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CCDs AND CCD CONTROLLERS FOR THE GTC DAY ONE

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RESUMEN

La adquisición y el desarrollo de los diferentes detectores CCD y sus correspondientes controladores para el GTC ha estado vinculada a las necesidades de las cámaras de adquisición y guiado, sensores de frente de onda e instrumentos científicos en el intervalo visible del espectro. Si bien inicialmente se quiso proveer al GTC de un controlador único para todos los CCDs, los diferentes y exigentes requerimientos mecánicos, ambientales y científicos de cada sistema han provocado la coexistencia de dos controladores especializados, uno para los sistemas de adquisición y guiado y la cámara de verificación y otro para los instrumentos científicos. Describimos las especificaciones y el diseño de los dos sistemas diferentes de cámaras CCD, así como sus prestaciones, basadas en pruebas en el laboratorio.

ABSTRACT

The need of the GTC for acquisition cameras, wavefront sensors and scientific instrumentation operating in the optical wavelength range has led to the acquisition of various CCDs and CCD controllers. Due to stringent science, mechanical and ambient requirements the initial idea to employ a general purpose controller had been dropped in favor of two specialized systems, one for the acquisition and guiding purposes of the telescope and the commissioning camera and the other for scientific instrumentation. We describe the specifications, design and performance of the two different CCD camera systems based on laboratory test results.

Key Words: **INSTRUMENTATION: DETECTORS — TELESCOPES**

1. INTRODUCTION

The GTC as all large astronomical telescope facilities has a range of imaging detector systems in the optical wavebands to aid complying with the science goals of the facility. The design of the GTC made a clear distinction between detector systems for science instruments and those for telescope purposes. The latter are part of fully integrated acquisition and guiding (AG) units, which will be available at each telescope focus. As scope for Day-1, first the two Nasmyth foci will be equipped with AG units. Therefore, the science instruments in general do not need to have their own guiding detectors added.

The science instruments operating at optical wavelengths are OSIRIS and ELMER, both imagers and multi-object spectrographs but with different field-of-views, spectral resolutions and observing modes. While OSIRIS will exploit a large field-of-view and will offer unique observing modes like imaging with tuneable filters, ELMER's concept is based on providing a versatile, low-risk, low-budget instrument optimized in efficiency.

One task of the GTC project office (PO) has been to pool the requirements for the different CCD camera systems and to standardize them as much as possible, including the selection, acquisition and characterization of the detectors. The initial market analysis carried out in 1998 revealed, that no unique CCD controller system could be found to match all camera requirements, partly due to the stringent space and weight limitations of the AG units. During the following years the decision was made to develop CCD camera systems separately for AG and the commissioning instrument and for scientific instrumentation. The former is an internal development based on the small, lightweight AG cameras for the Magellan telescopes (G. Burley, OCIW) but equipped with remote, Peltier-cooled CCD heads, and the latter is a state-of-the-art system based on a standard LN_2-cooled cryostat and a commercial science instrument CCD controller (SDSU-II).

2. CCD CAMERA SYSTEMS FOR AG

The GTC acquisition and guiding system has been designed to provide services for verification and positioning of stellar objects in respect with the scientific instrument apertures (acquisition), guiding for closed-loop active optics (slow and fast guiding), and verification of the telescope optical qual-

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Fig. 1. Assembled AG CCD controllers with sample CCD heads.

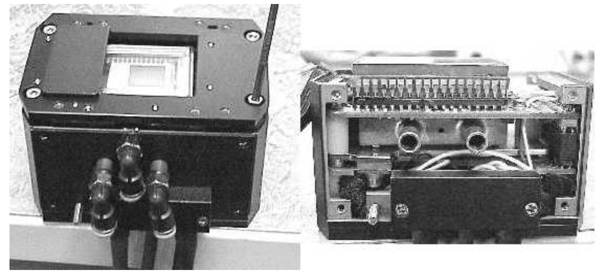

Fig. 2. CCD47-20 head completely assembled (left image) and partially disassembled (right image). The overall dimensions of the compact head without connectors are 86 mm x 56 mm x 54 mm (HxWxD). The weight of the head is about 500 g.

