 to 18 hours
12 VDC Power Supply — 12 volts DC regulated - 1000 mA

EYEPIECE
Focal Length — 25 mm
Type — Ramsden
Reticle Illumination — Green LED
Field of View (80 inch FL) — 0.4 degrees

MECHANICAL
Body Material — Aluminum 6061-T6 alloy
Finish — Bright Dip Black Anodized
Overall Length — 9 inches (tip to tip)
Weight — 2 lbs. 14 oz.
Telescope Coupler — 1.25 inch (standard)

SECTION 6.0

JOHNSON UBVRI FILTERS

The UBVRI filter system established by Johnson is generally followed today and exactly defines color bands in the spectrum interval from 300 to 1200 nm. Table 6-2 lists the filter-detector responses of this system as originally established by Johnson. Filter-detector response is defined as the normalized product of filter transmission times detector response for each wavelength interval. Table 6-3 lists the filter-detector responses for the filters used with the SSP-3.

The OPTEC UBVRI filters are all made from combinations of Schott and Hoya colored glass. The glass types and thicknesses for each filter has been computer optimized for the best fit with the Johnson standards. The exact glass formulas are proprietary but complete filters can be purchased separate from the photometer for those persons constructing their own solid-state photometer.

As can be seen from Tables 6-2 and 6-3, the B, V, R and I filters match closely the standard Johnson values and give correspondingly small correction coefficients. Blocking the red leak of the glass used in the U filter results in loss of UV transmission from 300 to 350 nm. The filter is still useful for comparison purposes even though it does not transform into the standard Johnson system precisely. It is interesting to note that the U filter is the most difficult one to transform accurately for all observers including those with photomultiplier systems. UV transmission through the atmosphere varies considerably and any optical glass in the telescope (corrector lens) or photometer will absorb light shorter than 350 nm making accurate U magnitude determinations difficult at best.

For those persons interested in the exact filter transmission and detector responsivity, Table 6-4 has been prepared using the latest filter and detector batch data. Filter characteristics are subject to change since we continually review our filter formulas and attempt to achieve near zero transformation coefficients.

Flatness	6 fringes maximum
Surface Quality	scratch and dig 80-50
Diameter	12.7 mm
Thickness	7 mm

Table 6-1. Physical Characteristics of Optec UBVRI Filters.

nm	U	B	V	R	I
300	0.00	-----	-----	-----	-----
310	0.10	-----	-----	-----	-----
320	0.61	-----	-----	-----	-----
330	0.84	-----	-----	-----	-----
340	0.93	-----	-----	-----	-----
350	0.97	-----	-----	-----	-----
360	1.00	0.00	-----	-----	-----
370	0.97	-----	-----	-----	-----
380	0.73	0.11	-----	-----	-----
390	0.36	-----	-----	-----	-----
400	0.05	0.92	-----	-----	-----
410	0.01	-----	-----	-----	-----
420	0.00	1.00	-----	-----	-----
440	-----	0.94	-----	-----	-----
460	-----	0.79	0.00	-----	-----
480	-----	0.58	0.02	-----	-----
500	-----	0.36	0.38	-----	-----
520	-----	0.15	0.91	0.00	-----
540	-----	0.04	0.98	0.06	-----
560	-----	0.00	0.72	0.28	-----
580	-----	-----	0.62	0.50	-----
600	-----	-----	0.40	0.69	-----
620	-----	-----	0.20	0.79	-----
640	-----	-----	0.08	0.88	-----
660	-----	-----	0.02	0.94	-----
680	-----	-----	0.01	0.98	0.00
700	-----	-----	0.01	1.00	0.01
720	-----	-----	0.01	0.94	0.17
740	-----	-----	0.00	0.85	0.36
760	-----	-----	-----	0.73	0.56
780	-----	-----	-----	0.57	0.76
800	-----	-----	-----	0.42	0.96
820	-----	-----	-----	0.31	0.98
840	-----	-----	-----	0.17	0.99
860	-----	-----	-----	0.11	1.00
880	-----	-----	-----	0.06	0.98
900	-----	-----	-----	0.04	0.93
920	-----	-----	-----	0.02	0.84
940	-----	-----	-----	0.01	0.71
960	-----	-----	-----	0.00	0.58
980	-----	-----	-----	-----	0.47
1000	-----	-----	-----	-----	0.36
1020	-----	-----	-----	-----	0.28
1040	-----	-----	-----	-----	0.20
1060	-----	-----	-----	-----	0.15
1080	-----	-----	-----	-----	0.10
1100	-----	-----	-----	-----	0.08
1120	-----	-----	-----	-----	0.05
1140	-----	-----	-----	-----	0.03

