THE OMEGACAM 16K X 16K CCD DETECTOR SYSTEM FOR THE ESO VLT SURVEY TELESCOPE (VST)

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Abstract: A broad account of the main characteristics of the OmegaCAM 16K x 16K detector system is given. Starting from the requirements and additional constraints, the design strategy, its actual implementation, and first laboratort results are described for the detector head, the cooling system, temperature and shutter control, synchronization of multiple controllers, and the careful safety provisions are described. The system has already passed most acceptance tests and will soon be ready for shipment. Commissioning in Chile is planned for 2006.

Key words: mosaic, multiple controllers, synchronization, contamination, plasma cleaning, straylight, coating, cooling, Pt100, safety

1. INTRODUCTION

A 16K x 16K detector system was developed for the OmegaCAM instrument at the newly constructed ESO VLT Survey Telescope (VST; Capaccioli et al 2005), featuring a 1 degree x 1 degree field. While the OmegaCAM instrument was built by a multinational consortium (Kuijken et al. 2004), the 16K x 16K OmegaCAM Detector System was developed by ESO, but funded by the consortium. The focal plane consists of an 8 x 4 mosaic of 2K x 4K e2v CCDs with 15μm pixels, accompanied by four 2K x 4K CCDs on the periphery for the opto-mechanical control of the telescope.

2. INTERFACES & MAIN REQUIREMENTS

Compared to the ESO 8K x 8K Wide Field Imager (Iwert 1998, unpublished) the 16K x 16K OmegaCAM detector system is not just a fourfold replica. In the OmegaCAM case the basically identical 2K x 4K unit detectors have to be butted on fours sides. This leads to considerable complexity of the mechanics and electronics within the cryostat head. In spite of this, the two instruments and telescopes have comparable size, so that the overall filling factor at the Cassegrain focus is very much larger, and the instrument reaches the weight and momentum limits of the VST. The very small back-focal distance forces the cryostat to be deeply imbedded into the instrument while the optical design foresees - as an additional constraint - the last field flattener element as the cryostat entrance window. The lack of space eliminates all possibilities to mount the cooling system around the cryostat head and a customized CCD controller with the shortest cable length below.

The cryostat had to be equipped with a fully self-contained vibration-free cooling system providing about 65 W of cooling power to the CCD mosaic, while having a high degree of autonomy. Following standardization requirements, FIERA controllers had to be used in multiple synchronized configuration within the hierarchical VLT computer control system. Whereas the CCD mosaic is challenging in terms of data volume, the auxiliary CCDs present additional challenges in the number functions to be accommodated in the design and rapidly coordinated in real-time operation: The need for differential guiding required two fixed large field guider CCDs in the same focal plane, whereas two large field CCDs are offset against the focal plane with +/- 2 mm for the telescope active optics control. As OmegaCAM is the only instrument on the VST, a maximum downtime of 1% has to be satisfied by the OmegaCAM detector system because switching to an alternative instrument is impossible.

In response to these challenges, the OmegaCAM system incorporates several novel ideas that are customized to the VST and OmegaCAM but are nevertheless complaints with the VLT standards.

3. THE CCD DETECTORS

The unit detectors are e2v CCD44-80 devices, the UV sensitivity of which was vital for this project. They have been further enhanced by means of an integrated Pt100 temperature sensor, which helped to homogenize e2v and ESO test data, as well as permitting direct control loops of the CCD temperature. A revised package has been designed in connection with a custom-made ZIF socket especially for the enhanced four side buttability and the space constraints of the underlying flexrigid connector boards. All detectors have been tested and qualified individually on the ESO test bench against the contractual specifications. As the CCDs in each quadrant of the cryostat are partially sharing parallel and serial clocks, they have for each quadrant been selected according to their channel potential. The cosmetic defects are well below the specified global defect budget. CCD flatness and accurate package metrology by e2v eased the integration into the mosaic without further spacer adaptations. More details about the individual testing procedures for these detectors can be found in Christen et al. (2004).