ity (figure and tilt sensing). To accomplish these services, the system comprises three different CCD cameras, one for object acquisition and slow guide service (ASG), one for primary mirror segment figure sensing (SFS) and one for fast guiding and segment tilt sensing (FG, STS). The cameras of the first two services, ASG and SFS, use the E2V Technologies CCD47-20 detector, a 1Kx1K, frame-transfer device with two output ports. Object acquisition is done at a frame rate of approximately 1 Hz, while slow guiding requires the readout of two 30x30 pixel windows at a frame rate of 10 Hz in synchronization with the maximum chopping frequency of 5 Hz of the secondary mirror. The segment figure sensing service uses a Shack-Hartmann type sensor to guarantee the optical quality of the GTC in parallel with scientific observations. The micro-lenslets used for the SFS service produce a maximum of 812 sub-images on the detector requiring the large 1Kx1K field. Both cameras are mounted on the same mechanism and therefore share positioning and movement control.

The fast guide camera is mounted on a separate mechanism in the same acquisition and guiding unit, which allows independent positioning and movement for the fast guide and segment tilt sensing service. This camera is based on the E2V Technologies CCD39-01 detector, a 80x80 pixels, split-frame-transfer device with 4 output ports. Corrections for wind shake and atmospheric turbulence measurements make high frame rates of up to 200 Hz with this camera system necessary.

The detectors of the AG camera systems have been delivered in hermetically sealed Peltier packages with BK7 entrance windows. Later on we discovered a high cosmic ray background originating from a decay of radioactive potassium within the windows, which could have been avoided by ordering the packages with fused silica windows. BK7 was chosen, because E2V's AR-coated BK7 windows had a higher transmission for the redder wavelengths, while the fused silica windows were optimized for the UV, which is of minor importance for the AG system. Nevertheless, due to usually short exposure times and the glitch correction for guiding, the impact on the AG performance will be minimal.

The package size and layout is identical for the CCD39-01 as for the CCD47-20, although the package pin-out is different for the two detectors. The packages include 2-stage TECs for CCD cooling and are back-filled with Krypton for thermal isolation.

The detector packages are mounted in small remote CCD heads, with slightly different designs for each detector type. They include the TEC drive electronics, a liquid cooled heat exchanger and the preamplification circuitry based on fast settling, JFET-buffered amplifiers. Low torque cabling and tubing of 1.5 m connects the CCD heads with the CCD controller (see Figure 1 for the complete assembly). The water temperature of the heat exchanger will be a few degrees below ambient. Maximum ambient temperature in the telescope dome will be 19°C. With this setting the final detector temperature is expected to be below -30°C. To avoid possible condensation a dry air blower has been added to the CCD head design, which produces a constant flow over the entrance window of the CCD package. The final design and production of the CCD heads has been carried out by the Spanish company NTE. Figure 2 shows the CCD head for the CCD47-20.

The controller is based on the guider cameras for the Magellan telescopes, but it had to undergo some design changes to be able to operate both de-

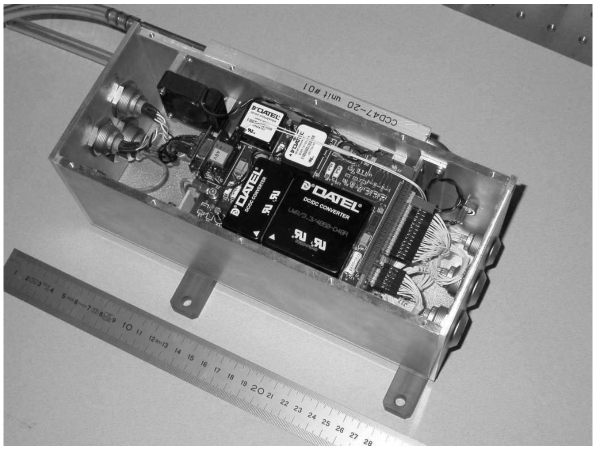

Fig. 3. AG CCD controller completely assembled. The top cover has been removed to allow an inside view. The topmost PCB is the power board with its DC/DC converters.

