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ASTRONOMY
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The Reticon spectrophotometer of the Merate Observatory

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Summary. The performances of the Reticon spectrophotometer developed at the Merate Astrophysical Observatory are reported. The basic design of the instrument and technical solutions minimizing the noise figure are described. The system proved to have a low read-out noise and to be very useful for many different astronomical applications. Examples of astronomical results obtained at the Cima Ekar of the Asiago Observatory 182-cm telescope showing capabilities of the instrument are given.

Key words: solid state detectors – spectrophotometry

1. Introduction

Unintensified Reticon photodiode arrays have been widely used for astronomical spectroscopy in the last fifteen years. The main advantages of the use of these systems are: linear response over a large dynamic range, high responsive quantum efficiency (RQE), spectral response from 3500 Å to 11 000 Å and direct digital acquisition with the possibility of real time observations. Reticon arrays are particularly convenient with respect to other detectors when high signal-to-noise (S/N) ratios (about 1000) are required. In fact the high RQE in the spectral range 5000–9000 Å, produces a detective quantum efficiency (DQE) that can exceed the one of photon counting systems with conventional photocathodes (Walker et al., 1983).

In this paper we describe the Reticon spectrophotometer developed at the Merate Astrophysical Observatory. The main goal of this project was to build a versatile and compact system to be used for astronomical spectrophotometry.

The design of the electronics system is based on previous systems (Geary, 1979; Vogt. 1981). However we have applied some changes, mainly regarding the cooling of the preamplifier FET and the extraction charge technique, that allow us to improve the performances of the whole system. Our system confirms that this type of technical solution gives very satisfactory results.

In Sect. 2 we give a description of the hardware of the system and the achieved low noise figure; in the same section we describe the software developed to control the Reticon and to acquire the data. Finally in Sect. 3 we report examples of astronomical observations obtained with the system attached to the Boller & Chivens spectrograph of the 182-cm telescope at the Asiago Observatory.

2. Description of the system

The hardware of the system consists essentially of four parts: the mechanical mounting, a liquid nitrogen dewar for cooling, the electronics and the microcomputer. In the following section we give a brief description of the hardware configuration of the system. More detailed information is reported by Bonanno et al. (1984).

2.1. Mechanical and cooling

Figure 1 shows a block diagram of the whole system. Some parts (mechanics, dewar and control electronics) are mounted at the telescope while other parts (interface, computer and peripherals) are situated in an observing control room. The mechanical structure is designed so as to achieve maximum stability with minimum weight and dimensions. It allows a movement along the optical axis to adjust the detector on the focal plane, and translation and rotation movements in order to align the array with the spectrum image. A schematic diagram of the mechanical and cooling parts showing the solutions adopted is given in Fig. 2.

To reduce the dark current, the photodiodes array is cooled lodging it in a liquid nitrogen dewar (model ND 2) manufactured by the Infrared Laboratories. We found this dewar is very efficient as cooling system, however to increase the mechanical stability of the detector we needed two additional nylon stand-offs.

An optimal operating temperature chosen as a compromise between dark current reduction and the decrease of sensitivity (especially beyond 8000 Å) at low temperature, is stabilized by a temperature controller with accuracy of $\pm 0.05\,°$K. To do this a thermal impedance of teflon has been interposed between the cold work surface of the dewar and the Reticon (see Fig. 2). The typical temperature used ranges from -105 to -115°C as determined from calibration of the temperature sensor. With these values we obtain, on an average, 0.01 to 0.005 ADU/s respectively from long dark exposures.

The expected dark current at these temperatures, derived using the gain of the system given below, is consistent within 5 degrees with our measured values.

2.2. Electronics

The Reticon electronics is similar to the one designed by Vogt (1981).

