THE DIGICON SYSTEM OF CIMA EKAR OBSERVATORY

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Abstract. This paper describes the Digicon system in current operation for spectroscopic acquisition at the 182-cm telescope of Cima Ekar (Asiago). An example of observation of the emission-line galaxy VV 565 provides evidence of the quality of the system.

1. Introduction

The Digicon tube has been developed for astronomical spectroscopy in the last 10 years; it has high sensitivity, good linearity, low noise and high dynamic range. It operates with silicon diodes at the anode of a photoelectric vacuum tube, so that the accelerated photoelectrons impinge directly on them instead of on the phosphor of a conventional image tube.

The Digicon concept has been exploited in two different ways: Beawer and McIlwain (1971) read out in parallel each single diode, in a pulse counting mode, effectively treating each diode as a separate photomultiplier with its associated electronic chain. The advantages of photon counting are thus reached at the expense of complex electronics; the size of the diode array is therefore limited to about 500 elements.

A different solution, developed by Tull *et al.* (1975), uses self-scanned Reticon arrays serially read out on one or on a few video lines. Although this system used in slow-scan mode is not capable of photon counting, its electronics is simpler, and was finally chosen for our application.

This Report will describe the 2×936 diodes, Self-Scanned Digicon system operating at the Boller & Chivens Spectrograph of the 182-cm telescope at Cima Ekar since September 1979. Section 2 provides the overall description, Section 3 contains some details of the control electronics, Section 4 describes the control software, Section 5 gives the results of laboratory tests and an example of observation at the telescope.

2. Description of the System

The Digicon tube was manufactured by the Electronic Vision Company of San Diego (Ca., USA), who also provided the magnetic focus section and the deflection coils.

Before the deposition of the S20 cathode and the vacuum sealing, the window

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of the image tube was properly figured by Boller and Chivens to act as a field-flattener lens. A thin metal ring was deposited at the edge of the window to insure proper grounding. The photoelectrons are accelerated by a voltage of up to 30 kV (cathode at negative voltage) and impinge on a 2×936 diode array manufactured by Reticon Co. (Sunnyvale, Ca., USA). Each diode measures $30 \times 370\ \mu m^2$, while the two rows of diodes (joined together side by side on the same chip) are separated by a gap of $8\ \mu m$. During the observations, the spectrum of the object and the spectrum of the adjacent night sky are separately imaged on each array, to allow the subtraction of the background from the object signal. To overcome the small disuniformities between the two arrays and the two different regions of the cathode, the star and the sky are alternated between them by means of a computer-controlled tilting quartz plate located above the telescope focal plane. A special slit assembly has been manufactured with two pairs of rectangular holes; the astronomer can select the 0.30 mm or the 0.15 mm wide pair, according to seeing conditions (the scale of the telescope is $12\overset{''}{.}6\ mm^{-1}$). The separation and the height of the holes of both pairs has been