tector types and to provide a remote connection to the CCD heads (Magellan only uses the CCD47-20 for guiding and the head forms part of the controller box). The controller has a standard design with a dedicated backplane which interconnects four type of controller boards: power supply, DSP timing, clock driver and video processing board. All necessary voltages are derived from a 48VDC input by switched DC/DC convertors. The data connection is over 40 m LVDS link to a custom PCI card running at 1.5 Mpixels/s. Each signal processing board contains 2 signal chains with dual-slope integrators, 2-stage switchable gain and 14-bit ADCs. Maximum pixel frequency is 500 kpixels/s, though the standard readout is limited to about 300 kpixels/s. The electronic noise of the signal processing boards has been measured to below 0.8 ADU. The controller box is small (105 mm x 106 mm x 260 mm) and weights about 3 kg including heat exchanger. Power consumption is low (about 23 W with the TEC operating at maximum). A TTL signal for shutter control has been routed to an external BNC connector. The aluminium box and the PCBs have been fabricated at the IAC workshops. Figure 3 shows the inside of a fully mounted AG controller.

The CCD cameras have been tested in the GTC PO laboratory and on a single test run on the mountain at the IAC80 of the Teide Observatory. The systems behaved well achieving minimum read-out noise of 4.3 e^- at 100 kpixels/s. On all detectors peak QE is about 90% or higher, linearity within 1% from 10% to 90% full well, dark current is about 0.1 e^-/s/pixel at -35°C for the AIMO CCD47-20 and about 70 e^-/s/pixel at -35°C for the non-AIMO CCD39-01. 11 AG CCD camera systems have been built so far to satisfy the telescope needs for first light. They are currently in their integration and commissioning phase.

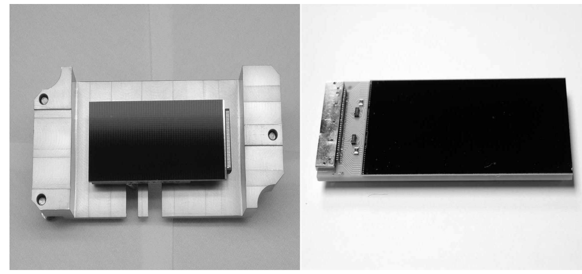

Fig. 4. E2V Technologies CCD44-82 in its transport carrier (left image) and MIT/LL CCID-20 (right image).

3. CCD CAMERA SYSTEMS FOR SCIENTIFIC INSTRUMENTS

OSIRIS needed a 4Kx4K detector, with overall high quantum efficiency (QE), optimized in the red and with low fringing. At the time of ordering the detectors, monolithic CCDs with these properties were not readily available. The choice fell therefore on a mosaic of two 2Kx4K, 15 μm pixel size, buttable CCDs with frame-transfer structure and built on 40 μm high-resistivity silicon to improve red response.

The GTC project entered the UH/IfA consortium to develop the MIT/LL CCID-20 detectors and bought shortly after a batch of E2V Technologies CCD44-82 detectors to ensure the availability of high-performance detectors for the Day-1 science instruments. Both detectors have nearly the same characteristics and could be interchanged without too much trouble (Figure 4 shows the two detector types side-by-side). Due to its backside passivation process, the CCID-20 could prove to have higher overall QE, but development problems have delayed its delivery. The CCD44-82 is now the default detector for OSIRIS.

ELMER has a smaller FOV (4.2′ diameter in imaging referring to about 1300 pixels on the detector), but for cost reasons no dedicated CCD has been obtained for this instrument. Instead, a single CCD44-82 from the OSIRIS batch has been assigned to ELMER, and observing modes like fast photometry and spectroscopy have been incorporated to make excellent use of the not-illuminated detector area. The spectroscopy modes also use the full 2K width of the detector for spectral coverage.

To be able to test all the detectors for the Day-1 scientific instruments a test cryostat (LN_2 bath dewar, based on an ESO design) has been developed to provide support for either detector type. This cryostat including the fan-out electronics has been kept flexible to be able to rapidly exchange the detectors. To minimize efforts, this cryostat and the data acquisition system is identical to the one used in ELMER (see Kohley R. et al., these proceedings, for more details). The CCD camera system of OSIRIS is very similar as well, although they use their own cryostat design.

