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The SSP-3 Photometer

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I. INTRODUCTION

From computers to televisions, electronic instruments of all types are becoming better, smaller, and more user-friendly. It is to be expected that the same should happen to photometers used for astronomy. With the introduction in August 1982 of the SSP-3 Solid-State Photometer at the Astronomical League Convention in Peoria, Illinois, a new and radically different stellar photometer was made available to amateur and small observatory astronomers. Figure 1 shows the SSP-3 photometer attached to a Celestron C-8 telescope. The SSP-3 photometer is low in cost, which makes it affordable to those on a limited budget; moreover, it has the high sensitivity, stability, and accuracy needed for serious research. Its simplified controls and portability make accurate measurements of stellar magnitude routine and shift the causes of error from the instrument to the observing techniques and atmospheric conditions. A schematic diagram of the complete SSP-3 system is shown in Figure 2.

II. BASIC PHYSICAL CHARACTERISTICS

Figure 3 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.

A two-position filter slider is mounted between the flip mirror and the detector. Any pair of UBVRI 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. Unless specified otherwise, a slider with the B and V filters is included with the SSP-3 as standard.

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 which is placed on top of the photodiode. Sizes of 0.5, 0.75, 1.0 and 2.0 mm are available, with

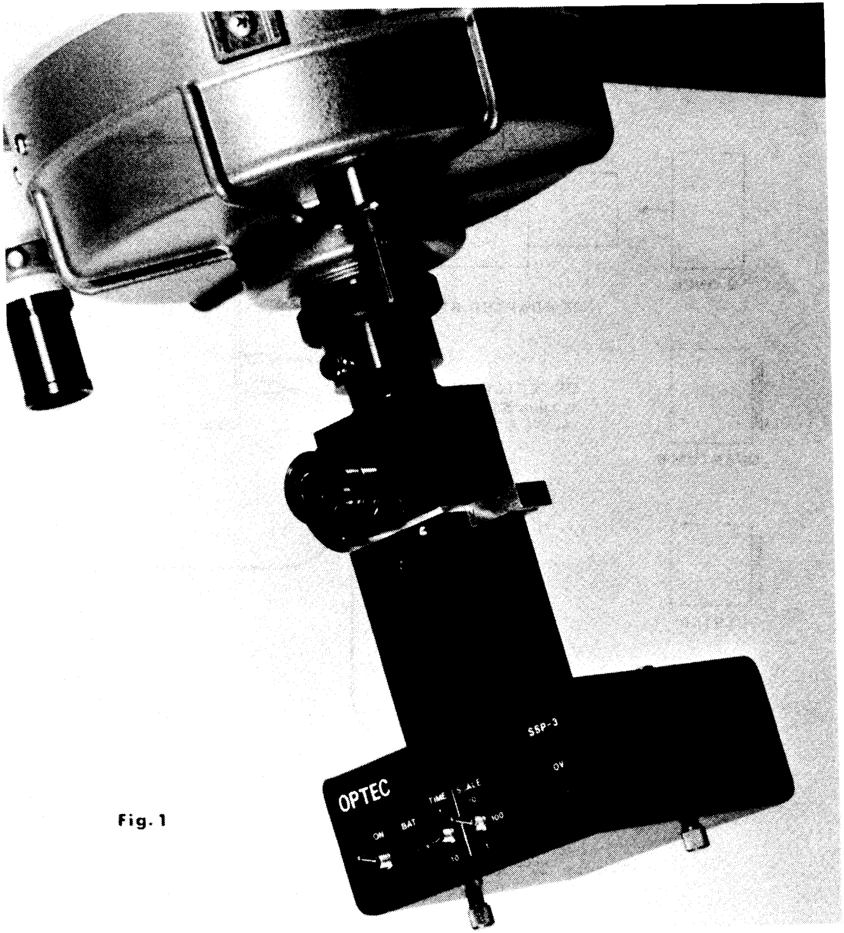

Fig. 1

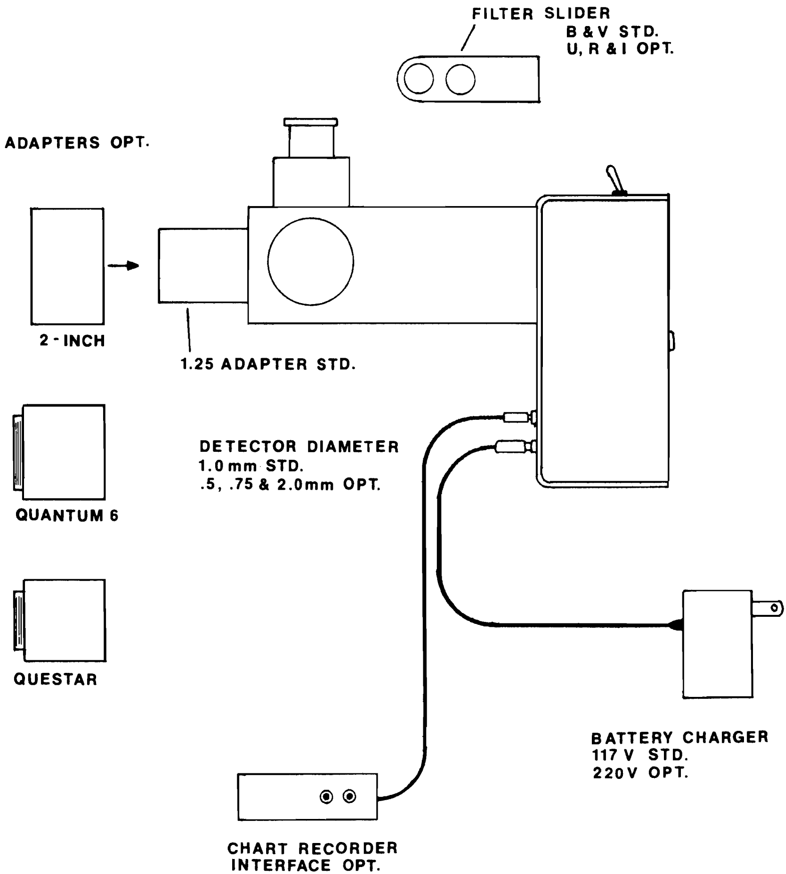

Figure 2. The SSP-3 Photometer System.

the 1.0 mm size considered best for most telescopes with focal lengths in range of 50 to 150 inches and therefore supplied in the standard package.

The electrometer amplifies the current from the photodiode by a factor of 5×10^{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 1 and 10 second gate time intervals.

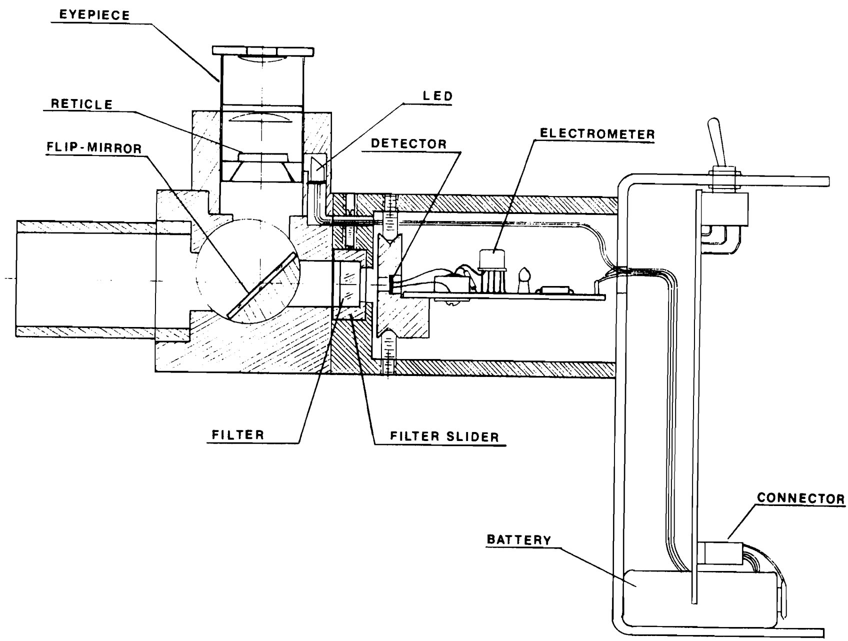

Fig. 3. Cross-sectional view.

III. DETECTOR/ELECTROMETER DESIGN

The wide spectral response of the silicon PIN-photodiode is a unique advantage of this photometer. Figure 4 displays a typical spectral response having a peak responsivity of 0.5 A/W at 850 nm.

Recently available from Hamamatsu, the new silicon PIN-photodiode detector used in the SSP-3 functions in the photovoltaic mode and features an NEP (Noise Equivalent Power) of typically 8×10^{-16} W/Hz and an incredible shunt resistance of 50 G Ohms. These characteristics are at least an order of magnitude better than the EG & G-040 detectors which were used in SSP-2 photometers delivered between January 1980 and May 1982. NEP and shunt resistance for the EG & G detector were typically 1×10^{-14} W/Hz and 2.5 G Ohms, respectively. The EG & G detector was considered the best available at that time.

To better understand the significance of these numbers, the basic principles of the detector-electrometer circuit must first be discussed. Figure 5 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 flowing in the opposite direction so that the inverting input is near 0 potential. The output voltage is thus

$$E_{out} = R_f \times I_s \, , \tag{1}$$

where R_f is equal to 50 G Ohm for the SSP-3.

In an "ideal" op-amp, this simple equation would describe the output completely and stars to the sky limit could be measured. Unfortunately, a variety of voltage and current error sources reduce the sensitivity and make E_{out} far more difficult to define.

Table I shows the major error sources for this amplifier configuration. The offset voltage (E_{os}), offset voltage drift (E_{osd}), input voltage noise (E_{na}), offset bias current (I_b), input bias current drift (I_{bd}), and bias current noise (I_{na}) are all related to electrometer errors. Photodiode noise current (I_{nd}) relates to the error contribution of the detector.

In Figure 6 the current-to-voltage amplifier is shown as an equivalent circuit, which makes it easier to visualize the dependency of E_{out} on the various error sources. R_s is then called the dynamic shunt resistance and is related physically to the purity of the silicon used in the detector fabrication. The quality of a silicon photodiode in terms of noise performance and response linearity is directly related to the magnitude of the shunt resistance. Also, input voltage drift and noise due to the electrometer amplifier are enhanced by small shunt resistance values. The following equation describes the relationship of E_{out} to the signal, error voltages, and error currents:

$$E_{out} = \underbrace{R_f I_s}_{\text{signal}} + \underbrace{R_f\left(I_b + \frac{E_{os}}{R_s /\!/ R_f}\right)}_{\text{offset terms}} + \underbrace{R_f\left(I_{bd} + \frac{E_{osd}}{R_s /\!/ R_f}\right)}_{\text{drift terms}} + \underbrace{R_f\left(I_{nd}^2 + I_{na}^2 + \left(\frac{E_{na}}{R_s /\!/ R_f}\right)^2\right)^{1/2}}_{\text{noise terms}} . \tag{2}$$

As can be seen in equation (2), small values of R_s inflate the last term in each set of

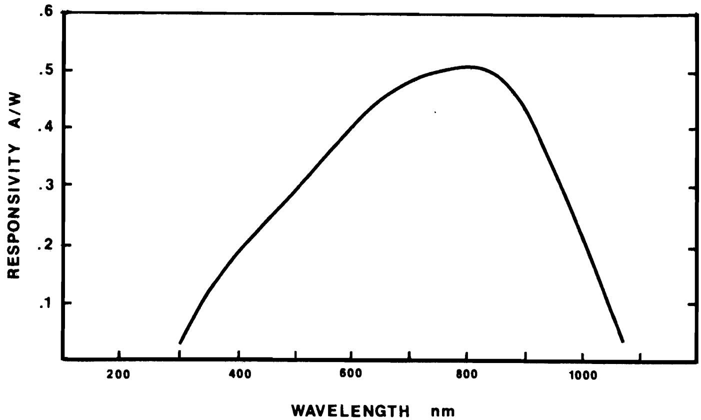

Figure 4. Spectral response of the photodiode detector.

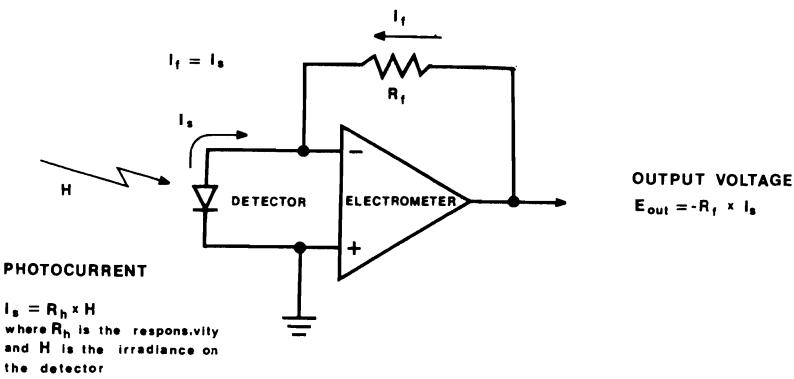

Figure 5. Current-to-voltage amplifier configuration.

TABLE I

Error Terms for the Current-to-Voltage Amplifier

DETECTOR	ELECTROMETER
I_s Photocurrent	E_{os} Offset Voltage
I_{nd} Noise Current	E_{osd} Offset Voltage Drift with T^{o}
	E_{na} Input Voltage Noise
	I_b Offset Bias Current
	I_{bd} Offset Bias Current Drift
	I_{na} Bias Current Noise

parentheses. With the new detector, R_s is now approximately equal to R_f and the effect of this term is minimized. Compared to the old detector, this term is now about 1/5 of what it was. Overall, E_{out} due to temperature drift is about 1/4 of the previous value and total noise has been reduced to less than 1/2.

IV. 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 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 some other rechargeable battery. These objectives were all achieved with the power supply design shown in Figure 7.

The first block represents the Battery Charger, which is similar in design and appearance to the common calculator charger. It 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 Power Plug jack to connect the charger.

The second part of the supply consists of a 9-volt NiCd rechargeable battery available from General Electric as model GC9. This battery can be purchased from any well-equipped hardware or department store for under $10.00. One battery is supplied with the unit when purchased.

The battery can be used alone for at least five hours, or indefinitely with the charger attached. In addition, a common 9-volt radio battery can be substituted if the battery is drained and there isn't time or any power for recharging it. There is also a low-battery indicator, on the front panel. This will light a 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 5.3 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. In previous designs this was a problem that could be solved economically only by using a second battery. Today a much better solution is available with an ICL7660, which is a negative voltage converter IC available only recently from Intersil. The ICL7660 delivers a negative voltage at the same level as the positive input voltage with only a few external components. This voltage is then regulated at -5.3 volts to provide a stable negative supply.

V. SIGNAL PROCESSING

The signal processed by the voltage-to-frequency chip is converted to a frequency that is directly proportional to the input voltage. It is extremely linear, resulting in a laboratory measured correlation coefficient, based on least squares regression, of

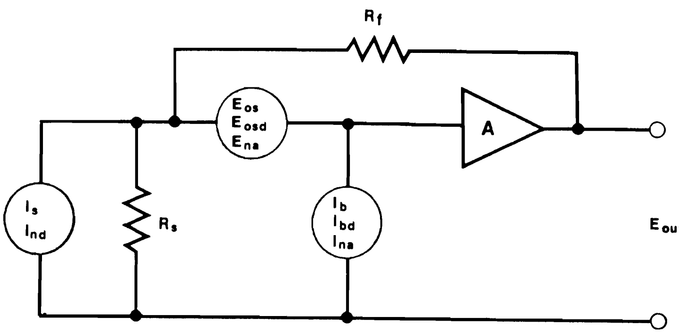

Figure 6. Current-to-voltage amplifier equivalent circuit.

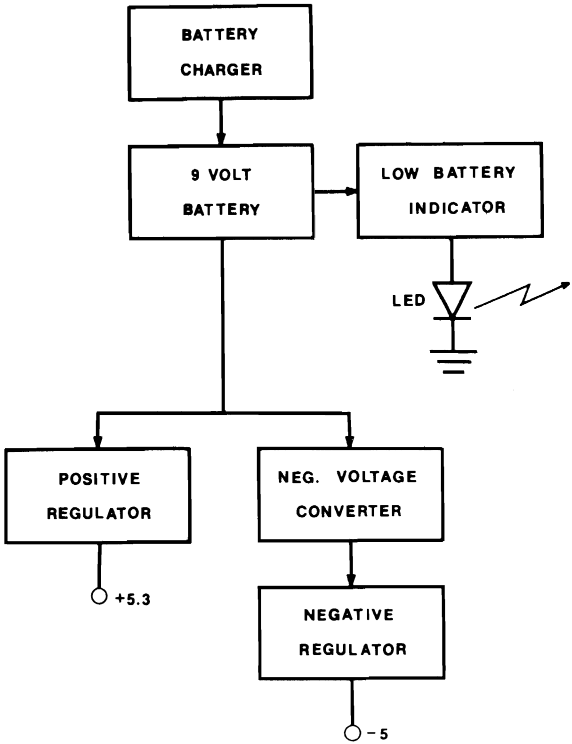

Figure 7. Power supply function diagram.

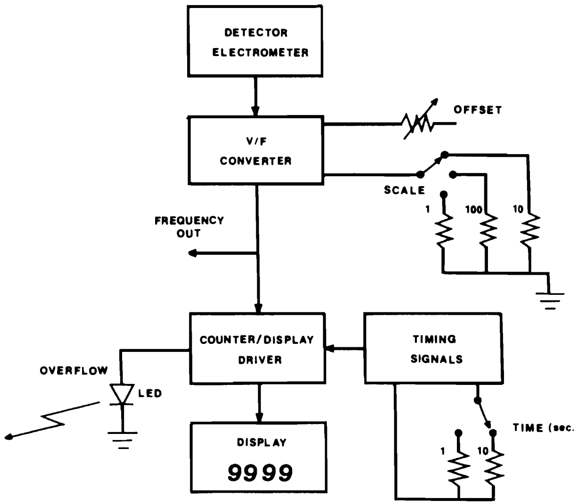

Figure 8. Signal processing circuit function diagram.

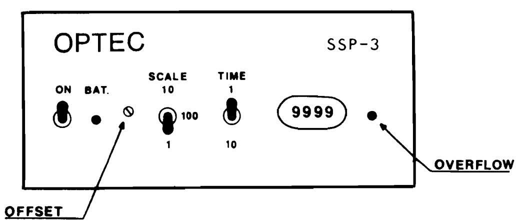

Figure 9. Front control panel.

r=0.99995. There is an offset adjustment on the front control panel, which allows the user to select the output count for zero input light. It is important to set this to a positive count of around five on the 1 scale with a 1-second gate time. This insures that, if the electrometer amplifier drifts slightly, the count will still be accurate when doing differential photometry.

The SCALE adjustment is located in the center of the front panel and consists of a three-position switch labeled 1, 100, and 10. This control sets the electrometer voltage that will result in a full scale frequency of 10 K hertz. On 1, the least sensitive scale, an input of -5 volts corresponds to 9999 counts, while on the 10 and 100 scales this corresponds to -500 mv and -50 mv, respectively. The user can adjust his 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.

This frequency is also available at a jack on the back of the unit. It may be used to connect to an external counter, or interface with a small computer or other digital recording equipment. When the SCALE adjustment is set correctly so there is no overflow, the frequency will range from 0 to 10 K hertz. For chart recorder users, a frequency-to-voltage converter interface will be made available around January 1983.

The display makes use of a combination counter/display driver chip from Intersil. It provides a four-digit output, which is used to drive the display on the front panel. The count displayed will range from the offset count to a full count reading of 9999. If the scale or gate time is set too high for a given star brightness, an overflow will result. This is indicated by the LED on the front panel labeled OV. If this occurs, the user reduces his amplification or gate time to lower the count. The store and reset inputs to the counter/display driver chip are supplied by a circuit consisting of an RC network and a number of Schmitt Trigger inverters. This gate time control is called TIME on the front panel and allows the user to accumulate counts for either 1 or 10 seconds. By using the 10-second gate time the counts displayed on dim stars can be increased, giving a better signal-to-noise ratio.

Figure 8 shows a functional diagram of the signal processing circuit and Figure 9 shows front panel controls.

VI. UBVRI FILTERS

The UBVRI filter system established by Johnson et al. (1966) is generally followed today and exactly defines color bands in the spectrum from 300 to 1200 nm. Table II lists the filter-detector response of this system as originally defined; all data have been normalized to 100% at the filter transmission peaks. Table III lists the filter-detector response for the filters used with the SSP-3.

The OPTEC UBVRI filters are all made from combinations of Schott colored glass. The glass types and thicknesses for each filter have been computer-optimized for the best fit with the Johnson standards.

TABLE II

Standard UBVRI Response Functions According to Johnson

λ, μ	U	B	V	R	I
0.30	0.00	----	----	----	----
0.31	0.10	----	----	----	----
0.32	0.61	----	----	----	----
0.33	0.84	----	----	----	----
0.34	0.93	----	----	----	----
0.35	0.97	----	----	----	----
0.36	1.00	0.00	----	----	----
0.37	0.97	----	----	----	----
0.38	0.73	0.11	----	----	----
0.39	0.36	----	----	----	----
0.40	0.05	0.92	----	----	----
0.41	0.01	----	----	----	----
0.42	0.00	1.00	----	----	----
0.44	----	0.94	----	----	----
0.46	----	0.79	0.00	----	----
0.48	----	0.58	0.02	----	----
0.50	----	0.36	0.38	----	----
0.52	----	0.15	0.91	0.00	----
0.54	----	0.04	0.98	0.06	----
0.56	----	0.00	0.72	0.28	----
0.58	----	----	0.62	0.50	----
0.60	----	----	0.40	0.69	----
0.62	----	----	0.20	0.79	----
0.64	----	----	0.08	0.88	----
0.66	----	----	0.02	0.94	----
0.68	----	----	0.01	0.98	0.00
0.70	----	----	0.01	1.00	0.01
0.72	----	----	0.01	0.94	0.17
0.74	----	----	0.00	0.85	0.36
0.76	----	----	----	0.73	0.56
0.78	----	----	----	0.57	0.76
0.80	----	----	----	0.42	0.96
0.82	----	----	----	0.31	0.98
0.84	----	----	----	0.17	0.99
0.86	----	----	----	0.11	1.00
0.88	----	----	----	0.06	0.98
0.90	----	----	----	0.04	0.93
0.92	----	----	----	0.02	0.84
0.94	----	----	----	0.01	0.71
0.96	----	----	----	0.00	0.58
0.98	----	----	----	----	0.47
1.00	----	----	----	----	0.36
1.02	----	----	----	----	0.28
1.04	----	----	----	----	0.20
1.06	----	----	----	----	0.15
1.08	----	----	----	----	0.10
1.10	----	----	----	----	0.08
1.12	----	----	----	----	0.05
1.14	----	----	----	----	0.03

TABLE III

UBVRI Response Functions of Filters Used in the SSP-3

λ, μ	U	B	V	R	I
0.30	0.00	----	----	----	----
0.31	0.00	----	----	----	----
0.32	0.00	----	----	----	----
0.33	0.02	----	----	----	----
0.34	0.19	----	----	----	----
0.35	0.42	----	----	----	----
0.36	0.75	0.00	----	----	----
0.37	1.00	----	----	----	----
0.38	0.84	0.28	----	----	----
0.39	0.31	----	----	----	----
0.40	0.04	0.63	----	----	----
0.41	0.01	----	----	----	----
0.42	0.00	0.87	----	----	----
0.44	----	1.00	----	----	----
0.46	----	0.95	0.00	----	----
0.48	----	0.60	0.04	----	----
0.50	----	0.20	0.10	----	----
0.52	----	0.06	0.85	0.00	----
0.54	----	0.02	1.00	0.02	----
0.56	----	0.01	0.95	0.25	----
0.58	----	0.00	0.66	0.59	----
0.60	----	----	0.48	0.70	----
0.62	----	----	0.27	0.85	----
0.64	----	----	0.10	0.93	----
0.66	----	----	0.04	1.00	----
0.68	----	----	0.00	0.96	0.00
0.70	----	----	0.00	0.93	0.00
0.72	----	----	----	0.85	0.09
0.74	----	----	----	0.74	0.52
0.76	----	----	----	0.66	0.71
0.78	----	----	----	0.51	0.83
0.80	----	----	----	0.41	0.94
0.82	----	----	----	0.31	0.96
0.84	----	----	----	0.22	0.96
0.86	----	----	----	0.16	0.97
0.88	----	----	----	0.12	1.00
0.90	----	----	----	0.09	0.96
0.92	----	----	----	0.07	0.96
0.94	----	----	----	0.05	0.89
0.96	----	----	----	0.03	0.76
0.98	----	----	----	0.01	0.64
1.00	----	----	----	0.00	0.46
1.02	----	----	----	----	0.31
1.04	----	----	----	----	0.21
1.06	----	----	----	----	0.10
1.08	----	----	----	----	0.05
1.10	----	----	----	----	0.02
1.12	----	----	----	----	0.01
1.14	----	----	----	----	0.00

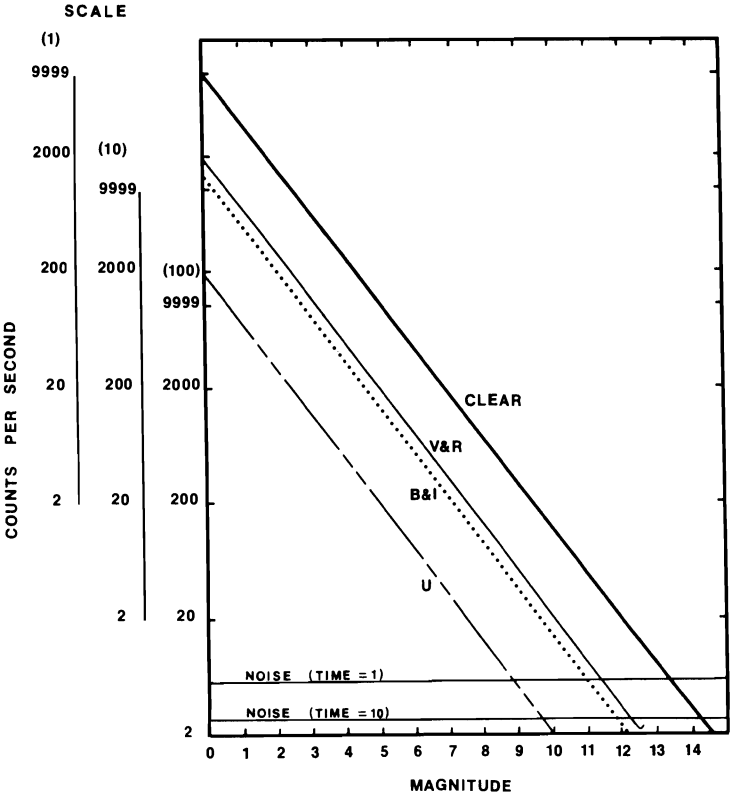

Figure 10. Counts per second vs. steller magnitude. These are typical values obtained with an 11 inch aperture telescope and average seeing conditions.

