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LOWELL OBSERVATORY

BULLETIN NO. 143

VOL. VII — May 22, 1968, Flagstaff, Arizona — NO. 6

A SCANNING POLARIMETER

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ABSTRACT

A scanning polarimeter is a device which measures light intensity in different planes of vibration as an aperture is repeatedly and rapidly driven across the image of an object in the focal plane of a telescope.

The observations of Rakos (1965) showed that improved photoelectric resolution could be obtained by the use of area scanning technique. Further observations by Franz (1966) indicated that this improvement could be several times that of conventional photoelectric techniques used in UBV work on close visual binaries. Boyce (1966) has successfully combined area and spectral scanning in investigations of planetary nebulae, Mars, and other objects.

It has been found that the use of a scanning polarimeter has advantages over some previous methods and can be efficiently applied to the study of a wide variety of astronomical objects.

The idea of integrating the output of a photomultiplier during successive scans of a focal plane aperture has occurred to many people over a period of many years. The recent development of small computers or multichannel analyzers containing several hundred separate memory units has very recently made this technique practical.

BACKGROUND

Rakos (1965) used an area scanner in 1965 to measure the brightness of Phobos as it was eclipsed by Mars. In so doing, he was able to detect Phobos at only six seconds of arc from the Martian limb and when Mars was 10^5 times brighter than the satellite. He used extensive photographic records of an oscilloscope screen to record the data. More than one quarter of a million of such photographs were obtained and analyzed.

Franz (1966) later used the same equipment to make photoelectric measurement of magnitude differences, separations, and position angles of close double stars. Although most of his quantitative data were obtained by means of the cumbersome photographic technique, a few measures with a multichannel analyzer proved that the method is both accurate and practical. Compared to conventional photoelectric techniques he found, among other advantages, a gain of several fold in resolution.

Boyce (1966) designed an area scanner which he mounted at the entrance slit of a spectral scanner. He obtained "monochromatic" intensity profiles of planetary nebulae, Mars, and other objects.

THE POLARIMETER

The polarimeter to be described in more detail here (1967) is of the dual-beam type, first introduced by Hiltner (1952) and also used by Behr (1956), Visvanathan (1956), Gehrels (1960), Serkowski (1966), Elvius and Engbert (1967), Appenzeller (1967), and others.

A schematic diagram is shown in Figure 1. A calcite Wollaston prism with a clear aperture of 24 mm and made of three elements, instead of the usual two, separates the beam into two components. The resulting ordinary and extraordinary images of the primary mirror projected on the cathodes are similar in shape and size.

For parallel incident light the separation of the two beams emerging from the prism is 16″8 and 14″3 at wavelenghts of 3600A and 9000A, respectively. Both the Wollaston prism and calcite depolarizer transmit the ultraviolet freely in the photoelectric region at wavelengths longer than 3000A.

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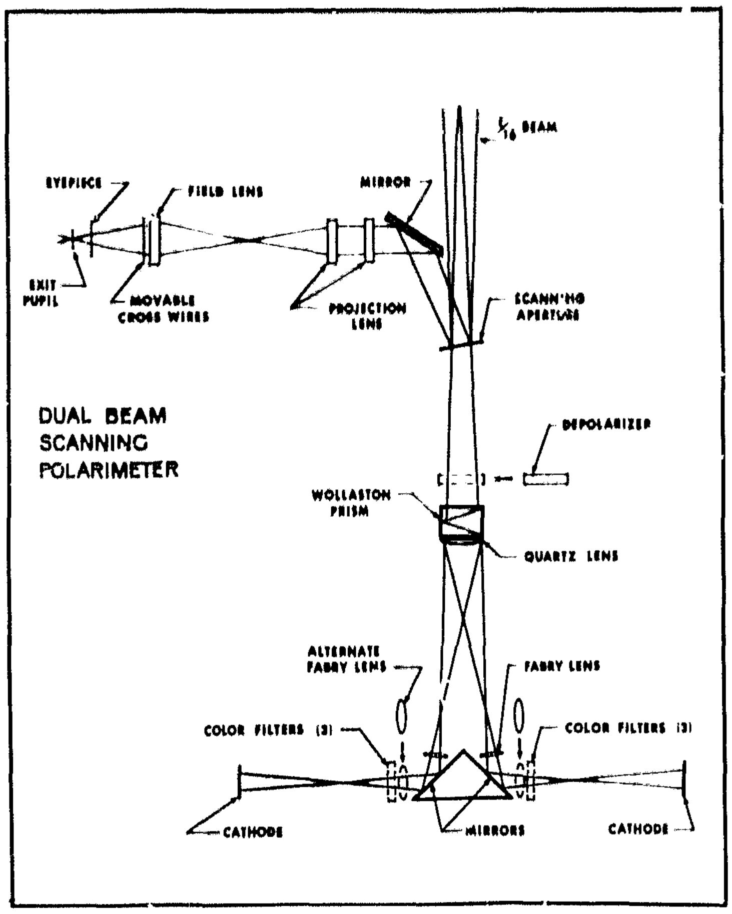