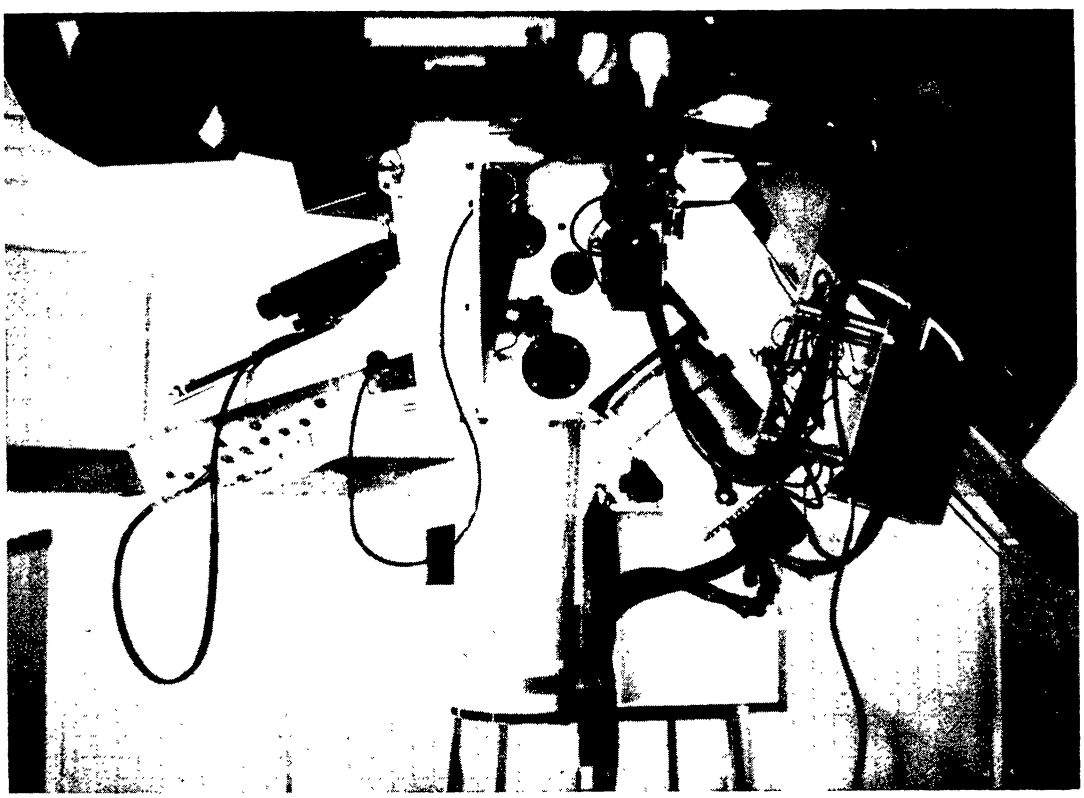

Fig. 1. The Digicon mounted at the Boller and Chivens spectrograph of the Cima Ekar 182-cm telescope. The tube is encapsulated in the gray cylinder on the right of the collimator. The black box on its right contains part of the electronics. The two black pipes in the lower part of the photograph carry the cool alcohol from the refrigerator (the white box behind the spectrograph) to the back of the tube.