As can be seen in Tables II and III, the B, V, R, and I filters match closely the standard values. Blocking the red leak in the glass used for 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 system precisely. It is interesting to note that 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.

VII. SENSITIVITY OF THE INSTRUMENT

The sensitivity of the model SSP-3 photometer is shown in the graph of Figure 10. The data were determined experimentally with a Celestron 11-inch telescope at an air temperature of about 70 F. The spectral type for the star used to compute the CLEAR line was G. The display output is expressed in counts per second vs. magnitude using various filters. It should be noted that these are the approximate display counts, and that accurate magnitude should be determined using the accepted techniques of differential photometry.

Each line on the graph represents the relationship between stellar magnitude and counts on the photometer. The R and V lines were too close together to show separately and so were made one line for the sake of clarity; the same is true of the B and I lines.

VIII. SPECIFICATION SUMMARY

DETECTOR	
Type	silicon PIN-photodiode
NEP	8×10^{-16} W/ Hz (typical)
Detector Diameter	1mm std. (.5, .75, 2mm opt.)
Spectral Range (5% points)	300 to 1100 nm
Shunt Resistance	50 G Ohms (typical)
Surface Uniformity	<1%
ELECTROMETER	
Type	Current-to-Voltage
Bias Current	.15pa Max.
Offset Voltage	<.5mv
Open Loop Gain	10 V/V Min.
Closed Loop Gain	5×10^{10}
Input Voltage Noise	4uV(p-p) (.1 to 10Hz)
Input Current Noise	.003pA (.1 to 10Hz)

A/D CONVERTER	
Type	Voltage-to-Frequency
Full Scale Frequency	10 KHz
Full Scale Input Voltages	50mv (100 SCALE) .5V (10 SCALE) 5V (1 SCALE)
Linearity	<0.1%
Offset	<.5mv (adjustable to 0)
COUNTER/DISPLAY	
Integration Times (Gate)	1 and 10 seconds
Timer	R-C Circuit (low T-C)
Display	4-digit (9999)
Character Height/Color	.11 inch, Red
POWER SUPPLY	
Battery	9 volt NiCd (Type GE GC9)
Operating Time	5 hours
Recharge Time	15 hours
Battery Charger	12 volts DC, 100 ma
EYEPIECE	
Focal Length	25 mm
Type	Ramsden
Reticle Illumination	Green LED
FILTERS	
Type	Schott Colored Glass
Standard Filter Slider	B and V according to Johnson
Optional Filters	R and I according to Johnson U approx. Johnson standard
Flatness	<4 fringes
Surface Quality	Pelon Polish, scratch and dig 80-50
Diameter	12.7 mm
Thickness	7.0 mm
MECHANICAL	
Body Material	Aluminum 2024 or 6061 alloy
Finish	Bright Dip Black Anodize
Overall Length	9 inches (tip to tip)
Weight	2 lbs. 14 oz.
Telescope Coupler	1.25 inch (standard)

REFERENCES

Johnson, H. L. et al. 1966, Communications of the Lunar and Planetary Laboratory, No. 63.

11

A Constant Current Source For Gain Step Calibration

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I. INTRODUCTION

For dc amplifiers used in photoelectric photometry, it is imperative that gain steps be calibrated to take into account resistor tolerances, temperature effects, aging of gain step resistors, etc. Constant current sources are commercially available, but these units are generally expensive. For example, the Keithley Model 261 is an excellent unit, but it sells for $1800.

Constant current sources are mostly ignored in the astronomical literature. Hall and Genet (1982) stress the need for careful gain step calibration, but give no details or suitable circuits. Kaitchuck and Henden (1982) give a circuit with a battery and a large resistor, and this type of device should be adequate as long as the dc amplifier exhibits an input impedance that remains constant as the gain is changed. But in practice, how does one insure that this is true? Several dc amplifier circuits have recently been published which employ a passive current-to-voltage converter (i.e. a resistor) on the input, so that the input impedance changes by a factor of ten on each gain change. A simple Ohm's law current source will likely lead to an incorrect gain calibration under those circumstances.

The requirements of a current source for calibrating dc photometry amplifiers are relatively simple and easy to meet. The usual procedure, beginning with the least sensitive scale, is to input a current such that an almost full-scale deflection will be registered when the next more sensitive gain step is employed. For example, let us assume gain steps of ten for simplicity (2.5X or 3X are more common). The least sensitive scale might be 1×10^{-6} amperes. Set the current source for 1×10^{-7} amperes, and measure the output on both the 10^{-7} and 10^{-6} scales, thereby obtaining the ratio, or gain step. Hence, a current source must be capable of providing a negative current in the usual photocurrent range of

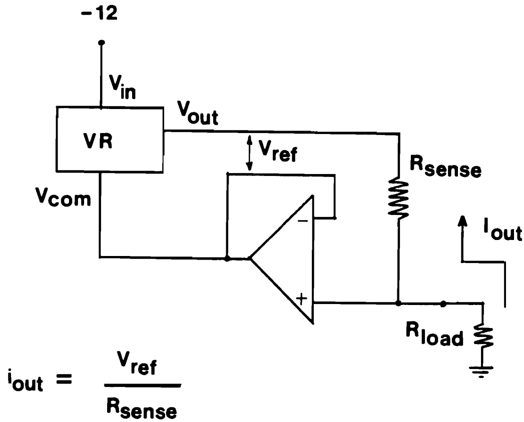


Fig. 1. The basic circuit for the constant current source.

about 10^{-6} to 10^{-10} amperes, and it must be stable over the time required for the calibration measurements. There is therefore no need for either long-term stability or for an absolute accuracy in the current, regardless of the load, i.e. the amplifier input impedence.

The above considerations have led to the development of a simple, low-cost, true constant current source for gain step calibration whenever a dc amplifier is chosen for photometry instead of a pulse counting system.

II. CIRCUIT DESIGN

The circuit for the basic constant current source is shown in Figure 1. This scheme is a standard design and can be found in several references, although it is generally shown for positive current. Note that the voltage reference is not tied to ground, but is floating at a level determined by the op-amp. The voltage reference still maintains its rated voltage between the V_{out} and V_{com} pins, i.e. the voltage at V_{out} measured with respect to ground will be V_{ref} volts above the V_{com} potential, also measured with respect to ground. Hence, the V_{ref} potential must appear across the R_{sense} resistor, regardless of R_{load}. With a carefully chosen op-amp, no *significant* current will flow in either op-amp input. Choice of op-amp is important, since we are dealing with currents in a range where many op-amps have significant input error currents.

Because of the range of current desired, it is not practical to use the circuit exactly as shown in Figure 1. A 10-volt reference would require 10^{11} ohm resistor to provide 10^{-10} amperes, and resistors in this range are expensive and subject to leakage currents. This problem can be avoided by feeding back only part of the reference voltage, say 1/100 or 1/1000 of V_{ref}, and that reduces the requirements on R_{sense} by a corresponding amount. Resistors R1 and R2 (in Figure 2, discussed below) serve this purpose in the final circuit, and the effective reference voltage can be found with the usual relation for a voltage divider.

III. CHOICE OF VOLTAGE REFERENCE AND OP-AMP

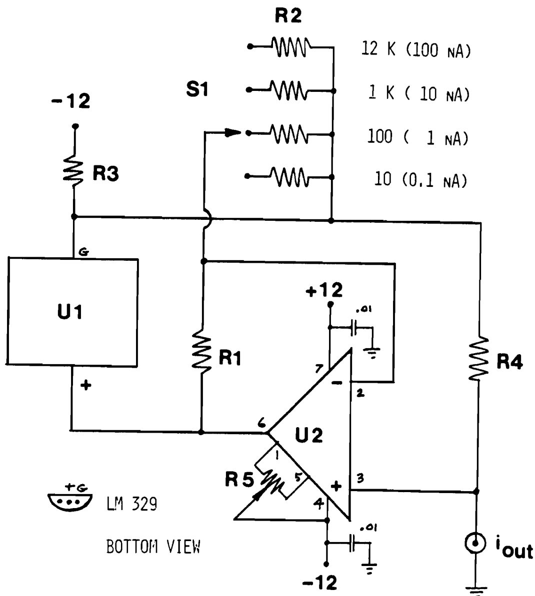
The final circuit is shown in Figure 2. The output current is given by:

$$i_{out} = (V_{ref}\ R2)/(R4(R1 + R2)).$$

R2 is switched to provide the proper current, and the values shown in Figure 2 provide four decade ranges with nominal outputs of 1×10^{-7}, 10^{-8}, 10^{-9}, and 10^{-10} amperes.

Any of several voltage references could be used here. The LM 329 shown is inexpensive ($0.65) and readily available from Jameco Electronics, 1355 Shoreway Road, Belmont, CA 94002. It is a two-terminal zener diode voltage reference IC, and hence requires a resistor (R3) to limit the current. This is a temperature-compensated reference with very good drift characteristics (50 to 100 ppm/^{o}C). Two precautions should be observed if changes are made to the circuit shown in Figure 2: (1) be sure not to draw excessive current so that the voltage reference no longer has adequate voltage for proper zener action, and (2) since zener references are known to be relatively noisy, care should be taken not to operate in a region where this noise becomes significant (for the LM 329, the typical noise is 7μV). It is for this reason that a 10 megohm resistor has been chosen for R4. Reasonably satisfactory results can be obtained down to 0.1 nA with 1 megohm at R4 and corresponding changes on R2.

For the op-amp, the primary requirement is low input bias current. An inexpensive ($0.69 from Jameco Electronics) LF 13741 (a biFET-input version of the 741) was used for initial experiments and performance tests. Two other op-amps were tested in this circuit which are even better choices than the LF 13741: the LF 355 ($1.10) and the AD 515J ($20). (Note that the zero offset circuit is different for these two op-amps, so they are not plug-in replacements for the LM 13741 until that change is made.) A good temperature drift specification is unimportant here since the circuit will be used only for a few minutes at a time. If the current source is stored in a warm, dry environment (recommended), and then used in a cold dome, adequate time should be allowed for all elements to stabilize to the new ambient temperature before using it.



R1	63 K	S1	SP4T CERAMIC ROTARY SWITCH
R2	SEE DIAGRAM	U1	LM 329 VOLTAGE REFERENCE IC
R3	2 K	U2	LF 13741 (OR LF 355, SEE TEXT)
R4	10 M		
R5	10 K POT		

Figure 2. The final circuit for the constant current source for calibration of gain steps. See text for details.

IV. CONSTRUCTION AND PERFORMANCE

The current source was built on a printed circuit board, along with a chopper-stabilized dc amplifier (DuPuy, 1983). It is important that metal film resistors be used for stability and low noise. A small power supply with ±12 volts for the amplifier and current source was provided using three-terminal regulators. Because the current source draws about 10 milliamperes, and because the unit will be used only for a few minutes at a time, it is quite practical to use two 9-volt batteries instead of a power supply. The 10K potentiometer on pins 1 and 5 is used to compensate for any non-zero offset in the op-amp, and this can be adjusted by shorting out R2 and adjusting the potentiometer for zero volts across R_{sense}. The 10K potentiometer should be a 20-turn Cermet potentiometer for P.C. board mounting (the wiper should be returned to pin 7 if the LF 355 or AD515 is used). A P.C. board layout is available from the author (specify 2X or 1X size artwork).

The performance of the current source was evaluated with a Keithley model 480 Picoammeter having a basic accuracy of 0.5%. A 1 Megohm resistor inserted in the output to the picoammeter had no discernible effect. Test data were obtained with a series of 1% metal film resistors at R2 and the measured current was plotted versus the calculated current on a log-log scale. These data were fitted with a linear least squares solution, and deviations from this least squares fit are shown in Figure 3. The deviations shown can be completely accounted for with the 1% tolerance on the resistors in the voltage divider chain (R1 and R2), and the 0.5% to 0.8% accuracy of the Keithley Picoammeter. Figure 3 illustrates that the constant current source performs well down to currents below the 0.1 nA level.

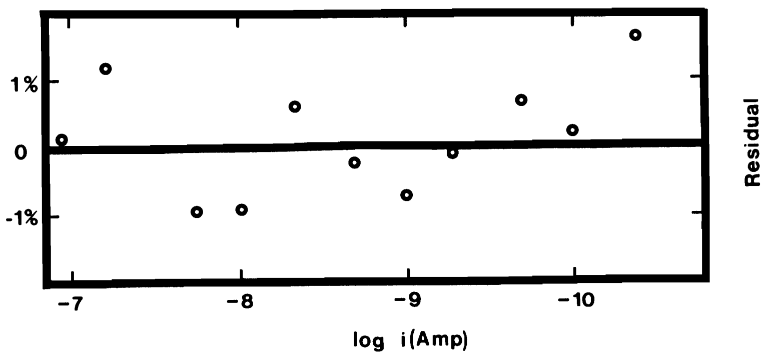


Figure 3. The residuals from a linear least squares solution of $i_{measured}$ versus $i_{calculated}$ over a range from 100 nA to below 0.1 nA. The 1% tolerance on the resistors in the voltage divider chain and the 0.5 - 0.8% accuracy of the picoammeter account for the deviations shown.

In summary, details are given for a simple and inexpensive constant current source, suitable for calibration of gain steps in a d.c. amplifier for photoelectric photometry. A simple evaluation of this circuit's performance indicates a reliable constant current over a range of 10^{-6} to 10^{-10} amperes.

REFERENCES

DuPuy, D.L. (1983) "An Ultra Low Drift DC Amplifier For Use With Photomultipliers", P.A.S.P., 95, 86.

Hall, D.S. and Genet, R.M. (1982) Photoelectric Photometry of Variable Stars, I.A.P.P.P.

Kaitchuck, R.H. and Hendon, A.A. (1982) Astronomical Photometry, Van Nostrand Reinhold Co., New York.

12

A COMPUTERIZED PHOTOELECTRIC TELESCOPE

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I. INTRODUCTION

From the viewpoint of computerized photoelectric telescopes, variable star photometry naturally breaks down into two catagories: (1) short-period variables; and (2) long-period variables. A short-period variable changes so rapidly that it must be observed almost continuously, while a long-period variable changes so slowly that one good observation or short observational sequence per night is sufficient. One typically observes a single short-period variable all night long, while one observes many long-period variables in a single night, but continues to observe the same set of stars night-after-night.

This chapter will discuss one approach to observing short-period variable stars under computer control, while the following chapter will discuss another approach to observing long-period variable stars. In both chapters, some emphasis will be given to the basic questions and options involved, as well as to the actual systems which are still under development. While one hesitates to describe a not yet fully operational system, there are others working on or contemplating similar systems, and it would be unfair for them not to begin with every possible advantage of knowing what has been done to date in this area.

We are deeply indebted for the considerable help we have recieved in designing and building the system described in this chapter. A number of STD Bus manufacturers have generously donated STD equipment and cards to this project, and we are most grateful for this.

II. THE BASIC PROBLEM AND APPROACHES

For purposes of this discussion, a short-period variable star will be one in which a complete and independently useful observing record can be obtained in a single night. Foremost among these variables are the eclipsing binary stars. Many of the W UMa-type binaries have periods of less than 10 hours, with some less than 6 hours. With these stars it is possible to observe a complete cycle in a single evening - especially in the winter. Some of these W UMa and the related BY Dra binaries change their light curves from one cycle to the next.

Another class of "one-night" variables is the primary eclipses of Algol-type eclipsing binary stars. Many of these eclipses are of less than 10 hours duration, and some are as short as two hours, or even less. The change in brightness of these stars during eclipse can be very rapid, and nearly continuous coverage is desirable.

Many of the "microvariables" and a few of the RS CVn binaries discussed earlier are of the short-period type as defined above. There are other classes that qualify, but we need not be exhaustive.

On a good night at a mountaintop site with a manually controlled telescope and a single-channel photometer, the procedure for observing a short-period variable is fairly well established. One observes the variable star for several minutes - perhaps making 10-second integrations. Then one observes the sky background next to the variable, a nearby comparison star, and its sky background (all as quickly as possible) and then one goes back and "sits" on the variable for a few more minutes. This is repeated over and over again all night long, with perhaps an occasional swing over to a check star if the constancy of the comparison star is in question; or to an occasional standard star. On a poorer night or at a low-land site, the procedure is the same except one must observe the comparison star more frequently.

While one could automate this sequence directly, the tendency has been not to do this, but to take other approaches more suited to automation. The "single-channel moving telescope" approach described in the following chapter for long-period variable stars is also quite applicable to the short-period variable problem. Such a system can be set to go between variable, comparison, and even check stars and their backgrounds automatically. Having only a single-channel and a fixed-position photometer, such a system is relatively straight-forward from a hardware viewpoint. The accuracy of such a system under poor atmospheric conditions is better than that of a manual single-channel system because of the speed with which the system can move between the variable and comparison stars and their backgrounds (giving the atmosphere less chance to change). This speed can be increased if only the secondary mirror is moved, as in the system developed at the University of Calgary by Milone (1982) and others.

The other basic approach is to leave the telescope and secondary mirror steadily tracking at stellar rate, and simultaneously or almost simultaneously observe the variable and comparison stars, and perhaps even their backgrounds. The four-channel photometer described in an earlier chapter by Norman Walker is an excellent example of a photometer that uses a single sensor that is rapidly switched between the variable and comparison stars and their backgrounds. By making almost simultaneous observations with the same sensor, the ultimate in accuracy is achieved, although the system quantum efficiency is not high.

Several dual-channel, two-sensor photometers have been built. One of the earliest of these "two-star" photometers was developed by Nather (1972) at the University of Texas. This system was primarily intended for high-speed occultation photometry with a second "monitor" channel, but A. Grauer and H. Bond have adopted this system to differential photometry of short-period variable stars with good results. The system to be described in this chapter is similar to the "Nather" system except that the position of each channel can be individually adjusted, and both channels are capable of displacing the diaphragms to take "sky" readings near the variable and comparison stars without moving the telescope.

It is probably too soon to determine which basic approach to automated observing of short-period variable stars will prove to be most effective. The approach described herein is not necessarily superior. It is a complex approach, and the use of more than one sensor may limit its accuracy. It remains to be seen whether or not the lack of telescope motion, a high duty cycle, and true simultaneous observations, will more than offset the difficulties inherent with any complex, multi-sensor system.

III. TELESCOPE

The 0.4-meter telescope used in this system has been described previously (Genet *et al* 1983). It was specifically designed for dual-channel photometry. It has a wide, 1-degree, fully illuminated field of view at a scale of 25 arcsec/mm. This gives a field diameter at focus of 5 inches. The optical system is a classical Cassegrain configuration with an f/3.75 primary and an overall effective f/ratio of 18.0.

The telescope mount is a sturdy cross-axis type. Slewing is provided via geared steppers acting through electrical clutches. Fine motion in RA is provided by a geared stepper motor and a 14-inch precision worm gear, while fine Dec motion is supplied by a geared stepper and a tangent arm. Position information is provided by optical encoders in each axis.

IV. PHOTOMETER HEADS AND X-Y STAGES

The two identical photometer heads use EMI #9924 end-on photomultiplier tubes, with 30-mm bialkali photocathodes. These PMT's have high quantum efficiency with low dark counts at ambient temperature. EMI Gencom amplifier/discriminators are located in each head. Small geared steppers control the positioning of separate diaphragm and filter wheels.

The two heads are mounted on X-Y stages driven by linear stepper motors. Each photometer can be independently positioned anywhere in the entire field except where the small mirror pickoffs would actually conflict with each other.

V. CONTROL SYSTEM APPROACH

Early data logging systems at the Fairborn Observatory had used a Radio Shack TRS-80 computer and custom-built external boards with "smart" peripheral chips (Genet 1982). All software was written in BASIC, and a software-polled port structure was used, avoiding hardware interrupts and assembly-level programming.

A similar approach was tried with the much more complex control system designed for the 0.4-meter telescope and dual-channel photometer. The performance of this system was marginal at best. It was plagued with random system "crashes" and with interconnector reliability problems. These problems were caused by the "spread out" approach taken. The usual cure for such a problem is to use a standard bus of some sort for the computer and the peripheral electronics.

The bus PC board (sometimes called a *motherboard*) makes most of the interconnections between the various pulg-in PC cards in an easy, reliable, and low-noise manner. The motherboard and plug-in PC cards are usually physically held together in a "card cage", and with supporting power supplies. This approach provides a compact, noise-free system with a minimum of interconnecting cables.

While one can define one's own bus, a number of "standard busses" have also been defined. It is advantageous to use one of these standard busses because of the availability of commercially made, off-the-shelf, plug-in PC card computers and peripheral cards. A number of standard busses were investigated for this particular situation, including the Apple II+, the S-100, the STD, the Multibus, Q-bus, and a few others.

The Apple II+ has plug-in slots which will accept various cards from a number of different manufacturers; however, it is not a complete bus in that it cannot accept different computers, and it is normally limited to 7 available slots. The Apple II+ is a good choice for a photometer data logging/control system, although the number of slots and the variety of cards is somewhat limited if one wants to control an entire telescope and a dual-channel photometer.

The S-100 bus was given very serious consideration. It has a wide variety of computers and cards available, and the large-sized cards are attractive for those wanting to build their own plug-in cards. Most S-100 based systems use the popular and versatile CP/M operating system.

The STD Bus was also given very serious consideration since it also has a wide variety of computers and cards available, and in the area of real-time control, it has the largest selection of off-the-shelf cards. The cards are small in size (the smallest of any standard bus). As with the S-100 bus, most STD-based systems use the CP/M operating system.

The Multibus and Q-Bus are basically 16-bit (16 data lines) systems, and the cards are much larger and considerably more expensive than those available for the S-100 and STD busses. While a 16-bit bus is very desirable for some applications, it is an expensive overkill for this application, and therefore these busses were not considered further.

In the end, the STD bus was chosen over the S-100 bus because of the availability of a large variety of stepper controller cards, optical angle-shaft encoder cards, DC servo controller cards, and other real-time control cards. Altogether, over 80 different manufacturers make more than 500 different cards for the STD bus. The STD bus is not a hobbiest's bus, and thus does not receive as much publicity as the S-100 bus. The STD bus is primarily used in various industrial real-time control and data logging situations. The STD cards are 4½"x6½" in size, and have 58 contacts (28 on each side). While a sizable number of different microprocessors and operating systems are supported, the Zilog Z-80 and CP/M are most widely used.

A number of the available STD cards are highly intelligent, and contain their own microprocessors which are "transparent" to the main computer. An example is the Whedico Intelligent Stepper Controller. This card contains its own Zilog Z-80 microprocessor and machine-language progrma in PROM. To the main computer it looks like a series of 8-bit ports, and only a simple command from the main computer is needed to move a stepper. The peripheral computer aboard the Whedico card automatically calculates and controls the ramp-up, slew, and ramp-down of the stepper, bringing it to a smooth stop exactly where requested. The advantage is that all the high-speed computations and control are handled by a preprogrammed, transparent computer on the peripheral card; and all that the user has to do is issue a few high-level commands from a relatively slow but easy-to-use language such as BASIC. The result is high performance with simple software.

VI. CONTROL SYSTEM DETAILS

A functional block diagram of the control system is shown in the figure on the following page. The power supplies, STD bus motherboard, and all 18 of the STD cards are contained in the STD Control Unit. The entire control unit is contained in a portable container that can be carried under one arm. This replaced the two relay racks of equipment on the earlier TRS-80-based system. All items external to the STD Control Unit, such as the terminal, stepper motors, keypads, etc., are connected to the back panel of the STD Control Unit with quick disconnect cables and sockets. Each of the STD cards and their functions are discussed separately below.

(1). Pulsar Computer: The Pulsar is a single-board STD bus computer made in Australia by Pulsar Electronics Ltd., and distributed in the United States by Infinity, Inc. The CPU is a 4 MHz Zilog Z-80. On board is 64K of RAM and a 2K Monitor ROM. A disc controller (up to 4 discs), two RS-232 serial ports (terminal and printer), and a clock/calendar with battery back-up round out this amazing little 4½"x6½" board! The Pulsar CPU is in Slot No. 1 of the 24-slot Scanbe Inc. motherboard and card cage; and the Pulsar communicates with all the other boards via the lines on this STD bus motherboard. As might be expected, the Pulsar easily handles CP/M, and it comes with many helpful utilities.

(2). <u>MCPI Relay Control Board</u>: The MCPI (Mullins Computer Products, Inc.) board contains 8 reed relays, along with appropriate address decoders and a data latch. At present, it is used to control the high voltage power supply for the PMT's, leaving plenty of reserve capabilities.

(3) & (4). <u>Whedico Intelligent Stepper Controllers</u>: Each of the two identical Whedico Stepper Controllers are complete computers in their own right with their own preprogrammed "canned" software stored in ROM. They can operate in a positioning mode, a constant velocity mode, or a single-step mode. The positioning mode is the most interesting. The Whedico controller automatically ramps a stepper up to slewing speed and then ramps it down to a stop exactly at the commanded position. The initial start speed, acceleration rate, and maximum slew speed are all set with software, allowing one intelligent controller to handle a number of different steppers with different inertia, friction leads, and allowable top speeds. As the photoelectric telescope control system has some 14 different steppers, it is easy to appreciate why the Whedico boards are amoung the most important in the system. With the two Whedico boards, any two steppers can be controlled at the same time.

(5). <u>Circuits & Systems Counter I/O Board</u>: The C&S board contains three 16-bit programmable counters, and four 8-bit parallel I/O ports. Two of the counters are used to count the pulses coming from the two photometer heads. The third counter is used as a programmable "divide by N" to set the stellar rate for the RA fine stepper. This avoids tying up one of the precious Whedico controllers in such a mundane task. Three of the 8-bit ports are in an "output" mode and are used to select which two steppers will be driven by the Whedico controllers, enable the stepper driver chips, and set the stepper direction. The fourth port is used as an "input" port, and it senses *overflow* flags from the counters, and the *busy* and *ready* flags from the Whedico stepper controllers.

(6). <u>STD Patch Card</u>: As the Whedico controllers are used to control a number of different steppers, provisions must be made for logically switching the pulse streams and for making interconnections between the various cards. This is taken care of by a single wire-wrap board. It is the only wire-wrapped board in the entire system - all others are PC Boards.

