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A D C AMPLIFIER FOR PHOTOELECTRIC PHOTOMETRY

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ABSTRACT

We describe the construction and discuss the performance of a d c amplifier which was installed at the 34 cm telescope of Vainu Bappu Observatory in 1987 January and since then extensively used for variable star photometry

Key Words d c amplifier photoelectric photometry

1 Introduction

In astronomical photometry the most commonly used detector is the photomultiplier For each photon detected at the photocathode of the tube, an electron is released which is then multiplied by the secondary emissions from a series of dynodes before being collected at the anode Though the gain thus achieved in a photomultiplier is very large (typically~10^6), because of low flux of photons, the output current is still extremely small Hence, it is necessary to amplify the output from the photomultiplier by external circuitry before it can be measured easily There are two modes of measuring photomultiplier outputs produced by the photons from celestial sources At very high time resolutions (< 1msec), the anode current can be resolved into individual bursts which can produce sharp voltage pulses across a suitable load resistor In the pulse counting mode, these pulses are amplified, shaped and then discriminated against low level noise pulses before finally being counted In the alternative conventional d c method, the average anode current is directly amplified to a conveniently measurable value (~1mA) and then registered using a strip chart recorder In this mode of operation, the most important electronic unit is a current amplifier The photomultiplier output is linear over a wide range of input light flux (Stebbins, Whitford and Johnson 1950) Hence, to match the performance of photomultipliers, it is imperative that the amplifier used in astronomical photometry should also be highly linear with a good gain stability over a wide range of input signals This has to be achieved against unfavourable conditions normally existing on the open observing floor with a large variation in temperature and humidity that occur during the course of a night as well as during different seasons Oliver (1975) has summarised the basic requirements of a good current amplifier used for photoelectric photometry

While working at the telescope it is convenient to have half-magnitude gain steps. Since the commercially available amplifiers seldom meet all the requirements needed for accurate astronomical photometry, many observatories have built their own amplifiers (Johnson 1962). Our Observatory is not an exception to this and until recently, an amplifier based on the circuit described by Valley and Wallman (Code 1963) was used at the 34-cm relfector of Vainu Bappu Observatory, Kavalur. Of late, due to the aging of the various components, the coarse gain calibration was found to be non-repetitive. This was often a handicap while choosing comparison stars for variable star photometry. The problem of the amplifier output drift was sometimes severe and was slowing down the pace of observations because of the necessity of monitoring the zero reference quite frequently. In the present days of on-line computations, the scene of astronomical photometry is dominated by the pulse counting methods. But still there are situations where the d.c. technique can be a better choice than the pulse counting mode (Henden and Kaitchuk 1982; Dupuy 1983). For small telescopes and not very faint sources the d.c. technique is more suitable.

In this paper we report on the construction and performance of a d.c. amplifier, recently installed at the 34-cm reflector.

2. Circuit description

Our design has been primarily based on that given by Oliver (1975) because of its simplicity, employment of a few components, high reliability, and ease of maintenance. The important circuit elements of the d.c. amplifier are schematically represented in Figure 1. It has two stages, a basic amplifier stage and a buffer and time constant stage. The key component of the basic amplifier stage is a varactor bridge op amp