4. THE DETECTOR HEAD

The cryostat head is the nexus of all interfaces of the detector system. Conflicting requirements from different domains had to be accommodated while the instrument was developed external to ESO. As the cryostat could not be prototyped due to cost and time, all solutions had to be designed in one go for the final product. The outside space limitations from the surrounding instrument together with the circular field flattener imposed a high filling factor and several form factors onto the cryostat. Following the symmetrical focal plane layout with ′left, left, right, right′ CCD output register location (per mosaic column), the mechanics of the detector head was designed with a square housing. But the instrument housing (above) and the cooling system (below) are both circular. Symmetrical mechanical design - wherever possible - helped the modularity, the thermal properties of the CCD mosaic table, as well as the space, flexure and earthquake safety constraints.

Due to the limited access to all parts inside the cryostat and the fact that all mechanical and electronics parts had to be mounted without prior prototypes, the system was in a first step integrated without ultra-cleaning. After some small modifications the final cleaning was applied with strategies suitable to the types of materials in question. Owing to the sheer size of the parts conventional cleaning mehtods could not always be applied. Therefore - amongst others - plasma cleaning was employed in-situ in the cryostat vessel. (Further details can be found in Deiries et al, these proceedings). Thereafter the clean cryostat head was integrated inside the clean room with the other cleaned component groups. Over some months, it was gradually put into cryogenic and electrical operation. The CCD mosaic was stepwise populated and tested with different numbers and different grades (mechanical, engineering, science) of detectors in order to reduce the possible impact of risks of mechanical, chemical, and electrical damage.

Key design drivers of the cryostat detector head were therefore symmetry, modularity, and easy access to all parts during all phases of assembly, integration, and testing. *On the outside* this concerned mainly the easily separable but precisely tilt-aligned and centered optical field flattener with integrated defogging system at the top and the cooling system at the bottom with a special interface for the easy lift-off of the detector head. *Inside* the detector head, cryogenic connections and electronic boards had to be disentangled such as to make them from the beginning independent and not crossing each other, so that each part inside the detector head can be integrated or disintegrated at any time without a need for removing others.

In spite of the external diameter of 70 cm, the overall alignment error budget required all critical parts to be machined with a precision of a few microns.

In order to ensure the effective cooling of the CCD mosaic, all intermediate levels of cooling parts were largely abandoned. The CCD mosaic table was produced of aluminum based on previous experience and its ability to distribute thermal energy quickly and uniformly. Following detailed detailled calculations, this base plate was designed as a light-weight but stiff 3D structure by integrating into an outer frame. On the top side it resembles a Swiss cheese for the mounting openings of CCDs and ZIF sockets, the bottom side interfaces with its cold fingers directly to the clamps that connect it both mechanically and thermally to the cooling system. After application of different machining technologies and many thermal cycles to release mechanical stress, a flatness of some µm was achieved. It is held and thermally isolated by fiberglass parts which were dimensioned according to the flexure budget and earthquake safety. All fiberglass parts have been Parylene coated to reduce outgassing in the vacuum.

The integrated electronics with about 1400 contacts to the outside world was designed such as to have low thermal conductivity, high modularity, and good signal separation. As a trade-off between manufacturing cost and routing space a ´four-in-one bus board´ was developed. It is mounted in the bottom cavities of the mosaic table. Per quadrant, two of these boards support eight CCDs and interface with one flexrigid interface board per signal group to a total of three vacuum connectors with 128 pins each. The connections for each of the four auxiliary CCD are fed through this board set of the respective nearest quadrant. The symmetry of the focal plane in connection with the symmetry of the mechanics permits the electronics of two quadrants each to be identical with the two pairs being mirror images of one another. All quadrants link to identical outside cabling for testability and ease of cabling. A total of 28 flexrigid boards have been designed and handrouted in complex 3 D shapes for the cryostat system. The use of glue-free materials was mandatory to avoid contamination.