The fan-out board is a common design for both detector types. The specific CCD is selected by the set of components mounted. The board provides ESD and overvoltage protection to the CCD, clock waveshaping and bias filtering, and pre-amplification of the video signals. To be able to test for the most adequate pre-amplification circuit, different amplifier configurations can be mounted. The design also provides the necessary current to run the nearly 2 m video coaxial cabling to the CCD controller. All elements of the fan-out board have been packed into a very small footprint of 80 mm x 60 mm to fit into the CCD head envelope.

The CCD controller for testing the CCDs is a standard SDSU-II controller, now commercialized through Astronomical Research Cameras (ARC). The set of boards consists of Fiber Optics Timing board, Clock Driver board, dual-channel Video board, and an in-house designed low noise board to provide power supply to the fan-out board. Some of the original SDSU-II boards have undergone changes to accommodate our requirements. For example, on the video board the pre-amplification stage is bypassed, since it is already carried out on the fan-out board. The fiber optics link goes to a PCI board in a PC running software provided by Robert Leach (ARC).

The final controller solution for ELMER and OSIRIS uses a Parallel Timing board instead of the Fiber Optics board and has an Utility board added to be able to better codify all observing modes. Communication to the CCD controller is through a RS-232 serial link to the Utility board and image data is transferred via the RS-422 parallel link from the Parallel Timing board to a commercial frame grabber. The DSP codes for the observing modes are developed by Francis Beigbeder.

An internal cabling has been added to provide the necessary connectors for CCD operation and communication on the controller box instead of passing the cables through the front panel to the different board connectors (see Figure 5).

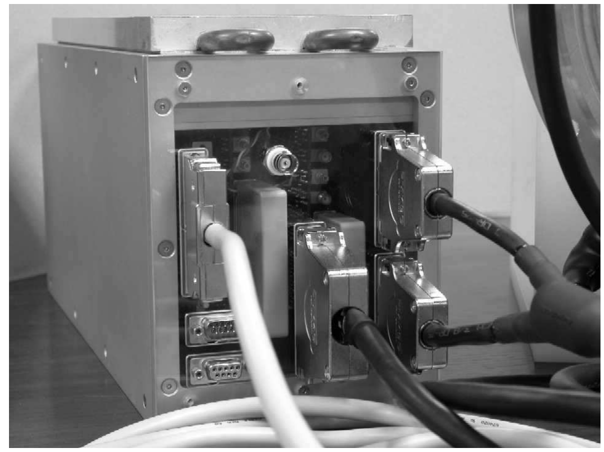

Fig. 5. SDSU-II controller for ELMER with external connectors. The custom prototype front plate has been made from plastic to verify the tracing of the internal cabling. In the final system a metal front plate will be used.

The system is now in its integration and commissioning phase and has just recently seen "first light" on an engineering grade CCD44-82 detector.

4. TEST BENCH FACILITY

To be able to test the different CCD camera systems, we developed our CCD test bench as a multipurpose facility fulfilling the following requirements:

- Support for Peltier and cryogenically cooled detector systems
- Stabilized light source (good short and long term stability)
- High throughput from UV to NIR
- Homogeneous illumination over at least 90 mm diameter circular FOV (detector sizes up to 4Kx4K, 15 μm including mosaics)
- Support for visual inspections
- Test procedures fully automated

The requirements let to a simple and compact design using an arc lamp (Xenon or Mercury) with a close loop intensity control as illumination source. The wavelength selection is done by choosing one of 12 interference filters with 10 nm bandwidth in a 14-position filter wheel. The current filter set covers the visible wavelength range from 350 nm to

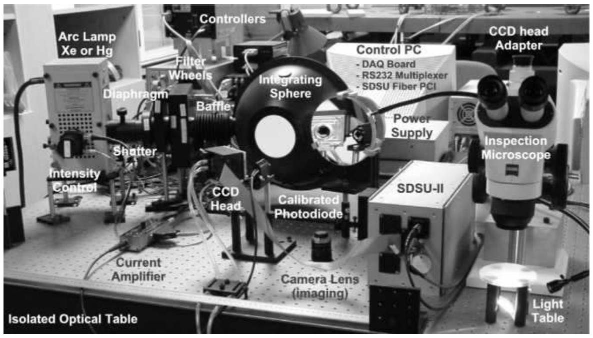

Fig. 6. CCD test bench facility mounted at the GTC PO laboratory.