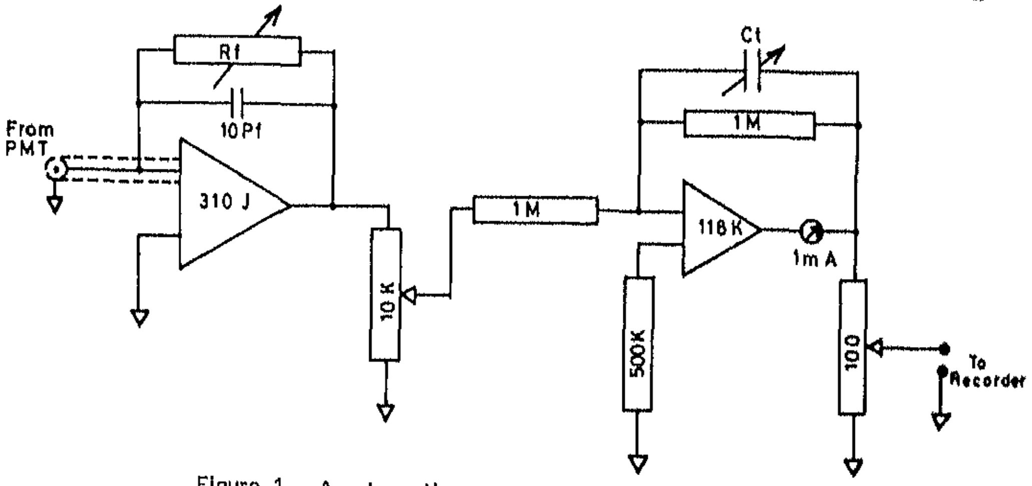

Figure 1. A schematic representation of the d.c. amplifier.

(Analog Devices Model 310J) which has a low bias current ($\sim 10^{-14}$ A) and a very high input impedence ($\sim 10^{14}\,\Omega$), making it ideal for measurement of low current signals. The negative feed back through the resistor Rf ensures that the input terminal is at virtual ground and hence the anode of the photomultiplier is always at the ground potential. This is essential for a linear tube response because any variation in the anode potential may cause nonlinearity (Young 1974). Coarse gain steps are achieved by selecting different values of the feed back resistor Rf. The second stage (built around an Analog Devices Model 118K op amp) has a unit voltage gain and the fine gain adjustments are made by selecting the input to this stage through the output voltage divider of the basic amplifier unit. Different time constants of integration are obtained by selecting the capacitor Ct connected in the feed back loop of the buffer stage.

We have included three additional features in the circuit given by Oliver (1975) which make the amplifier unit more flexible in use. Some of the commercially available strip chart recorders (such as Brown recorder made by Minneapolis - Honeywell) do not have facilities for the adjustment of zero level externally. If the photomultiplier is refrigerated or the observations are made at low amplitude gains (for bright objects), the sky deflections will be very small, almost at the lower limit of the recorder pen movement, especially during the dark moon periods. It is always desirable to keep the zero point of measurement slightly above the lower limit for a better reading accuracy and so, we incorporated changes in the circuit so that the zero reference on the recorder chart can be adjusted at will. We also introduced a voltage divider at the output end of the amplifier so that from a range of output voltages (10, 15, 25, 50 mv and any combination of these) a suitable value can be selected to give full scale deflection for any particular chart recorder used. Further, we made a provision to change the polarity of the current passing through the meter to make the unit a more general purpose electrometer.

For long-term gain stability, it is very essential that the resistors used in the circuit have very low temperature coefficients. All the resistors upto the value of 1M used in the circuit are of metal film with temperature coefficients of 25 ppm and are accurate to 0.05%. The high megohm carbon resistors with tolerance values of 1% are in glass encapsulation for longer life. Attention to insulation is extremely important while working with low current signals ($\sim 10^{-10}$A). It is highly essential that the contacts of the selector switches are proper and absolutely clean for the repeatability of the gain calibration. Hence in the construction of the amplifier we have used ceramic selector switches with silver coated contacts to achieve the above requirements. When the amplifier is used with the zero adjustment, because of the passive nature of the related circuit, the variations in power supply may cause significant drift problems and so it is imperative to have a well-regulated power supply. We have used a modular power supply (Analog Devices Model 904E) which has line and load regulations of 0.02% each. Its temperature coefficient is only 0.015%.

3. Performance

Three versions of the d.c. amplifier described above have been built which differ from each other only in the size and general lay-out of the different control switches. One unit has been in use at Infrared Astronomical Site Survey Observatory, Leh since 1985 (Singh et al. 1987). The most compact version of the amplifier (8" X 6 1/2" X 5 1/2") built with the idea of mounting directly on the telescope, was installed at the 34-cm reflector of Vainu Bappu Observatory in 1987 January and was extensively used for the photoelectric photometry of late type emission binaries and RV Tauri stars during the last observing season (Mohin and Raveendran 1987; Raveendran and Kameswara Rao 1987). In the following, we discuss the performance of this amplifier based on the observational results obtained during the 1987 observing season.

3.1 Gain calibration

Regular calibration of the gain steps is very important in the d.c. technique since the accuracy of the photometry depends partly on the accurate knowledge of the various gain step differences. This is done with the help of the built-in current source. The procedure for the calibration of the gain steps has been given in detail elsewhere (Oliver 1975; Henden and Kaitchuck 1982).