The read-out noise is fundamental for the design of Reticons (Geary, 1979). This noise depends mainly on the extraction charge mode and on the connection technique between the Reticon and

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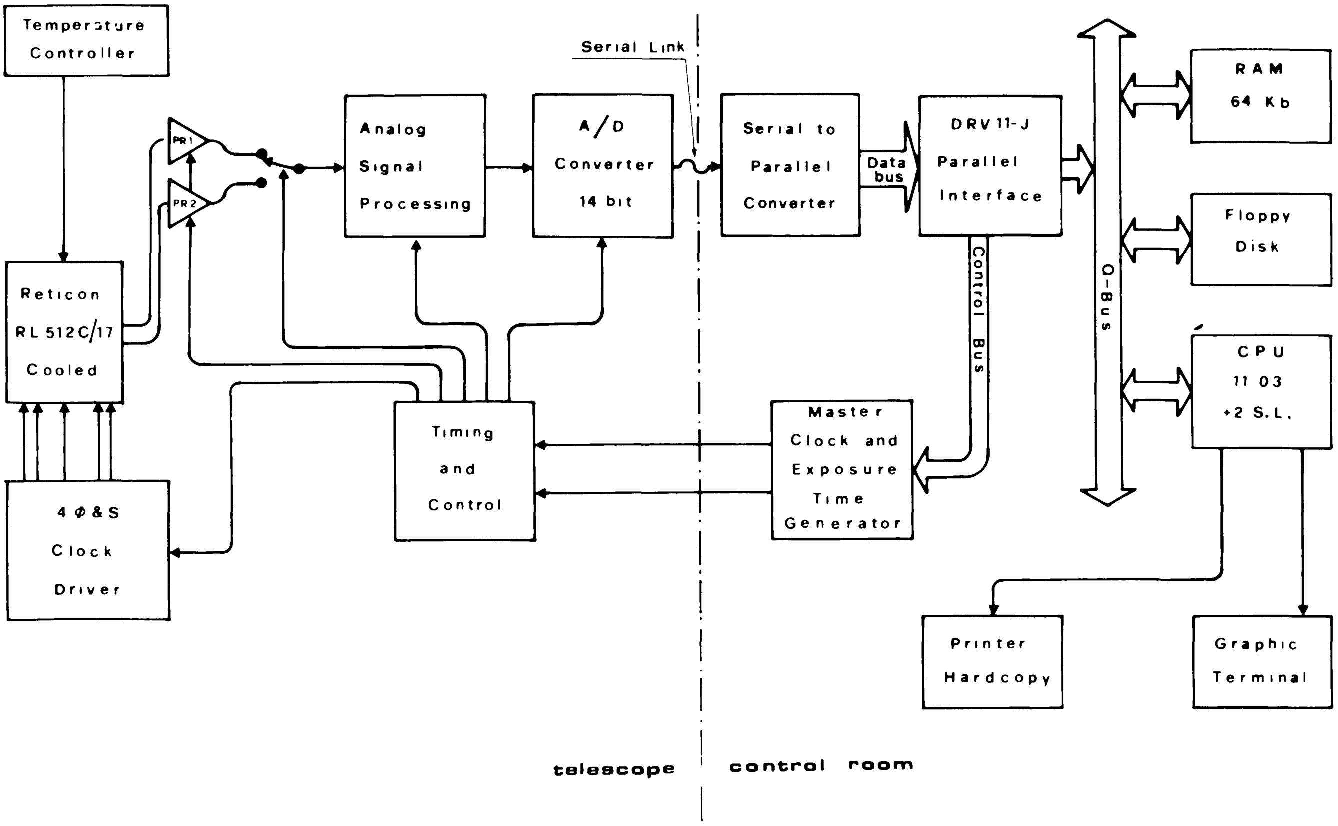