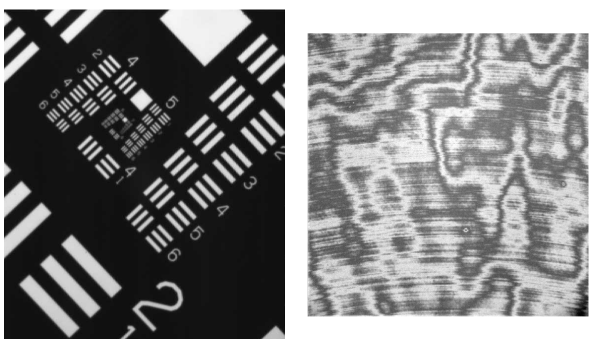

Fig. 7. Resolution target image (left), and 950 nm flat field image (right) on the CCD47-20 detector. the flat field shows the typical fringing pattern (15% with a spacing of 20 to 30 pixels overlayed by a 7% fringing at a 4 to 6 pixels scale possibly caused by surface variation due to the lapping process during detector thinning. The width of the used filter was 10 nm.

990 nm. To reduce stray light blocking filters in a second filter wheel are combined with the interference filters. The monochromatic beam enters a 12-inch integrating sphere, which finally produces a 4-inch (101.6 mm) diameter flat field at its output. A motorized diaphragm and an iris shutter control illumination flux and exposure times, respectively. Throughput is high also at the UV and NIR ends of the spectrum due to the availability of lines in the arc lamp spectrum. Figure 6 shows the different components of the test bench facility.

All components are under PC control operated via RS-232 with National Instrument's LabVIEW drivers. Automated test procedures for all standard CCD tests like QE, dark current, linearity, read-out noise, full well, transfer efficiency, etc. are currently being written. Plans are to add a Fe55 source in the future to be able to accurately determine system gain and CTE effects. Figure 7 shows some examples of images obtained with the test bench.

5. CONCLUSIONS

The initial idea to standardize as much of the CCD camera systems for the GTC Day-1 has only been partially fulfilled. No complete system has been found to match the stringent and different requirements of the subsystems in which these cameras were to be used. Especially the division between AG services and science instrumentation in terms of the CCD controller became too obvious to be ignored. It was decided to branch the CCD controllers into less powerful but smaller and light-weighted AG camera units and into standard instrumentation CCD controllers. The first became an in-house development under the aid of the original designer (Greg Burley, OCIW) and the latter the SDSU Generation II controller. Both systems are working now and are in their integration and commissioning phases.

All CCDs were ordered at a very early stage (during 1999 and 2000) and the consortium development of the MIT/LL CCID-20 detectors were backed up with the commercial available E2V CCD44-82. Due to both decisions the acquisition of the detectors were never on the critical path and science grade detectors for all instruments (AG and instrumentation) are now at the PO. The only missing detectors are the science grade CCID-20's. The already tested detectors behave well and comply with their specifications. Only few surprises like the high cosmic ray rate from the entrance windows of the AG CCDs were encountered. The E2V CCD44-82 detectors for the science instruments were only just recently put into operation due to delays in the production of the in-cryostat fan-out board. Nevertheless, first images were obtained showing that the CCD test camera system is operative now. Our CCID-20 engineering grade detector could not be tested yet because of the still missing molybdenum subpackages, though it is expected to put this detector also into operation this summer.

First units of the AG CCD camera systems have shown during laboratory tests and at the telescope (IAC80, Izaña) that they match the initial performance requirements, though still some more optimization is needed. Failures in the SDSU-II hardware, especially with the Utility board, have caused several delays and it is considered to modify or upgrade the science instruments controller system in the near future.

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