Table 6-2. Standard UBVRI Response Functions According to Johnson.

nm	U	B	V	R	I
300	0.00	-----	-----	-----	-----
310	0.00	-----	-----	-----	-----
320	0.00	-----	-----	-----	-----
330	0.05	-----	-----	-----	-----
340	0.28	-----	-----	-----	-----
350	0.58	-----	-----	-----	-----
360	0.86	0.01	-----	-----	-----
370	1.00	0.10	-----	-----	-----
380	0.83	0.29	-----	-----	-----
390	0.37	0.48	-----	-----	-----
400	0.04	0.66	-----	-----	-----
410	0.00	0.77	-----	-----	-----
420	0.00	0.88	-----	-----	-----
440	-----	1.00	-----	-----	-----
460	-----	0.98	0.00	-----	-----
480	-----	0.87	0.01	-----	-----
500	-----	0.27	0.62	-----	-----
520	-----	0.05	0.95	0.00	-----
540	-----	0.01	1.00	0.08	-----
560	-----	0.01	0.88	0.53	-----
580	-----	0.00	0.62	0.75	-----
600	-----	-----	0.32	0.91	-----
620	-----	-----	0.14	0.98	-----
640	-----	-----	0.04	1.00	-----
660	-----	-----	0.01	0.97	-----
680	-----	-----	0.00	0.86	0.00
700	-----	-----	0.00	0.74	0.00
720	-----	-----	-----	0.64	0.24
740	-----	-----	-----	0.52	0.50
760	-----	-----	-----	0.44	0.86
780	-----	-----	-----	0.36	0.91
800	-----	-----	-----	0.28	0.96
820	-----	-----	-----	0.23	0.98
840	-----	-----	-----	0.18	0.99
860	-----	-----	-----	0.13	0.99
880	-----	-----	-----	0.10	1.00
900	-----	-----	-----	0.07	0.99
920	-----	-----	-----	0.05	0.98
940	-----	-----	-----	0.03	0.96
960	-----	-----	-----	0.02	0.90
980	-----	-----	-----	0.02	0.76
1000	-----	-----	-----	0.01	0.61
1020	-----	-----	-----	0.00	0.45
1040	-----	-----	-----	-----	0.31
1060	-----	-----	-----	-----	0.21
1080	-----	-----	-----	-----	0.12
1100	-----	-----	-----	-----	0.03
1120	-----	-----	-----	-----	0.01
1140	-----	-----	-----	-----	0.00

Table 6-3. UBVRI Response Functions of Filters Used in the SSP-3.

