

CCD DETECTORS FOR ASTRONOMY

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INTRODUCTION

The light levels available to astronomers are at least a factor of 10^{-10} lower than those normally encountered in studio or day-light photography. The most important scientific information is frequently contained in the finest visible structures. Faint sources are seen superimposed on the bright background of the night sky and frequently they lie close to much brighter objects. While large telescope apertures can increase the available flux and satellite altitudes both improve image quality and allow observations over the whole spectrum, as well as providing a darker sky; the characteristics of the detector crucially limit the precision of the observations. Astronomers want to achieve photon-noise limited measurements from a single frame with high DQE and geometrical stability, a large dynamic range and linear response over a wide spectral range, and minimal signal induced noise and lag. These goals are not achieved with any multielement detector currently available. CCDs using buried channel technology and sensitised to include the ultraviolet region appear to offer the best solution for signal generating area sensors in the future.

DETECTOR CHARACTERISTICS

In order to exploit the images already being produced by ground-based telescopes and those expected to be available from orbiting telescopes the following characteristics are desirable for a CCD sensor:

- a) linear response
- b) no dead-space between elements and minimal charge spreading
- c) centre to centre spacing of elements approximately 15 microns
- d) on-chip amplification with noise equivalent to 20 electrons or better
- e) high, uniform, responsive quantum efficiency from 0.1 to 1 micron
- f) saturation charge approximately 10^6 electrons per element
- g) thinned to limit cosmic ray background
- h) high photometric stability with no optical fringing at long wavelengths
- i) up to 2000 x 2000 elements
- j) operate regularly at temperatures $< -100^{\circ}\text{C}$ with exposure times between a fraction of a second and several hours.

EXPERIENCE WITH AVAILABLE CCDS

We have successfully used arrays of silicon diodes for astronomical spectroscopy and area photometry for several years (ref 1). Their principal limitation is a large source capacitance leading to an

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irreducible noise of several hundred electrons per diode. We have had the opportunity of using a Texas Instruments 400 x 400 element developmental CCD made available at Cerro Tololo Inter-American Observatory in Chile. This device approached but did not fully meet the requirements set out in (a) to (j) above except for (e) and (h). The photometric transfer function of the device was not uniform or stable particularly at wavelengths longer than the peak response. The problem is illustrated in Figure 1 which shows a photographic image generated with the device when observing the emission nebula in Orion (M42) in the essentially monochromatic light of the [SIII] lines at $\lambda 9532$. The fringing is apparent. It was not possible to remove this with observations of a uniformly illuminated screen as the fringe structure is very sensitive to the geometry of illumination and telescope position. Two further difficulties are illustrated in Figure 1. There is an underlying gradient in response and there are several dead columns. Such problems are to be expected in a developmental device.

UV SENSITISATION STUDY AT CRESS

The fluorescence of Coronene near $\lambda 5000$ has been the standard technique for the down conversion of UV photons to the peak of normal photocathode responses and it is proposed for use with the TI CCD detectors on the Wide Field Camera of Space Telescope. The match to the peak silicon response near $\lambda 8000$ is not optimum and in a study funded by the Canadian NRC Space Science Coordination Office (ref 2) we have suggested a composite of sodium salicylate and ruby. Sodium salicylate fluoresces in the region 4000 to 5000A with a peak at 4500A which coincides with an absorption band in ruby which fluoresces strongly between 6600 and 7700A. This provides a much closer match with the silicon response. Although the fluorescent efficiency of sodium salicylate is rather less than that of coronen, the combination with ruby is expected to provide a high overall efficiency. A testing program is planned.