(7). <u>Quad Stepper No. 1</u>: There are four identical quad stepper cards in the control system. Each card contains four Hurst hybrid stepper controller/driver chips. The Hurst chips provide the direct switching logic for controlling four phase steppers, and also contain drivers with sufficient power to drive low-powered stepper motors. Pulse signals are provided via a jumper form the STD Patch Card. Only power is drawn from the STD bus itself. This fairly simple card was not available commercially, so Doug Sauer layed out our own PC card. Quad Stepper No. 1 drives the geared Hurst RA fine and Dec fine steppers directly, and drives the Slo Syn (Superior Electric) RA slew and Dec slew steppers through the dual stepper power driver on board 8.

(8). <u>Dual Stepper Driver</u>: Eight Darlington transistors provide the muscle for the RA and Dec Slo Syn slew motors. The four-phase signals are provided from two of the Hurst controller chips on Quad Stepper No 1.

(9). Quad Stepper No. 2: The four Hurst controller chips on this board provide the four-phased signals for the four linear Hurst stepper motors that drive the two X-Y stages. These stages position the two photometer heads, and can also be used in scanning photometry.

(10). Quad Stepper No. 3: The four steppers controlled by this card are the diaphragm and filter wheels in each of the photometer heads. These steppers are small, geared Hurst steppers.

(11). Quad Stepper No. 4: Only two of the four controllers in this board are currently utilized. These control the mirror focus (a linear Hurst stepper) and the flip mirror. This leaves two stepper controllers for future possibilities.

(12). MCPI DC Input: This board provides 8 opto-isolated DC inputs. All 8 of these inputs are used to sense limit switches. If any of these switches are activated, it results in the stopping (at maximum deceleration) of all steppers, and the removal of the high voltage, etc.

(13). Enlode Clock/Calendar Card: The Enlode clock/calendar card is another very smart card with its own on-board microprocessor. Besides the normal time-keeping functions, this card provides alarm and timed-interrupt functions. One of its unique features is a remote indicator that will automatically display the time and date, or if desired, any other commanded data such as RA and Dec.

(14). Electrologic Z-501 and Opto-22: The Z-501 card and Opto-22 controller form a team. The Z-501 provides up to 24 control signals to the remotely placed Opto-22 board. On the Opto-22 board are provisions for up to 24 plug-in control modules. These can be for AC power, DC switching, DC input sensing, or even AC input sensing. These control modules are industry standards, and are readily available from Opto-22 (their originator) and other companies. The Z-501 controls the modules, and the modules in turn control the slew clutches, roof motor, and other heavy loads.

(15). Enlode Keypad Encoder: The Enlode keypad encoder can handle up to four different keypads. However, only two Enlode hexidecimal keypads are used in this system. One is located on the floor of the observatory for "manual" telescope control (the remote keypad), while the other is located in the control room, and is used for semiautomatic control (the local keypad). The remote keypad has first priority on the theory that the observer at the telescope should not be overridden by someone in the control room.

(16). Amtek Dual Encoder: The Amtec dual encoder is another case of a smart card with its own microprocessor (Z-80) and a canned program permanently stored in PROM. This intelligent card can handle two incremental encoders at the same time, keeping continuous track of their positions. Two Litton Model-81 optical angle shaft encoders are used to sense position in RA and Dec., and the quadrature signals from these two sensors are fed directly to the Amtek dual encoder card.

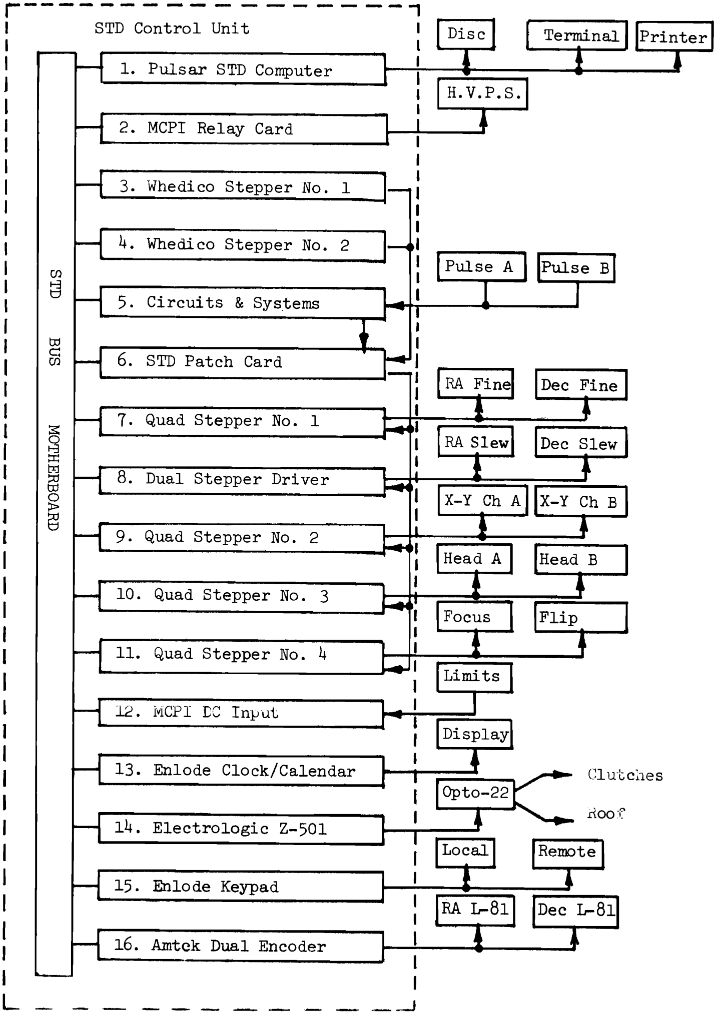

Figure 1. System functional diagram.

VII. DISTRIBUTED PROCESSING

The system described above has one main computer (the Pulsar board), and five "transparent" computers with preprogrammed software. These five "slave" computers really do all of the hard, fast work in the system; and the really difficult software work has already been done by their manufacturers. There is no need to delve into these canned programs, and it should be unnecessary to do so. The wide selection of such smart STD cards greatly simplifies both hardware and software development.

The system described in this chapter is often referred to as a *distributed processing* system. Since the slave computers do most of the work, the main CPU becomes more if a supervisor and issuer of high-level orders. Under these circumstances, it does not have to be fast, and a high-level language such as BASIC can readily be used. This additionally lightens the software programing task.

VIII. EVOLUTION TOWARDS AUTOMATION

We thought it best not to try and automate everything in one fell swoop. Instead we have embarked on an approach that starts with "manual" control with the observer on the observatory floor using the remote keypad to control the system through the computer and control system. This software provides the "primatives" for more complex software.

The next level up is the initial setting of the system on the variable and comparison stars from the observatory floor in the "manual" mode, and semi-automatic aquisition of the data while the astronomer is in the control room. This keeps the observer out of the cold during most of the observing run, and allows him to do other things while keeping an "eye" on things and making occasional adjustments.

At this point it will be relatively easy to operate the system remotely over the telephone lines using a terminal and modem at the remote control location. Astronomers in the Eastern United States have already operated telescopes at Kitt Peak National Observatory remotely. It might be appropriate if some Arizona amateur astronomers operated a telescope in Ohio remotely. A low bandwidth microwave link is also being considered between "Fairborn Observatory West" (in Lewisburg, Ohio) and the main observatory in Fairborn, Ohio. Developing this capability is important to Fairborn Observatory, since a considerable amount of the observing time on its 1-meter telescope is expected to be made remotely.

Automatic shut down, and perhaps even automatic start up are long-term goals. From our current perspective of primitive software development for "manual" control, these long-range goals seem to be a long ways off, and not of high importance. However, care has been taken during the design of the system not to preclude eventual total automation, even though our goal has never been automation, but rather just efficient photometry of short-period variable stars from a low-land site.

REFERENCES

Genet, R.M. (1982) Real-time Control With the TRS-80, Chapters 9 - 13, H.W. Sams, Indianapolis.

Genet, R.M., Sauer, D.J., Kissell, K.E., and Roberts, G.C. (1983) I.A.P.P.P. Comm., 9, 43.

Milone, E.F. (1982) (Preprint provided by J.D. Fernie).

Nather, R.E. (1972) Rev. Sci. Instrum., 43, 1012.

MANUFACTURERS

Amtek, 12740 28th N.E., PO Box 27128 Lake City Station, Seattle, WA 98125.

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Electrologic Inc., 1359 28th St., Signal Hill, CA 90806.

Enlode Inc., 1728 Kinsley Ave., Orange Park, FL 32073.

Hurst Mfg. Corp., Box 326, Princeton, IN 47670.

Infinity Inc., 29429 Southfield Rd., Suite 5, Southfield, MI 48076.

Litton Encoder Division, 20745 Nordhoff St., Chatsworth, CA 91311.

Mullins Computer Products Inc. (MCPI), Box 6214, Hayward, CA 94545.

Opto-22, 15461 Springdale St., Huntington Beach, CA 91731.

Pulsar Electronics Ltd., 323 Bell St., Pascoe Vale South, AUSTRALIA 3044.

Scanbe Inc., 3445 Fletcher Ave., El Monte, CA 91731.

Superior Electric Co., Slo Syn Division, Bristol, CT 06010.

THORN EMI Gencom Inc., 80 Express St., Plainview, NY 11803.

Whedico Inc., 6107 Jackson Road, Ann Arbor, MI 48103.

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Small Automated Photoelectric Telescopes

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In astronomical research, the small telescopes tend to be used mainly for photoelectric photometry. The wide bandwidth of photometry, the high quantum efficiency of the photodetectors used in photometry, and the "zero dimensional" nature of the data all tend to make the best use of the few photons available. While photometry of unique one-time events such as occultations provides valuable data, most small telescope photometry is of variable stars. Variable star photometry is generally a highly structured and repetitious task that lends itself well to automation.

It will be convenient for us to break variable stars into two broad classes: short-period variables and long-period variables. Short-period variables are those stars that would require observation continuously for many hours or all night long, while long-period variables are, conversely, those stars that only need to be observed once (one set of readings) per night. Typically, one would observe a single short-period variable all night long, while one would observe many long-period variables in a single night and repeat these observations for many nights. As these two situations are quite different, it would be expected that different systems would evolve to meet each situation.

Short-period variables, especially eclipsing binary stars with short-duration eclipses, have been favorite photometric objects since the beginning of photometry. The first small-telescope automated system to observe these (that we are aware of) was designed and built by David Skillman (1979). This single-channel system, which is controlled by Apple and Kim microcomputers, has been in operation for several years now. A small-telescope dual-channel system for observing short-period variable stars has been developed by one of us (Genet) and Douglas Sauer (1982), and is just becoming operational as this chapter is being written. However, in this chapter we will not be concerned with automated systems for short-period variables, but will concentrate our attention of such systems designed for use on long-period variable stars.

The small automated photoelectric telescope (APT) described by McNall, Miedaner, and Code (1968) was fully capable of observing long-period stars, although it was not applied to this task to our knowledge. Rather, it was used to observe a number of standard stars spread across the sky for purposes of determining nightly extinction coefficients. This 8-inch telescope was controlled by a PDP-8 minicomputer, and its photometer was at prime focus. It was housed in a small roll-off roof building, and its operation was fully automated. This promising start on an automatic small telescope was not followed (except in space telescopes) until, to the best of our knowledge, one of us (Boyd) started development of a small APT specifically for observing long-period variable stars. A number of large telescopes, however, are quite capable of automatic photometry of long-period variable stars. One of the most interesting of these is the 1.2-meter Cloudcroft telescope described by Worden *et al.* (1981). This telescope is controlled by a large IBM computer, and has been used in a sucessful program to determine the variability of solar-type stars (Radick *et al* 1982).

Perhaps the main reason for fully automating a small photoelectric telescope is the efficiency with which such an instrument can observe long-period variable stars. Such an automated system is much faster in acquiring and centering stars than any human can be, and of course, an automated system never needs a break nor does it quit early to catch some sleep. Consider the following rough comparison between an automated and manual approach.

Assume that a set of readings consists of a variable, comparison, check, and sky reading; and each are read twice (once in reverse order) in three colors for a total of 24 measurements. With 10-second integrations this can be accomplished in about 6 minutes by an automated system, including the acquisition time. This gives about 10 readings per hour, 6 hours per night, for 100 nights per year (limited by clouds and moon), for a total of 6,000 measurements per year. If one is very fast, one might manually do 4 stars per hour (same measurements as above) for 3 hours per night, and (allowing for meetings, vacations, etc.) 50 nights per year, for a total of 600 readings per year. The estimated automatic-to-manual ratio of stars observed is 10:1. This is a sufficiently large ratio to motivate the development of a relatively low-cost, fully automatic system based on microcomputer control.

In this chapter we will discuss some of the considerations involved in designing a small automatic photoelectric telescope for observing a large number of different stars per night. It is not our intent to be either exhaustive in enumerating design alternatives or to give specific recommendations. Rather it is our intent only to introduce the subject and recount some of our own thoughts and experiences and those we have picked-up from others working in similar areas.

II. ASTRONOMICAL CONSIDERATIONS

For an APT to realize its full potential it must be able to observe enough different variable stars each night to keep it occupied. If the telescope is too small, it could run out of accessible objects and have to spend time waiting between observations; if it were too large, it would become too expensive for the typical amateur to afford. The actual size needed to keep such a telescope fully occupied is a complex function of sky brightness, pointing accuracy, slewing rates, and a number of less important parameters. Since a star is observed many more times during the process of acquisition and centering than it is for the actual measurement, the acquisition observations must be of short duration. Thus the need for a measurable photon level during the acquisition process could place the lower limit on the acceptable telescope size. An 8-inch aperture telescope can be kept fully occupied, and a 14-inch telescope would have a tremendous selection of stars if used in a location with fairly dark sky.

Larger telescopes will very rapidly increase the costs in order to gain the necessary performance improvement, i.e. faint stars will require high precision drives and unusually sturdy mounts to ensure acquisition of the correct stars.

Another important consideration is the accuracy of the observations. Small observatories tend to be located at less than the ideal mountaintop sites, and short-term variability of atmospheric extinction can be a serious problem. The speed at which an automated system can move between and acquire stars can increase the accuracy of differential measurements since there would be less time spent between measurements, minimizing changes in atmospheric extinction. The same thought applies to variations in the sky readings. Generally, the atmospheric scintillation, and not the sensitivity of the photometer, places the lower limit on integration times for an automated system. A larger telescope helps this somewhat but the difference between an 8" and 14" instrument might only cut the required integration time in half. It is not practical to operate an automated system on stars which are at the threshold of detection because of the problems with locating and centering the stars.

Finally, for long-period variables it is possible to arrange the observing schedule so that most observations are made close to the meridian, thus providing the smallest air mass.

III. THE TELESCOPE

Photometers have been sucessfully placed at prime, Newtonian, and Cassegrain focusses of the APT's mentioned earlier. All things being equal, photometers are easier to design for higher f-ratios, and the more timid observer may wish to still be able to look through an eyepiece to see if the automatic system can actually obtain the correct star and accurately center it. This feature only adds to the complexity of the system, and will be found to be of little use once the telescope is operational. A large finder scope is more useful in watching the actual acquisition process. If a short focus mirror is used, a Barlow lens may be permanently mounted in front of the photometer.

Of necessity, a (micro)computer is at the heart of an APT. It is tempting to consider an alt-azimuth mount since the computer is at hand to make the complex drive calculations required for such a mount. While it is true that an alt-azimuth mount is slightly simpler to design than an equatorial mount, it is our feeling that the complexity which an alt-azimuth system adds to the control system and software, simply does not make this approach attractive for telescopes smaller than a couple of meters in aperture. Also, the alt-azimuth mount has the poorest performance near the zenith - just the place where photometry is at its best! If one uses stepper motors for tracking (and there are many reasons to do so), the variable tracking rates involved in an alt-azimuth mount almost assure that some unpleasant resonances will be encountered somewhere in the sky.

When an astronomer is at the telescope eyepiece, it is possible to take a few liberties with polar alignment and the orthogonality of the R.A. and Dec. axes; but a computer is not as forgiving! It is wise to make provision for the fine adjustment of the polar axis and the orthogonality of the axes should be assured. It is also desirable to keep the size of the acquisition searches as small as possible.

Portable operation does not appear attractive, as it would be very time consuming to achieve proper alignment, and in general, it defeats the purpose of automated operation. Automatic alignment is simply not worth the bother with portable equipment.

An APT is unusual in that it makes a large number of quick, short movements during the course of a night's work. All of this starting and stopping places special demands upon the telescope design. It is, of course, much easier to move the telescope around quickly if it has a low moment of inertia. A symetrical fork or yoke design is most desirable, and the compact and light-weight Schmidt-Cassegrain optical assemblies such as those made by Celestron, Meade, etc., have much to recommend them in this application. As image quality is of little importance, the thin, short-focus "Dobsonian" mirrors are suitable if used with a Barlow or specially designed photometer, but the "Dobsonian" mount is out of the question. Closed tubes are desirable to keep out stray light which is present at every observing site when the moon is up. The photometer should be baffled so the only light path is through the primary mirror.

All of the short, fast movements tend to induce vibrations in the telescope, and observations can not be made until these vibrations die down sufficiently. The vibrations are minimized and die down most quickly when the natural resonant frequency of the telescope structure is high. A very stiff, relatively light-weight telescope structure tends to have a high natural frequency. Cylindrical metal tubes offer a good combination of stiffness, opacity, and light weight. Square metal tubes are almost as stiff and allow easy attachment of the mount and photometer fittings. Prime focus and Newtonian does not extend behind the primary mirror, allowing minimum length of the fork arms. Prime focus designs require a specialized photometer of small diameter.

IV. MOUNT AND DRIVES

The necessity to make many quick movements requires a strong rigid mount with low inertia. The drives must be able to make these movements occur with a minimum of backlash. It is difficult to eliminate all of the backlash from a telescope using a worm gear as the final drive unless it is heavily preloaded. Two inexpensive drives which have very low backlash are (1) the chain and disc type, and (2) the disc and roller type. The chain and disc drive has been used by one of us (Boyd) with some success, but it presents problems from the elasticity of the chain lowering the resonant frequency. It also introduces a periodic error because of the varying effective radius of the drive sprocket. We feel that the best solution is to use a disc and roller with the final drive disc attached directly to the fork (or yoke) for the R.A. drive, and to the tube of the telescope for the Dec. drive. This would be more ridgid than if attached to even generously proportioned R.A. and Dec. shafts. The discs and rollers should be made of steel or a metal of similar hardness. Such a drive is delicate in that it cannot withstand much mechanical shock, and it may be damaged if forced to slip on the drive roller. It must also be enclosed to prevent dirt from being ground into the disc and roller.

Most large telescopes have separate slewing and tracking motors. The requirements for an APT are different, however, from a telescope designed for photography. In a photographic telescope, high tracking accuracy for long periods of time is a prime requirement, and rapid slewing rates are desirable for operator convenience. Large telescopes are usually equipped with absolute encoders to determine the position of the telescope, but these are unnecessary for the APT. The sudden stopping and starting will place special demands on the design of an APT, but the ability to actually measure the light from a star reduces the requirements for the drives in some respects. Since the APT stays on one star for less than a minute and since it can update the position of the telescope relative to the sky each time a star is centered, high tracking accuracy is not required (although it should be close). More vibration of the telescope is acceptable in photometry than with photography or visual observation, and this allows the size of the steps of the tracking motors to be greater (even as high as one arcsec per step). The step size in seconds of arc is not necessarily the same as the angle of movement caused by vibration. The vibration may be greater or smaller than the step size, depending upon the mechanics of the mount and telescope combined. If the stepping rate happens to match a resonant frequency of the mount-telescope combination, the vibration can be several times the step size, This can be cured by modifying the drive ratio and rate to produce a different vibration frequency.

When using stepping motors, it is desirable to accelerate and decelerate smoothly at the ends of each movement. This technique is called ramping. It is well recognized that stepping motors can run much faster if accelerated smoothly than if a fixed stepping rate is used. In addition, and possibly more important, the use of ramping will result in less vibration in the telescope as it stops. In other words, the acceleration is needed to achieve high slewing speeds, and the deceleration to prevent vibration in the telescope. The system built by one of us (Boyd) initially ran with no ramping but is being modified to include this feature. In that system, a step size of 1.6 seconds of arc was used with a tracking rate of 11.5 steps/second and a slewing speed of about 300 steps/second. This resulted in long travel times on long moves and considerable vibration when stopping from 300 to 0 steps per second in a single step.

There are two methods of improving the performance of a stepping motor in addition to ramping. Both techniques involve special hardware in the drive circuitry. The maximum step rate of a stepping motor can be increased if the time required to establish the drive current in the windings of the motor, as each step is made, can be reduced. The windings look electrically like a resistance and inductance in series. The application of a high voltage pulse (typically 10 times the normal voltage rating of the motor) for a very short period at the beginning of each pulse, will rapidly establish the torque producing current flow. There are many ways to accomplish this, and these techniques can be found in stepper motor manufacturers' literature.

The second technique is called microstepping. Instead of simply turning one winding on and the other off, the current flow is divided either in magnitude using analog techniques or in time using pulse width modulation. This technique will yield smaller steps, less vibration with each step, and generally improved performance. Typically, microstepping will allow the steppers to be operated at about a tenth of the speed which they could normally be run without introducing noticable vibration. Likewise, ramping and high voltage drivers can achieve at least a ten times increase in performance over simply starting and stopping the pulses. Since steppers can be operated over about a 100:1 speed range without special techniques, using both will typically yield a 10,000:1 speed range. To put it in terms of the motion of the telescope, a drive which is not stepped could track at 15 steps/second (time) and slew at 1000 steps per second with 1 second of arc steps. This would give a slewing rate of 16 degrees of arc per minute. While this would be acceptable, more sophisticated drives can provide 160 degree/minute slewing performance with an imperceptable vibration while tracking with step sizes of 0.1 arc seconds, and have less vibration at the end of each move.

Stepper motor drivers are available commercially which can deliver this kind of performance. Even higher performance is available with specially matched driver-motor packages. Our designs have taken different approaches to this problem. One of us (Genet) has chosen to use commercial stepper drivers which have built in ramping features. The other (Boyd) prefers to let the main microprocessor handle the slewing, and simple external hardware to provide the tracking rate. The first method is easier to implement, the second is less expensive.

There are two sets of motions which the system must take into account. The sidereal rotation of the earth must be accounted for at all times. This can be accomplished with either a constant speed motor and differential, or a hardware driver to run the steppers. It is tempting to allow the main processor to perform this function using interrupts, but this method runs into trouble when disc storage is used. Most disc systems do not allow interrupts during disc access, and disc access usually lasts an unpredictable length of time.

Other approaches are possible for the drives, such as using incremental encoders with DC motors, or these in conjunction with steppers. We consider these methods as unnecessarily complex, but they have been used successfully on large telescopes.

V. CONTROL SYSTEM

The control systems on large conventional telescopes are very expensive because the pointing accuracy <u>without reference to any stars in the sky</u> must be a few arcseconds or less. This requires very expensive encoders mounted directly on each axis, as well as many corrections for atmospheric refraction, flexure of the telescope, and a long list of other minor corrections. Because of the ability to search for, acquire, and center a star, the APT can dispense with most or all of these corrections; and there is no need for high-cost encoders. The loop, so to speak, is closed on the star. When making a long move across the sky it might be expected that it will take longer than usual to acquire a star, and it might be advisable to acquire a bright star to prevent locking on the wrong star. Once acquired, however, the system will then know exactly where it is, and movements to other stars in the local area can be made with good accuracy, usually only requiring centering.

In a conventional telescope control system, the need to continually calculate all the many corrections for atmospheric refraction, telescope flexure, etc., keeps the computer very busy, and can require multiple computers or a large minicomputer with a complex interrupt scheme. Programming often needs to be done in either Editor/Assembler or a somewhat primative but fast language such as FORTH. By dispensing with the requirement for calculating all the corrections, the APT can easily make do with a modest microcomputer, and if appropriate steps are taken (pardon the pun) to use hardware stepper motor drivers, programming can be accomplished in a high level language such as BASIC, FORTRAN, or PASCAL without the use of interrupts. The use of a high-level language without interrupts can reduce the software programming effort by perhaps an order of magnitude. In many cases, this could be the difference between success and failure of the project.

When time is more plentiful than money, and when electronic skills are available, it is practical to build one's own drive electronics. Likewise, if one is skilled in assembly language programming, the ramping for slewing may be handled by the main processor. For those who must buy their equipment commercially, it is good to consider all of the required hardware and software before selecting any. Few of the personal computers have good controllers available for stepping motors. The best selection of suitable controllers appears to be available for the STD bus, which was developed for industrial controls. If one is willing to build some of your own cards, a personal computer with plug-in I/O slots such as the S100, SS50, Apple, or IBM PC are suitable.

VI. PHOTOMETER

The photometer in an APT is generally similar to photometers in manual systems, but with a few important exceptions. Obviously, with no one present to change the filters, they would need to be controlled by the computer. This is most easily done by using a small geared stepper. The Hurst steppers are very easy to use, and the even smaller Litton steppers can also be used. One of the filter positions should be opaque, and it should be moved into place while slewing (in case the telescope slews past the moon or a first magnitude star) and at shutdown. If more than one diaphragm size will be used, it will also require a stepper. Changing diaphragm sizes adds to the complexity of the software in an automated system because it changes the search and centering routines. Unless there is a specific reason to change diaphragms, we recommend a fixed diaphragm in the order of 30" to 1' of arc in diameter.

If the photometer is placed at prime focus, the post viewing microscope must be dispensed with, and in practice, there is no real need for one on a Newtonian or Cassegrain telescope. It is not possible to observe the movements of the telescope through a post viewer, and it is not required for centering the object. There is a requirement for verifying the star field in order to locate a suitable place to take the dark readings, but this can be accomplished with a fairly large aperture, medium power "finder". Such an auxiliary scope will be of most use if it can also be used to photograph the starfield surrounding the object. Faint stars near the edge of the diaphragm may be detected in the sky reading. The finder can also be used to detect problems with the search and centering routines, as well as to detect vibration of the telescope.