FIG. 1. Optical system of scanning polarimeter. As shown in this diagram, the direction of the aperture scan is perpendicular to the plane of the paper.

The optics of the polarimeter are easily accessible when the front cover of a rectangular box is removed. The filter slides can be operated either together or separately. When the filters ar posi- tioned as shown in Figure 1, then the light from an extended source moves across them as the aperture moves in the focal plane of the telescope. The filters can also be placed at a null point (where there is no image motion) a few centimeters below the analyzer. A second null point is at the photocathodes.

The multipliers are of type EMI 9526A with cathode diameters of 22 mm. Their sensitivities, according to the manufacturer, are 82 and 77 μ A/L. The dark current of each is 0.4 mμ A with 1050 volts across the tube. They are also well matched with regard to sensitivity at different wavelengths; their spectral response is S-13. One tube is operated at 1600 and the other at 1625 volts from the same high-voltage supply.

A photograph of the polarimeter is shown in Plate I. The rectangular box containing the analyzer and associated components is mounted on a ball-bearing system so that this portion of the equipment can be rotated and easily set to any desired position angle between 0° and 360°.

The focal-plane aperture, scanner motor, and associated optical equipment (referred to hereafter as the scanning head) are mounted on separate bearings and can be rotated and set, independently of the polarimeter, at any position angle between 0° and 180°.

The orientations of both the scanning head and the polarimeter are indicated by separate pointers and circular scales. Therefore, the scan can be made in any desired direction in the sky, although the sense of the scan motion is fixed with reference to the scanning head and the observer must be prepared to look into an eyepiece which is fixed relative to the direction of the scan. The scanning head is shown schematically in Plate II.

A focal-plane aperture is located behind a polished stainless steel plate which serves as a mirror and is tilted 79° with respect to the optical axis of the telescope. The light from any object or portion of an object not passing through the aperture is reflected back through the observing eyepiece. The observer can therefore see the image at all times and note its fixed position relative to the moving aperture. The reflecting plates are rectangles 25 x 40 mm with central apertures somewhat larger than those directly below them which limit the light beam. The limiting apertures are openings in very thin metal. The circular one used for measures of Jupiter is 100 microns in diameter, but that used for observations of some faint nebulae has a 4 x 8 mm rectangular opening. Changes of aperture and reflecting plate can be made in less than a minute.

The aperture holder is pushed by a cam driven by a synchronous motor. The motion is linear for 300° of cam rotation but during "flyback", or the 60° remaining, a shutter cuts off all light, and the dark current from each multiplier is measured.

Four cams are available—providing scan amplitudes of 3, 6, 9, and 12 mm.

The sweeps on both multichannel analyzers are simultaneously triggered by a magnetic sensor. Its actuator is mounted on the scanning head on the same gear as the flyback shutter. The sweeps are of 1^{s}00 duration, while the period of the cam is 1^{s}042; consequently, there is a loss of only 42 milliseconds between sweeps.