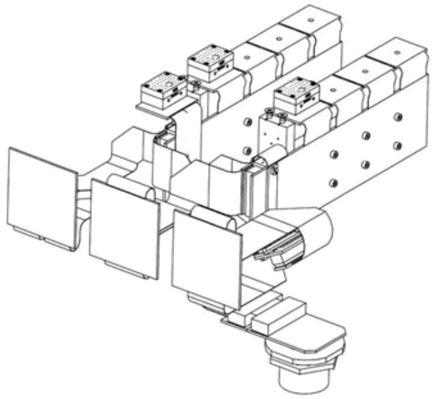

Figure 1. One quadrant of cryostat electronics

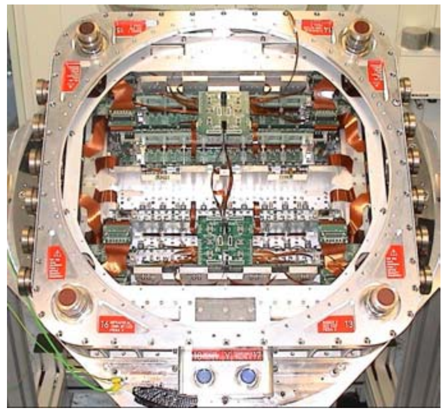

Figure 2. Bottom view of cryostat head

All parts and baffles in the light entrance part between auxiliary CCDs and CCD mosaic were blackened with Kepla coating to avoid contamination and straylight. An actively cooled shield acts as ice barrier. The shiny bond wires of the CCDs were masked with both cold and warm shields. After stepwise qualification of all alignment-critical parts, the CCD mosaic flatness was laser-triangulated at -120 C (and through a special dewar entrance window without optical power); a value of 25 μ (pp) had been achieved.

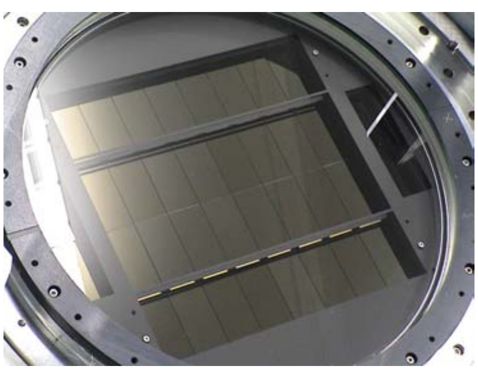

Figure 3. The 16K x 16K mosaic

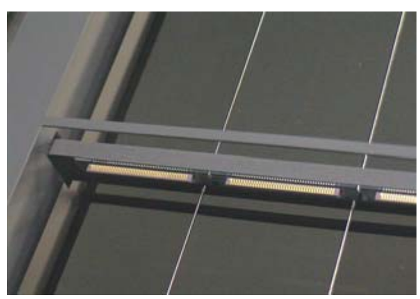

Figure 4. Close-up of baffling

5. THE COOLING SYSTEM

According to model calculations a heat load of 65 W had to be compensated by the cooling system, mounted below the CCD detector head. As no options for external compressors or the feeding of cooling lines through the telescope cable wrap existed, a self contained LN2-based system was developed. It utilizes the maximum cooling power of liquid nitrogen through the combination of an integrated 40 liter LN2 tank, combined with the main top heat exchanger operated in continuous flow mode by the cryostat cooling controller. The top heat exchanger is coupled by means of electrically isolated silver foils to cooling clamps which link directly to the bottom cooling fingers of the CCD mosaic table in the CCD detector head. This way the weight of the cooling system (about 120 Kg) could be decoupled from the flexure of the mosaic table, vibration could be minimized and the position-angle dependent performance of conventional bath cryostat systems at Cassegrain focus could be overcome. As the cooling clamps can be opened and closed through the vacuum vessel, the cooling connections are easily separable before the detector head is mounted or dismounted.

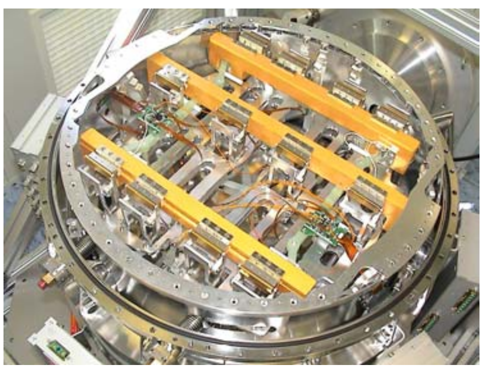

Figure 5. Cooling system top interface

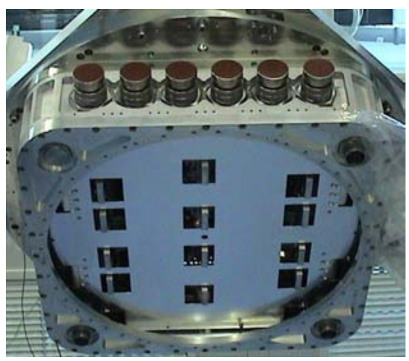

Figure 6. Detector head bottom interface

During laboratory operation, very good margins have been obtained to reach the necessary CCD operating temperature of -120 degrees C and a hold time of about 40 hrs. For the cryogenic and vacuum system control, the cooling system has integrated (heated) sensors for level sensing at top and bottom, a heatable charcoal sorption pump, and two fully redundant sets of temperature and vacuum sensors. Further details about the cooling system can be found in Lizon et al. (these proceedings).