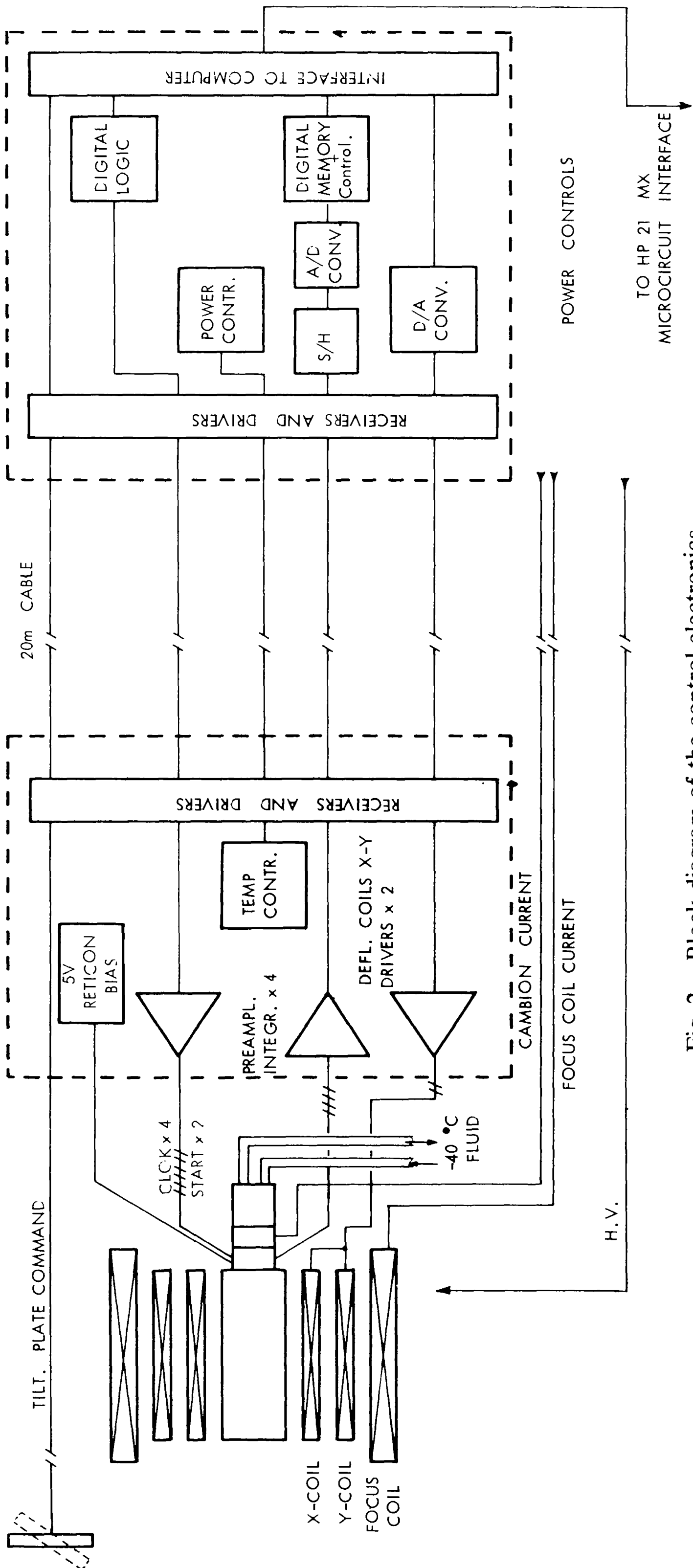

Fig. 2. Block diagram of the control electronics.

fixed at 1 mm, in order to insure the proper illumination of the diode arrays after the spectrograph demagnification of approximately six times.

The electronic spectra can be also displaced in respect to the diodes by means of the computer controlled deflection coils, either parallel (direction X) or perpendicular (direction Y) to the arrays.

The Digicon tube has a magnetic shield of μ-metal, and has been encapsulated in a mounting (Figure 1) which allows slight mechanical adjustment of focus, rotation and centering. A copper plug has been sealed to the back of the tube, in thermal contact with the diode arrays on one side, and with a Cambion thermoelectric cooler on the other side. The hot face of the Cambion is refrigerated with circulating alcohol kept at −40°C; in this way the temperature of the diode arrays is lower than −70°C, and stable at better than 0.5°C over at least one hour.

3. The Control Electronics

The control electronics, shown in the block diagram of Figure 2, have been built by the Gruppo Tecniche Avanzate (GTA) of Trieste, Italy.

There are two connectors on the back of the tube: one for the four video lines

Fig. 3. The control room on the observing floor. The rack on the right contains the computer (bottom), the Digicon main electronic unit (top), the CRT and the power supplies.

and the 5-V bias for the diodes, and the other for the clock of the scanning circuitry. On each clock cycle (500 μsec) the output signals of four different diodes come out in parallel on the video lines; 468 of such cycles are necessary to read out the two arrays.

A thermally controlled box mounted a few centimeters from the end of the tube, contains the four charge preamplifiers and integrators, the clock drivers and the current drivers for the X and Y deflection coils.

A 20-m long shielded cable, with line-drivers and receivers on each end, connects this box with the main unit (located in the control room, see Figure 3), which contains the four 12-bit A/D converters, the 4K byte 8-bit memory to temporarily store each read out, the two 8-bit D/A converters for the deflection coils, the main programmable clock, the interface with the computer and the power supplies.

Separate power supplies provide the high voltage with negative polarity (up to −30 kV) for the tube, the current of about 0.7 A for the coils of the focussing magnetic field, and the current for the Cambion thermoelectric cooler, which is usually run at 6 A.

4. The Control Software

The layout of the computer System is shown in Figure 4: the satellite HP 2108 MX, devoted to the data acquisition, is connected to the central unit HP 2100 by the high-speed link HP Distributed System. The HP 2100, which has a fairly complete set of peripherals, is used for data reduction and interactive program development. The Digicon software (written in cooperation with R. Mottola of the Istituto di Elettrotechnica ed Elettronica of the Trieste University) requires both computers: it uses the HP 2108 MX to control the instrument, to acquire each readout and to insure the interactivity with the observer (program DIGIC), while the floating point addition of the data and the final storage is performed on the HP 2100 and its magnetic tape (program DIMEM).

The observer by answering questions of Program DIGIC can select four different phases: (a) the setup phase, readouts going on continuously with a given integration time, but no data permanently stored. This phase is used as an occasional check and during the initial adjustment of focus, deflections, high voltage and cooling system; (b) the lamp phase which allows the acquisition of a comparison source or of a flat-field calibration lamp, (c) the object-phase for the normal observations and (d) the end phase.