FUTURE USE OF CCD's AT UBC

A 100 x 100 element CCD array with 32 micron spacing, little optical dead space, and with on-chip amplification made by, and on loan from, Bell Northern Research, Ottawa, will be put into operation in the summer of 1979. Data acquisition and exposure control will be through a Digital PDP 11/03 computer and the array will be mounted in an existing liquid nitrogen cooled housing. The system is illustrated in Figure 2. The detector is in a sealed housing and cooled by a copper "cold finger" immersed in liquid nitrogen. A printed circuit board within the housing provides drive electronics for the array, and a video preamplifier. Readout circuits, controlled remotely by computer are located in a box beside the housing video circuitry, also in this box, consists of a clamp, integrator, sample-hold, and analog-digital converter. Readout proceeds at about 10^4 pixels per second and is synchronized with the line frequency. Noise is reduced by integrating the voltage levels corresponding to picture element charge packets, and clamping the video line between integrations when a reference voltage appears. 14 bit digitized data passes down a 30 meter cable to a portable computing system consisting of a DEC PDP 11/03 computer with 32K words of memory, two dual density floppy disk drives, a video terminal, and X-Y plotter. The "camera" interface uses a parallel I/O port and can support a variety of detectors. Picture frames are stored on flexible diskettes which have a $\frac{1}{2}$ Megabyte capacity (about 25 100 x 100 images). Frames can be processed, displayed on the video terminal, or plotted as they are received, or can simply be

stored for more extensive analysis using the computing center facilities at U.B.C. We plan future observations using larger CCD arrays and will be upgrading our system as needed.

DATA PROCESSING AND ANALYSIS

Currently all data acquired with our linear Reticon arrays is reduced with an interactive FORTRAN coded program, RETICENT, which accepts input instructions in a simple command format. A key feature of RETICENT is the ability to execute repeated sequences of instructions with nested DO loops and Assembler-like MACRO statements. Prior to RETICENT, a command oriented program, FIRM, was written by S. Mochnacki (ref 3) for the reduction of images obtained with a now obsolete 50 x 50 Reticon array and we anticipate the development of a more sophisticated program, incorporating features of RETICENT, for use with the 100 x 100 CCD array and larger format devices.

A related concern arising from the use of large multi-element arrays is how to best present the data. In our work to date we have relied mainly on contour diagrams but these have obvious limitations particularly when fine detail in a large field is to be represented. Photographic images are familiar and provide discernable resolution matched only by impractically large contour maps. With the addition of pulse colour to represent intensity levels, the dynamic range in the photograph can be enhanced to do justice to the original data. UBC has recently acquired a Comptal Vision I Image System which consists primarily of a colour television monitor under computer control through a user operated keyboard. Although attended primarily for application to satellite imagery of the earth, this system has been used (ref 4) successfully to display 200 x 200 pixel CCD images. Its long term potential for Astronomical imagery is limited because the maximum field size is only 256 x 256 pixels and the maximum dynamic range which can be displayed is 256:1. It is important to emphasize that the benefits of using multielement arrays can be realized only if the data reduction facilities are available which fully exploit the characteristics of the detectors. The provision of such facilities should be regarded as an integral part of a detector development program.