Fig. 1. Block diagram of the Merate Reticon system

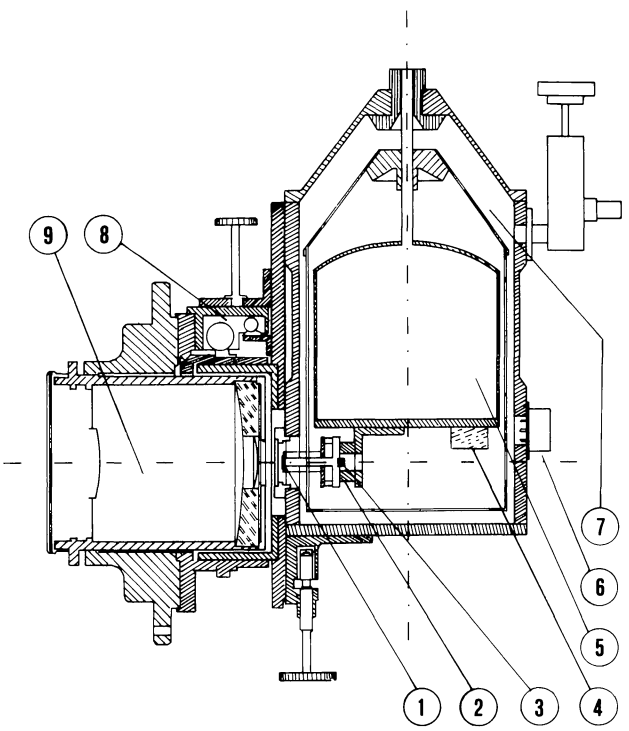

Fig. 2. Cut-away view of the mechanical and cooling system. 1. Reticon; 2. thermal impedance; 3. thermoresistor; 4. zeolite cryopump; 5. LN2 container; 6. 32 pins connector; 7. dewar; 8. movements mechanical group; 9. spectrographic Schmidt camera

the preamplifier. We have used, as Vogt, the extraction charge technique similar to the one used on CCD detectors to achieve low noise levels. With this configuration the principal noise source becomes the reset noise associated with the total capacitance seen by the input node of the preamplifier.

To minimize this capacitance we have taken particular care in the electronic circuit layout design, installing the JFET preamplifiers as close as possible to the Reticon video lines inside the evacuated dewar. Furthermore these JFET are cooled at the same temperature as the array, reducing significantly the thermal noise of the preamplifiers (Klein, 1985).

The gain of the electronics in our system was set to 1.82 $\mu V/e^-$ (according to the saturation charge of the Reticon $2\,10^7$ electrons). With this gain one ADU (analog-to-digital converter unit) corresponds to 337 electrons. The saturation level of our ADC is reached with $5.5\,10^6$ electrons, 28% of the Reticon saturation, well within the photodiode linearity range.

An alternative way to determine this gain (e^-/ADU) is to use pairs of exposures at different intensities and compare the signal to its variance squared. At low light level we found the read-out noise is dominant while at higher level the photon noise is prevalent and the variance squared is proportional to the signal. A best linear fit of data where photon noise is dominant gives a gain of 450e^-/ADU (correlation coefficient 0.996) and a variance squared of 2.1 ($\sigma = 652e^-$ with gain of 450e^-/ADU).

From repeated measurements of dark exposures we obtain an average read-out noise of 1.8 ADU/diode.

Using the values of gain derived above we obtain a read-out noise of 600–800 electrons r.m.s respectively per diode.

Under these conditions the linearity of the system has been checked, by taking several measurements of increasing exposure times with the same source. We have found that the deviations from linearity are less than 0.5% for the first half of the dynamical range and less than 1.0% for the whole range. Since checking the linearity over the whole dynamical range requires long exposure time (about 1 hour), small instability of the light source could account for the less good latter result.

2.3. *Microcomputer and software*

The control of the Reticon system, and the preliminary data analysis and reductions are based on the Digital PDP 11/03 microcomputer with the RT-11 operating system. The hardware configuration of the computer is reported in Fig. 1. The useful work memory is 56 Kbytes and is sufficient both for the acquisition and the preliminary reduction programs. The acquired spectra, displayed on a VT 100 terminal (graphics up-graded), can be hard-copied on a line printer and stored on a floppy disk unit. The controls for the electronics and the data communication between Reticon and computer are provided by the DRV-11 *J* parallel interface.