It is desirable to choose a low dark current photomultiplier tube rather than to attempt to cool the tube. Cooling usually leads to condensation problems, which can do much more harm than the benefits provided by cooling the tube. In this same vein, it may even be desirable to place very small heaters (low power resistors) near the primary and secondary mirrors. Remember that a diffraction limited image is not required, but a mirror which is partially covered with dew will be very troublesome. Very slight warming of the photomultiplier head may actually help to eliminate annoying moisture problems. Since the photometer will usually be located at one end of the telescope, its inertia will be of great importance, and the elimination of unnecessary hardware will be an advantage.

Our experiences have shown that voltage to frequency (V-F) converters interface well with computers, are linear and reliable, and have a wide dynamic range. Sampling type A-D converters will not intergrate the varying signal from the photometer. Even if these are used by taking a large number of readings, it would take at least a 12-bit converter to equal the performance of a cheap V-F converter chip. Both of us use photon counters, but we occasionally question whether the benefits warrent the extra problems involved. A photon counter or V-F converter can be easily interfaced to a parallel port with counter chips such as the Motorola 14553 or 14534, or directly to the bus with various counter/timer chips.

Because of the speed at which an APT works, drift of the components is less of a problem than with manual photometry, but good design practices should still be used. A magnetic shield is a necessity in the presence of stepper motors since the magnetic field changes between measurements. A solid-state photometer, such as the OPTEC unit, could also be used in an automated system. For these units, the V-F technique is certainly recommended.

VII. SOFTWARE

In any complex, real-time control system, the easy part is the hardware. *Be Warned!* The hard part is the software. In designing a system and making the various tradeoffs between hardware and software, we strongly recommend that no effort be spared to make things as easy to program as possible. The most dangerous words of all are "Oh, we can take care of that in software". This is particularly true if one is trying to correct a poor mount or a drive with backlash or periodic error. The software to drive an APT could be written in almost any language, and could be made to work on almost any computer, but if a great amount of consideration is given at the start of the project as to the exact requirements and objectives, a lot of backtracking will be prevented. Frequently a few external chips can eliminate a large portion of the software, or can eliminate the need for high accuracy timing by the computer. This will save large amounts of programming time.

The choice of languages will depend on several things. First, does the language have the capabilities to do the job? Several languages offer all of the requirements. BASIC, FORTRAN, and PASCAL all can handle trancendentals (desirable but not absolutely necessary), and good implementations will handle both floating point and integer arithmetic (very desirable). File handling capability on disc is essential for a practical APT. Interpreters will be strained to keep up but could be used. In general, the choice of languages will be determined by what is available for a particular computer if an existing computer is used. Otherwise, it is wise to stick with a machine which has a good selection of quality software to choose from. The CP/M operating system probably offers the best array of fast compilers of any, and there are many suitable machines. There are both STD and S100 compatible machines which work with CP/M. If you prefer BASIC, the Microsoft MBASIC offers a separate interpreter (for software development) and compiler (for program execution) which are compatible and run under CP/M. If assembly language routines are required, languages other than BASIC might be most desirable because of more elegant and simpler ability to link to machine code than BASIC's USER command.

Even under the best of circumstances the software development will not be an easy task. However, it can be reasonably undertaken if it is treated in a rational manner and code developed in modules to perform each of the required tasks. A decision must be made early in the system design as to how much data reduction will be done in real time, and exactly how automated the system will be. It is also important to define the file structures for the input and output files early in program development.

The software task for an APT is sufficiently immense that thought needs to be given to breaking it into separate programs. There are undoubtedly numerous ways that this could be accomplished but the following diagram might be considered:

(1) Build a file containing groups of stars to be observed, including comparison stars, check stars, and sky reading positions. This may be manually entered and only updated as required. Each star requires:
- a. Unique name (usually HD number)
- b. Coordinates for specific epoch
- c. Nominal B and V magnitudes (for verification)

(2) Start the run for the evening:
- a. Calculate beginning and ending of twilight
- b. Calculate lunar position (to avoid moon)

c. Open file of star groups
d. Determine if star group is observable
e. Calculate time of meridian transit (observe then if possible)
f. Eliminate groups which are near moon
g. Insert bright navigation stars as needed
h. Precess observable groups to current epoch
i. Calculate heliocentric correction for variables at the time of expected measurements (if desired)
j. Build file of groups to be measured containing the time to start measurement, position, expected B-V color
k. Rewind file

(3) Open Observatory
  a. Check external detectors for high wind, precipitation, and sky brightness
  b. Open observatory roof
  c. Turn on power to drives
  d. Move to first navigation star
    1. calculate position from coordinates
    2. slew, search, center
    3. verify color match

(4) Make Measurement
  a. Wait for time match (usually meridian transit)
  b. Read each star (order: check, comp, sky, variable)
    1. search and center
    2. read in U , B , V
    3. calculate zenith angle
    4. store universal time, heliocentric corrected date, zenith angle, instrumental magnitude for each color to data file
    5. check if conditions ok,close down if not
  c. Repeat 2 above in reverse star order
  d. If not end of file get next star group and slew

(5) Close Observatory
  a. Home telescope, shut off drive power
  b. Close observatory roof
  c. Close all files

(6) Data Reduction
  a. Open data file for read
  b. Calculate extinction factors from night's data (use comparison and check stars)
  c. Reduce data to delta magnitudes
  d. Save reduced data in appropriate files for each star
  e. Close all files and wait for next day

Many of the algorithms needed for doing the tasks shown above will be dependent upon the hardware used to implement the system. We have found that some of the following algorithms work well.

Slewing can be handled by making each move in two segments, the first a diagonal move with both motors running for an equal number of steps; the second move with one motor running for the remaining number of steps. Therefore, the computer need only pass a single number of steps plus a direction (one of eight) to the stepper controller, whether it be hardware or machine language. The high-level language can calculate the values for each move and keep track of the current position. Ramping can be handled completely by the controller. Making the single direction move last results in a lower velocity of the telescope prior to stopping (by the square root of two). There is actually a disadvantage in making the move in a single segment with one motor running slower than maximum and having them arrive at the end of the move together: by keeping the motors together, a single microcomputer can easily control both steppers. With external hardware controllers, the motors will run independently, but will complete the move in two segments.

Searching can be handled by a square spiral pattern, in which the size of each side is incremented by a constant on opposite corners. The constant should produce a motion about half the size of diaphragm. This insures sufficient overlap on each loop so that a star will not be missed in the presence of vibration or small errors in the drive. The pattern shown below would be typical of the routine:

20	21	22	23	24	etc.
19	6	7	8	9	
18	5	0	1	10	
17	4	3	2	11	
16	15	14	13	12	

At each numbered position a reading would be taken for about 1/10th of a second to determine if a star is present. In a decently designed system, the star will always be found within ten loops, but provision must be made to exit after a reasonable search if the star isn't found. Clouds cause that!

Centering is no more difficult. The most obvious method is to make a cross shaped pattern, checking whether the star is in or out and then dividing each by two. This method is slow and vibration of the telescope can give false centering. A much simpler way is to move the telescope to four corners, each the square root of two times 1/4 the diameter of the diaphragm. This requires only moving 1/4 the diameter of the diaphragm in both axis simultaneously, as shown:

1		4
	0	
2		3

A reading is taken at each position (1-4) and the following logic applied. If all spots indicate a star is present, the star is centered. If one spot is outside the diaphragm, move toward that direction 1/4 the diameter of the diaphragm in both axes. If two adjacent spots are outside the diaphragm (as 1 & 2), then move on 1 axis 1/4 the diameter of the diaphragm. If three spots are outside the diaphragm, move away from the one which is in the diaphragm by 1/2 the diameter of the diaphragm. In each of these cases, repeat the process until all four stars are in the diaphragm. If an invalid combination occurs, such as showing spots 2 and 4 out with 1 and 3 in, the process should be repeated. Scintillation can cause that and it is common on faint stars. If a complete miss occurs, return to the search routine. On the second try this should either result in success, or determine the star to be unobservable (clouds). The values 1/4 and 1/2 may not be optimum, but they are easy to calculate. This centering process does not place the star in the exact center of the diaphragm, but it will be close.

It is suggested that a fixed, short integration time be used on all readings (perhaps 0.1 second) and then as many of them be made as required for the actual measurement integration times. A 0.1 second integration will allow a sum-of-squares computation to be made while making the readings (if desired) and also allow a statistical evaluation of the quality of each reading. If the reading proves to be poor statistically, it may be repeated, reducing the errors caused by scintillation. The other advantage is that the hardware counter used need only count the maximum number of pulses the V-F converter of photon counter can put out in the shorter period. This will simplify both hardware and software. Use care in generating the time base for the counter. Be sure that if a loop in a high level language is used, that it does not vary in speed with other factors. Reading a hardware timer with a high level language can also result in unpredictable times. Machine language timers or purely hardware timers with a "count complete" flag are safe. When searching or centering, it is important to select a decision threshold (star present or not) which will be reliable. That threshold must be, of course, greater than the sky readings. It has been found that the most reliable threshold will be slightly less than half the difference between the expected value of star reading and the sky reading. Scintillation produces greater variation in the value of the star reading than in the sky reading. For most applications, simply using a value of twice the sky reading will prove acceptable. A threshold must be selected which will not lock onto a faint nearby star, or miss the desired star entirely. This problem is the major factor limiting the faintest star which may be measured automatically. In practice, a star which gives only four times the sky reading can be easily acquired. Usually, searching and centering should be done with the filter in place, providing the best ratio of star-to-sky reading. This will depend on the color index of the star and the local sky conditions.

Storage of data files can be in any medium, but if data is to be made available to others in machine readable form, it is suggested that the most standard medium is a single-sided, single-density, 8" floppy disc with IBM 3740 format using straight ASCII code. CP/M and many other operating systems can produce this format. It should be a project for the I.A.P.P.P. to set up data interchange standards for microcomputers. Files might also be transferred reliably by modem, but at greater expense. Manual entry of data from printed output is much more error prone than direct machine-to-machine interchange. The only files which are likely to require exchange are the final reduced data, and possibly the input data in the form of a datalog.

The automated system will need to know what long-period variables to observe. We feel that a computerized "Catalog of Long-Period Variable Stars" needs to be developed. This catalog could be used by anyone interested in observing these stars photoelectrically, whether their system is automated or not. The catalog would contain the needed information on the variable, comparison, and check stars in a standardized format. A computerized version of the Yale Bright Star Catalog might be a good starting place. Information from the AAVSO would also be very helpful. In any event, lots of work will be required to select appropriate comparison and check stars, etc., and there is no need for a number of persons to independently re-invent the wheel on such a Catalog.

The Catalog would, hopefully, contain many more stars than could be observed by any one telescope at one location. To select and order the stars to be observed by a particular system at some given latitude, a "filter" program would be needed. One could specify an acceptable range in declination, minimum and maximum magnitude, and other pertinent parameters. A search would then be made through the catalog for all star sets meeting the requirements. Ideally there would still be more stars selected than could be observed. Finally, an efficient observing sequence algorithm would be used to maximize useful information. An example of a computerized catalog and selection program is the area of eclipsing binary stars was given by N. Hasler (1982). It is a good one and has been frequently used among the very active BBSAG membership.

VIII. CONCLUDING REMARKS

The automatic photoelectric telescope capable of observing a large number of variable stars every clear night has been technically feasible for some 15 years, but only within the last few years have the capabilities of microcomputers increased (along with their falling prices) to the point where control by a single, low-cost microcomputer is possible. The work required to actually design and build such a system remains formidable. One of us (Boyd) has spent all available spare time for the last four years to put together a system that is just now beginning to function. Many lessons were learned along the way (most of them the hard way), and much more will be learned before it is all over. Some of the ideas developed for automated systems for observing short-period variable stars (systems by Skillman and by Genet) appear to have application in systems intended for long-period variable stars, and vice versa.

As there have been a number of persistent rumors of similar systems being thought about or actually developed, it seemed best to make known our views on this topic. Certainly better approaches than we have described here will evolve over time, as this field is in its infancy.

REFERENCES

Genet, R.M. and Sauer, D.J. (1983) "Telescope Control with the STD Bus", Microcomputers In Astronomy, Editor: R. Genet, Fairborn Observatory Press.

Hassler, N. (1982) I.A.P.P.P. Communications, 10, 35.

McNall, J.F., Miedaner, T.L. and Code, A.D. (1968) Astronomical Journal, 73, 756.

Skillman, D.R. (1981) Sky and Telescope, 61, 71.

Worden, S.P., Schneeberger, T.J., Kuhn, J.R. and Africano, J.L. (1981) Astrophysical Journal, 244, 520.

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Several years ago, I decided to build the largest telescope I could afford and mount it in an observatory in my back yard. At the time, I was in the habit of lugging a 6" f/8 reflector in and out of the house for observing sessions. In the time it took to set-up and align this telescope, either frostbite would set in, or, with the rapidly changing weather conditions here on the leeward side of Lake Erie, you would set-up the telescope and upon returning with the eyepieces, find the star-studded night had dissolved into cloudy gloom.

The idea of having an observatory was very appealing. Though nothing could be done to change the local weather conditions, an observatory would eliminate the physical drudgeries associated with set-up, and also solve the storage problem. Little did I realize that the decision to build an observatory would not only solve these problems, but would result in a working photoelectric observatory.

My major interests at the time were the planets and double stars, so I selected a Cassegrain to be the main instrument. This decision was the result of several years of observing with a small refractor and the 6" reflector. The long focal length of a Cassegrain would be ideal for my interests and when combined with an observatory, lend some creature comforts as the observatory walls can be built high enough to serve as windbreaks.

Not being an optical technician (though someday I would like to try my hand at mirror grinding), I purchased a mirror set from Cave Optical. These mirrors were very expensive and if I could have ground them, a substantial savings would have been realized. Mirror mounts by Novak completed the fiberglass tube assembly.

A fork mount was selected to eliminate the awkward roll-over technique necessary with a German equitorial mount to follow a star as it passes through the meridian. The fork (shown in Figure 1) was constructed of plywood, using seven layers of 3/4 inch thick plywood to build up to the desired thickness using the approach described by Mr. Bruce Lundegard (1976). The seven layers are glued and reinforced with 1/2 inch diameter bolts. Shafts of

Figure 1. This view shows the telescope tube assembly with the photometer head attached, the laminated plywood fork and the fabricated drive unit. In the background are the supporting electronics and the chart recorder.

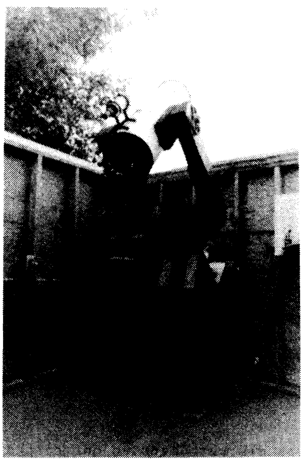


Figure 2. Looking through the observatory door, one sees the telescope and its mount. On top of a roll-around cabinet are the electronics and chart recorder. Electrical outlets are located on the observatory sidewalls as shown.

1-inch diameter are used in the declination axis to mount the tube assembly to the fork. These shafts are glued to wooden cleats also made from laminated plywood. Ball bearings are used in the fork to accept the 1 inch shafts. To help stabilize the declination axis, a wooden drag mechanism was made which is also adjustable.

Since the telescope was to be permanently mounted, the support design had to be substantial. See Figure 2. The drive unit was fabricated out of steel plate and encloses the motor drive by Schmidt Associates, the flange mounted bearings, and the polar shaft. Provisions were made for latitude adjustment by use of a push-pull bolt arrangement. This drive unit sets on a pier made from steel pipe welded to steel plates which bolt to the drive unit and the floor of the observatory. Once mounted in the observatory, a hole was drilled in this assembly and the supporting pipe was filled with sand to help dampen vibrations. If I were to do it over, I would eliminate this pipe fabrication for a good solid pier of concrete.

Once the telescope was completed, my energies turned to the observatory. My decision to build this telescope and the observatory was influenced by a 10' x 10' pad of concrete lying in the back yard. It had been intended for one of those little metal buildings everyone seems to have. However, before my wife and I had purchased one, a severe storm came through and demolished several of our neighbors' metal sheds and this idea was put aside. Now the cement pad sat there, temptingly!

When it comes to observatories, there are only several basic designs to consider. These are the rotating dome, rotating building, and roll-off roof designs. The design of a roll-off roof observatory is simple, and the construction straightforward. No special fabrications, heavy rolled rings, or (most importantly) exceptional carpentry skills or tools are necessary. Also, it doesn't call attention to itself as a fancy dome might: an important consideration if one lives in a "suburban-turning-urban" area. However, probably the most important reason for selecting the roll-off roof design was the large expanse of sky it provided. I'm sure star identification would be much more difficult if only a narrow slit of the sky was available. See Figures 3 and 4.

The observatory details began to take shape in my mind and simple sketches of the building were made. As plywood is available in four by eight foot sizes, the observatory was to be eight foot square. This helped to keep building costs down, although I now regret not taking advantage of the whole concrete slab and building to a ten foot square dimension. The sketches were made, revised, and revised again. As funds became available, two-by-fours and plywood sheets were purchased and hoarded away in the garage. When the weather broke, I spent evenings in the garage assembling the wall sections and reviewing my inventory. Also, the design became more resolved during this period. The long list of problems like, how will the roof be built, how will it move, where will the wheels or track come from were carefully thought out during this time and one by one, all these problems were overcome.

Finally, vacation arrived in July and the wall panels were carried out to the slab and the observatory was begun. Lifted into place and tacked with nails, the walls were

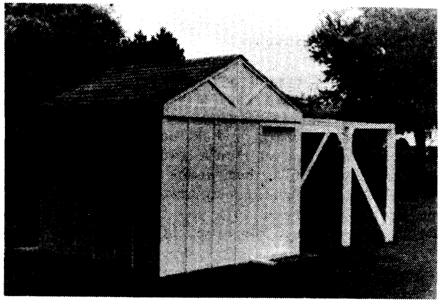


Figure 3. Rolling Ridge Observatory as it sits in my backyard. The peaked roof design was selected to accomodate snow loadings and to complement other structures in the neighborhood.

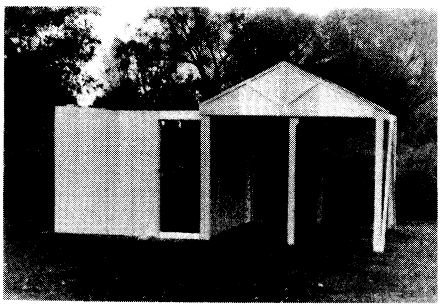


Figure 4. The observatory is shown opened. Through the door, the telescope and mount can be seen. The area around the outriggers can be enclosed to make a warm room or storage area.

quickly set. Once the wall was positioned, the concrete pad was drilled to accept lag bolts and the walls were then tied down. Plywood was installed around the exterior and the building began to take shape. The roof was constructed in place and then jacked up for installation of the wheels. A peaked roof was built to accomodate snow loadings (this roof rolls well with six to eight inches of snow on it as long as the track is clean). The wheels are of solid metal construction and do not pivot around the axis, but are fixed to roll back and forth in one plane. I couldn't find a track or channel suitable for the roof to roll on and had to settle on flat bar stock. Sections of bar were screwed down on top of the outriggers for the roof wheels to travel on. Another length of bar was secured vertically to keep the wheels on track. It was probably more expensive to construct this L-shape track than to use a channel section, but, one must use what is available at the time.

Once completed, the roof was given several test rolls and upon sucessful operation, the telescope mount was carried out to the observatory and set into place. The drive unit, fork and tube assembly were quickly installed. Then, that evening, August 25, 1979 - first light!

In the weeks that followed, the 8" Cassegrain proved itself to be a good performer. Every clear night was spent trying out the telescope on the planets and my favorite double stars. It was really great to be able to walk out back, unlock the door, roll the roof aside, and view the heavens in comfort. After a year had passed of pleasant viewing, I felt that something more should be done with the observatory.

Skimming through back issues of "Telescope Making" magazine led to an article by Russ Genet *et al* (1980) entitled "The PEP Gang". Here I found pictures of amateurs who, using a technique called photoelectric photometry, were making meaningful observations and contributing scientifically useful data. I found the combination of telescopes, little black boxes, meters and chart recorders more than interesting. Having a deep interest in electronics, I dug out the referenced material and read everything I could on this type of astronomy. I purchased Wood's book, the PEP manual from the AAVSO, and began corresponding with Russ Genet. Anyone who has met Russ is aware of his ability to offer a tremendous amount of encouragement and direction. Through Russ I met Art Stokes, who after a short note, responded with a package of ideas in the form of sketches and drawings of photometer heads, power supplies, and amplifiers. After reviewing all this data, I felt that in keeping with the tradition of the observatory, the photometry gear should be homebuilt. Maybe someday I will purchase one of the many excellent commercial units available, however the experience of homebuilding has always given me a better understanding of what is going on and how things function.

Work was begun on the power supply using a pretty good "junk box" of electronic components accumulated after 25 years in Ham Radio. The tube-type power supply designed by Stokes was selected since I had all the vacuum tubes with the exception of the 6AG5 tube (which turned into an experience in itself when I went to purchase one). In this day of solid-state devices, vacuum tubes are getting hard to find and once found, *expensive*! Another experience was locating a suitable transformer. It would seem that everytime I mentioned a transformer with a secondary of 400 to 500 volts, the clerk would wheel out a cubic-foot mass of iron on his dolly. Finally, a suitable unit was found and the supply was completed. I should state here that anyone who begins a project like this should have previous experience in wiring electronic circuits and a healthy respect for the voltages involved. This supply provides an adjustable output from -400 volts to -1200 volts. The regulation of the output appears to be excellent and well suited for my purpose. The low voltage supply is one designed by Dick *et al* (1978) and supplies ±7.5 volts D.C. to the amplifier. The supply is fused and a pilot light indicates when the unit is operating. A single toggle switch is used to turn on both the high and low voltage supplies simultaneously. The high voltage output is read on the panel meter and is adjusted by the potentiometer (R1) mounted on the front panel. See Figure 5.

Once the power supply was completed, work on the amplifier was started. Again, the search for components began. Since the CA3130 and the 741 were readily available and only one selector switch is required, the amplifier design by Dick *et al* (1980) was selected (figure 6). Good quality ceramic switches are recommended in these circuits, and it turned out not to be a problem locating relatively inexpensive ones. Another concern was the input resistors. I was only able to purchase 5% tolerance units, but these have worked out well since I avoid switching inputs between the variable and comparison stars, and only do differential photometry. Don't expect that you can purchase all the items necessary for a project like this at one or two stores, be prepared to hunt all over and even look to mail order houses for components.

The front panel of the amplifier cabinet has a pilot light, meter, input selector switch, zero adjust potentiometer, and two toggle switches. The first toggle switch (SW2) increases the time constant of the amplifier, smoothing out the signal variations if the star exhibits strong scintillation. This also allows easier reading of the panel meter and the chart recording. If the photometer is to be used to observe occultations, this switch would be left open to catch the rapid change in the light signal. The other switch (SW3) doubles the meter sensitivity, and is used only when the observed signal indicates at the bottom end of the meter scale. Though the amplifier circuit was built on a small 3" x 4" board, it was mounted (for appearance sake) in a Radio Shack cabinet which is similar to the power supply (Figure 9). It was later found that the pilot lights mounted on the front panels of both units not only indicated when the units were operating, but also provided adequate illumination to read the panel meters.

The photometer head was saved for last, but having the power supply and amplifier completed provided additional incentive to get on with the project. As shown in Figures 7 and 8, the photometer head is constructed very simply using a 3" x 4" x 5" metal box as the housing. The aperture plate and the flip mirror holder were cut from small pieces of aluminum and epoxied to dismantled Radio Shack rotary selector switch mechanisms. The aperture plate has only two positions, a large opening fitted with crosshairs for star acquisition, and a smaller aperture used for making the measurement. This aperture was originally to be 1/32" in diameter, providing a view of 50 arcseconds with my system; however the smallest drill I could locate was 1/16" in diameter. This provides a 100 arcsecond field of view, and while on the large size, it compensates for any drive errors and makes tracking easier. It has proven satisfactory for the type of stars being studied.

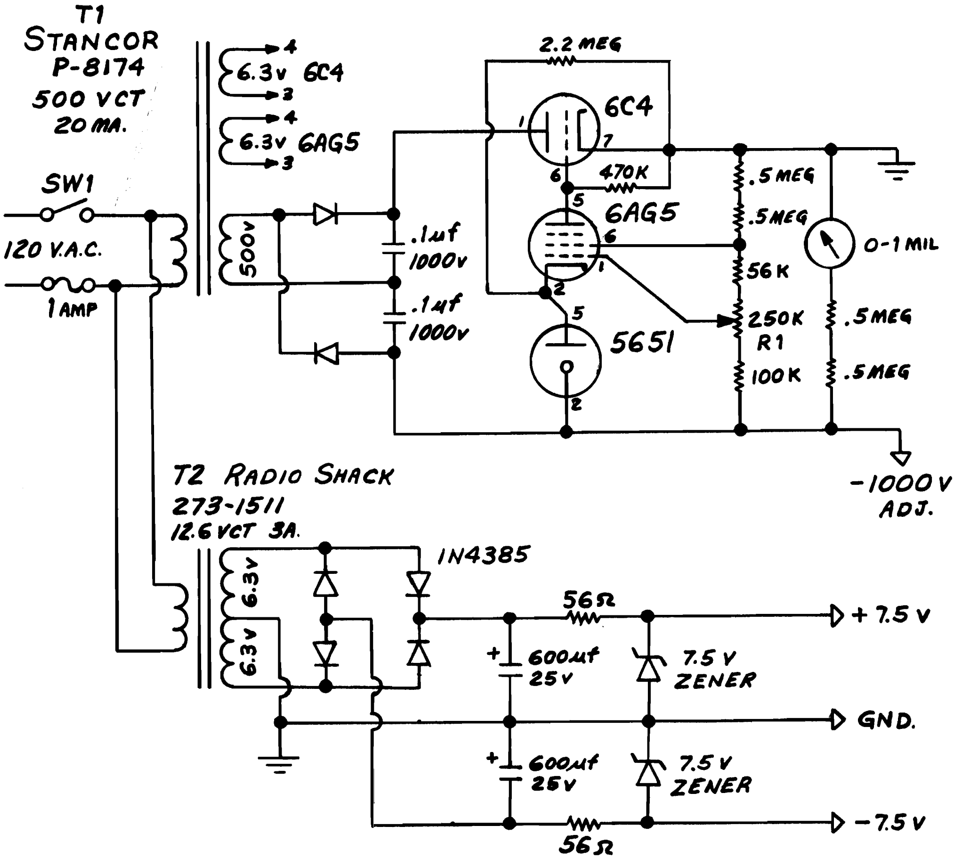


Figure 5. The high and low voltage power supply circuit.