nm	U	B	V	R	I	DET. A/W
300	0.00	-----	-----	-----	-----	0.030
310	0.00	-----	-----	-----	-----	0.045
320	0.00	-----	-----	-----	-----	0.065
330	0.05	-----	-----	-----	-----	0.080
340	0.20	-----	-----	-----	-----	0.115
350	0.37	0.00	-----	-----	-----	0.130
360	0.46	0.01	-----	-----	-----	0.150
370	0.50	0.08	-----	-----	-----	0.160
380	0.41	0.24	-----	-----	-----	0.165
390	0.17	0.37	-----	-----	-----	0.175
400	0.00	0.48	-----	-----	-----	0.185
410	-----	0.54	-----	-----	-----	0.190
420	-----	0.60	-----	-----	-----	0.200
440	-----	0.63	-----	-----	-----	0.215
460	-----	0.58	-----	-----	-----	0.230
480	-----	0.35	0.01	-----	-----	0.245
500	-----	0.13	0.53	-----	-----	0.265
520	-----	0.02	0.76	-----	-----	0.280
540	-----	0.01	0.75	0.07	-----	0.300
560	-----	0.00	0.62	0.47	-----	0.320
580	-----	0.00	0.42	0.63	-----	0.335
600	-----	-----	0.20	0.71	-----	0.355
620	-----	-----	0.09	0.74	-----	0.370
640	-----	-----	0.02	0.72	-----	0.385
660	-----	-----	0.00	0.68	-----	0.400
680	-----	-----	0.00	0.59	-----	0.410
700	-----	-----	0.00	0.49	-----	0.420
720	-----	-----	-----	0.40	0.28	0.440
740	-----	-----	-----	0.32	0.79	0.455
760	-----	-----	-----	0.26	0.91	0.470
780	-----	-----	-----	0.21	0.93	0.485
800	-----	-----	-----	0.15	0.93	0.500
820	-----	-----	-----	0.11	0.93	0.510
840	-----	-----	-----	0.08	0.93	0.515
860	-----	-----	-----	0.06	0.93	0.525
880	-----	-----	-----	0.05	0.93	0.540
900	-----	-----	-----	0.03	0.91	0.550
920	-----	-----	-----	0.02	0.88	0.560
940	-----	-----	-----	0.01	0.86	0.565
960	-----	-----	-----	0.01	0.81	0.560
980	-----	-----	-----	0.01	0.77	0.505
1000	-----	-----	-----	0.01	0.70	0.430
1020	-----	-----	-----	-----	0.63	0.355
1040	-----	-----	-----	-----	0.58	0.270
1060	-----	-----	-----	-----	0.52	0.205
1080	-----	-----	-----	-----	0.44	0.140
1100	-----	-----	-----	-----	0.36	0.080
1120	-----	-----	-----	-----	0.30	0.040
1140	-----	-----	-----	-----	0.23	0.010

Table 6-4. Filter Transmission and Detector Responsivity in A/W

SECTION 7.0

WING FILTERS
(Discontinued –no longer available)

With the cooperation of Dr. Robert F. Wing of Ohio State University, Optec has designed three filters for the SSP-3 photometer which are useful in measuring the absorption of TiO (titanium oxide), and the true color temperature of late type stars such as Miras. These three filters labeled MA, MB and MI comprise a subset of the Wing 8-color system[1]. See Table 7.1 for filter specifications.

It is widely known that the B-V color index of stars with spectral type K5 to M8 is nearly constant although the surface temperature of stars in this range varies considerably. The cooler the surface temperature of these stars the greater the TiO absorption in the visual band, which prevents the color index from becoming redder. As a result, the common B and V magnitude contain little useful information about these stars.

Used together, the MA and MB filters measure the amount of TiO absorption in the star's outer atmosphere. The MA filter is centered on an absorption band at 712 nm and the MB filter is centered just off the band and on the continuum at 754 nm. The ratio of readings taken with these filters is proportional to the amount of TiO absorption.

The MI filter is centered on the continuum at 1025 nm. Readings taken with this filter and the MB filter can be used together to measure the slope of blackbody curve between these two points, and thus the temperature of the star may be calculated.

Because these stars radiate most of their energy in the infrared and the SSP-3 is exceptionally sensitive for part of this band, very high instrument readings are obtained with these filters when only marginal readings are obtained in the B and V bands. In addition, the amount of background light from the atmosphere due to scatter from the moon or ground lights is nearly unmeasurable at these wavelengths which allows useful work to be done even when B and V photometry is impossible due to high sky readings.

FILTER NAME	CENTER WAVELENGTH	BANDPASS 1/2T POINTS	PEAK TRANSMISSION
MA	712 nm	10 nm	75 %
MB	754 nm	10 nm	75 %
MI	1025 nm	40 nm	55 %

Table 7-1. Specifications for Wing Filters.

1 Wing, R. F., 1971, *Proceedings of the Conference on Late Type Stars*, ed. G. W. Lockwood and H. M. Dyck (KPNO Contribution No. 554), p. 145.

Appendix A

MOTORIZED FILTER BAR OPTION

A motorized filter slider option can be added to the SSP-3 to make it an SSP-3a. This allows the SSPDATAQ program to select filters under program control. A Nippon model PF35 stepper motor is added to the instrument to operate the filter slider. The slider can hold up to six of the 1/2" diameter filters in any order the user wishes. Filters must be mounted by Optec since it involves sealing the filters in place with an RTV compound. Filters can be removed if necessary.