The general structure of the acquisition program was planned as a menu driven commands. From the master menu the observer can have access to sub-menus. Each of these is able to do a special task as object exposure, input comments, data handling and so on. In addition, during long exposures it is possible to perform some reductions on a previous spectrum, as for example flat field correction, data filtering and flux calibrations, in order to get information on data quality and modify subsequent observations if necessary.

3. Astronomical observations and results

Since the end of 1984 the system has been installed at the Boller and Chivens spectrograph of the 182-cm telescope of the Padova-Asiago observatory. The availability of different spectrographic cameras and gratings allows one to operate at different dispersions, from 9 to 170 Å/mm and therefore to use the system for several research programs. To test the performances of the system under observing conditions we have done a series of observations both of standard stars and of typical objects.

From several observations of standard stars we have estimated the total efficiency of the system mounted at the 182-cm telescope with a grating at 600 gr/mm which gives a dispersion of 115 Å/mm. The resulting total efficiency (including atmosphere, telescope, spectrograph and detector) measured at 5000 Å is 2.5%. The expected value obtained from the total transmission of the optical surfaces and from the quantum efficiency of the detector is slightly higher (about 3.2%). However if one account for seeing losses the two values are in good agreement. This total efficiency gives us only a typical value of efficiency to be compared with different configurations or other instruments. The performances of the whole equipment are better obtained from the signal-to-noise ratio of observations.

Due to its high RQE, Reticon works quite well at intermediate S/N levels, however it is really optimized for high S/N. In fact in this regime, the read-out noise becomes insignificant with respect to photon shot noise, and the effective speed depends mainly on the RQE.

In Fig. 3 we show the result of four flux calibrated spectra, in different spectral regions, of Nova Vul No. 1 1984 combined together. Each single spectrum combines quite well with adjacent spectra showing no more than 5% in the difference of the continuum level. Two different enlargements of the data are reported in Fig. 3 in order to show both strong lines such as Hα and weak features. The average S/N is 200 and has been obtained with 10 min of exposure for each spectrum. The spectrum shows the Balmer lines in emission with a typical P Cygni profile, as well as the Balmer jump in emission. This instrument proved to be also very useful in obtaining spectrophotometry of sources of intermediate brightness. Symbiotic stars are currently monitored with the Reticon spectrophotometer in order to study the time variability both of continuum and emission lines. In Fig. 4a,b we report two different spectra of Z Andromedae in the blue region, obtained about 1 month apart. On the latter spectrum (Fig. 4b) the He II 4686 significantly weakened with respect to the previous one (Fig. 4a) and the emission lines of [O III], He I and N III–C III strengthened. This result indicates that Z And was in an outburst stage during the second observation and agrees with the photometric results (IAU Circ. 4122).

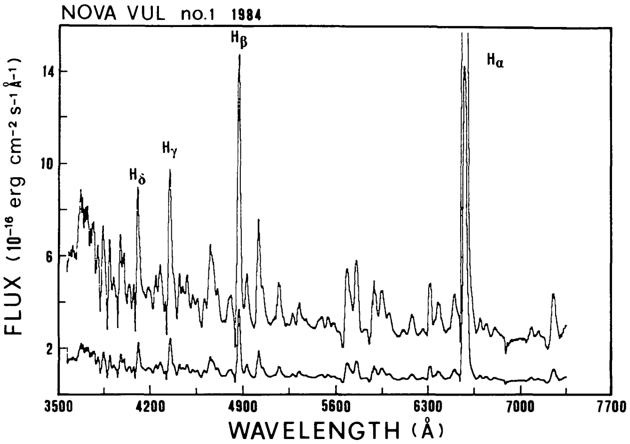

Fig. 3. Combined calibrated spectra of Nova Vul N.1 1984 ($V = 9.0$; integration time 600 seconds); units are 10^{-16} erg cm^{-2} s^{-1} Å^{-1} for the lower spectrum