EYEPIECE OFFSET GUIDER

The eyepiece is fitted with a small offset guider having a 20 mm field. It consists of two movable crosshairs which can be made to intersect at any point within the field of the eyepiece. This field is an unmagnified image of the reflecting plate in the focal plane of the telescope. I am grateful to Ger-

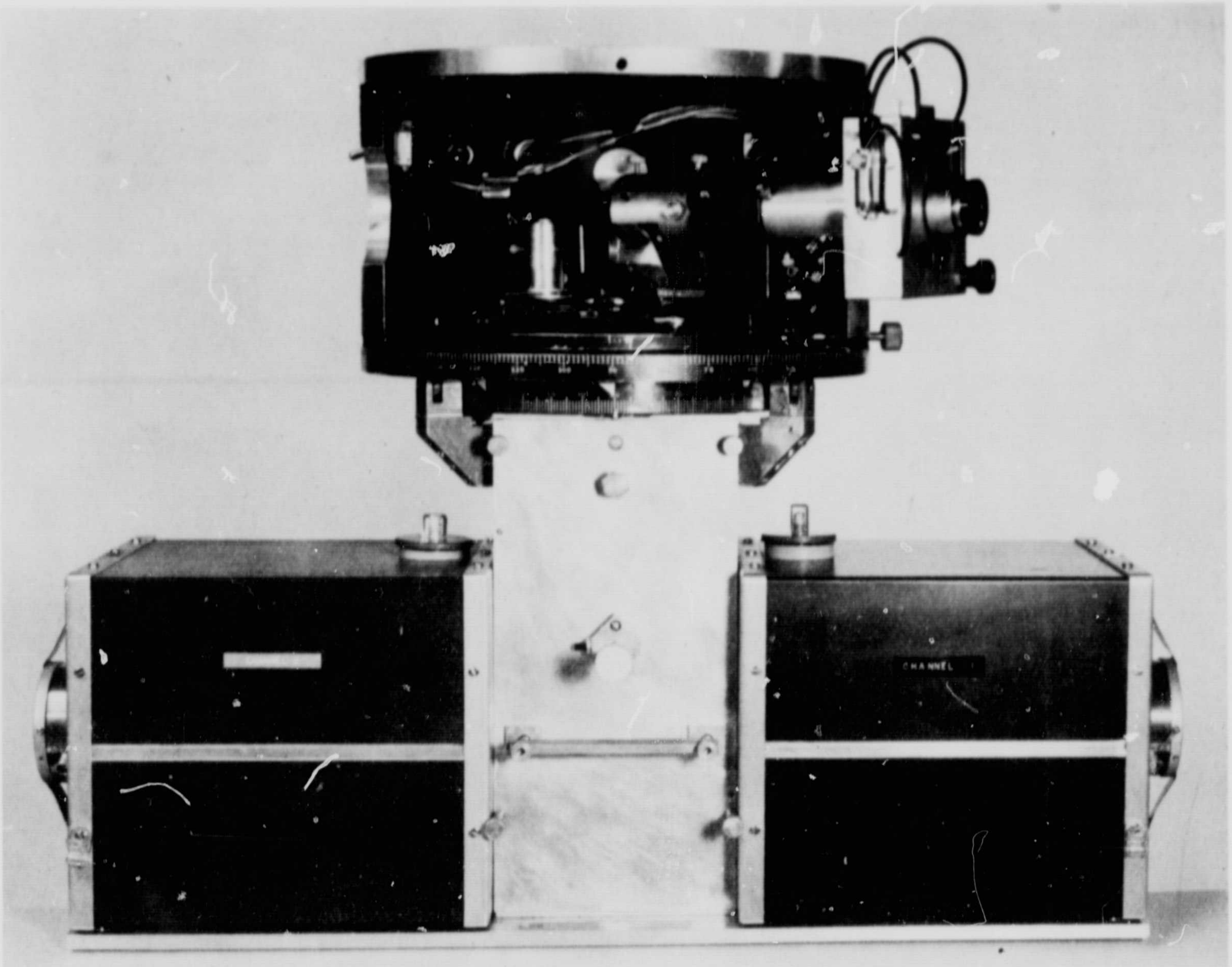

PLATE I. Photograph of polarimeter. The eyepieces and scanning mechanism can be rotated through 180° independently of the rotation of the polarimeter below it.

ald Kron for suggesting this simple method of placing a "crosswire" at any desired point in the field of the guider. The position of each wire can be read on a millimeter vernier scale and set to 0.1 mm. The crosswires and scales are mounted on an inexpensive microscope substage especially modified for this application.

DATA HANDLING EQUIPMENT

General Procedure. There are many ways of collecting large quantities of data at the telescope and of transferring them to the memory of a computer. Certainly as time goes on, more and more efficient ways of doing this will become available at less and less cost. Despite this rapidly changing technology it may be of interest to provide a general outline of the method used here. Figure 2 shows a flow chart containing the principal electronic components.

