PUB. ASTRON. SOC. PACIFIC, Volume 83, August 1971

# AN INEXPENSIVE PULSE COUNTER FOR PHOTOMETRY OF OCCULTATIONS

RICHARD A. BERG*
Leander McCormick Observatory, University of Virginia

*Received 5 April 1971*

RUFAS is a two-channel pulse counter for photoelectric occultation observations. The minimum pulse pair resolution is 80 nanoseconds, although under normal observing conditions the dead time is at least 200 nanoseconds. The counter can be used in other photon-counting applications; because of the large amount of data output, computer interfacing is desirable and possible.

*Key words:* photon counting — occultations

A photon counter was designed and built for the purpose of observing occultations of stars by the moon. Successful photoelectric observations of lunar occultations require that three important constraints be placed on the observing equipment. These are (1) integration time not greater than one or two milliseconds, (2) accurate and sufficient intensity resolution, and (3) capability to store large numbers of data values for later analysis. For a typical occultation, the separation of fringe maxima at the earth is about ten meters, or about ten milliseconds of time at a fringe velocity of one km/sec. Thus, adequate time resolution requires integration times small compared to ten milliseconds. In a pulse-counting mode, adequate intensity resolution is fixed by the total number of expected photons per integration time unit. Code and Liller (1962) have given an equation which one can modify to predict the expected number of anode pulses as a function of stellar brightness, telescope aperture, and other instrumental parameters. Using a telescope with an aperture of 32 inches, a photomultiplier whose quantum efficiency is 0.2, a filter with a bandwidth of 200 Å, and an atmospheric and instrumental transmission factor of 0.1, their equation reduces to

$$\log R^*_{(\lambda 5460)} = 7.31 - 0.4 \times m_v \quad , \qquad (1)$$

where $R^*$ is the expected number of anode pulses per second. For a star with apparent magnitude 4.5 one would expect to count about 300 pulses per millisecond. This necessitates a binary-counting register with at least eight bits. The third requirement arises from inaccuracy in the predicted times of occultation events. If a typical prediction error is ± 2 seconds ($1\sigma$), at least 12,000 consecutive data values must be stored, with one-millisecond resolution, in order to assure a $3\sigma$ probability that the event occurs within the specified window. (This requirement is eased at much higher costs by using a recycling multichannel analyzer as a mass storage device.) As described in the following paragraphs, RUFAS (Redick Ultra Fast Data Acquisition System), the photon counter, can be used for other photon-counting applications as well, and has the capability of being used as a peripheral device on a minicomputer for on-line data analysis. The total hardware cost for the photon counter did not exceed $400. This cost included building duplicate circuits to enable simultaneous two-channel observations to be made.

Figure 1 illustrates the interconnection of logical units of the pulse counter. A dual emitter-follower preamplifier functions as an impedance matching device. It is attached as closely as possible to the photomultiplier anode, and it passes low-impedance pulses to the amplifier

---

*Now at the Physics Department, University of Delaware.

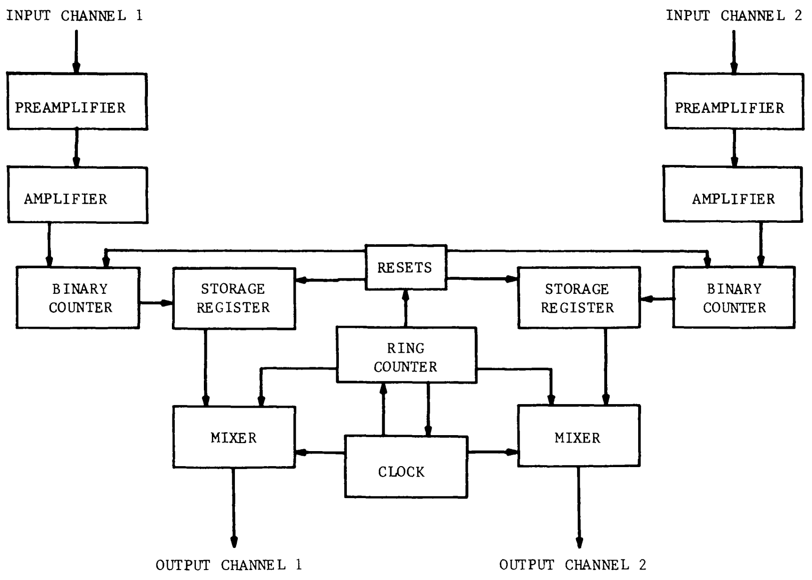

Fig. 1 — Interconnection of logical units of the counter.

