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STAR BRIGHTNESS MEASUREMENT USING PHOTON COUNTING

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Abstract

A brief overview of the use of photon counting for star brightness measurement is presented. The advent of integrated-circuit components, particularly for the pulse amplifier/discriminator, should make this technology more affordable to amateurs.

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1. Background

Light from a star can be described as a flux of incoming quanta (photons), each carrying a small amount of energy. Photon counting is an approach to measuring a star brightness by counting these photons one by one. This differs from the method which is more familiar to amateurs, analog measurement of the photo-multiplier tube (PMT) output current, in several significant respects:

1. High Linearity - Since the comparison of two stars is made on the basis of count rate, not signal amplitude, stars differing by many magnitudes can be easily compared. In an analog system, amplifier nonlinearities, calibration changes, etc., make comparisons over a large brightness range more difficult and potentially less accurate.

2. Low Noise - With some currently available PMTs, the dark-count rate at room temperature is negligible. Thus the only noise source affecting a measurement is the fluctuation in the arrival rate of incoming photons due to atmospheric effects and counting statistics. While these noise sources are also present in analog systems, such systems are often dominated by system noise due to the amplifier or photomultiplier itself (PMT noise and leakage current are largely ignored by the counting system, as described below).

3. Low Drift - A photomultiplier designed for photon counting is configured so that a small change in the applied high voltage will have a negligible effect on count rate. This is not possible for analog systems since a small change in the applied voltage must produce an amplified change in output current. Similarly, photon-counting circuits, being digital, are essentially immune to drifts while analog circuits are not.

The net effect of these factors is a clear performance advantage for photon-counting systems, particularly when measuring faint stars. Any star which is visible in the telescope, and even those beyond the visible limit, can be reached with such a system.

2. System Description

Figure 1 illustrates the basic elements of the author's system, with a dashed line to indicate the differences for an analog approach. The PMT used (EMI 9789B) is specifically designed for photon-counting. An important feature of this and similar tubes is that individual photoelectrons from the cathode produce well-defined negative pulses at the anode which are significantly larger (~10mv) than pulses generated from noise sources within the tube (<1 mv). This means that it is possible to discriminate against noise pulses, and count only pulses derived from electrons leaving the photocathode. Since the cathode has a very low rate of spontaneous emission (dark count ~5/s), almost all the pulses counted are those due to absorption of one or more photons. By contrast, the analog system measures the integrated effect of all pulses, the noise component of which can overwhelm the desired signal at low light levels.

In addition to the PMT, a key element of any photon-counting system is the amplifier/discriminator. This unit converts the small, varying-amplitude, single-photon pulses from the photomultiplier into large, repeatable, logic-level pulses. The amplifier/discriminator should be mounted very close to the PMT to avoid noise pickup. A number of commercial units are available (Pacific Photometric Instruments, Princeton Applied Research), but prices, on the order of $1000, have been a major stumbling block to most amateurs. Now, at least one manufacturer (LeCroy) supplies a single integrated circuit ($17), or a complete PC board, which will perform this function. An implementation using this IC has recently been described by DuPuy (1981).

Once the photon pulses have been converted to logic-level pulses the rest is easy. I used standard TTL logic (~$1 per IC) to build up a counter chain which can integrate counts over intervals from 100μs to 100s. Originally, the output of this chain was scaled and converted to analog for a chart recorder output. However, a direct digital interface to a microcomputer has now been established which permits storage of the raw data for later processing. With a typical integration time of 2 seconds, the available computer memory is not filled until 6 hours of continuous data have been accumulated. These data can be immediately stored on a floppy disk while additional data accumulate. Thus there is no need to edit data or select chart recorder scales, etc., during the observing session. The system is usually left running all night to provide a continuous record of what was observed, even during coffee breaks!

Table 1 summarizes the system implementation built by the author in 1975 but incorporating 1981 prices and recent technology improvements. It is assumed that a minimum system includes a chart recorder rather than a simple meter. Costs are approximate, and depend to some extent on the electronics capability of the user. Although the price of the entire system is by no means trivial, the advantages of the photon-counting approach are so dramatic that any amateur considering photometry should give serious consideration to going this way. Figures 2-5 show a limited selection of some of the results obtained by the author using a 16-inch Cassegrain reflector.