The output pulses of each multiplier on the polarimeter are conducted through coaxial cables to a small cabinet containing a 100 MHz pulse amplifier, a discriminator, and two prescalers. The modified pulses are then converted into digital BCD code by a multichannel analyzer (hereafter referred to as a CAT or Computer of Average Transients). Each channel of the CAT contains only those pulses which pertain to a specific position of the focal-plane aperture as successive scans are made. In order to record all pulses from the two photomultipliers, two CATs must be used.

The connections are so arranged that in one CAT the odd channels store the output of one multiplier and the even channels store that of the other. In the second CAT the pattern is the same, but the even and odd channels are connected to the other multiplier. In this way possible changes in the operation of the multichannel analyzers do not

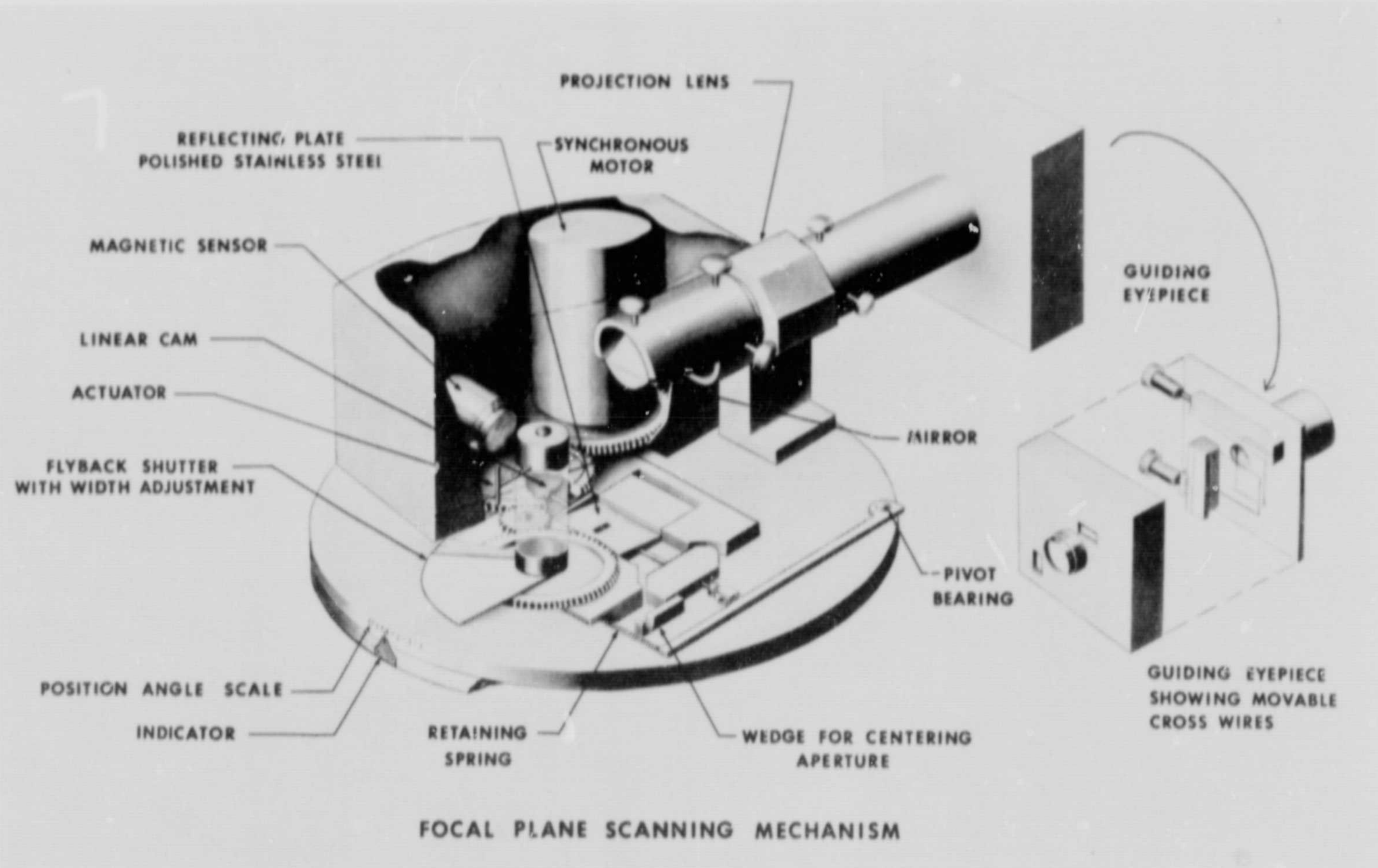

PLATE II. Focal plane scanner and eyepiece offset guider. Drawing by Jay Inge.

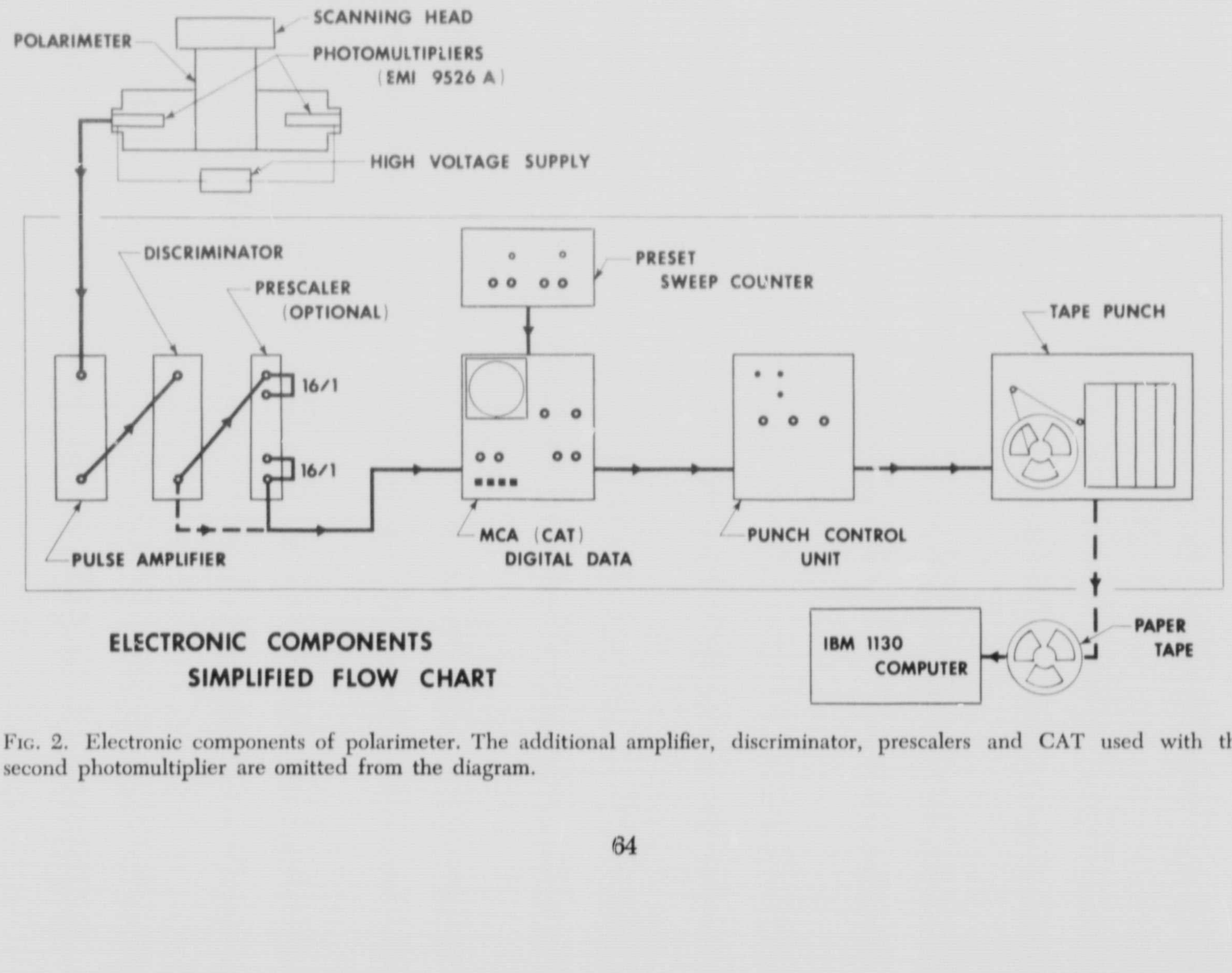

FIG. 2. Electronic components of polarimeter. The additional amplifier, discriminator, prescalers and CAT used with the second photomultiplier are omitted from the diagram.

introduce systematic errors in the results. The total time loss per scan in switching 200 channels is 0ˢ01.