The filter slider is first HOMED by moving the slider a sufficient number of steps in one direction until the slider bottoms out on the filter cover; this defines filter position one. From that position, the other 5 positions can be found by moving the slider the appropriate number of steps. Each filter position is 33 steps apart. Approximate time to move from one filter to the next is 0.5 seconds. A UCN5804B driver chip is used to interface to the stepper motor.

Number of Phases	4
Step Angle (full step)	7.5 degrees
Steps per Revolution	48
Holding Torque	2.8 oz.-in.
Operating Temperature Range	-15 to +50°C
DC Operating Voltage	12 volts
Resistance per Winding	70 Ω

Table A-1. Specifications for Model PF35-48C Stepper Motor from Nippon.

Appendix B

DETERMINATION OF FIELD APERTURE ANGULAR SIZE

The SSP-3 and SSP-5 photometers offer a fixed aperture that must be selected at initial purchase. In most instances the standard field aperture of 1mm diameter is best suited. However, 0.5mm, 0.75mm and 2mm field apertures are also offered optionally.

To determine the angular size of each field aperture with a particular telescope, refer to Table B-1 below. Remember that even though the seeing disk of a star may appear as small as 2 arc seconds, the stellar profile may be many times larger. A good rule of thumb is to ensure the star's image remains within the central 70% of the field aperture to ensure that 99% of the stellar energy falls upon the detector. The reader is referred to section 9.4 of *Astronomical Photometry* by Henden & Kaitchuck (Optec stock no. 17330) for a full discussion of diaphragm selection and stellar profiles.

Another important consideration in selecting an aperture size is the accuracy of the telescope mounting system. Periodic errors (as well as erratic errors) can cause the star to drift within the field. Your aperture must be large enough to ensure that the star remains within the center of the detector field of view for the duration of the photometer integration period, typically 10 to 60 seconds.

TELESCOPE FOCAL	DETECTOR APERTURE SIZE			
(Common Configurations)	0.5mm	0.75mm	1.0mm	2.0mm
1280 mm (8 inch f/6.3)	81"	121"	161"	322"
1600 mm (10 inch f/6.3)	64"	97"	129"	258"
2000 mm (17½ inch f/4.5)	52"	77"	103"	206"
2032 mm (8 inch f/10)	51"	76"	101"	203"
2540 mm (10 inch f/10)	41"	61"	81"	162"
2794 mm (11 inch f/10)	37"	55"	74"	148"
3912 mm (14 inch f/11)	26"	40"	53"	105"

Table B-1. Angular Size of Common Telescope/Aperture Combinations in Arc-seconds.

Appendix C

SSP-3 WIRING DIAGRAM

STEPPER MOTOR OPTION
PF35-48
PN1962

T-1 GREEN LED
PN2320

RETICLE   WHITE   26 AWG
GND   BLACK   26 AWG

YELLOW
ORANGE
BROWN
BLACK
RED + RED

JP7

MAIN CIRCUIT BOARD 17-03051

JP3

-9VDC BLUE   26 AWG
+9VDC RED   26 AWG
SIG.   YELLOW   26 AWG
AGND   GREEN   22 AWG
PULSE   GRAY   26 AWG

JP1

JP2

JP4

INSTALL UCN5804B IF
STEPPER MOTOR OPTION
IS INCLUDED

TX   BLUE   26 AWG
GND   GREEN   26 AWG
RX   WHITE   26 AWG

SUB-D 9-PIN MALE
PN 3491

9V BATTERY CLIP
PN1934
(NOT USED IF STEPPER MOTOR OPTION IS INCLUDED)

+9VDC RED
RETURN BLACK

2.5MM DC POWER JACK
PN3143   CENTER TAB TERMINAL
+5   ORANGE   22 AWG
RETURN BLACK   22AWG
CUT SWITCHED TAB TERMINAL

RCA PHONO JACK, GOLD
PN1648

OPTEC, Inc.