In Table 1, we have given the magnitude differences between the fine steps, available in the amplifier, obtained on two occasions with about a month's interval. Table 2 contains the results of coarse gain calibration. The recording device was a Brown recorder. Due to the uncertainty (Δd) in the readout from the chart, the expected error in the magnitude calibration is given by,

$$\Delta m = 1.086\, \Delta d\, (d_1^{-2} + d_2^{-2})^{1/2},$$

where d_1 and d_2 are the deflections corresponding to the steps being compared. In the fine gain calibration, $d_1 \sim 95\%$ and $d_2 \sim 60\%$, whereas in the coarse gain calibration both

Table 1. Fine gain magnitude differences

Date 1987	2-1	3-2	4-3	5-4	6-5	7-6	8-7	9-8	10-9	11-10
				Fine gain steps						
Feb 26	0.499	0.499	0.499	0.499	0.498	0.499	0.500	0.500	0.499	0.504
Mar 21	0.495	0.496	0.495	0.495	0.495	0.494	0.495	0.495	0.496	0.498

Table 2. Coarse gain calibration. The number inside the bracket indicates the coarse gain step and that outside the fine gain step

Date 1987	1(11)-2(6)	2(6)-3(1)	2(11)-3(6)	3(6)-4(1)	3(11)-4(6)	4(6)-5(1)	4(11)-5(6)
			Magnitude differences				
Feb 26	+0.002	-0.002	-	+0.006	+0.006	+0.002	+0.001
Mar 21	+0.008	-0.007	+0.000	+0.002	+0.006	-	-
Mar 28	-	-	-	-	-	+0.002	-0.001

d_1 and d_2 are ~ 95%. With $\Delta d \sim 0.2\%$, the expected uncertainties in the two cases are 0.004 mag and 0.003 mag respectively. It is to be noted that the two sets of values given in Table 1 and 2 agree with each other within the expected uncertainties, indicating an excellent repeatability of the gain differences. Further, the fine gain magnitude differences are within the errors of exactly 0.500 mag, consistent with the very low tolerance values of the metal film resistors used.

3.2 Linearity

We observed fifteen stars in Pleiades cluster which lie in the 2.87 ÷ 12.02 mag interval with the 34-cm telescope for the purpose of checking the linearity of the amplifier, On 1987 Feb 19th night. The advantages of using a cluster for such a study come from the following: (1) the uncertainty in the atmospheric extinction coefficient will have negligible effect on the results obtained, and (2) a cluster will contain stars with wide range of magnitudes. The limit on the brighter side was set by the brightest star in the cluster (ηTauri, V = 2.87 mag). The detector was an uncooled RCA 1P21 tube operated at 900 V and the dark current was~3nA. A 12.0 mag star was giving an output current of 0.5 nA, about a sixth of the ambient dark current. We could not observe stars fainter than 12.02 mag because the dark current fluctuation was introducing significant error in the measurement. The results of observations are plotted in Figure 2 and it is quite evident that in the magnitude interval considered (2.87 - 12.02 mag) the amplifier has an excellent linear response (slope = 0.998 ± 0.002

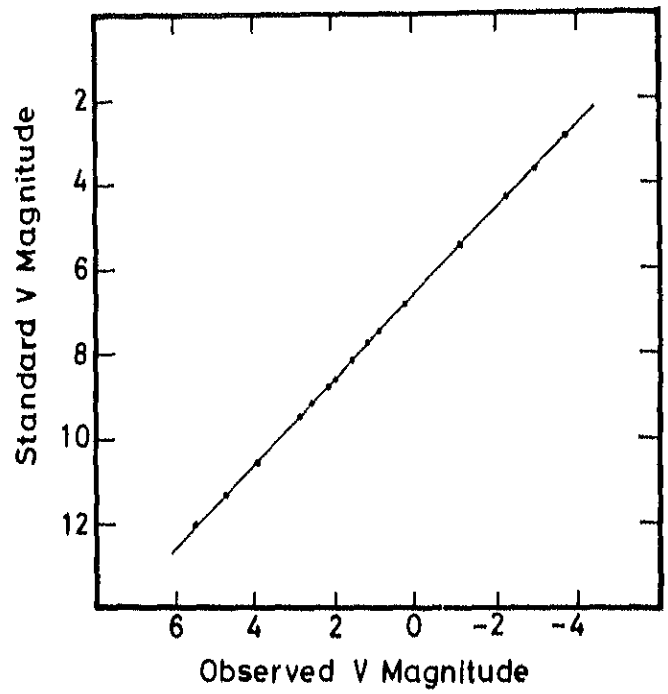

Figure 2. Plot of standard V magnitudes of Pleiades stars against the corresponding atmospheric extinction-corrected observed magnitudes. Correction for the differences in the (B-V) colours of the stars have also been applied from the known system transformation coefficients.