The advantages and limitations of pulse amplification are well known. It not only provides high detection efficiency but also, since it introduces no zero drift, long "exposures" become practical. Fifteen-minute exposures have been successfully made and much longer ones appear entirely practical.

The maximum counting rate which a CAT of the type used can accept without an appreciable pulse overlap correction is 20,000 counts per second. For many objects the aperture size can be adjusted to keep the counting rate well below this figure. When this is not the case, one or more 16/1 prescalers are used. With two scalers (256/1) in each system and a prescaler output of 20,000 counts per second, the pulse amplifiers, as well as the CATs, begin to exceed their linear range.

Data Cabinet. The arrangement of the components in the cabinet can best be described with the help of Plate III.

A preset scan counter is shown at the upper right. The observer can, in advance, dial into the unit the exact number of scans he wishes to record.

The punch control unit is at the upper left. It automatically punches a sequence number on the paper tape just prior to each readout of the 200 channels of each CAT. The memories of the two CATs can be alternately punched on tape. The time required for a single punchout of each CAT is 22 seconds. The number sequences on the last punchout is prominently displayed (471 on Plate III) below the two CATs.

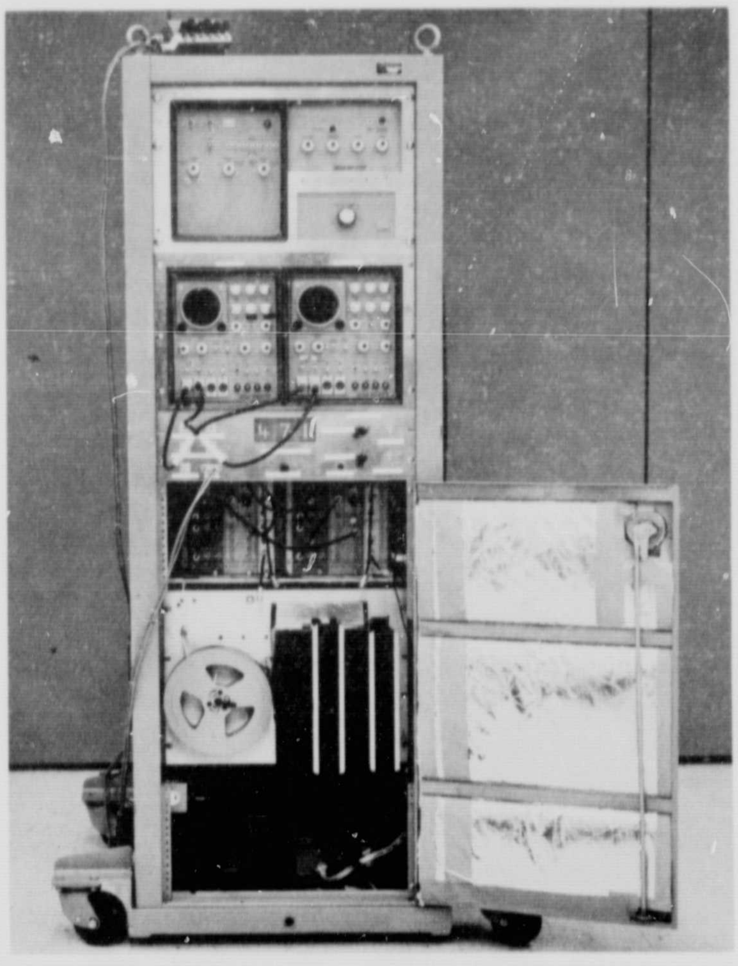

PLATE III. Data handling equipment. The various components can be identified from the descriptions in the text.

The pulse amplifiers, the discriminators and the prescalers can be seen near the middle of the cabinet just above the punch. Since the punch and some other circuits in the cabinet are temperature sensitive, its interior temperature is regulated to 65° ± 5° F.