In the object phase the user types a series of comments and parameters, which will be stored at the beginning of the data file, and selects the total exposure time and how this is divided in cycles with the object alternatively on array 1 and 2; the commutation can be done automatically by the tilting plate or can be performed by moving the telescope in case of extended objects. The rapid

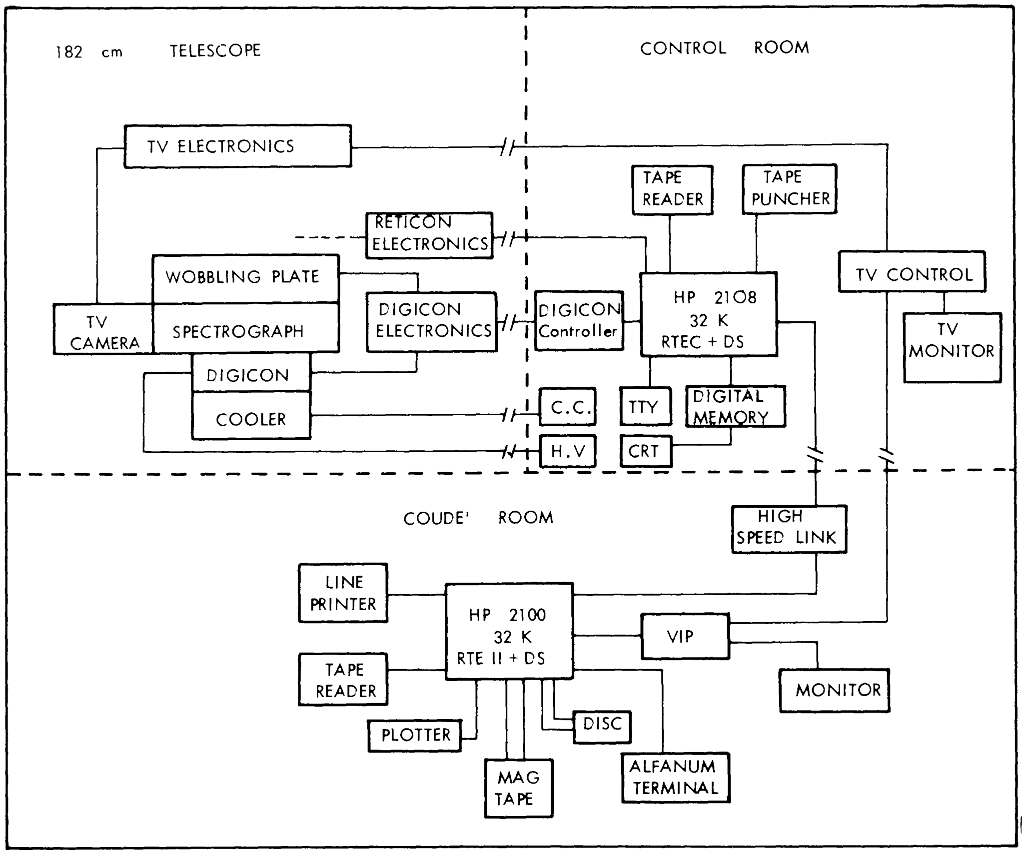

Fig. 4. Layout of the Cima Ekar computer system.

interactivity between astronomer and computer which is required during the set-up phase and for the display functions is ensured through the operation of the front panel switches of the HP 21 MX: the current readout, or the accumulating object + background spectrum or the background spectrum or the difference between them can be displayed by depressing different switches of the front panel S-register. Since the available CRT can display only 256 points with different abscissae, the operator can quickly select between three different enlargements: one point every fourth diode, one point every diode and four points every diode; in these two latter modes one whole array cannot be seen at once, but the observer can shift the displayed portion to the right or to the left over the whole array. All these capabilities, coupled with the speed of the Distributed Systems, do not allow observations shorter than 3 s.

An observation can always be interrupted by depressing a high-priority switch on the front panel and rejected, if it is not useful, or definitively stored if already satisfactory.

A set of interacting programs is available on the HP 2100 to display on TV screen, to list and to plot the Digicon spectra stored on magnetic tape.

Other programs can be run on the HP 21 MX to test the instrument, including one (program PHA), which performs pulse height analysis of the readout signal emitted from selectable diodes. Another set of programs is available on the HP System 1000 at Padova Observatory to perform the final processing of the spectra.