REFERENCE

DuPuy, D. L. 1981, Publ. Astron. Soc. Pacific 93, 144.

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TABLE I. Photon Counting System

Tube - EMI[1]9789B	$ 295
High Voltage Supply Venus Scientific[2] DC/DC Converter Model C-30	110
Amplifier/Discriminator LeCroy[3] MVI 100 TB	95
Counter/Timer Approximately 30 TTL parts & boards	100
Digital/Analog Converter	20
Heathkit[4] model IR-5204 chart recorder	290
Miscellaneous electronics parts (Power supply, voltage regulators, connectors, cables, switches, etc.)	200
Total (exclusive of optical/mechanical parts)	$1110

Sources

1. EMI Gencom Inc., 80 Express St., Plainville, NY 11803.
2. Venus Scientific Inc., 339 Smith St., Farmingdale, NY 11735.
3. LeCroy Research Systems Corp., 700 S. Main St., Spring Valley, NY 10977.
4. Heath Company, Benton Harbor, MI 49022.

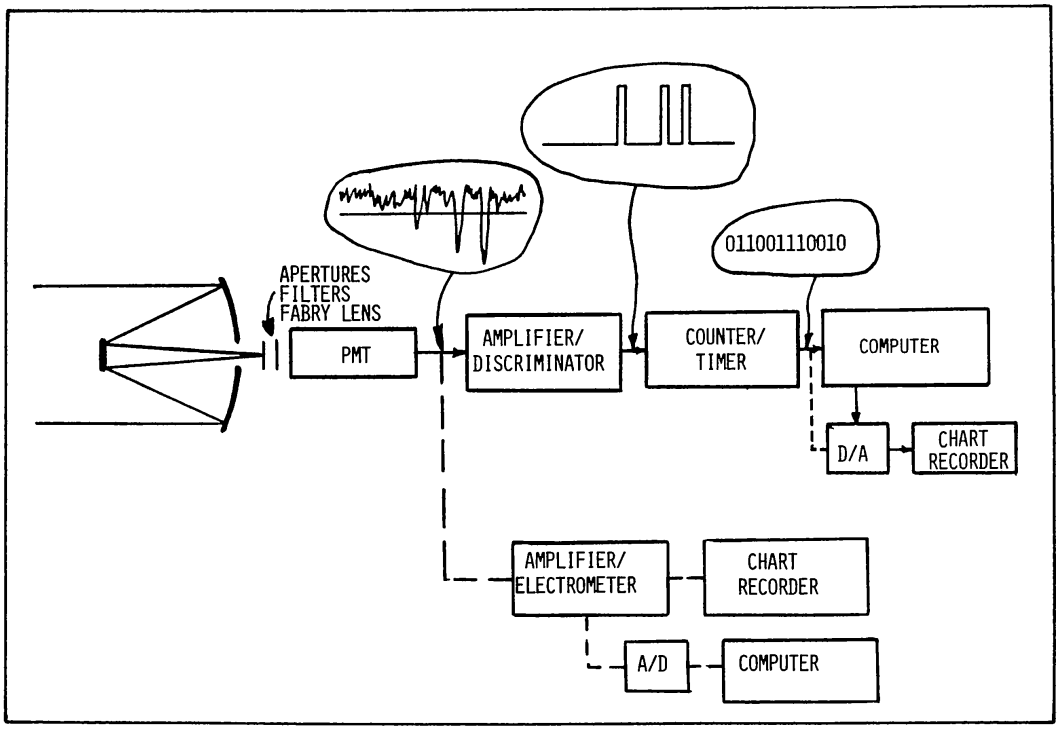

Figure 1. Block diagram of author's system, illustrating schematically the signals present at each point (lower branch illustrates analog approach). Note that by only counting pulses larger (more negative) than a fixed threshold, photon-counting eliminates most of the noise coming from the photomultiplier.