Remote control buttons are shown on top of the cabinet. These make it possible for the observer to remain at the eyepiece of the scanning head while observations are under way. If he wishes to do so, he can stop recording the scan data and then continue the integrating process, without loss of previous information, until the preset number of scans has occurred.

Statistics. Some of the vital statistics regarding the transfer of data from the telescope to the computer may be of interest. It is possible to make 50 punchouts of 200 channels or 25 punchouts of 400 channels on a single roll of paper tape.

If a bright object is observed the statistical errors are often very small and consequently the data stored in the second CAT are not punched out because they would add little to the overall accuracy.

If eight analyzer position angles and one CAT only are used at the telescope to measure the polarization of a sequence of objects along a scan line, it requires 35 minutes of computer time to read out and plot the data, to compute the polarization and print out the results for 15 points evenly distributed along the scan. Nearly half of the "computer" time is consumed in plotting the data. It is, however, possible to plot the data, in analog form, on a strip-chart recorder at the telescope and in this way cut the computer time in half.

A very substantial further reduction in computer time could often be achieved if the equipment were so modified that fewer channels are used. For instance, if 200 channels are used with a scan of 60 arc seconds in the sky, each channel relates to a segment of only 0.″3 along the scan line—resolution which is quite beyond present achievement even if a correspondingly small aperture were used. Sixty channels and a 1″ aperture are usually adequate. Both the punchout time and computer time could be halved again by this modification.

APPLICATIONS

Observations of polarization of a wide variety of objects have been made with the scanning polarimeter just described. These include quasars, nebulae, stars, planets and the moon.

Faint Small Sources. Elvius has recently published a paper (pg. 55 of this volume) which describes in detail the method of reduction she has used for observations made of quasars in the spring of 1967 with the scanning polarimeter described here. She has also summarized the statistics of the problem and found, for the observations described, that the observed deviations were close to the expected statistical errors. A plot, showing her observations of 3C 273 and 3C 345, is shown on page 56. Observations of faint stars show a similar pattern.

For faint point sources the advantages of the scanning method lies in its ability to measure the sky background on both sides of the source "simultaneously" with the sky background plus source. The loss due to flyback time and to the uncertain part of the scan when the edges of the aperture partially occult the source is about 20 percent. (With improved cam design this loss can be made less than 10 percent.) The resultant small loss in accidental accuracy is negligible in comparison to the elimination of large systematic errors which could otherwise be caused by changes in sky background.

Faint Extended Sources. For faint extended sources where the aperture scans into the dark sky, the advantages are similar in nature (but with loss of symmetry) to those mentioned for faint point sources. For larger objects when the aperture does not go into the dark sky, two telescope settings are generally required. In some cases, however, it appears possible to keep the aperture fixed and to scan the area by moving the telescope at a rate which corresponds to a very slow sweep of the CAT; each sweep would be initiated manually by the observer as a particular reference point passes a crosswire in the eyepiece.

Bright Stars. For stars so bright that the sky background is negligibly small, it is preferable to use the polarimeter in a fixed rather than a scanning mode. In such a case the aperture remains centered as the sweeps on the CAT are internally triggered and all channels of each CAT can be used for measures of star brightness only. This increases the effective data-collection rate by a substantial amount. Since a single channel can store up to 10^6-1 counts, the minimum number of channels should be used. However, for this application, although the method is satisfactory it has no advantage over much simpler procedures.

Bright Extended Objects. Gains in angular resolution have already been mentioned. Here large amounts of data can be easily handled and consequently the polarization at many points along a scan (the number is limited by the seeing resolution) can be very efficiently measured. Polarization and intensity measures in the ultraviolet have been made at 97 points on Jupiter's disk within a two-hour period.

ACKNOWLEDGMENTS

The scanning polarimeter and associated components have been developed with the support of Air Force contract No. AF 19(628)-4070. Many modifications were made with support from NASA grant NsG-451.

The author acknowledges with pleasure the valuable advice given him with regard to the data-handling problems by P. B. Boyce.

Kurt Rost and James Chastain have greatly improved the reliability and performance of some of the electrical circuits. Figures 1 and 2 were skillfully prepared by Terry McCann.

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