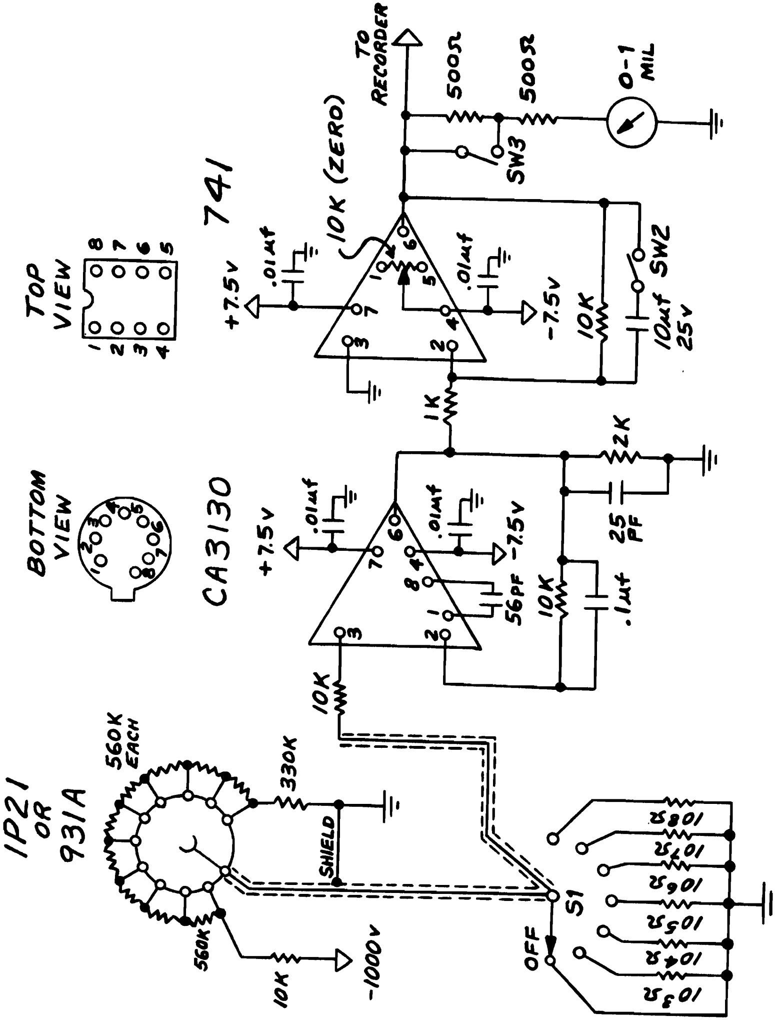


Figure 6. The photomultiplier tube socket wiring and the amplifier circuits.

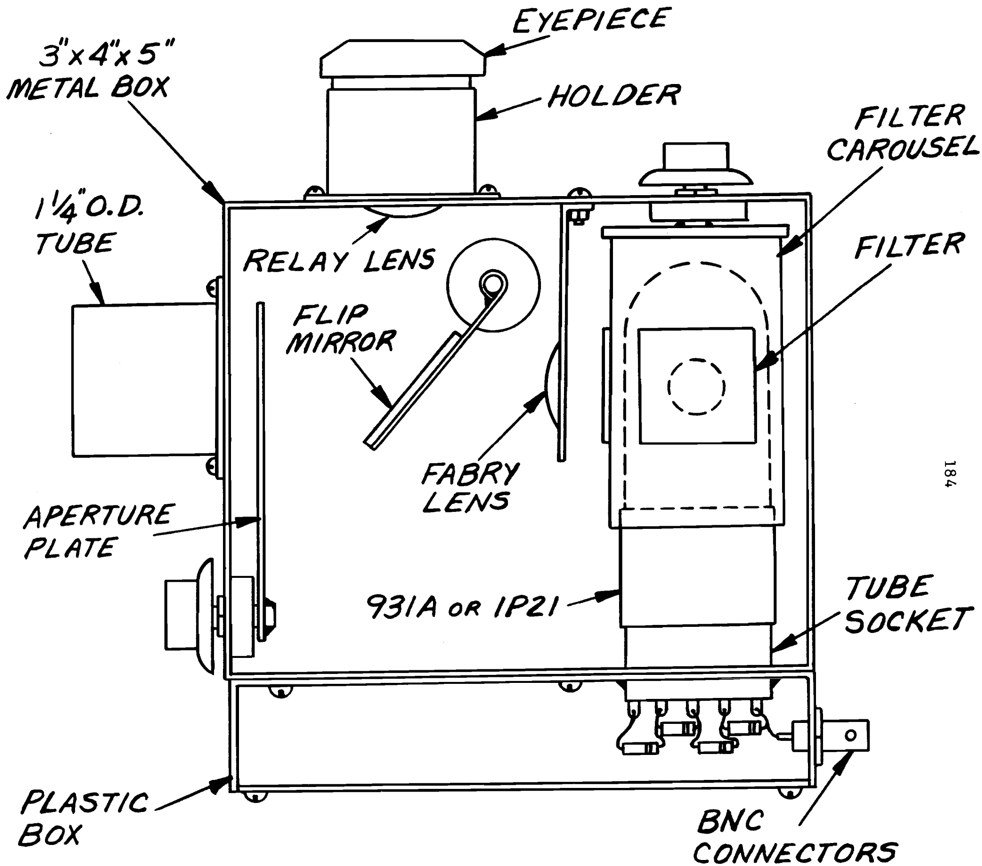


Figure 7. The Stokes photometer head showing all of the main components.

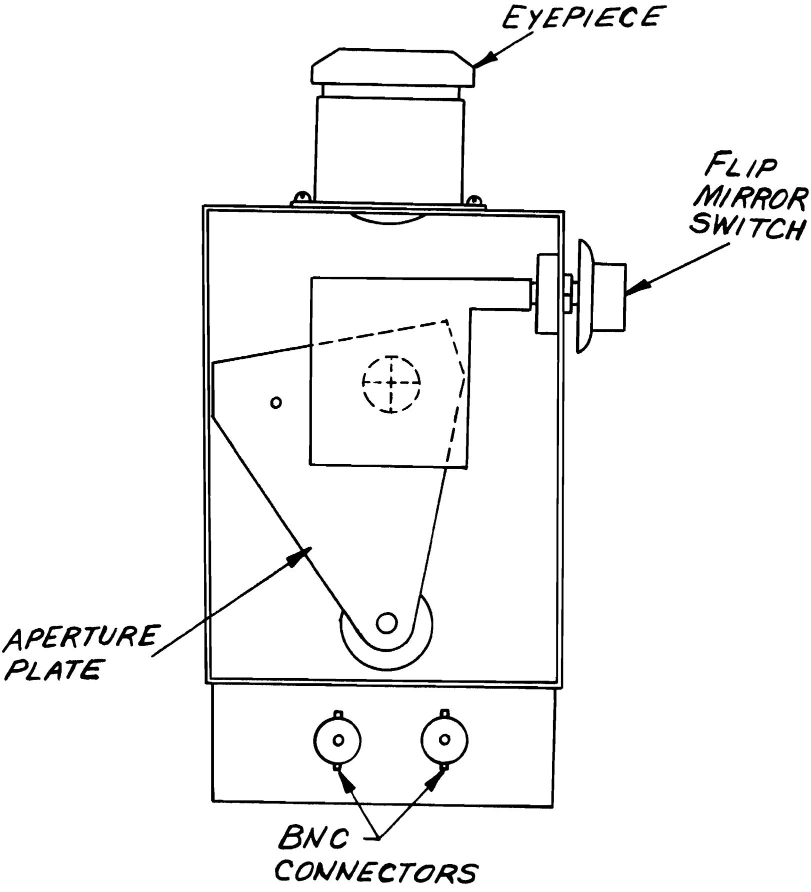


Figure 8. This cross-sectional view of the photometer head shows the aperture plate and flip mirror arrangement.

The flip mirror is a front surface mirror purchased from Edmund Scientific. Careful cutting of this piece yielded four pieces approximately 1" x 1½". One of the mirror pieces was glued to the piece of aluminum on the flip mirror switch mechanism. The relay and Fabry lenses were also purchased from Edmund Scientific. A relay lense of 24mm focal length works well with a 12.5mm ocular. This lense was cemented directly to the box underneath the eyepiece holder. The Fabry lense worked out to be 85mm in focal length. This lense allows the focused star light to spread out to an approximate 0.210 inch diameter spot on the photomultiplier tube. Code's advice is not to have a spot smaller than 1/8 inch nor greater than 1/4 inch in diameter. Results with the photometer head indicate these lenses are performing properly.

The filter carousel was made by cutting off the corners of an aluminum chassis and mounting these pieces to an aluminum plate which had been epoxied to a rotary switch mechanism. Aluminum putty was applied where the pieces butt together to make a one-piece unit. One-half inch diameter holes were put in three sides of the carousel. The fourth side was left blank and is used as a dark slide to protect the photomultiplier tube during daylight hours (a hole may be put in this side to allow use without a filter). The U, B, and V filters are 1-inch square Schott glass filters glued over the appropriate openings in the carousel.

Bolted to the bottom of the photometer case is a plastic box containing the photomultiplier tube socket and the voltage divider network. Type BNC connectors are used for the cable connections.

All the major components of the photometer head can be cut from aluminum using hand tools. However, the one nagging problem was how to make the eyepiece holder and the tube which connects the head to the telescope. I solved half of the problem by purchasing a 1¼ inch metal drain tubing from the local plumbing house. If you cut a section off of the large end, it provides a snug fit for the eyepiece, and a section off of the small end will mate well with the telescope's eyepiece holder. The remaining problem was how to mount these pieces to the head. Searching through the junk box, I came across some old octal tube sockets. These are not the molded type of units available today, but a three piece design consisting of the tube socket, a retaining plate, and a wavy spring which holds everything together. After removing the spring, the retaining or mounting plate comes free. This piece provides a solid plate on which to solder the tube pieces. Once everything was shown to fit properly, the assemblies were removed from the box and all were given several coats of flat black paint. Taking care to ensure all the components fit and were aligned, the photometer head was reassembled, the box buttoned up, and the head was carefully tested in a darkened basement.

Once the filters arrived and a Heathkit strip chart recorder was constructed, every thing was carried out to the observatory and set up (see Figures 10 and 11). As darkness fell, the telescope was pointed at a bright star. It was centered in the diaphragm and the mirror flipped, allowing the star light to fall on the photomultiplier tube. The chart recorder's pen immediately swept across the chart paper and began recording the deflection. After a half hour or so of getting used to operating the equipment, the telescope was aimed at 31 Cygni and photoelectric observations at Rolling Ridge Observatory were finally begun.

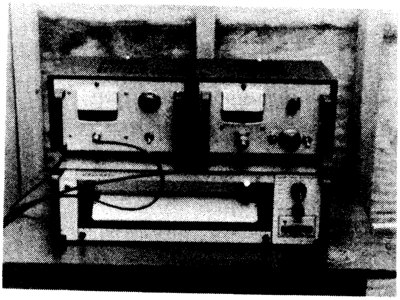


Figure 9. The power supply and amplifier sit on top of the strip chart recorder for convenience during observations.

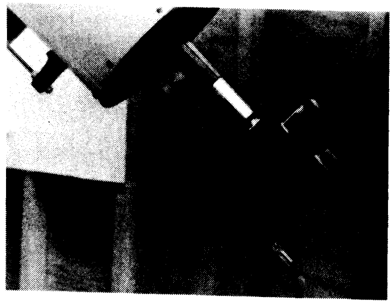


Figure 10. The completed photometer head is shown attached to the telescope. The control knobs and cables are conveniently placed during observations

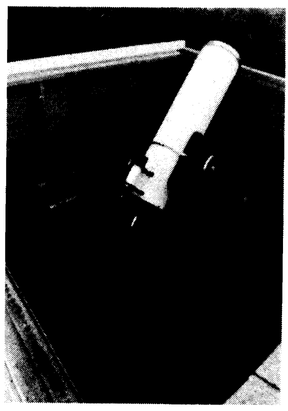


Figure 11. Looking down from the roof of the observatory one gets a complete view of the system. This compact observatory allows efficient use by one or two people while observations are being made.

In conclusion, I wish to thank all of those who gave so much encouragement and advice. Without you, I may never have stepped into an observatory equipped for photometry and experienced the soft glow of pilot lights and the soft scratching of the chart recorder pen. Thanks!

REFERENCES

Boyd, R.W. (1981) IAPPP Communications, 6, 4.

Code, A.D. (1963) Photoelectric Astronomy for Amateurs, Edited by F.B. Wood, New York, Macmillin.

Dick, R., Fraser, A., Lossing, F. and Welch, D. (1978) J.R.A.S.C., 72, No. 1, 40.

Genet, R.M. (1979) Telescope Making, 5, 28.

Genet, R., Hall, D., Henry, G., Kalish, L., Landis, H., Louth, H., Lovell, L., Mattei, J., McFaul, T., Minton, R., Renner, T., Stokes, A., and Walsh, R. (1980) Telescope Making, 7, 38.

Hopkins, J.L. (1982) AAVSO Newsletter, 3, No.1, 12.

Lovell, L.P. (1981) IAPPP Communications, 6, 19.

Lundegard, B. (1976) Sky and Telescope, 51, 56.

Reisenweber, R.C. (1980) Telescope Making, 8, 42.

Reisenweber, R.C. (1981) Telescope Making, 10, 8.

Stokes, A. (1980) In paper presented at IAPPP Symposium, Dayton, Ohio.

Stokes, A. (1981) In paper presented at IAPPP Symposium, Dayton, Ohio.

15

NIGEL OBSERVATORY

LUCIANO PAZZI

39 Buxton Avenue
Nigel, 1490
South Africa

An observatory near a large city, with its light and atmospheric pollution, may not seem to be the ideal site to carry out significant astronomical research. However, dark mountaintop sites are not readily accessible and telescope time has to be booked well in advance and generally only for short runs, making the study of certain long-term phenomenon particularily difficult. On the other hand, the amateur's backyard observatory is very accessible and available at all times; and with the right choice of observing programs, the problem inherent to a city location can be overcome.

Nigel Observatory is situated in my backyard on the south-western periphery of the town of Nigel in the Transvaal. Being nearly at the edge of town, it affords relatively dark skies to the south and west. A 4-meter dome with motorized shutter houses a 12¼" Newtonian telescope on a very sturdy German equatorial mount (see Figures 1 and 2). The f/6 primary mirror was ground and polished at the Johannesburg Planetarium. Slow motions are provided on both axes via DC motors, and a R.A. synchronous motor (controlled by a square wave oscillator) provides compensation for the motion of the earth. The position of the telescope can be read on both axes directly off the analogue setting circles, or displayed digitally via optical encoders. A 4-inch f/10 Newtonian reflector and a finder telescope with illuminated reticle ride on the main telescope.

Until a few years ago, the main bulk of the observations consisted of occultation timings, and it was for improving time accuracy that the idea of building a photoelectric photometer came about. Enquiries were made to various organizations and private individuals seeking advice. Advice and encouragement were certainly not lacking, and with them came variable stars - never before attempted at Nigel Observatory! With a grant from Powerlines (PTY) LTD., the construction of the photometer began in earnest. By May 1982 it was ready for first light, and the photometer counted its first photons at the end of that month; but by then it was realized that the head was too clumsy to be used successfully, and a new head is now ready for testing.

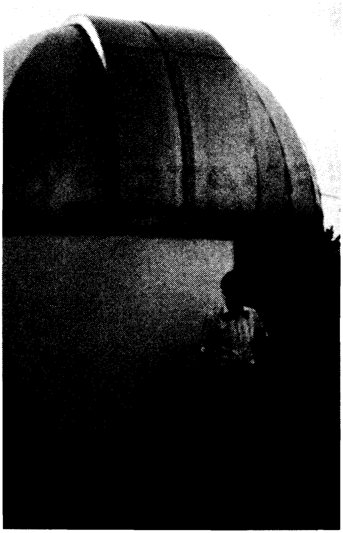


Figure 1. The author stands outside Nigel Observatory.

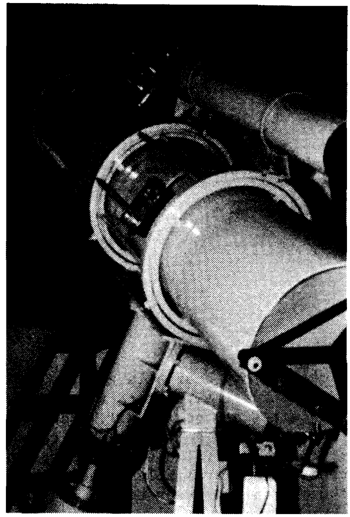


Figure 2. The 12¼" f/6 Newtonian telescope is shown.

The photometer shown in Figure 3 is of conventional design. That is, light from the telescope is collimated by a Fabry lens and passes through the appropriate filter before falling on the photocathode of an EMI 9781A side-window photomultiplier tube. The signal is carried to a DC amplifier whose output is converted to a digital display by an Intersil 7107 A/D converter. The DC amplifier also has output for a strip chart recorder and a BCD output which can be interfaced with a microcomputer. The HV power supply is modelled after the design by Stokes which was described in the previous chapter (see Figures 4, 5, and 6).

The observing program now consists mainly of variable star measurements. A total of 87 stars is currently being observed, mostly with very far south declination to take advantage of the dark skies to the south of the observatory. With the help of Dr. Hall, a number of stars have been selected for observation, including suspected variables and RS CVn type stars.

As a matter of interest, there are no plans to use the photometer for timing occultations. Plans for the future include semi-automated data acquisition and processing utilizing a microcomputer, and possibly automated object acquisition using setting circle encoders and the microcomputer.

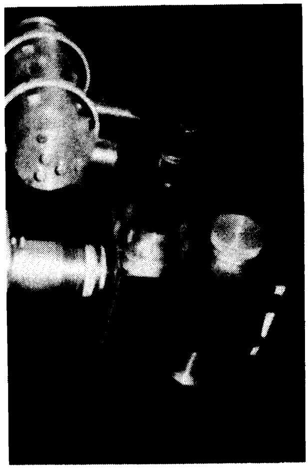


Figure 3. A close-up view of the photometer head.

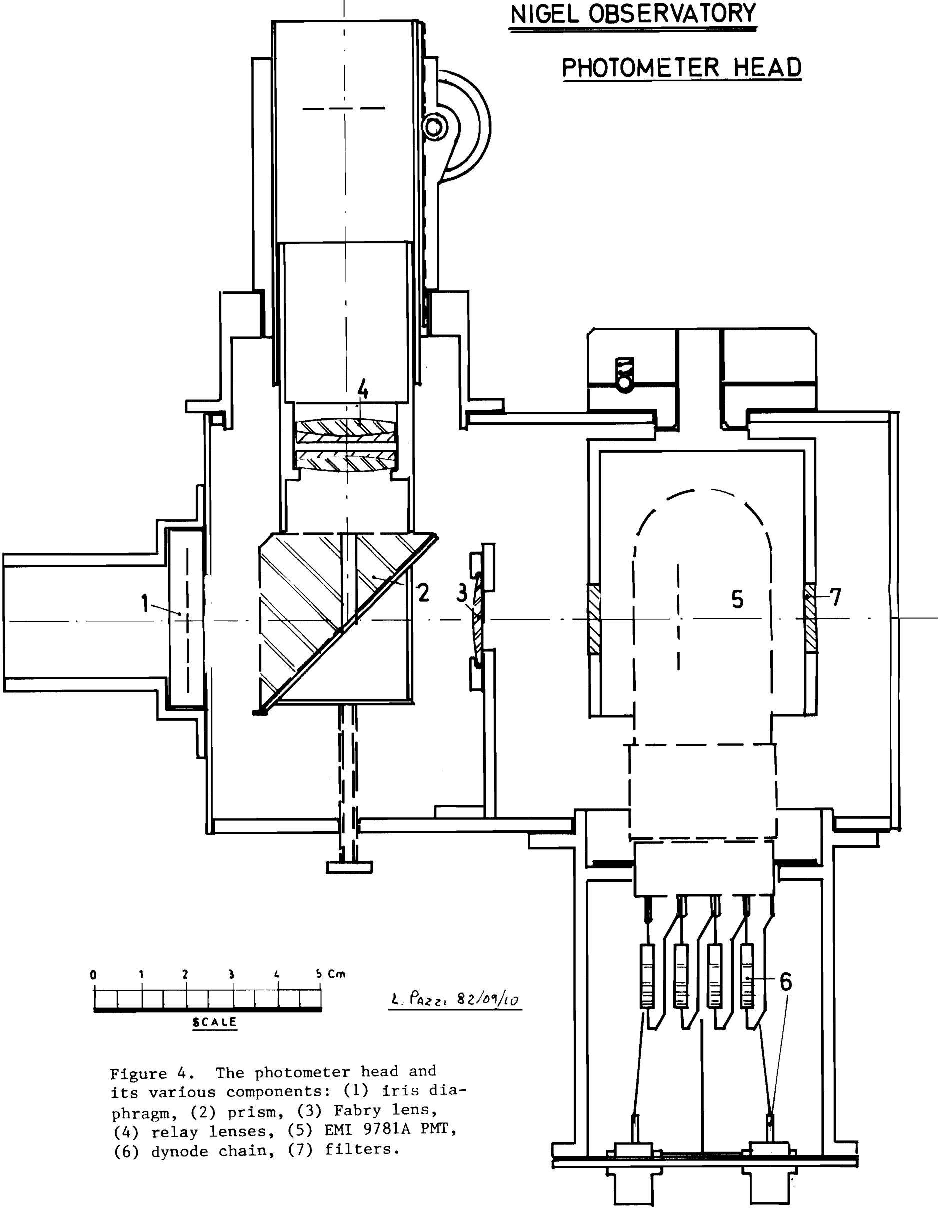


Figure 4. The photometer head and its various components: (1) iris diaphragm, (2) prism, (3) Fabry lens, (4) relay lenses, (5) EMI 9781A PMT, (6) dynode chain, (7) filters.

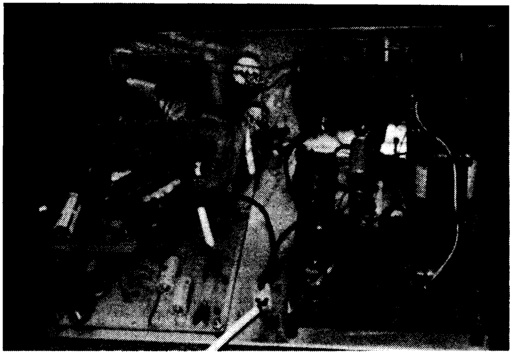


Figure 5. A view of the electronics with the cover removed. the HV power supply is to the right, the DC amplifier to the bottom left, and the A/D converter board to the top left.

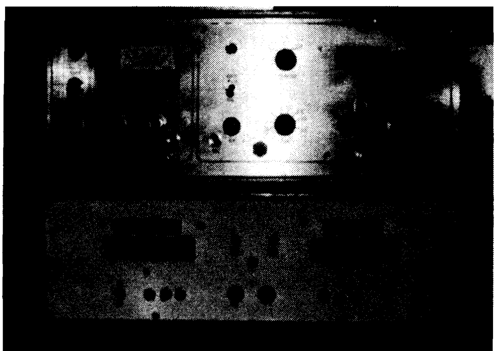


Figure 6. The photometer electronics package is shown standing on top of the observatory clocks.

TABLE 1.

Nigel Observatory Report Format
Showing Data from the First Test

** NIGEL ASTRONOMICAL OBSERVATORY **

39 BUXTON AVENUE,NIGEL 1490,SOUTH AFRICA

PHOTOELECTRIC PHOTOMETRY REPORT

VARIABLE : π4 ORI   COMPARISON : π3 ORI   DATE 83-01-18

YEAR	MONTH	DAY	U.T.	J.D.(GEO.)	HEL.CORR.	FILT	Am	DIAPH.	NOTES
1983	JAN	10	19 35 32	2445345.3163	.0042	V	.4256	120''	
1983	JAN	10	20 5 10	2445345.3369	.0042	V	.4356	120''	
1983	JAN	11	19 30 -0	2445346.3125	.0042	V	.3890	120''	
1983	JAN	11	20 32 52	2445346.3562	.0042	V	.4111	120''	
1983	JAN	12	19 35 30	2445347.3163	.0041	V	.4501	120''	

*** END OF REPORT ***

16

T. A. O. OBSERVATORY

STIG I. INGVARSSON

T.A.O. Observatory
Glashed 302
S-440 60 Skarhamn
Sweden

The T.A.O. Observatory is situated 50 km. north of Gothenburg on the west coast of Sweden. This is a good location with dark sky and low horizon. The most hampering factor is the weather, since the Scandinavian climate is often humid and cloudy. The best observing conditions occur during periods with dry arctic air.

The observatory was founded in 1970. After ten years of construction the first observations were made in May 1980. The 20' dome is made of masonite and covered with fiberglass resin (see Figure 1). It is controlled from either a remote control panel or a hand control box.

The main instrument of the T.A.O. Observatory is a 14-inch f/7 reflector (Figure 2) that can be used either as a Newtonian or broken Cassegrain. It is fork mounted with an open Surrier truss tube design. Detachable spider rings at top end of the telescope makes it easy to shift secondary mirrors or the prime focus camera. With a system like this, ancillary equipment (photometers, cameras, etc.) may be permanently mounted at different focus positions. Both right ascension and declination are driven and controlled from the remote panel or hand control box. The R.A. drive also has a drive corrector, a must for long photographic exposures, and very useful for centering the photometer diaphragm. A 5-inch refractor is used as finder and guidescope.

In Jan. 1982 a Starlight-1 photon counting photometer made by THORN EMI Gencom was added (see Figures 3 and 4). With the 14-inch telescope and this sensitive photometer, very faint stars can be observed (an important fact since much of the observations are made on flare stars). Ivar Hamberg is currently building a computer control system. This system will provide digital readout on both axes and positioning of the telescope. It will also provide automatic recording and data analysis, and open the path to high speed photometry.

Thanks tothe help from several companies, institutions, and private persons, this observatory is now working very well. If it were not for their willingness to help, this venture would have been a total loss.

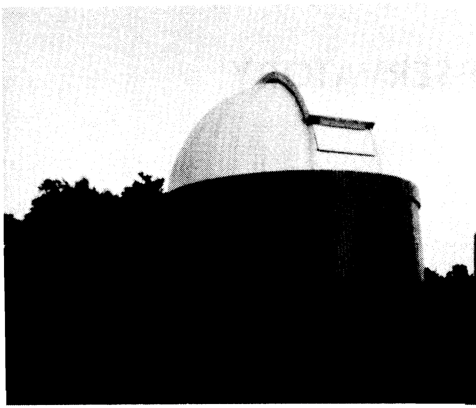


Fig. 1. The 20-foot dome of T.A.O. Observatory covered with masonite and fiberglass resin.