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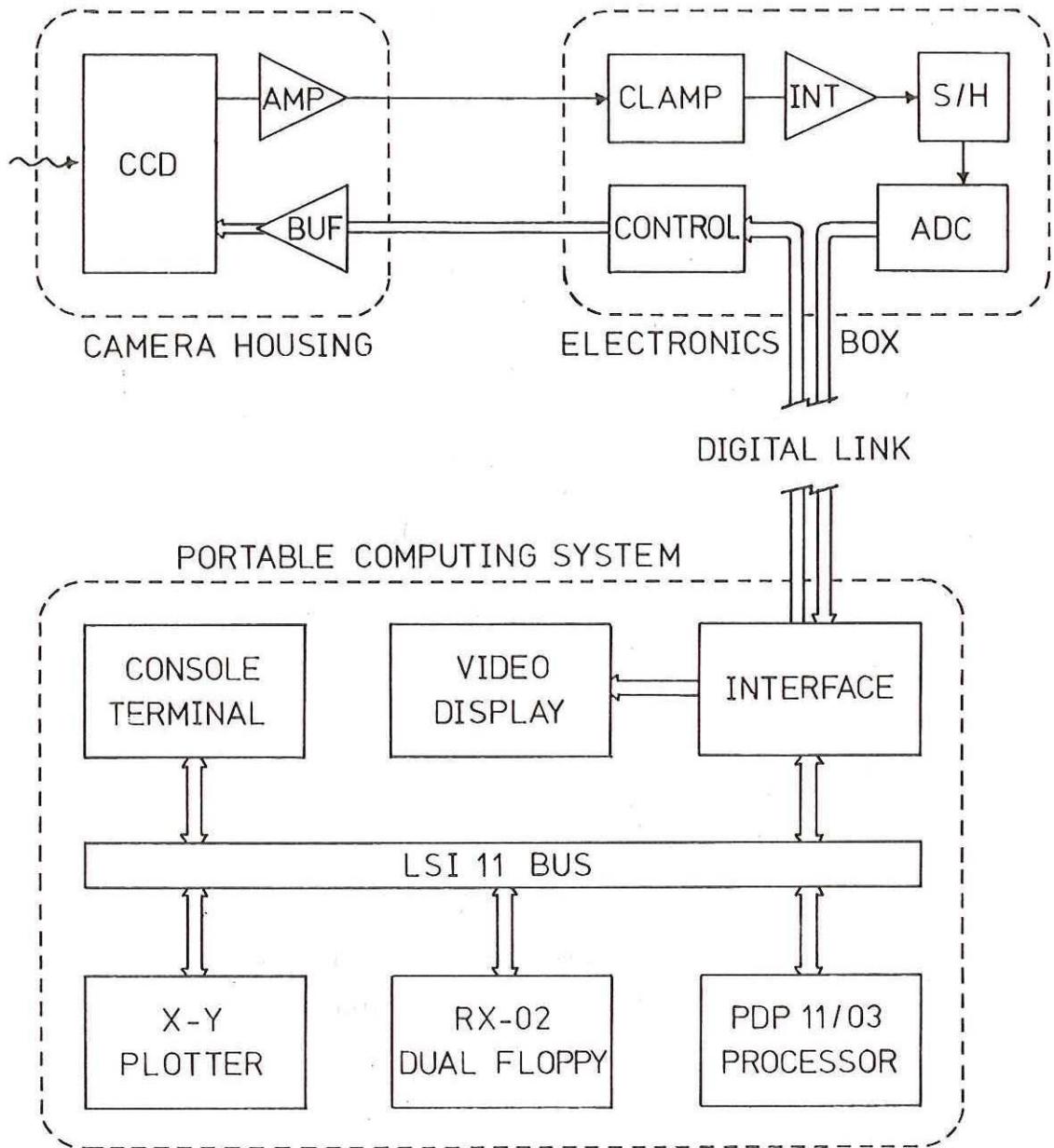


FIG. 2: UBC DATA SYSTEM

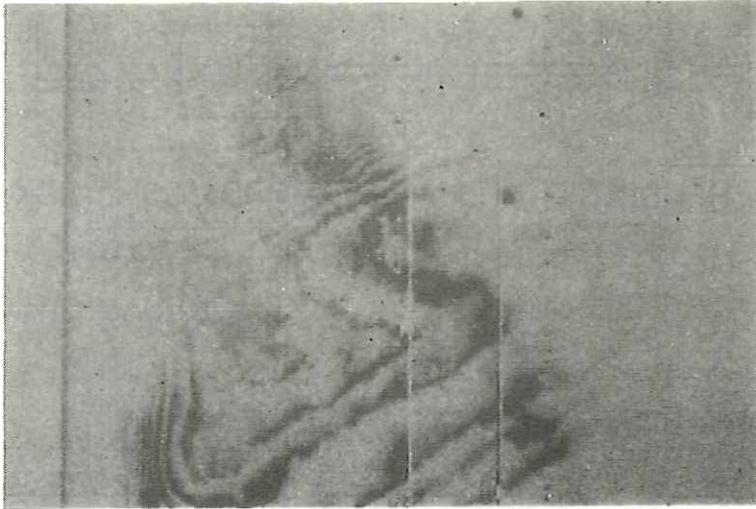


FIG. 1: IMAGE OF THE ORION NEBULA IN THE
LIGHT OF [SIII] 0.9532 MICRON