6. TEMPERATURE CONTROL AND PULPO 2

As diagnostics of the completely new construction of both the detector head and the cooling system (considering also all integrated electronics), about 100 temperature sensors with optional permanent logging were integrated into the cryostat at intermediate levels. They will again prove very useful for the checking of the cooling clamp interface after re-integration of detector head and cooling system in Chile.

Pt100 boards with standardized completely glue-free mechanical mounting interface have been developed for universal use. They interface by means of an interconnection kit in different lengths to four multiplexers within the head. Heat dissipation and wiring are minimized.

The P1100 boards are connected to PULPO2 (Geimer et al., these proceedings) which takes care of reading, logging and alarm signaling of up to 125 temperature and vacuum sensors. Furthermore PULPO2 operates four independent PID heater control loops with freely programmable control sensor assignments. In full CCD mosaic operation a homogeneity of 2 K (pp) was achieved across the focal plane.

7. COORDINATION AND SYNCHRONIZATION OF MUTIPLE CCD CONTROLLERS

Three ESO's standard FIERA CCD controllers are used to satisfy all operational needs. Two identical FIERA systems had to be assigned to one mosaic half each of them supports the maximum number of 4x4 video channels. Together with their associated UltraSparc control computers, the basically form two almost independent systems. But, because of the sharing of parallel and serial clocks, they had to be synchronized in soft- and hardware to an accuracy of 0 ns for wipe, integrate, and read functions of the mosaic CCDs. A jitter of one sequencer tick (25ns) would already lead to a jump in bias level of several ADU´s. With the exception of the individual CCD voltages, the software on these two controllers is identical (also with respect to image assembly). FIERA1 operates as the master controller, which triggers the slave controller FIERA2 and also communicates via PULPO2 with the shutter controller (Reif et al, these proceedings).

On FIERA3 are defined software camera #1 for the two guider CCDs and software camera #2 for the two image analyzers. Its synchronization to the master controller is only needed for the shutter opening and the full-frame acquisition images of each auxiliary CCD. After the (automatic or interactive) selection of the guide stars and the setting of the respective readout windows and exposure times on the auxiliary CCDs, the operation sequence for a scientific exposure is as follows: Wipe both mosaic halves synchronously (FIERA ##1 & 2), set to synchronized integration, open shutter. Start staggered continuous rapid readout loops with the two guiders (software camera #1 on FIERA #3). Ditto for the two image analyzer CCDs but somewhat longer exposure times (software camera #2 on FIERA #3). When camera #2 on FIERA3 requires readout, operation of camera #1 is suspended. Both loops stop when the integration time on the mosaic is finished, the shutter is closed, and the subsequent synchronized readout of the two mosaic halves takes place. The data of the two half image are assembled, sent to the instrument workstation, combined, displayed, archived, and made available for automatic (pipeline) or interactive analysis.

The full mosaic is read out in 30s with a read noise of $5e^-$. The overhead for file merging and storage adds 15s.

8. SAFETY & EMERGENCY FEATURES

During the daily nitrogen refilling operation, the cryostat cooling controller is responsible for a number of automatic, safety relevant actions, such as to trigger the interlock of the telescope motion and to open and close the relevant valves for the tanking process. Likewise PULPO2 takes preventive actions for the safety of the detector mosaic. E.g., it heats it up to a preset temperature in order to avoid uncontrolled warm-up and subsequent contamination in the case of operational errors or problems with the cooling or vacuum systems. In the case of loss of vacuum, an on-board emergency pump with associated electromagnetic valve is activated. Both subsystems have user definable parameters in their firmware for their respective alarms and emergency actions. They link to the Central Alarm System (CAS) which notifies maintenance personnel via wireless pagers. Loss of power cuts and overheating of the FIERA controllers are signaled in the same way. Furthermore, the instrument control software can be configured for each of these parameters to issue a software warning on the instrument control before the value of a hardware CAS alarm is triggered. Continuous logging of all essential parameters on the instrument workstation level permits trend monitoring and fault analysis.

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