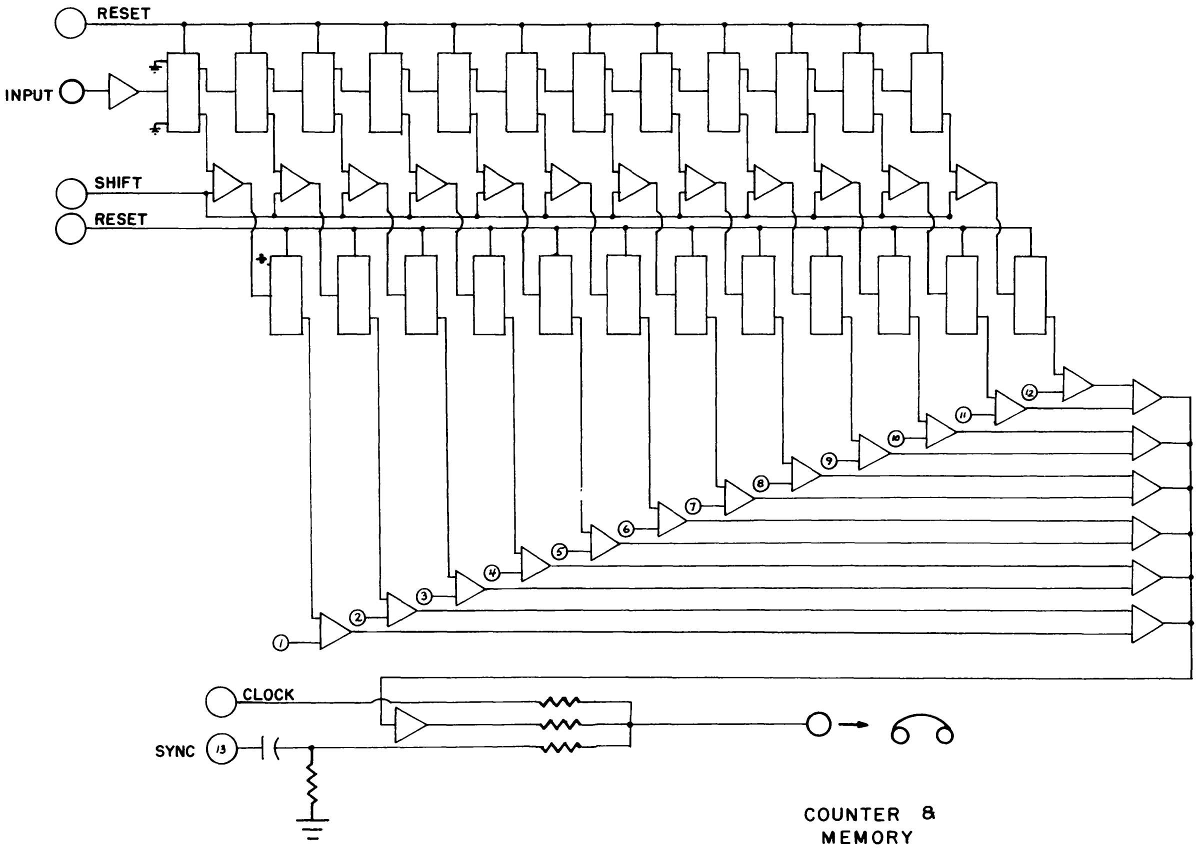

Fig. 2 — Twelve-bit binary counter and memory registers.

through a length of cable. A two-stage amplifier provides sufficient gain for the pulses to trigger the input counter gate. Power for these devices is supplied by internal 9.8-volt mercury cell batteries or a reasonably regulated power supply.

The counter itself consists of a twelve-bit binary counting register, a twelve-bit binary memory register, and necessary logic and switching circuits (Fig. 2). A 12.5 kHz crystal-controlled oscillator, combined with 13-bit data readout, fixes the minimum integration time at 1.04 milliseconds. By switching additional flip-flops into the oscillator divider chain the integration time can be lengthened in factors of two up to $2^{10} \times$ 0.00104 seconds (1.06 seconds). The clock provides the square wave which drives the ring-counter and which is the data-output carrier wave.

The ring-counter (Fig. 3) performs two functions. First, it generates the pulse which at intervals equal to the integration time cause, in turn, the memory register to be cleared, the counter-bit configuration to be transferred to memory, and the counter register to be cleared to zeroes. Photoelectric pulses are continuously fed to the binary counter so that the only pulses lost are those which are counted after the counter register contents have been shifted to memory but before the counter register has been cleared. Since the elapsed time for these two "instructions" is less than 750 nanoseconds, only about 0.05 percent of the data is lost at the minimum integration time of 0.00104 seconds. Second, the ring-counter scans each of the twelve bits in the memory register in turn. During an integration cycle, the memory register contains the binary count of