5. Laboratory Measurements and Astronomical Observations

During one of the first laboratory tests of the Digicon tube, an irrecoverable failure was suddenly experienced: the second array could be read only from the first to the 238th diode whilst all subsequent diodes were "dead", i.e. completely insensitive to light, to accelerated electrons and even to the thermal leakage. This defect is probably due to an interruption in the register which shifts the readout pulse along the array. The other array works well with only two "dead" diodes. All our trials of slightly adjusting the voltage levels of the start pulse and of the phase were unsuccessful: the result is that only one-fourth of the second array is working properly, forcing the astronomer to double the exposure time in order to remove the sky background. Furthermore, the high voltage cannot be raised to the expected level, because frequent discharges are noticed above 23 kV. To avoid further permanent damages of the diodes, we run the tube at 21 kV or lower; the current which is then necessary to properly focus the image is about 0.7 A and can be easily adjusted. Supposing that on the average 10 keV of energy are lost by each infalling photoelectron to the SiO_2 layer overcoating each diode and that one electron-hole pair is produced every 3.66 eV of absorbed energy, one photoelectron at 21 kV produces about 3000 electronic charges in the silicon. The intensity resolution of the system is such that one unit of the 12-bit A/D converter corresponds to about a thousand of electronic charges in the diode, i.e. to about 5 photons at the peak QE of the tube ($\lambda\lambda$ 3500 ÷ 4500 Å). Tests performed with the PHA program demonstrate that the pulse height hystograms are roughly gaussian with a standard deviation of two converter units; in other words, approximately 120 photons are required in each readout to reach a S/N ratio of 10. This is the limiting performance of the present system.

The current drivers for the X and Y deflections are regulated so that one unit of the D/A converters produces a displacement of 3 and 47 μm respectively and the user can handle up to 256 such units.

As an example of the astronomical observations already performed with the Digicon system, Figure 5 shows the spectrum of the emission line galaxy VV 565 = NGC 1741, $m_v = 13.6$; the exposure time, divided in 30 cycles star/sky was 15 min on object and 15 min on sky; 10 lines of the Balmer series and the forbidden lines of [O III], [N II], [O II], [Ne III] and [S II] are clearly visible. For comparison, the figure shows also the tracing of a spectrum obtained with the same spectrograph but with an electrostatic Westinghouse image tube, in 60 min at a lower resolution (180 Å mm^{-1} against 115 Å mm^{-1}). In addition to the advantage in exposure time, one notices the perfect cancellation of the night sky lines.

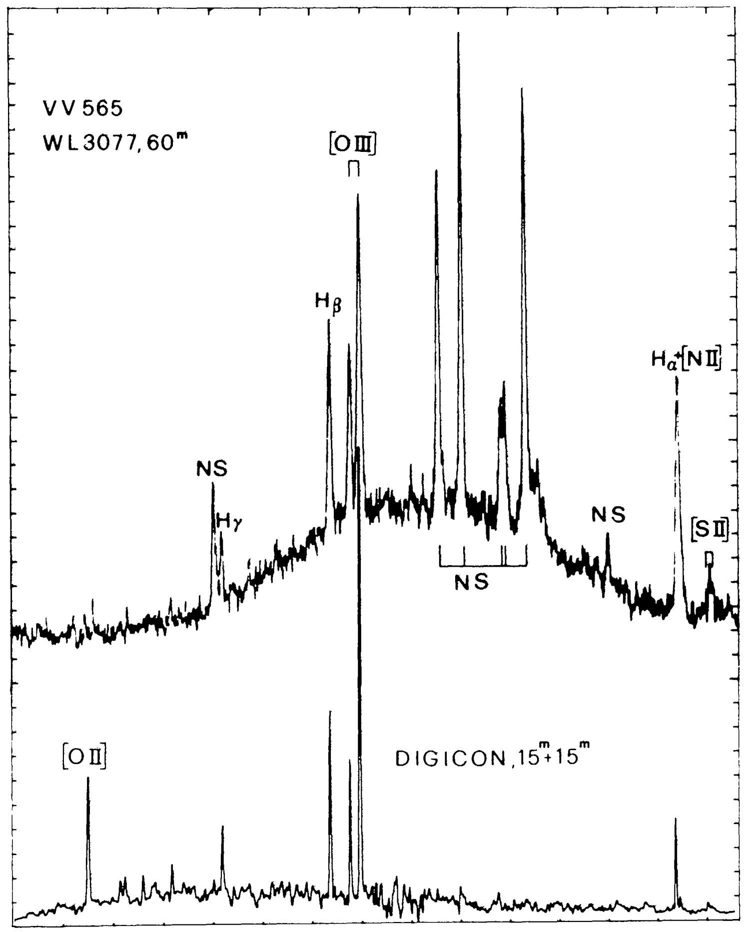

Fig. 5. Spectra of the emission-line galaxy VV 565 = NGC 1741, $m_v = 13.6$. The upper part is the tracing of a spectrum taken with a WL 30677 electrostatic image tube in 60 min, the lower part is the Digicon result obtained in 15^m on object plus 15^m on sky. One notices the gain in exposure time, the superior resolution and the perfect cancellation of the bright night sky lines permitted by the Digicon system.

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