SSP-3 WIRING
FOR 17-03051 BOARD

NO: 17-03053

SCALE:

CONTRACT
SSP-3, VER 2003

REVISION
9/2/2003
1/5/2004

C-2

Appendix D

SAMPLE DATA ENTRY FORM

The sample report form printed on the next page is useful for recording data when using the differential photometry technique. Basically, this method is to compare the brightness of the variable star to that of a nearby comparison star which is known to have no variability. No attempt is made here to educate the user in all aspects of proper observing procedure and the associated data reduction. A number of texts about astronomical photometry are available which describe the proper methodology.

Figure C-1 shows an observing report for the night of September 18-19, 1984, of Nova Vulpecula and the comparison star HD182618. Observations were made with the V filter using an 11 inch aperture telescope.

VAR..___NOVA_____   DOUBLE DATE ___Sept. 18-19, 1984__

COMP.____ HD 182618_____   PAGE _____ OF _____

OBSERVER __J.P. _____   NOTES _____

TELESCOPE _____C-11_____   _____

CONDITIONS_____GOOD_____   _____

UT	STAR	FILTER	SCALE	TIME	COUNT	SKY	COMMENTS
1::21	COMP	V	10	10	894	402	
					891	402	
					594	401	
1:24	NOVA	V	10	10	509		
					507		
					510		
1.:29	COMP	V	10	10	881		
					880		
					877		
					.		
					.		
					.		

Figure C-1. Sample Data Entry Using the Report Form.

VAR _____   DOUBLE DATE _____

COMP._____   PAGE _____ OF_____

OBSERVER_____   NOTES_____

TELESCOPE_____   _____

CONDITIONS_____   _____

UT	STAR	FILTER	SCALE	TIME	COUNT	SKY	COMMENTS

Appendix E

SSP FIRMWARE COMMANDS

```
'========serial mode commands
'
'                19.2K baud, no parity, inverted, always driven
'
'                n    is any real integer 0 <= n <= 9
'                x    is any character
'                LF   is a line feed character, decimal 10, hex A
'                CR   is a carriage return character, decimal 13, hex D
'                "!"  is the exclamation character, decimal 33, hex 21
'
'    SSMODE      if in manual mode, this command will initate the serial loop mode and
'                only serial commands will control the instrument
'                after the serial loop mode is entered, a "!" LF CR is sent on the
'                serial port to acknowledge the mode change
'                if the instrument is already in the serial loop mode, the
'                acknowledgement code is sent again, "!" LF CR to confrim that the
'                instrument is in the serial loop mode
'
'    SGAINn      sets gain of instrument of preamp stage. n can be 1, 2 or 3 only
'                1 = gain of 100, 2 = gain of 10, 3 = gain of 100
'                "!" LF CR is returned on serial port to acknowledge command
'
'    SInnnn      sets integration time in units of 0.01 seconds. 0001 <= nnnn <= 9999
'                    "!" LF CR is returned on serial port to acknowledge command
'
'    SCOUNT      start a reading with selected gain and integration time.
'                after the count is completed, the results are displayed on the
'                instrument and sent on the serial port in the following format:
'                C=nnnnn LF CR, where 00000 <= nnnnn <= 65535, leading zeros are sent
'
'    SMnnnn      initiate a fast reading cycle with selected gain and integration time.
'                nnnn is the number of readings to do, 0000 <= nnnn <= 9999, leading
'                zeros must be added for number to be correct
'                after each reading is done the value is sent on the serial in the
'                following format: nnnn LF CR where 0000 <= nnnn <= 9999
'                the fast mode sequence can be interrupted by sending a SS
'                once the fast mode is successfully stoped, a "!" LF CR is sent
'
'    SFILTn      if the auto filter option is available on the instrument, the filter
'                number can be selected. n can be 1, 2, 3, 4, 5 or 6 only.
'                once the filter move is complete a "!" LF CR is sent
'
'    SHOMEx      if the auto filter option is available on the instrument, this command
'                 makes the filter slider find position 1 and  stay there.
'                once the filter move is complete a "!" LF CR is sent
'
'    SENDxx      exits the serial loop mode and returns to manual mode.
'                before leaving the serial loop mode, an "END" LF CR is sent
'
'========serial error messages
'
'  "ER=1" LF CR   low battery voltage condition is sent at any time that the
'                 instrument detects a low voltage on the battery - SSP-3 only
'
'  "ER=2" LF CR   high voltage has shut down because of object to bright - SSP-5 only
```