Fig. 2. T.A.O. Observatory's 14-inch f/7 Newtonian/Cassegrain telescope, with 5-inch refractor finder and control boxes.

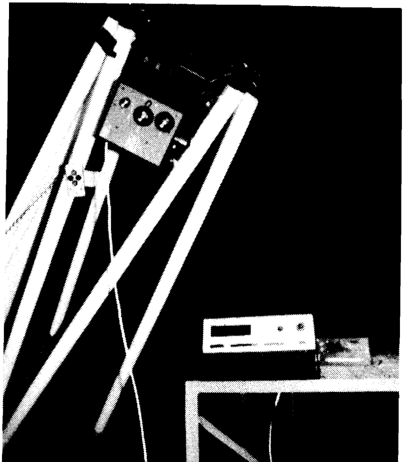
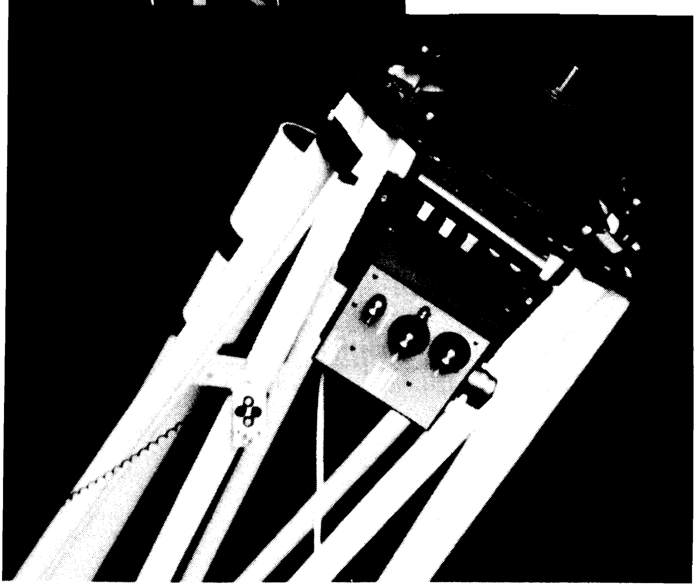


Fig. 3. The STARLIGHT-1 photometer head mounted at the Newtonian focus. The Head shows the Aperture and Filter controls (6 positions each), the View/Count switch, and the post-viewer eyepiece holder. The STARLIGHT-1 photon counter is sitting on the table.

Fig. 4. A close-up view of the STARLIGHT-1 photometer head.



17

Johnson Observatory

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Mitchellville, Maryland 20716

I. INTRODUCTION

If someone was to pay a surprise visit with thoughts of catching a glimpse of the Johnson Observatory, they would certainly be the one surprised. Instead of seeing a white gleaming dome or a neat shed with a roll-off roof, they would instead find a backyard covered with grass and a few trees and shrubs. There is no hint that an observatory exists at all; certainly not one that is deeply involved with serious astronomical observations.

My observatory is portable in the true sense of the word. Although I share the dreams of many amateur astronomers of having my own "Mt. Palomar Jr.", in reality this is not very feasible for me at my present location. Still, I wanted to have the capability of conducting serious astronomical observations and to be able to set up in 15 minutes or less. My employment requires me to travel almost 50 percent of the time, so it is important to me that I utilize as much of my time as possible observing stars rather than laboring through the task of manually reducing data and constructing plots.

II. EQUIPMENT

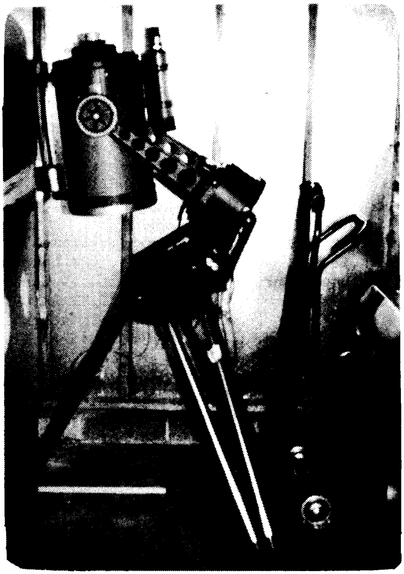
The telescope I use is the Celestron C-11, which is ideally suited for photoelectric photometry. The aperture is large enough to routinely measure stars close to eleventh magnitude. The short closed tube and fork mount make it rigid enough to withstand the early evening breezes that are often encountered and compact for easy storage. The telescope remains mounted on the wedge and tripod at all times along with the RA/Dec control boxes. When not in use, the entire assembly is stored in a corner of the garage (see Figure 1), still allowing both cars to be parked inside. It rests on a dolly that was rigged from a Sears hand truck, two 1"x6" boards, two "C" clamps, and two rod holders for the base of the tripod legs to rest in. It took about 20 minutes to put together at a cost of $70.

If the sky looks promising, the garage door is opened as soon as possible so that the telescope can achieve thermal equilibrium with the outside air. The telescope is wheeled around to the backyard with the dolly. The base of the tripod legs are lowered into three 4"x 1.5" pipes that are embedded in the ground and are properly aligned and leveled. Thus, the hastle of trying to accomplish polar alignment is completely eliminated.

Once in place, the telescope is connected to one of two retractable multiple outlet extention cords that are plugged into the outlets at the back of the house, the heated dew cap is placed on the tube, and the power supply plugged into a multiple outlet. Then the photometer is retrieved from the basement where it is stored. I use the EMI STARLIGHT - 1 photon counting photometer which is excellent for UBV measurements of variable stars. It is transported and remains on a reinforced serving tray that permits ease of portability and setup. The counter handle is taped to the tray and the head sits between some wooden blocks that are anchored to the tray (see Figure 2). This prevents the equipment from sliding off the tray in the event of an accidental tilt. After the photometer is powered up and the head is coupled to the telescope's eyepiece adapter, the only thing that remains to be done is to bring up from the basement a second serving tray containing the necessary charts, the datalogger, and a stool for sitting (see Figure 3). The stool is very important to me because I sometimes observe up to five hours at a time! The complete setup is usually achieved in about 12 minutes.

III. DATA RECORDING

Just prior to a run, the start/stop/reset STARLIGHT - 1 remote control box is clamped to the start position with a "C" clamp and the 10 second integration time is selected on the counter. This will cause a count to be displayed every 10 seconds without having to push any buttons, thus allowing for greater speed in recording the counts. The task of recording the counts manually can prove to be very tiring and troublesome. Ideally one would like to interface the photometer to a computer so that all counts are recorded and reduced at the time of the particular observation. I have considered just such a setup utilizing the I/O port of the STARLIGHT - 1. However, I feel that this will greatly impact the portability I desire and the amount of time it takes to get going. Also the environment must be taken into account. Because of the high humidity and cold temperatures the computer would probably have to remain indoors to function properly. The complexity factor starts to increase at this point. The line between the photometer and the computer would be well over 100 feet so the signals will have to be amplified, and running parallel lines at that distance



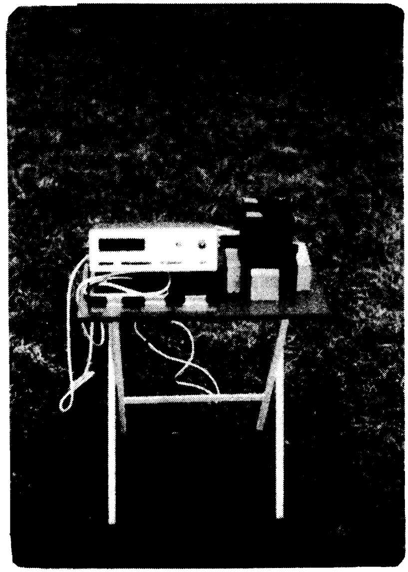


Figure 1. The Johnson Observatory is shown stored ia a corner of the garage when it is not in use.

Figure 2. The EMI STARLIGHT-1 photon counting photometer is shown on the reinforced serving tray which permits ease of portability and set-up.

may prove to be somewhat costly. Converting the photometer counter output to a serial bit stream in order to save on lines is not easy. Even the parallel interface may communicate with each other since the photometer output is multiplexed. My knowledge of electronics is somewhat lacking so I decided to skip the interfacing. Instead I have settled for a "pseudo automated" data logging system.

The counts are recorded with a Radio Shack EC-3008 rechargeable pocket printer calculator that is mounted on a clipboard. There is also a small adjustable light next to it in order to see the keys and LCD (see Figure 4). This calculator can do many things such as print monthly calendars and calculate dates from the year 1901 to 2099, but the unique feature about itis that it has a realtime clock! Not only can the time be displayed to the nearest second, it can also be printed. In order to facilitate data recording the ÷, +, −, x function keys have been relabled V,C,S,CS which stands for Variable, Comparison, Sky, and Check Star respectively. With the calculator in the "PRINT" mode, I key in the number that is displayed on the photometer counter display and then the appropriate function key. The printout shows the count plus the sign, hence I always know what the count represents when it's time to reduce the data. A touch on the "TM" and "P" keys prints the time of the observation as shown in Figure 5. The printer buffer can hold up to six lines of print so you do not have to wait until each line is printed before the next series of numbers are keyed in. Prior to each nightly run, the calculator clock is set to the precise universal time via a radio time cube.

The calculator has worked well even in cold, humid weather. I recently purchased a Casio CP-10, which is exactly like the EC-3008 (in fact Casio makes it for Radio Shack) except the cost is about $35, or half the price of the Radio Shack version.

IV. DATA REDUCTION

Once a run is completed, the data is reduced to the standatd UBV system by a microcomputer. The entire computer system consists of a TRS-80 MODEL 1 LEVEL 2 computer with 16K RAM, an EPSON MX-80 printer, a cassette recorder, and a MICROMINT expansion interface that includes a parallel printer port, an RS-232C serial port, a system bus, and an accoustic coupler/modem. The latter is sometimes used to access the Federal Aviation Administration's (whom I work for) National Weather Data Base for long range planning of observations. Figure 6 is a picture of the setup (the TI-59 calculator and printer which can also be seen are a leftover from an older system I used when I first got started in photometry). I use the program described by Genet (see IAPPP Communications No. 5) except that it's been modified to input raw count and universal time instead of delta magnitude and geocentric Julian Date, and the color of the filter can be UBVRI. Also, a REMARKS field has been added for annotation. The output is printed and at the same time a file is built containing the phase (or time of day) and the standard delta magnitude (or magnitude). At the completion of the data reduction session, a file is stored on cassete tape.

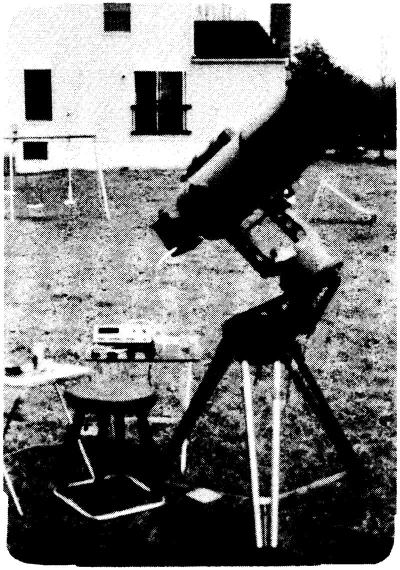


Figure 3. The complete system is shown set-up and ready for photometric observations.

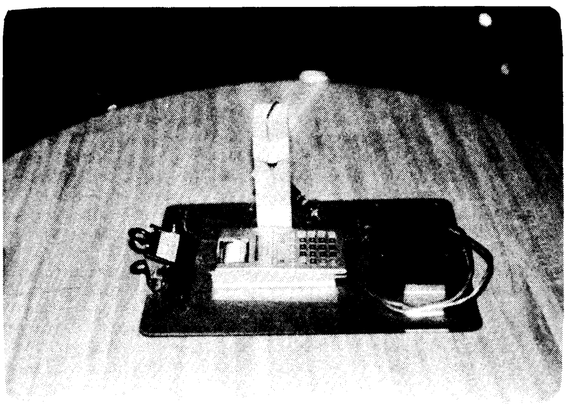


Figure 4. The Radio Shack EC-3008 Calculator mounted on a clipboard.

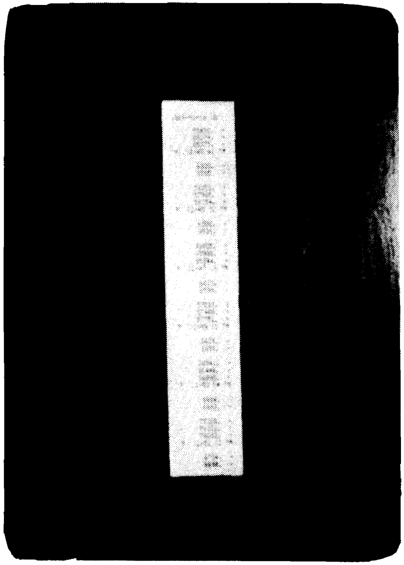


Figure 5. A sample printout from the Radio Shack calculator.

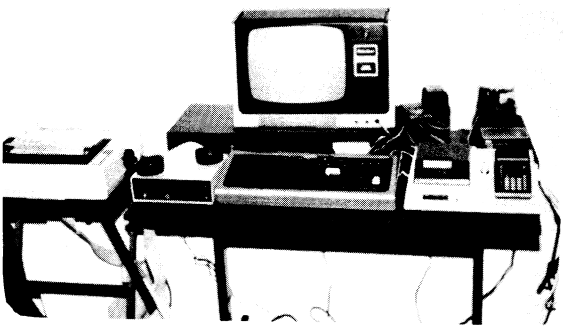


Figure 6. The complete data reduction system of Johnson Observatory.

Next, the Astroplot program is loaded and the data tape is read. Since the TRS-80/MX-80 configuration is such a popular combination, I have included a copy of the program in Table 1. It is written in BASIC language and should be able to run (with only minor changes) on other microcomputers with MX-80 printers. The input to Astroplot can be from tape or the keyboard (for those who have the advanced Statistical Analysis Package by Radio Shack, Astroplot is completely compatible with the tape data file program for building files). Figures 8 through 11 are plots from the program. Figure 10 shows the large scatter resulting from an observing run on a night when the "seeing" was quite poor. Figure 11 shows the same data that has been filtered using the "filter option" feature of Astroplot (by Titus, Titus, and Larson), thereby salvaging otherwise disastrous results. The data reduction program and Astroplot have saved me many hours of calculating and plotting. I sometimes record as many as 75 data sets in a single night's run, especially if a rapid eclipsing binary is being observed. Reducing that amount of data manually to standard UBV and plotting it can take a few days to complete.

V. FUTURE PROGRAMS

Future enhancement include modifying the Astroplot program to accomodate bit image (single dot) plots for greater resolution. The current version uses a period as a dot, which is actually made up of four single dots. The Graftrax chips for the printer have already been purchased and will be installed soon. The current dot matrix of the program is 100 x 100 (10,000) which is fine for partial light curves such as primary and secondary minima of eclipsing binaries, but rather coarse for complete light curves. My photoelectric program now includes obtaining complete curves of some of the short period eclipsers (YY GEM, YY ERI, UV LEO, to name a few) and I think a dot matrix of 300 x 350 (105,000) or 600 x 750 (450,000) is needed. However, the latter may require a microbuffer for the printer because of the enormous amount of time the computer will be tied up while the printer plots a few hundred to several hundred data points.

Another future enhancement may include replacing the printer calculator with one of the more powerful portable computers such as the EPSON HX-20. Among other things, this computer runs off of self-contained rechargeable batteries, has 16K of RAM (expandable to 32K) for storage, extended BASIC, a Realtime clock, RS-232C serial interface, and it is only the size of a notebook. The data can be logged and reduced as it is obtained, and later the data can be fed to the TRS-80 via the RS-232C port for printing (although the HX-20 has a built in microprinter), plotting, and permanent storage. Such a system would eliminate the time needed for reading numbers off of strips in preparation for data reduction. Results would be provided immediately thereby further increasing the amount of time available for observing.

VI. CONCLUSION

As you can see, it is not necessary to have a permanent observatory with sophisticated supporting equipment to seriously engage in one of the branches of astronomy. With a little planning and organization the amount of time needed to set up and get going can be greatly reduced. Although the use of microcomputers for data reduction and plotting of photoelectric photometry measurements are not essential, they are very helpful and should be considered.

Figure 7. The author is shown sitting "in" Johnson Observatory. Everything is designed for convenience during long observation runs.

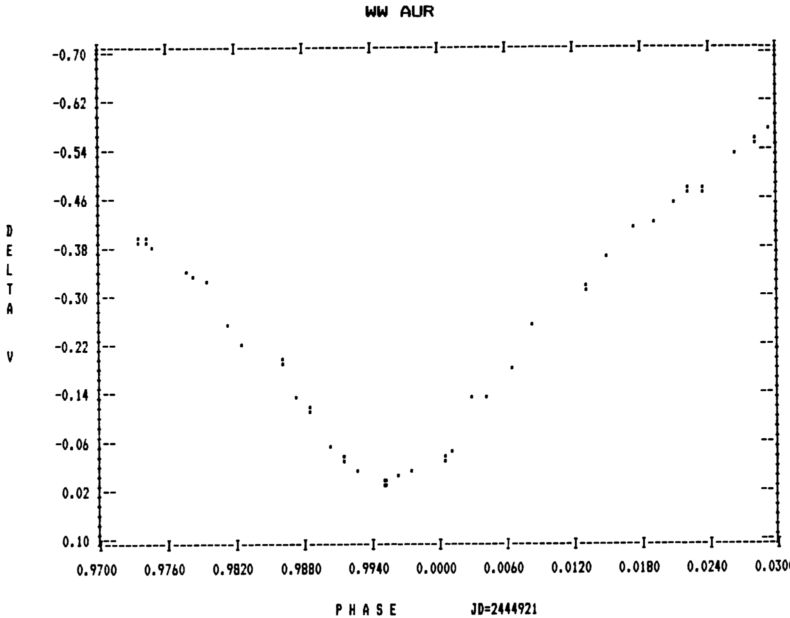


Figure 8. Johnson Observatory plot of WW Aur in the V bandpass.

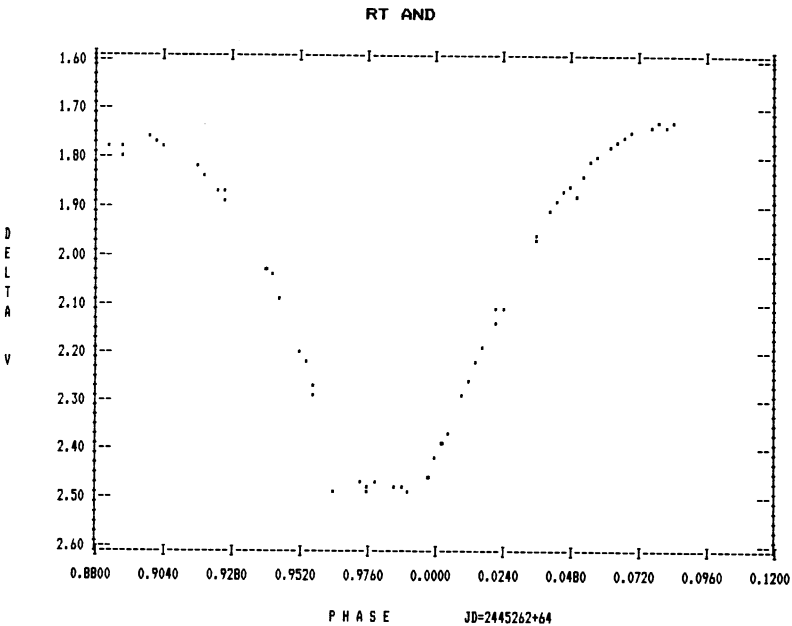


Figure 9. Johnson Observatory plot of RT And in the V bandpass.

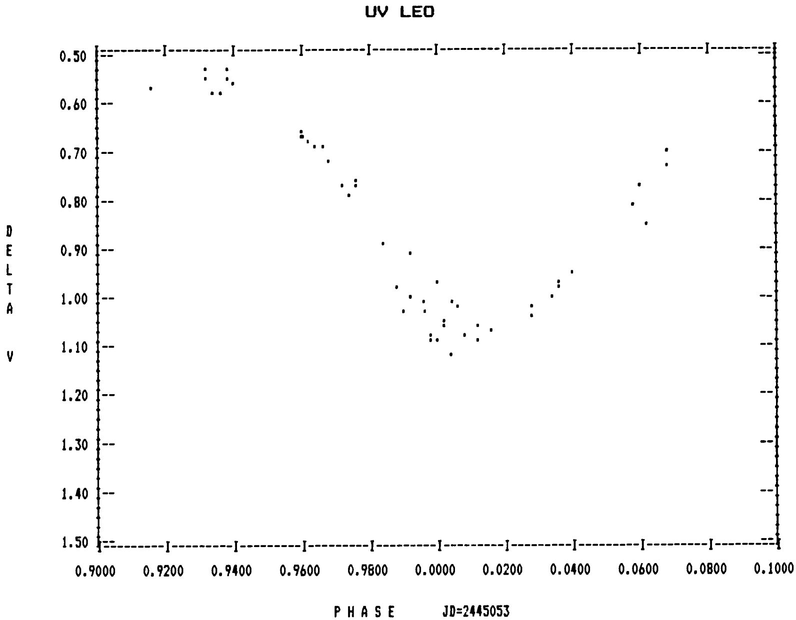


Figure 10. Johnson Observatory plot of UV Leo in the V bandpass. The large scattering is the result of observing during a night when the seeing was poor. See Figure 11.

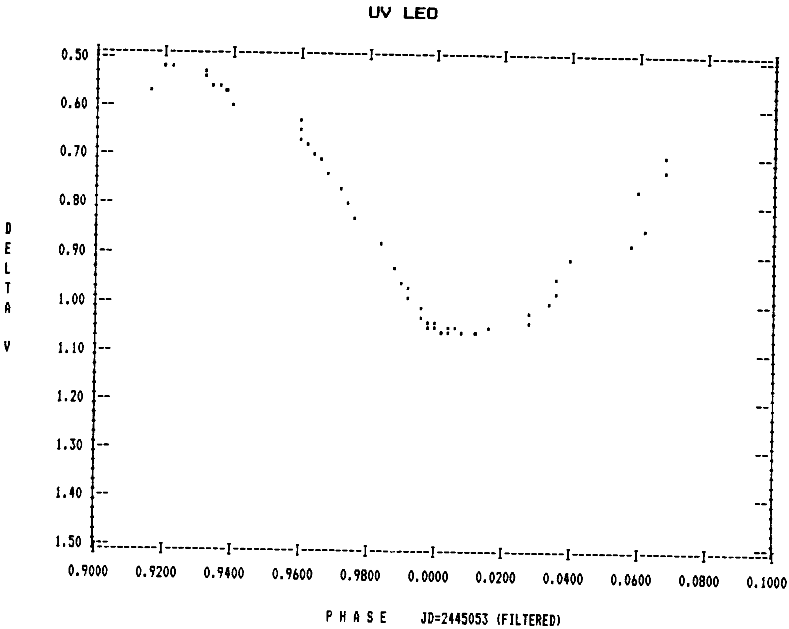


Figure 11. Johnson Observatory plot of UV Leo in V bandpass but with the filter option of the Astroplot program applied.