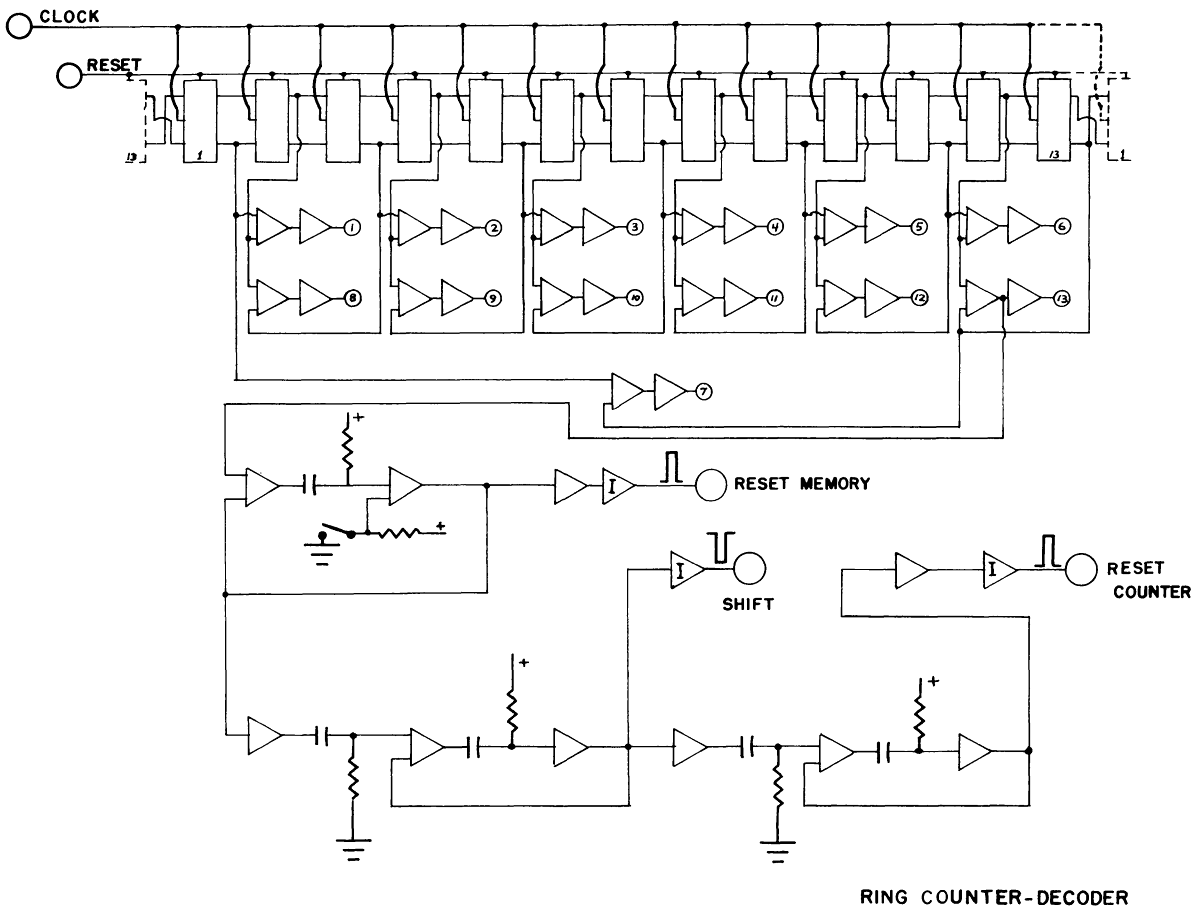

Fig. 3 — Switch-tail ring counter and decoder, with shift and reset logic.

the *previous* integration cycle. The ring-counter converts the twelve-bit parallel data to twelve-bit serial data, which modulate the carrier wave generated by the clock.

The data are recorded with a home-type four-track tape recorder in an analog mode on ¼-inch magnetic tape as a 12.5 kHz square wave modulated by the bit configuration. A thirteenth negative bit is attached as a flag indicating the beginning of the data word. A four-track recorder conveniently records two data channels, a time channel, and a voice channel. The requirement for a mass storage device is fulfilled since the recorder can be left on for long periods of time, recording continuously even though the significant portion of the occultation occupies only a few tenths of an inch on the tape.

The logic elements of the counter are built from Fairchild type $\mu$L914, $\mu$L923, $\mu$L926, and $\mu$L927 integrated circuits. Figures 2 and 3 are schematics for the counter, where rectangles are J-K flip-flops ($\mu$L923 or $\mu$L926), triangles are dual two-input NOR gates ($\mu$L914), and triangles enclosing 'I' are inverters ($\mu$L927). Power for the integrated circuits is provided by a Lambda Model LM252 regulated power supply. Not shown is the clock oscillator circuit and its divider chain.