The sensitivity of Reticons extends to the red as far as 11 000 Å. In this spectral region the system is more efficient than other conventional detectors whose sensitivity shows a drop-off at wavelengths longer than 9000 Å. Figure 5 reproduces the spectrum of SS 433 ($V = 14.5$) from 5800 to 11 000 Å obtained combining several spectra in different spectral regions. From Fig. 5 the strong line of He I 10830 is apparent as well as Hα and Paschen emission lines.

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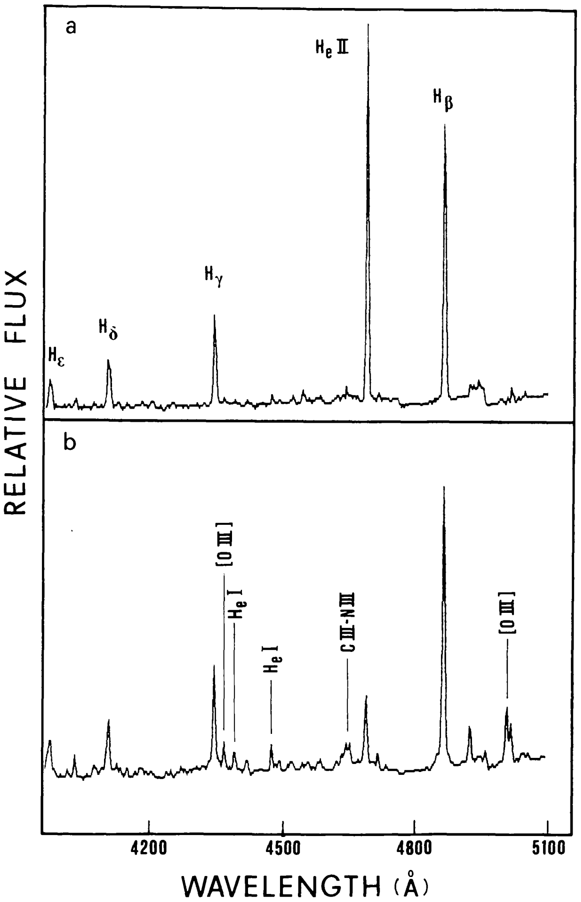

Fig. 4. Spectra of the symbiotic star Z And in two different states. In b the spectrum shows He II significantly weakened with respect to the one in a, taken one month before, while [O III] and He I are stronger

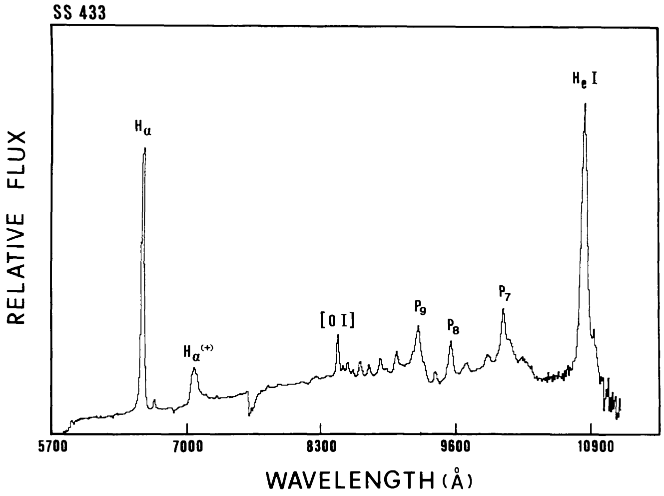

Fig. 5. Combined spectra of SS 433 ($V = 14.5$) from 6000 to 11,000 Å. The response of the Reticon in the near infrared region allows one to obtain spectra extended in the red as far as 11,000 Å

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