TABLE I.

```
1 REM     ***********************************
2 REM     *         ASTRO-PLOT WITH MX-80         *
3 REM     *                 BY                    *
4 REM     *          JAURVON W. JOHNSON           *
5 REM     ***********************************
6 CLEAR 350
10 CLS:PRINT:N=0:J=0:I=0:DEFINTI-N:DEFDBLX,Y:DEFSTRZ
15 IM=1:DIM Y(200),X(200),Q(200),C(11):G=0
25 REM    ***********************************
26 REM    *      DATA ENTRY. USE COMMA BETWEEN     *
27 REM    *                X AND Y                 *
28 REM    ***********************************
30 PRINT"HOW WILL DATA BE ENTERED - ";
40 INPUT"(K)EYBOARD OR (T)APE ";ZI
70 II=1:IF ZI="T" II=2
76 ON II GOTO 079,150
79 PRINT"BEGIN ENTERING YOUR DATA PAIRS (X,Y) .
80 PRINT"SIGNAL END OF DATA WITH @,@.":PRINT
90 INPUTZ,ZB:IFZ="@" GOTO 120
95 ON IM GOTO 100,110
100 X(N+1)=VAL(Z):X(N+2)=VAL(ZB):N=N+2:GOTO 90
120 N=N/2
140 PRINT:PRINT N;"PAIRS WERE ENTERED. ":GOTO 5200
150 INPUT"INSERT DATA TAPE - HIT ENTER ";ZI
160 INPUT#-1,IT:INPUT#-1,ZO:PRINT
170 PRINT"DATA FILE BEING READ = ";ZO:IF IT=2 GOTO 190
190 INPUT#-1,Z(1),Z(2),Z(3),Z(4),Z(5),Z(6),Z(7),Z(8)
200 FOR K=1 TO 8:IF Z(K)="@" THEN 230
205 X(N+K)=VAL(Z(K)):NEXT K:N=N+8:GOTO 190
230 IF IM=2 CLOSE
235 PRINT:N=(N+K-1)/2:PRINT N;"PAIRS WERE READ. ":GOTO 5200
1000 REM ***********************************
1005 REM *              FILTER OPTION             *
1010 REM ***********************************
2000 C(0)=.074:C(1)=.111:C(2)=.182:C(3)=.333:C(4)=.666:C(5)=1:C(6)=.666:C(7)=.33
3:C(8)=.182:C(9)=.111:C(10)=.074
2040 D=6:G=0:E=10
2050 IF G<6 THEN 3000
2060 F=3.732
2070 S=0
2080 FOR I=D TO E:S=S+(C(I)*Y(X)):X=X+1:NEXT I
2120 Q(G)=S/F:X=X-10:G=G+1
2140 IF G<N-4 THEN 2050
2150 IF G=N+1 THEN 4000
2160 E=E-1:F=0
2170 FOR I=D TO E:F=F+C(I):NEXT I
2200 X=G-5
2210 GOTO 2070
3000 F=0:X=0:D=D-1
3020 FOR I=D TO E:F=F+C(I):NEXT I
3050 GOTO 2070
4000 G=0
4002 FOR I=1 TO N
4004 G=G+1
4005 X(I)=X(I):IF N-G<5 THEN Y(I)=Y(I) ELSE Y(I)=Q(G)
```

```
4006 NEXT I
4007 G=0:INPUT"DO IT AGAIN? YES=1";X
4008 IF X=1 THEN 2000 ELSE 5440
5200 INPUT"DO YOU WISH TO FILTER DATA? YES=1";X
5250 REM ***************************************
5255 REM *   ENTER STAR NAME AND AXIS LEGENDS   *
5257 REM ***************************************
5260 INPUT"ENTER TITLE OF PLOT";ZP
5270 INPUT"ENTER TITLE OF Y AXIS";ZU
5280 INPUT"ENTER TITLE OF X AXIS";ZV
5330 GOTO 5360
5360 INPUT"ENTER MIN VALUE OF Y AXIS";YA
5370 INPUT"ENTER MAX VALUE OF Y AXIS";YI
5380 INPUT"ENTER MAX VALUE OF X AXIS";XA
5390 INPUT"ENTER MIN VALUE OF X AXIS";XI
5395 REM ---------------------------------------
5400 FOR J=1 TO 2*N-1 STEP 2
5402   X(I)=X(J):Y(I)=(YA+YI)-X(J+1)
5406   I=I+1
5408 NEXT J
5412 IF X=1 GOTO 2000
5440 LPRINT CHR$(27) "G"
5460 LPRINT:LPRINT:LPRINT TAB(35);ZP
5480 GOSUB 5810
5482 REM ---------------------------------------
5485 LPRINT TAB(20);"I---------I---------I---------I---------I---------I--------
-I---------I---------I---------I---------I";
5490 LS=1:GOSUB 5780
5505 REM ***************************************
5506 REM *          MAIN BODY OF PROGRAM          *
5507 REM ***************************************
5510 FOR LN=100 TO 0 STEP-1
5520 YN=YI-((YI-YA)/100)*LN
5530 YD=ABS((YI-YA)/100)
5535 LPRINT CHR$(13);
5540 GOSUB 6250
5550 IF LN/2-FIX(LN/2)=0 THEN GOSUB 5910
5555 GOSUB 6140
5560 GOSUB 6030
5570 GOSUB 6200
5575 IF LN/2-FIX(LN/2)=0 THEN GOSUB 5915
5580 LPRINT
5590 LPRINT
5610 NEXT LN
5613 REM ---------------------------------------
5615 LPRINT TAB(20);"I---------I---------I---------I---------I---------I--------
-I---------I---------I---------I---------I";
5617 LS=12:GOSUB 5780
5618 LPRINT
5619 LS=1:GOSUB 5780
5620 GOSUB 6350
5625 LS=12:GOSUB 5780
5627 LPRINT
5630 GOSUB 6460
```

```
5640 LS=12:GOSUB 5780
5650 GOSUB 5830
5670 GOTO 5260
5775 REM ****************************************
5776 REM *      PRINT CONTROL SUBROUTINES       *
5778 REM ****************************************
5780 LPRINT CHR$(27)"A"CHR$(LS+128)CHR$(27)"2"
5790 RETURN
5810 LPRINT CHR$(15):RETURN
5830 LPRINT CHR$(18):RETURN
5850 LPRINT CHR$(27)"D" CHR$(RS+128) CHR$(128);
5852 LPRINT CHR$(137)".";:RETURN
5870 LPRINT CHR$(27)"D" CHR$(RS+128) CHR$(128);
5872 LPRINT CHR$(137) CHR$(124);:RETURN
5880 LPRINT TAB(RS);CH$;:RETURN
5890 LPRINT TAB(RS);ZV;:RETURN
5910 LPRINT TAB(20);"I";:RETURN
5915 LPRINT CHR$(27) "D" CHR$(248) CHR$(128);
5917 LPRINT CHR$(137)"I";:RETURN
5918 REM ---------------------------------------
5920 RS=9
5930 FOR I=1 TO 10
5940 GOSUB 5870
5950 NEXT I
5960 RETURN
6025 REM ****************************************
6026 REM *         PLOT DATA SUBROUTINES        *
6027 REM ****************************************
6030 FOR I=0 TO N
6040 IF Y(I)>YN+.50001*YD OR Y(I)<YN-.50001*YD THEN 6080
6050 XP=FIX((X(I)-XI)*100/(XA-XI))
6060 IF XP<0 OR XP>100 THEN 6080
6070 RS=XP+20:GOSUB 5850
6080 NEXT I:RETURN
6135 REM ****************************************
6136 REM *   PRINT MAG. SCALE & HORIZ. LINES    *
6137 REM ****************************************
6140 IF LN/10-FIX(LN/10)<>0 THEN RETURN
6150 LPRINT CHR$(13);:RS=10:CH$="":GOSUB 5880
6160 LPRINT USING"######.##";(YA-YI)*(100-LN)/100+YI;
6170 LPRINT TAB(21);"--";:RETURN
6190 RETURN
6200 IF LN/10-FIX(LN/10)<>0 THEN RETURN
6201 LPRINT CHR$(27) "D" CHR$(246) CHR$(128);
6202 LPRINT CHR$(137)"--";:RETURN
6205 REM ****************************************
6210 REM *          PRINT Y AXIS TITLE          *
6215 REM ****************************************
6250 IF LN>65 THEN 6290
6252 IF LN/2-FIX(LN/2)<>0 THEN 6290
6260 RS=7
6270 G=G+1:CH$=MID$(ZU,G,1)
6280 GOSUB 5880
6290 RETURN
```

```
6295 REM ***************************************
6296 REM *              PRINT X SCALE          *
6297 REM ***************************************
6350 LPRINT
6360 RS=28:CH$=" ":GOSUB 5880
6365 LPRINT
6370 FOR I=0 TO 10
6380 PT=(XA-XI)*I/10+XI
6382 IF PT=>1 THEN PT=PT-1
6384 LPRINT TAB(15);:LPRINT USING"#####.####";PT;
6390 NEXT I
6400 RETURN
6405 REM ***************************************
6406 REM *          PRINT X AXIS TITLE         *
6407 REM ***************************************
6455 LPRINT:LPRINT:LPRINT
6460 LPRINT
6480 RS=55:GOSUB 5890
6490 RETURN
7000 REM ***************************************
7005 REM *        LIST OF VARIBLES USED        *
7010 REM ***************************************
7015 REM ZP                     NAME OF STAR OR PLOT
7020 REM ZU                     Y AXIS TITLE-ALLOW SPACE BETWEEN LETTERS
7025 REM ZV                     X AXIS TITLE-ALLOW SPACE BETWEEN LETTERS
7030 REM Y(I)                   Y AXIS DATA ARRAY (DELTA MAG. OR MAG.)
7035 REM X(I)                   X AXIS DATA ARRAY (PHASE, TIME OR DATE)
7037 REM                        ADD 1 TO EACH PT. IF PHASE IS .0000-.4999
7040 REM Q(G)                   FILTERED Y AXIS DATA ARRAY
7045 REM YA                     MIN MAG. OF STAR (OR Y AXIS)
7050 REM YI                     MAX MAG. OF STAR (OR Y AXIS)
7055 REM XA                     MAX VALUE OF X AXIS
7060 REM XI                     MIN VALUE OF X AXIS
7065 REM LN                     Y AXIS LINE NUMBER
7070 REM LS                     SIZE OF LINEFEED
7075 REM RS                     CHARACTER TAB STOP
7080 REM YN                     NORMALIZED Y AXIS VALUE
7085 REM YD                     DELTA VALUE FOR EACH Y AXIS LINE
7090 REM XP                     CHARACTER POSITION ON X AXIS
7095 REM CH$                    STRING PRINTED AT RS
7100 REM PT                     DETERMINES PHASE. IF NOT WORKING WITH PHASE
7105 REM                          DELETE LINE 6382 BEFORE RUN
```

18

Mouldsworth Observatory and Amateur PEP in England

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I. INTRODUCTION

Mouldsworth Observatory is the first amateur observatory in England dedicated to photoelectric photometry. It is situated in north-west England, 7 miles from the city of Chester, at 53° 14' 49" N, 2° 44' 49" W, and at an altitude of 45 meters above sea level. The observatory was constructed by the author with the prime intention of conducting photoelectric astronomical observations. The observatory has been operational since March 1982, and the author is at present engaged in various lines of observational work including UBV photometry of variable stars and asteroids, and occultation studies.

During recent years, it has become increasingly apparent that amateur astronomy has undergone a considerable shift in emphasis away from a descriptive or qualitative approach towards the more precise and quantitative observational techniques of astrometry, photometry, and occultation timing. In this way, amateurs are becoming increasingly able to provide information of direct value to professional astronomers, who through limited availability of telescope time at the larger observatories, find it difficult if not impossible to carry out extended observational programs in many fields of astronomy. Owing to recent rapid developments in electronic devices and computers, photoelectric photometry (PEP) now offers the amateur a real and unparalleled opportunity to participate in observational programs of immediate use to the astronomical community.

An amateur for many years, the author's interest in the topic was initiated in 1980 after reading an article by Dick *et al* (1978) in the Journal of the Royal Astronomical Society of Canada, which described the construction of a relatively simple, inexpensive photometer head and H.V. power supply suitable for use by amateurs, Coincidently, a few months later a letter from Russell Genet (1980) was published in the Journal of the British Astronomical Association announcing the formation of the International Amateur-Professional Photoelectric Photometry (IAPPP) group. The author signed up immediately as a Charter Member, thus beginning an association with PEP which ultimately lead to the construction of an amateur observatory dedicated to astronomical photometry.

The following diary traces in a concise way the main events which led to the establishment of a photometric facility at the Mouldsworth Observatory:

Date		Event
November	1980	Celestron 11 telescope ordered
January	1981	Charter membership of IAPPP
March	1981	Construction of observatory begun
May	1981	Completed observatory base
June	1981	Received telescope
October	1981	Started assembly of PEP head
November	1981	Observatory sliding roof completed
January	1982	Telescope installed
March	1982	Completed PEP head
		'First photons' registered
April	1982	First eclipsing binary (W UMa) observed
		UBV filters fitted
May	1982	First asteroid (2 Pallas) monitored
September	1982	First photoelectric timing of a lunar occultation event
		First dry-ice cooled PMT operation
November	1982	Calibration run
December	1982	Replaced RCA 1P28A by EMI 9661B PMT
February	1983	Composite light curve of 115 Thyra
		High speed lunar occultation photometry

A great deal of useful information was derived from the first few issues of the IAPPP Communications, together with much helpful advice and encouragement from Russ Genet and other IAPPP members, helped to solve many of the practical problems encountered in going "photometric", The following sections outline a description of the observatory, design of the telescope and photometer, and observational programs now underway, including a brief illustration of the observational results obtained to date.

II. TELESCOPE AND OBSERVATORY DESIGN

The observatory building (Figure 1) is of a sliding-roof type of construction built according to the original design of the author, and it houses an f/10, 280mm aperture Celestron 11-inch Schmidt-Cassegrain telescope. The building is exceptionally compact, measuring 8' x 10' in area, and is recessed into sloping ground to reduce the apparent external size. The brick walls are 5½' high and are surmounted by a low pitched 3/8" marine plywood roof made up of fixed end sections and two central sections mounted on roller bearings which manually slide in opposite directions to reveal a 5' x 8' area of access to the sky. The building is provided with electricity (50Hz, 220-240V) via an underground cable. Since the floor of the observatory is set below the level of the surrounding ground, special measures were taken to prevent the ingress of water, including an undercoat of asphalt-based sealant on the inner walls and a clear silicone waterproofing coat on the exterior.

Figure 1. The general view of Mouldsworth Observatory showing the sliding roof in both the closed and the fully open position.

Figure 2. The Mouldsworth Observatory Celestron 11-inch telescope, photometer, and ancillary equipment.

The telescope is fork-mounted and supported on a concrete filled steel pillar made from 6-inch I.D. steel pipe fitted with standard flanges welded to both ends (see Figure 2). The pillar is bolted to eight lengths of 5/8" diameter steel studding set in 30 cu. ft. of reinforced concrete. The Celestron C-11 telescope is well suited for use in photometric observation since the photometer head is conveniently mounted at the Cassegrain focus on the rear of the primary mirror cell. Furthermore, fairly heavy photometer heads can be easily supported on the "visual back" since focussing is performed by an adjustment in the position of the primary mirror only, and a suitable dewcap provides the necessary counterweight. The present PEP head weighs over 5 pounds and is counterbalanced by a home-built fiberglass tube with an encapsulated 0 - 100 Watt resistance wire heater set into the base to prevent condensation forming on the front corrector plate. A heated dewcap is an essential prerequisite in the cold moist nights often experienced in England. The variable frequency drive corrector allows the drive rate to be adjusted to sidereal (or solar) rate. In addition, a fast and slow motion facility in R.A. is available from a hand-held pushbutton control box, and fine adjustment in declination is achieved by means of a tangent arm screw. Photometry is readily performed by isolating the object of interest in the center of the aperture of the photometer head using the controls in R.A. and Dec. Sky readings are taken by manually offsetting the telescope in declination using the tangent arm. Comparison stars are most conveniently located (to $\pm$ 15 arcmin) using the instrument's setting circles.

The DC photometer was designed and built by the author and is generally operated at -700V to -900V using a commercial stabilized H.V. power supply. A +15V/0V/-15V supply powers the DC amplifier mounted in the PEP head which yields a 0V to -11V output, which is then either converted to a pulse output using a voltage-to-frequency converter or fed directly to a 2-pen chart recorder. Quantitative photometry is invariably performed using the V-toF/counter combination since this yields an exceptionally linear output. The chart recorder is most useful for monitoring occultation phenomena since the chart speed can be operated at up to 1 cm/s and time signals can be fed to the second pen. A further sophistication introduced early on involved lock-in signal detection using a rotating chopper and phase sensitive detector to eliminate DC drift mainly arising from changes in the PMT dark current. This approach has been replaced at present by refrigeration of the side-window PMT using a specially constructed compact dry-ice cryostat to effectively eliminate the thermal dark noise from the detector.

III. THE PHOTOMETER HEAD

Mechanical and Optical Layout

Many amateur photometrists throughout the world have successfully built photometer systems to their own design rather than purchase instruments available commercially. The present author was no exception in that the design of the Mouldsworth Observatory photometer was arrived at after taking into account various individual requirements such as the type of telescope, focal ratio, mounting facilities, observational program and local sky

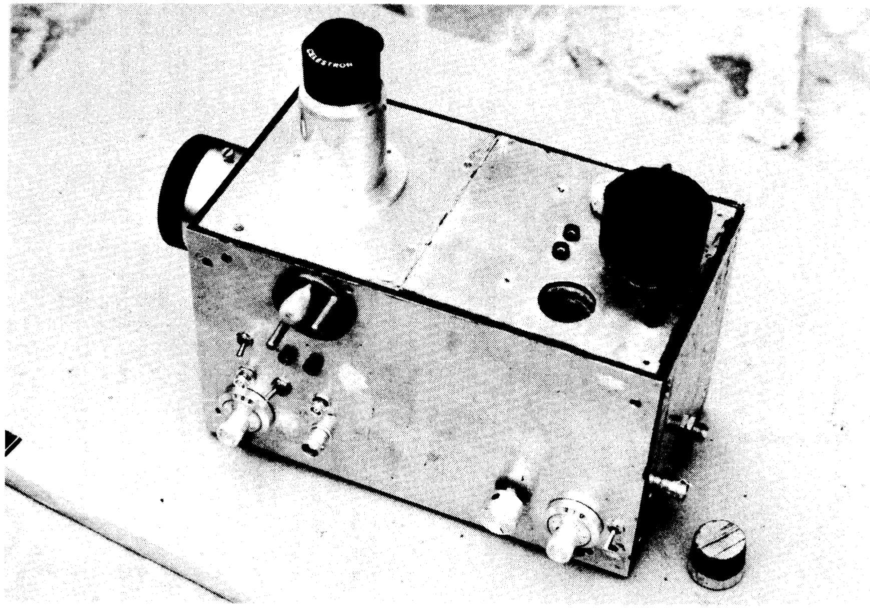

Figure 3. The Mouldsworth Observatory photometer head with dry ice cryostat in place.

conditions. Many photometer heads comprise optics, PMT, amplifier circuit, etc. mounted inside a metal box. The author's photometer (shown in Figure 3) differed in constructional approach in that the detector head was assembled entirely from 1/8" thick duraluminum sheet so as to produce four separate compartments in a rectangular box having overall dimensions of 8¼" in length, 4½" in width and 5 3/8" in height as shown diagrammatically in Figure 4. Three of the four compartments house: (1) the flip mirror, optics, and aperture/filter wheels, (2) the PMT and cryostat, and (3) the electronic circuits. The fourth compartment located in the central section and measuring 1½" in width has been used to house a chopper wheel enabling the photometer to operate in lock-in detection mode. This compartment may alternatively be used for interposing other filters in the optical train or for additional electronics, if required.

A selection of five diaphragm apertures (285, 140, 71, 48, and 33 arcsec) and a 4 x 160 arcsec slit is available. The diaphragm wheel also has two other "previewing" apertures, which enable a 16 arcmin diameter field to be examined. The aperture wheel is fixed to a thin stainless steel tube, which rotates in a PTFE bush, and can be positively located in any one of eight positions (45^{o} apart) by a detent mechanism comprised of a spring-mounted circular brass plate possessing suitable cutouts around its edge. The eight-position filter wheel is mounted in a similar fashion except that the shaft on which it rotates is itself located along the same axis as the aperture wheel. Two concentrically placed knobs at the front of the head allow manual adjustment of the filter and aperture wheels. At present only four filter wheel positions are used. The four apertures are elliptical in shape to avoid vignetting and measure 1/2' x 3/4". One aperture is clear for integrated light and the others comprise a set of UBV filters (V = 2mm Schott GG-495, B = 1mm Schott BG-12 and 2mm Schott GG-385, U = 2mm Schott UG-5). All four intervening filter wheel positions serve at present as dark slides. The flip mirror was made by aluminizing a 49mm diameter camera lens filter element supported on an aluminum plate which can be rotated between two fixed positions to allow light from the telescope to be either deflected via a relay lens to an illuminated reticle ½" f.l. eyepiece used for positioning objects within the diaphragm aperture, or pass unobstructed to the photocathode of the side-window PMT. The mounting plate of the flip mirror also possesses a 1" diameter circular hole so that, if required, the mirror can be replaced by a thin pellicle or beamsplitting filter for simultaneous viewing of the object under scrutiny, e.g. for occultation studies. Two red LED's are also mounted either side of the flip mirror to aid in positioning objects within the diaphragm aperture. Since the PMT is located about 6" from the aperture wheel, a positive two-element relay lens (f/9, 30mm diameter) placed in front of the filter wheel prevents vignetting of the f/10 cone of light from the telescope. The achromatic plano-convex Fabry lens (f/2, 18mm diameter) originally comprised the field lens of a 40mm f.l. Huyghenian microscope eyepiece, while a four-element x10 magnifier served as the relay lens for the previewing eyepiece.

Photomultiplier Cryostat

The side-window PMT is mounted in a separate compartment measuring 4 1/2" x 3 3/8" x 3". A compact dry-ice cryostat (see Figures 4 and 5) was constructed from 1/16" thick

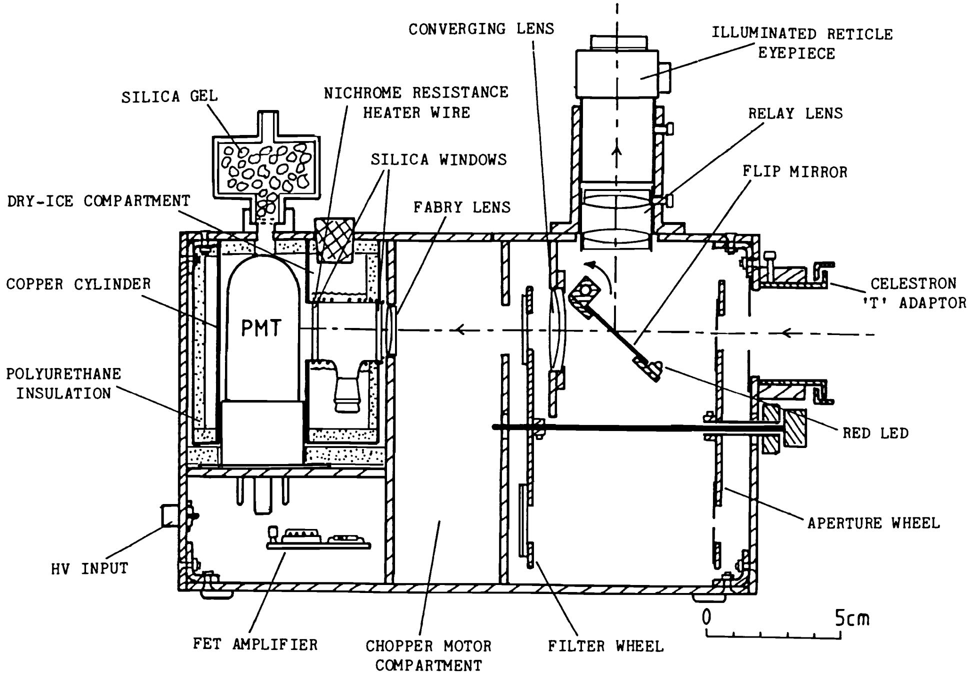

Figure 4. Cross-sectional diagram lay-out of the photometer head.

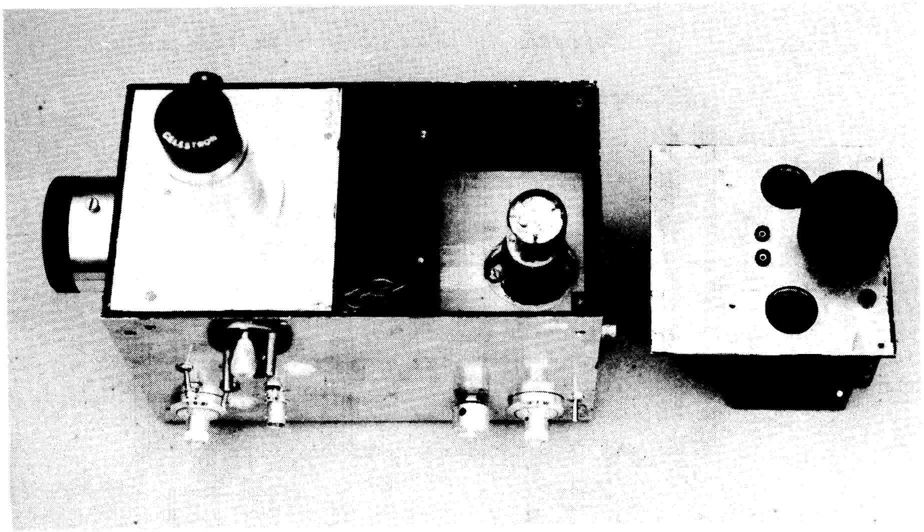

Figure 5. The photometer head with the cryostat removed to reveal the photomultiplier tube.

Bakelite (Tufnol) sheet and insulated with ¼" thick high-density polyurethane foam using fast-setting epoxy resin adhesive. A small glass cell filled with dry air, 3cm in length with 18mm diameter silica windows at each end, is sealed in the side of the cold box and is heated by encapsulated Nichrome wire to prevent condensation of moisture. The variable heater dissipates 1-5 Watts of electrical power and is insulated from the rest of the cryostat with glass fiber tape. The cryostat also contains a metal cylinder fabricated out of a sheet of copper which surrounds the PMT and accelerates the initial cooling of the tube. The metal cylinder of the cryostat push fits over the base of the PMT so that the space around the detector is isolated from the remainder of the box apart from a small Perspex holder containing silica gel, which screws into the top of the cold box and prevents traces of ice forming on the external surface of the PMT. In use, the drying container is replenished with fresh silica gel and attached to the cryostat module one hour or so before the addition of the dry-ice. The heater typically operates at 2V, 0.7A and is usually switched on several minutes before the addition of a ½ pound charge of solid carbon dioxide in pelletized form. A single charge lasts approximately 60-90 minutes.

Electronic Instrumentation

A commercial 0-1800V, 5mA power supply (Brandenburg, Model 472R) provides a stable high voltage input (drift less than 0.01% per day) via a PET 100 connector. A simple voltage divider made up of ¼W 82K carbon film resistors provides a linear voltage drop across the dynodes of the PMT. The anode signal is amplified by a relatively simple pre-amp/amp circuit mounted in the photometer head (see Figure 6). The output from the PMT is amplified initially using an inexpensive CA 3140E MOS/FET op-amp configured as a voltage follower. A set of switchable resistors (10K to 100M) connected across pin 2 and pin 6 of the 3140 provides 2.5 magnitude gain intervals. A 741S op-amp provides a further x10 voltage gain yielding a 0 to -11VDC output to a BNC socket.

The DC signal from the photometer head is then translated to a pulse output using a Teledyne Philbrick Model 4715 V-to-F converter mounted in a separate case, which also contains the -15V - 0V - +15V supply for the head. The 4715 possesses negligible drift (less than 10 ppm/day) and is configured to provide a 0-100 kHz output for inputs of 0.000V to -10.000V with a typical nonlinearity of better than 0.01% and a temperature coefficient of 30 ppm/^{o}C. The output from the 4715 is then integrated using a commercial frequency counter employing a gate time of 10 seconds. Voltage offset is achieved either by using a 10-turn 10K potentiometer connected across pin 1 and pin 5 of the 3140 for fine adjustment, or by means of a second 10-turn 10K potentiometer voltage stabilized by a 6.2 1N 827 temperature-compensated Zener diode to provide an adjustable offset into pin 2 of the 741S op-amp.

The photometer can also be operated using lock-in detection to eliminate dark current drift during uncooled operation. For this, a chopper motor is inserted in the central compartment of the PEP head and a synchronous signal is fed from this to the reference input of a commercial phase sensitive detector (PSD). The PSD accepts a ±1V input and applies a 10-fold gain to yield a 0-10VDC output, which is then fed to the counter via the V-to-F converter.