An appropriate measure of a photon counter's capability is its dead time. The parameter is needed to determine coincidence corrections in photon-counting statistics. If a counter has a dead time, $t$, after each recorded count during which it is insensitive to additional counts, then the fractional loss is $Rt$, where $R$ is the observed counts per second; the true count rate is $R^* = R/(1 - Rt)$ (Friedlander and Kennedy 1955). To determine the dead time, two laboratory tests of RUFAS were made.

In the first test, a Datatech pulse generator was used as a "photomultiplier" by generating equally spaced rectangular pulses of 30-nanoseconds width, variable frequency, and sufficient negative amplitude. These pulses were fed to the counter through the preamplifier and amplifier. Input rates, as measured by a General Radio (GR) digital-frequency meter, were compared to output rates as measured by the photon counter. When the pulse spacing was reduced to 125 nanoseconds (8 MHz) the GR meter failed to operate, but up to this limit the photon counter operated linearly and accurately. As the pulse spacing was reduced farther, RUFAS continued to count pulses, until the pulse spacing was reduced to 80 nanoseconds (12.5 MHz) at which point it, too, stopped counting. The pulse generator was also used at low frequency (less than 1 MHz) in the double-pulse mode. When the separation of the double pulses was decreased to 80 nanoseconds, RUFAS failed to distinguish each pulse separately, and the count rate halved.

Since equally spaced rectangular pulses of equal amplitude do not describe the real world, a second test was performed. Using a double-pinhole light source appropriately imaged on an EMI 6256/SA photomultiplier operated at 1250 volts DC, and by varying the brightness of the source, values of $t$ at different $R$ were determined. The dead time, $t$, appears to increase slightly with increasing $R$—an undesirable situation indicating that pulses occurring during the dead time are affecting the dead time. The least squares linear relation of $t$ with $R$, in the range $40{,}000 < R < 750{,}000$, is given by

$$t = 2.78 \times 10^{-13} \times R + 2.30 \times 10^{-7} \text{ seconds} \quad (2)$$

with $\sigma_t = \pm 50$ nanoseconds. Thus for a modest pulse-counting rate of 300,000 per second there is about 10 percent fractional loss. For the brighter stars one must sacrifice accuracy in terms of numbers of counts to achieve pulse rates low enough to avoid serious coincidence.

Recovery of the digital data is accomplished in the following manner. The original data tape, recorded at 7½ inches per second (12,500 bits per second) is first played to an oscilloscope to determine the point on the tape at which the occultation occurs. This instant is recognized by a sudden or unusual change in the bit pattern. The tape is stopped there, rewound several inches, and replayed at 15/16th inches per second (1500 bits per second) into a light-beam oscillograph. The resulting paper recording is a time-ordered duplicate of the original data signal. Since the basic data, photon counts vs. time, are in digital form, the frequency responses *and* speeds of initial recording, playback recording, and oscillograph recording need not be maintained to a critical tolerance. Under poor conditions the binary-bit configuration retains its recognizability.

RUFAS is also being used to investigate high-frequency variability of the H$\beta$ line in spectrum variable stars. With an integration time of 1/16 second (a function of the count rate and counter capacity), a continuous recording of 40 minute's duration produces about 40,000 data points for correlogram or Fourier analysis. Thirty hours of continuous observations have already been made for HR 9080, HR 812, HR 707, HR 945, HR 815, U Geminorum (a dwarf nova), and other standard stars.

For photoelectric occultation observations one is content to convert the recorded data to counts vs. time by creating a paper recording and reading and converting by hand; but the voluminous amount of data produced in extended observing sessions (over 1.7 million data points in the above study) necessitates automatic data conversion. To this end a level detector is being designed and built for use with a minicomputer (offline) which will accept prerecorded data, decode the analog signal, and produce a punched paper tape containing the time-ordered duplicate of the original data stream.

In addition to twelve-bit serial readout, RUFAS' twelve-bit (parallel) memory register can be accessed during normal operation. The minimum integration time of 1.04 milliseconds is adequate for a minicomputer to accept these twelve-bit words and store them in real time. Alternatively, the minicomputer can become the active device by producing resets, shift, and "read" pulses under software control. The counter thus becomes a flexible peripheral device for real-time data acquisition.

The author wishes to express his gratitude and thanks to Mr. Robert Redick, electronic engineer at the Department of Astronomy, for his help in designing RUFAS. He also thanks the National Science Foundation, whose grant GP-13596 to Dr. H. John Wood paid for construction of the counter. The four-track tape recorder was purchased with funds from the Mount Cuba Astronomical Observatory. The empirical pulse coincidence calibration was completed at the Department of Physics, University of Delaware.

## REFERENCES

Code, A. D., and Liller, W. C. 1962, in *Astronomical Techniques*, W. A. Hiltner, ed. (Chicago: University of Chicago Press), p. 284.

Friedlander, G., and Kennedy, J. W. 1955, *Nuclear and Radiochemistry* (New York: John Wiley & Sons), p. 266.