3.3. Repeatability

For variable star photometry it is desirable to have the brightness of comparison stars very similar to that of the variable. But, in practice it will not be always possible to choose such comparison stars. Hence to get a near full scale deflection on the recorder chart, it becomes a necessity to change the amplifier gain. If the amplifier sensitivity affects the comparison and variable stars differently, the advantage of the variable star photometry is lost. To demonstrate the repeatability of differential measurements using the d.c. amplifier, we give an example below. Both HD 65723 and HD 66559 were observed on fifteen nights during the period 1987 January 21 - March 28 as comparison stars of the RV Tauri star AR Puppis (Raveendran and Kameswara Rao, in preparation). The V magnitudes of these stars differ by ~ 1.5 mag and hence a change in the amplifier gain was necessary while observing them. In Figure 3, we have plotted the difference in V magnitudes of Hd 65723 and HD 66559 obtained against the corresponding Julian days of observation The differential magnitudes show a standard deviation of only 0 0075 mag The actual value would have been still smaller if the skies had been of better quality during JD 2446816 32

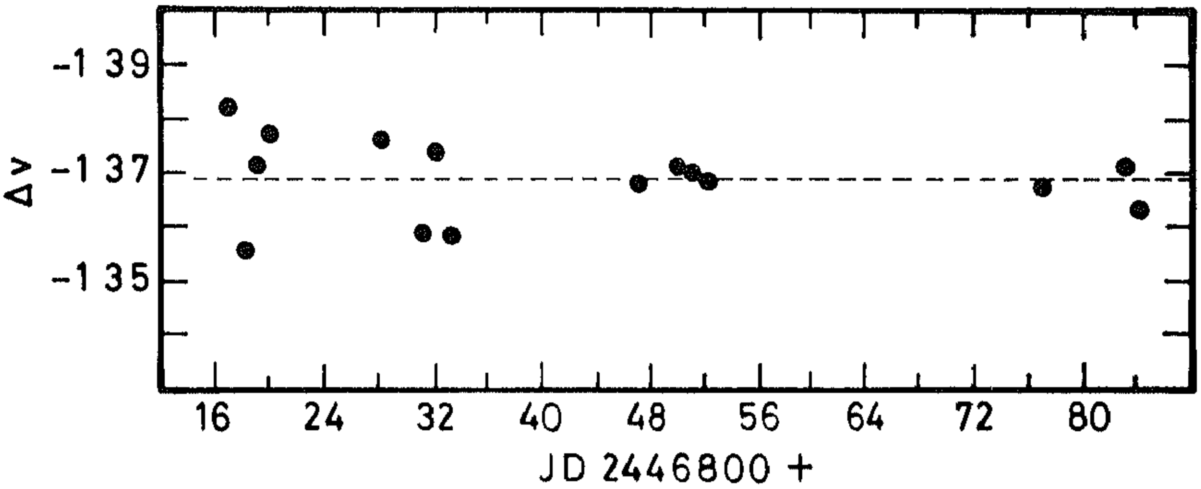

Figure 3 Plot of the differential magnitudes, in the sense HD 65723 HD 66559 against the corresponding Julian days of observation

4 Conclusions

We have built three d c amplifiers based on the design principles given by Oliver (1975) after incorporating three additional features to make the units more versatile both as an amplifier for photoelectric photometry in the d c mode and as an electrometer for the measurement of low current signals Maximum care was taken in the selection of the components and the construction of the units for a stable gain calibration and drift-free operation over continuous hours of use A compact version of the amplifier, suitable for mounting on the telescope directly, was extensively used at the 34-cm reflector of Vainu Bappu Observatory for variable star photometry and the performance was found to be excellent

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