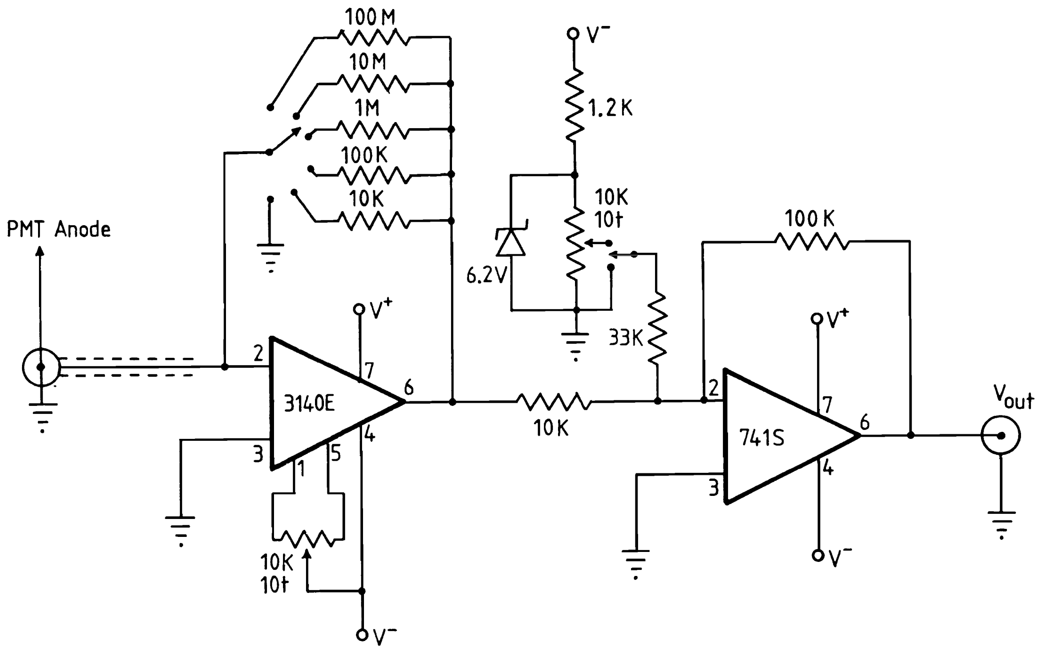

Figure 6. The DC amplifier circuit.

IV. OBSERVING PROGRAM

Preliminary photoelectric observations at the Mouldsworth Observatory during the first year of operation have included a wide range of astronomical phenomena in order to test out the capabilities of the photometer system using not only simple DC operation but also lock-in detection and PMT cooling. The following section outlines some of the initial results obtained with the equipment including: observations of eclipsing binaries, rotational light curves of asteroids, lunar occultations, and photoelectric monitoring of possible asteroid occultation events.

Eclipsing Variables

Any clear night can present the well-equipped PEP observer with a perplexing choice of objects worthy of scrutiny. Not least amongst these are the various families of short-period eclipsing variables such as the Algol types, RS CVn types, β Lyrae types, W UMa types, and ellipsoidal variables. Such objects easily lend themselves to photoelectric observation either in defining the complete light curve through one or more standard filters, or more simply, in determining the exact time of primary minima. Figure 7 illustrates the rise from primary minimum of AR Lac obtained using an uncooled 1P28A PMT and V-band filter. This observation was made under adverse conditions without a heated dewcap, when the front corrector plate of the telescope became gradually covered with condensation obscuring more than 50% of the admitted light. Since comparison star measurements were made at 5-10 minute intervals, an accurate light curve could still be constructed from the raw observational data. Lock-in detection was employed for this observation to effectively eliminate changes in the PMT dark signal.

Rotational Characteristics of Asteroids

Photometric study of asteroids has become increasingly popular during the past few years, especially at a number of smaller observatories (Gehrels 1979). Principally, a program of V-band determinations of the rotational light curve of individual minor planets is being carried out by professional astronomers. The change in reduced magnitude at maximum with phase angle during an apparition also yields information concerning the scattering characteristics of the surface of each asteroid. Furthermore, observations made at several oppositions (i.e. at different heliocentric longitudes) enables the spin-axis orientation of the body to be calculated. Several hundred asteroids reach at least magnitude 12 at favorable oppositions providing much scope for professional and amateur alike.

Differential photometry of the minor planet 115 Thyra was carried out on four nights during February1983 at the Mouldsworth Observatory in an effort to derive a composite rotational light curve. An EMI 9661B PMT was employed together with dry-ice cooling to reduce the dark current to an acceptably low level. During these observations, the V-magnitude of the asteroid varied between 10.1 and 10.8, whereas the dark current was effectively 12th magnitude or less. The nights chosen were fairly good apart from the presence of a waning moon for some of the observational runs, and relatively high atmospheric extinct-

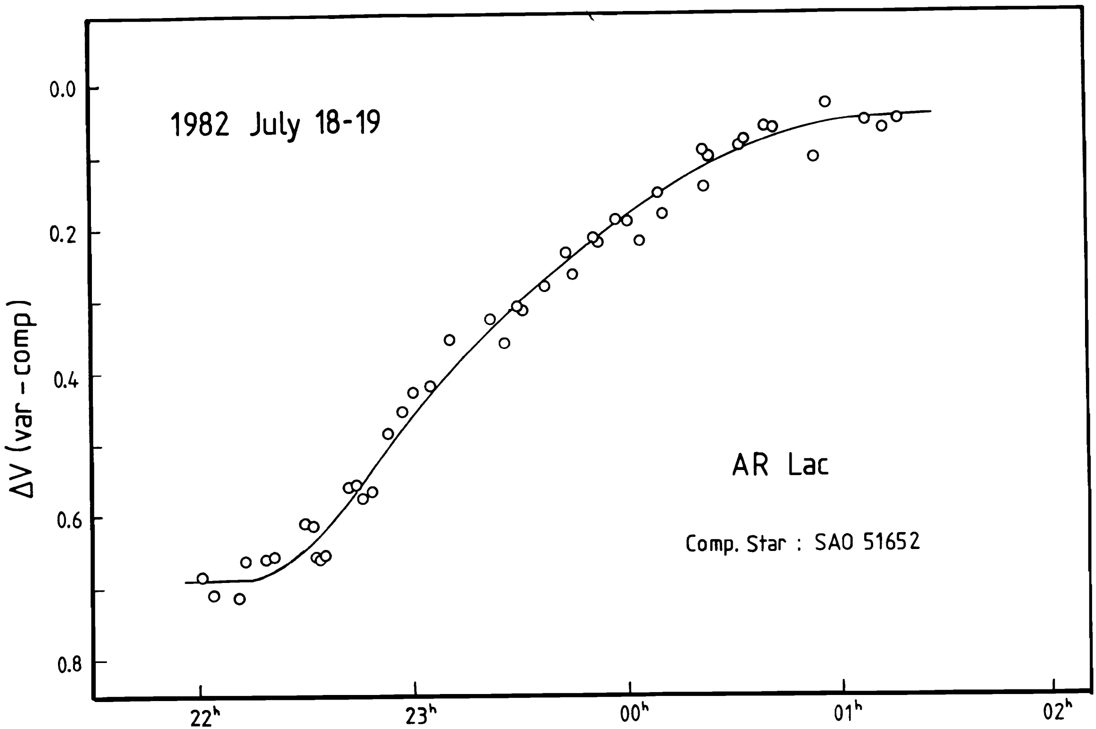

Figure 7. A V-magnitude plot of the rise from primary minimum of AR Lac.

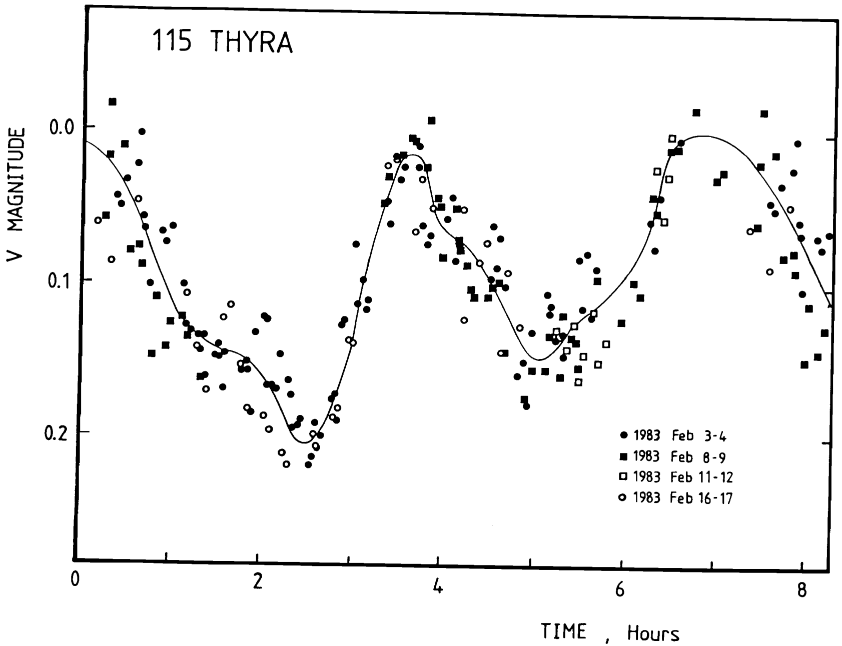

Figure 8. The preliminary composite light curve of asteroid 115 Thyra, arranged according to an apparent period of 7.236 hours. Dry-ice cooled EMI 9661B photomultiplier tube was used. The zero hour corresponds to 21:35 UT on February 3, 1983.

ion (k_V = 0.4 - 0.5). The same comparison star was used for all of the runs and this possessed a B-V index which differed by only 0.02 or 0.03 magnitudes from that of the asteroid, thus avoiding the need for higher order corrections during the reduction of the data.

The resultant light curve, corrected for differential extinction and normalized in brightness to allow for changes in phase angle, etc. is plotted in Figure 8. A mean synodic period of 7.240 hours was used to construct the composite curve which covers virtually the entire rotational cycle. Two distinct maxima and minima with a total amplitude of $0\overset{m}{.}20$ and equally spaced in time are clearly seen. This observation broadly agrees with the only published composite light curve (Scaltriti *et al* 1981) which was obtained during the 1978 opposition of 115 Thyra.

Occultation Phenomena

Photoelectric timings of lunar and planetary occultation events can provide relatively precise information concerning the Moon's orbit, the dimensions of asteroids and satellites, and in the case of high speed photometry, the diameters of stars. Figure 9 illustrates a typical lunar occultation event recorded at the Mouldsworth Observatory. A two-pen chart recorder was used to simultaneously monitor the DC output from the photometer head together with a series of 1 second time signals. Using this system, occultation timings accurate to ± 0.05 seconds can be performed. Close appulses of several minor planets have also been monitored, but in these cases no occultation phenomena have been detected.

Other Photoelectric Photometry

Several other PEP programs are at present underway in addition to those outlined above. The author has contributed UBV observations of the long-period eclipsing binary ε Aur as part of the 1982 - 1984 International Campaign (Stencel and Hopkins 1982). Some V-band determinations of certain RS CVn binaries have also been made.

Various other types of work are planned. One project involves photoelectric B and V measurements of comparison star sequences brighter than 12th magnitude as a service to other amateurs. Checks would be made of intrinsic variability and a revised, more accurately defined sequence would be derived taking into account the color index of the variable concerned. Also, photographic astrometry of the comparison star field accurate to ± 0.5 arcsec of better would be carried out as part of this project.

It is proposed to conduct high speed photometry of lunar occultations using a two-channel transient recorder loaned for the purpose. Time signals would be recorded on one channel and the photometer output stored in each of the 1024 memory locations of the other channel. Using this system in conjunction with radio time signals from MSF Rugby, a precision of better than 0.01 seconds should be readily obtainable. Also, for stars of 4th magnitude or brighter, it should be possible to measure occultation fringes using the same equipment.

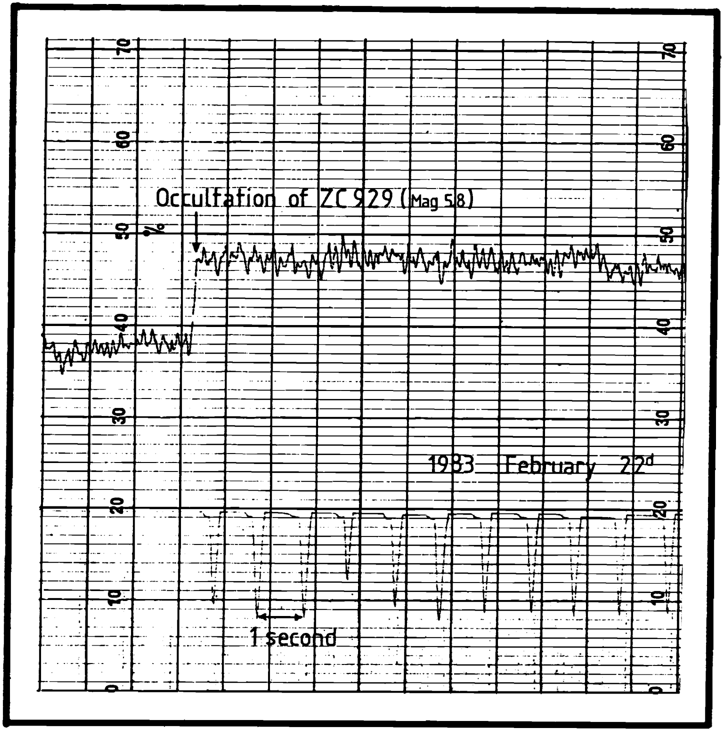

Figure 9. Plot of a high speed photometry lunar occultation event.

V. AMATEUR PHOTOELECTRIC PHOTOMETRY IN ENGLAND

Weather conditions in England are not very favorable for photometric observation, with usually only 20 - 30 "near-perfect" nights per year. Despite this fact, a number of other advanced amateurs in the U.K. are now assembling photoelectric equipment for use with their own telescopes. The author is in close cooperation with some of these, in particular, Mr. Andy Hollis (pictured with the author in Figure 10) of Cuddington, Cheshire, John Watson of Hartfield, Sussex , and Roger Pickard at Hadlow in Kent. A number of other British amateurs, most notably Patrick Moore, are planning on "going photometric".

Figure 10. Andy Hollis (on the right) and the author - pioneers in amateur photoelectric photometry in England.

Andy Hollis has now constructed a low-cost photon counting PEP system that would be of interest and within the means of other amateurs in England. The photometer head based on the Stokes design (Hall and Genet 1982a) is exceptionally compact and lightweight, and can be readily mounted in the $1\frac{1}{4}$" eyepiece tube of his 12-inch f/7 Newtonian reflector without any need to counterbalance the tube. Andy has also built a compact HV power supply, winding the step-up transformer and incorporating voltage doubling circuitry to give a variable 500 - 1000V output. The photon counting circuit is based upon the design of Jeffrey Hopkins (Hall and Genet 1982b) using the LeCroy MVL 100 amplifier/discriminator and the Intersil 7226A counter IC. As the Minor Planet Co-ordinator for the Terrestrial Planets Section of the BAA, Andy intends to carry out V-band photometry of asteroids in collaboration with the author. He also plans to use his equipment to study eclipsing binary stars and in establishing comparison star sequences for the Variable Star Section of the BAA.

John Watson now has a working system based on an end-window EMI 9789 PMT after some difficulty with alignment problems, Fabry lens design, and apparent non-linearity of the DC amplifier which is based on a LH0042C op-amp. He uses a commercial regulated HV power supply. His photometer head employs a sliding prism to deflect the light beam away from the previewing eyepiece onto the cathode of the PMT, which is mounted parallel to the long axis of his 10", f/6 Newtonian. Although the telescope is supported on a sturdy mounting, John is at present minimizing backlash in his drive and modifying his variable frequency supply to give improved guiding for photometry. He is also about to move to Battle, Sussex (a more favorable observing site) where he intends to re-establish his observatory and commission his PEP equipment.

Roger Pickard is working closely with another active BAA member, Jack Ells. Both are establishing a PEP system. Roger's will use an EMI 9524B end-window tube in combination with his 16", f/3.75 Newtonian "flux-collector". Roger has already built a prototype head (a useful learning exercise) and has carried out some preliminary tests. Jack Ells, who owns a fine 12 3/4" Newtonian telescope housed in a "heated" observatory, is at present building a second head, which Roger also intends to duplicate in the near future.

Two other amateurs, Harold K. Robin in Tunbridge Wells, Kent, and Mike Peel living near Preston, Lancashire, also possess photometers. Mike Peel has made some preliminary observations of eclipsing variables and has submitted an article to the BAA Journal. Harold Robin, who possesses a well-engineered 18" Cassegrain telescope, has recently invested in an EMI STARLIGHT-1 photon counting photometer and plans to start photometric measurements shortly. Some years ago, he made two prototype photometers employing valves in the amplifier circuitry, but then moved abroad and so was unable to fully test the equipment.

English photometrists are planning a workshop hosted by the Crayford Manor Astronomical Society during 1984. Ultimately, it is hoped that a network of PEP observers will be established throughout the U.K. so that observations can be co-ordinated to provide extensive coverage of certain phenomena. Gordon Taylor of the Royal Greenwich Observatory is particulary keen that an occultation monitoring group be set-up - English weather permitting! Andy Hollis and the author are also hopeful that a new Minor Planet Section will be set-up within the BAA. Photoelectric photometry would play a major role in the newly-created Section and enable amateurs to make a valuable contribution in this rapidly developing field.

REFERENCES

Dick, R., Fraser, A., Lossing, F. and Welch, D. (1978) J. roy. Astron. Soc. Canada, 72, 40.

Gehrels, T. (1979) Asteroids, Univ. of Arizona Press, Tucson.

Genet, R. M. (1980) J. British Astron. Assoc., 91(1), 92.

Hall, D.S. and Genet, R.M. (1982a) Photoelectric Photometry of Variable Stars, 4-34.

Hall, D.S. and Genet, R.M. (1982b) Photoelectric Photometry of Variable Stars, 5-35.

Scaltriti, F., Zappala, V. and Harris, A.W. (1981) Icarus, 46, 275.

Stencel, R.E. and Hopkins, J.L. (1982) Epsilon Aurigae Eclipse Campaign Newsletter, No. 1-6.

19

LINES OBSERVATORY

RICHARD D. LINES

Lines Observatory
P.O. Box 683
Mayer, Arizona 86333

The Lines Observatory was established in 1968. The original telescope, a 16-inch Newtonian, was replaced in 1979 by a 20-inch mirror and tube assembly, the original mount being retained. The telescope can be converted from f/19 Cassegrain to f/6 Newtonian by changing the top section of the tube. It is now used almost entirely in the Cassegrain configuration.

The 19-foot observatory dome, the telescope, and other instrumentation were built by Mrs. Lines and myself with the help of many good friends. I am one of the few amateur astronomers lucky enough to have a wife who is also interested in astronomy. Helen and I have been an observing team for many years, during which time we were active members of the A.L.P.O. Mars and Comet sections. Prior to photometry, the telescope was mostly used for photography. We took up photoelectric photometry in 1979 when I retired and had more time to devote to astronomy.

Our photometer head is constructed similar to that described in the original A.A.V.S.O. Photoelectric Photometry Manual. The first section of the head contains the diaphragm and filter slides, flip mirror and viewing eyepiece. The photomultiplier housing is separated from the first section by a removable section containing the 95mm focal length Fabry lens. The removal of this section and installation of a 30mm focal length Fabry lens into a cell provided in the photomultiplier housing, converts this system from f/19 to f/6. A DC amplifier with gain settings in decades is attached to the photomultiplier housing. A digital voltmeter readout is separate from the head and can be attached to the back of the telescope in several convenient locations. The regulated power supply is mounted on the telescope pier.

Working as a team, our photometry procedure may be unique. I operate the telescope and photometer, and call out the readings. Helen averages the readings using a pocket calculator and records the averages along with the time. The meter displays the reading every three seconds, and since a digital voltmeter only looks at the signal one third of the time, we take six readings and average them. This is equivalent to a six-second integration time, but is spread out over twenty seconds. This prodedure has proven quite satisfactory; the standard deviation of three averages being typically less than $0^{m}.01$. Our present observing program includes eclipsing binary stars, RS CVn stars, and RV Tauri stars. All stars are being observed in cooperative programs with professional astronomers contacted through I.A.P.P.P.

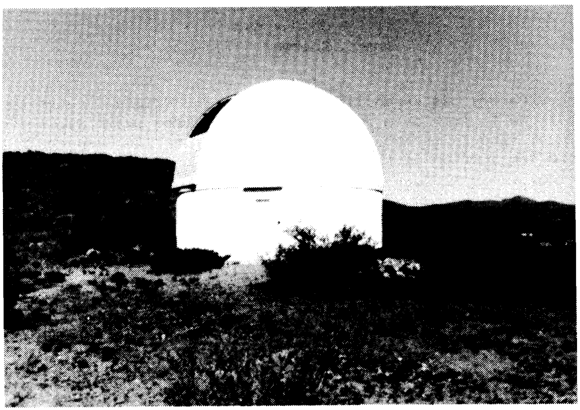

Fig. 1. The 19-foot observatory dome of the Lines Observatory.

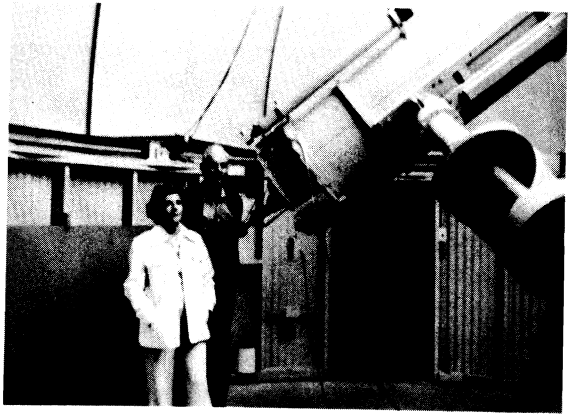

Fig. 2. Helen and Richard Lines stand beside their 20-inch Newtonian/ Cassegrain telescope.

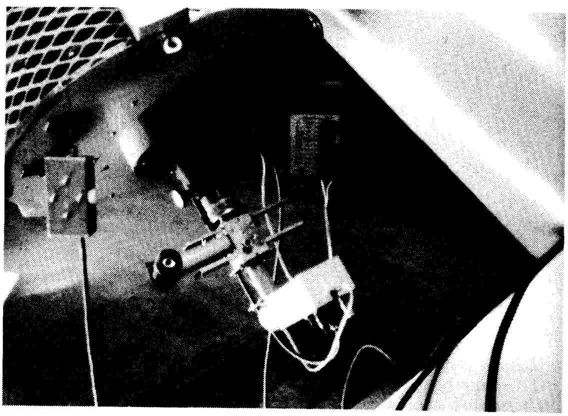

Fig. 3. The Lines' photometer attached to the Cassegrain focus. The telescope slow motion controls hang from the telescope.

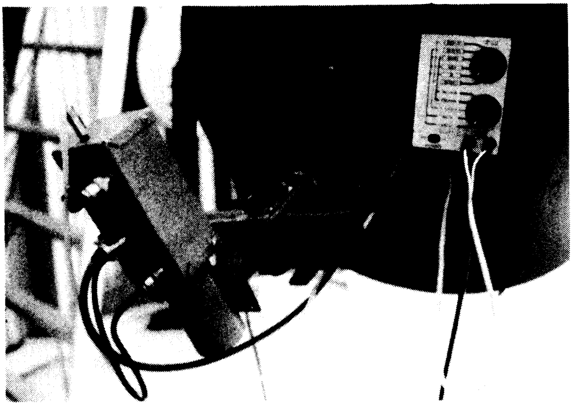

Fig. 4. A close-up view of the photometer head and digital readout voltmeter.

LINES OBSERVATORY LATITUDE : 34 23 44 LONGITUDE : 112 14 19

VARIABLE NAME : TX U MA R.A. : 10 44 21 DEC. : 45 39 20
COMPARISON NAME : BD +47 1797 R.A. : 10 39 05 DEC. : 46 55 41
UNIVERSAL DATE : D/M/Y 30/3/83 PERIOD: 3.063243 EPOCH 2445384.1238

UT	v	b	u	s	s	s	JD(HEL)	PH	DIF V	DIF B	DIF
3 13 0	116	151	0	4	4	0					
3 19 0	145	234	0	5	5	0	5423.64144	.9005	-.226	-.454	
3 24 0	120	156	0	5	5	0					
3 28 0	152	240	0	6	6	0	5423.64769	.9026	-.272	-.482	
3 31 0	118	152	0	6	6	0					
3 35 0	153	239	0	7	7	0	5423.65255	.9042	-.295	-.528	
3 39 0	118	144	0	8	8	0					

Fig. 5. A sample printout of the reduction program. The input readings for each filter are on the left, followed by the sky readings. The time is the mean time for the filters. Differential magnitudes are determined using the average of the two comparison magnitudes on either side of the variable magnitude.

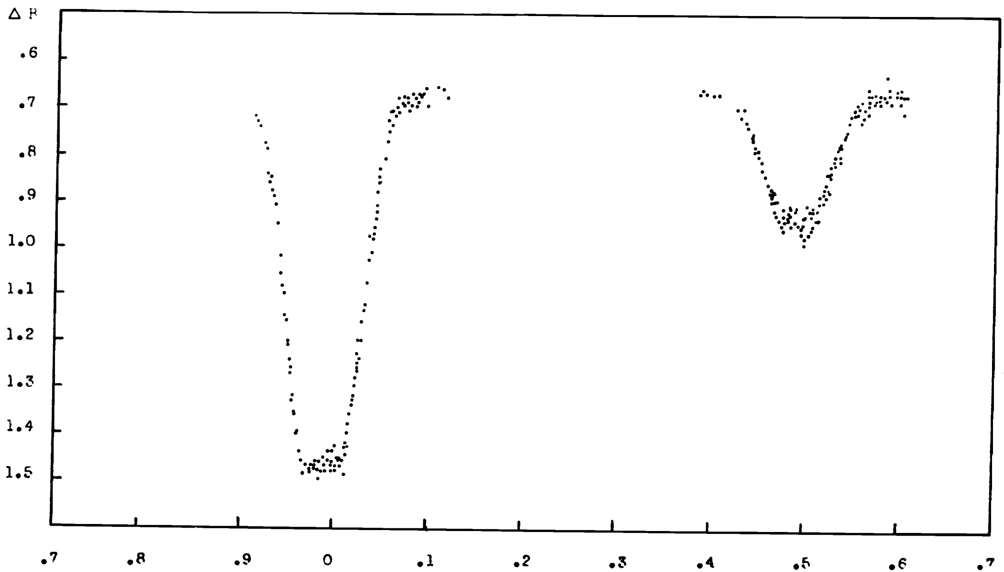

Fig. 6. Plot of AR Lacertae obtained at Lines Observatory in 1982. Shown are the results in the blue bandpass. JD2440933.3018 + 1.9831917E.

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