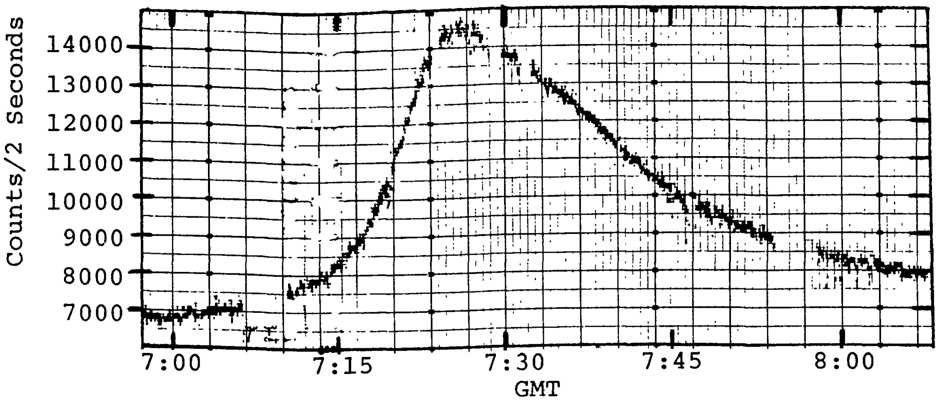

Figure 2. Trace of the short-period RR Lyrae star, CY Aquarii, through most of one cycle on 2/3 September 1977. This star is sufficiently bright ($10^{m}.6$ - $11^{m}.5$) that the bright moonlight on this night had only a minor effect. (Blue filter:2 second integration)

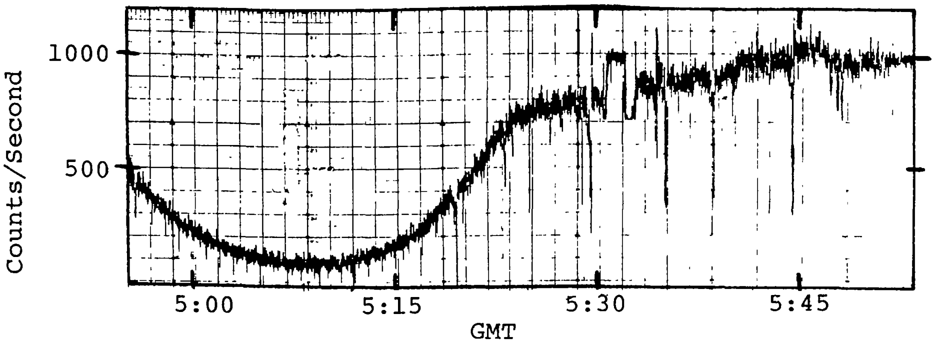

Figure 3. Eclipse of RW Trianguli ($13^{m}.5$ - $16^{m}.0$) on 12/13 November 1977, showing the short duration eclipse (~30 minutes) and a suggestion of flickering after recovery to maximum. The noise content of this trace could have been substantially reduced by selecting a longer integration period. (No filter:1 second integration)

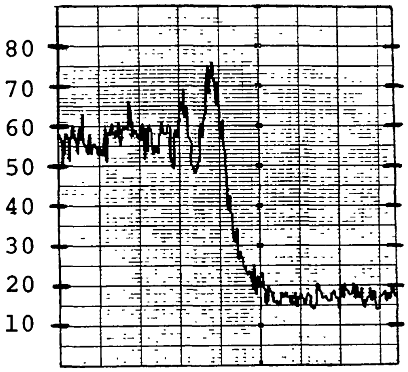

Figure 4. Occultation of the bright component of 77 Tauri on 4/5 March 1979 with an integration of 0.001 second/sample. Since the chart recorder does not have adequate speed to respond to millisecond events, the data were first recorded in the computer and played back later.

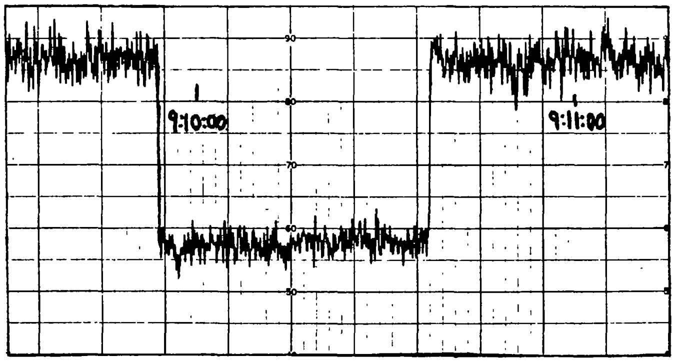

Figure 5. Occultation of $9^{m}.8$ star by Juno on 10/11 December 1979. (No filter:0.1 second integration)