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Technological developments at the LBT: the prime focus camera

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Abstract. This paper show the technological solutions adopted to build the blue (U and B bands) and red (V, R, I and Z bands) of the prime focus imagers at the LBT. We specially described the functional caracteristics and performances of the cryogenic and CCD control systems and the instrument management system.

Key words. LBC – camera – LBT – prime focus – CCD – controllers – LN2 cryostat – control software

1. Introduction

In 2000 we started the feasibility study of a prime-focus camera for the Large Binocular Telescope (LBT) (Ragazzoni et al. 2000; Pedichini et al. 2003; Ragazzoni et al. 2004). The final camera design consists of two different focal planes, one for each telescope arm, optimized for complementary bands: the blue channel at U and B bands and the red channel at V, R, I and Z bands. Each focal plane is feeded by an optical corrector made of 6 lenses in a modified Wynne scheme with one aspherical element. The resulting system features a F#/1.45 speed and a field of view of 23arcmin with 0.23arcsec square pixels. The optimization process of the channels involves detectors manifacturing, that are characterized by different thickness and coatings, and corrector optics, that are respectively made of fused silica and BK7 with sligthly different design (Diolaiti et al. 2003).

This camera now exists and is called Large Binocular Camera (LBC). Currently the blue channel has completed its Science Demonstration Time (SDT) period and is fully operational. The red channel instead is partially installed at the telescope and should be completed by the end of 2007 (Speziali et al. 2004, 2006; Ragazzoni et al. 2006).

We describe with some detail cryogenic and mechanic solutions studied to cope with the specific LBC mounting constraints, the CCD controllers and the highly automated control software.

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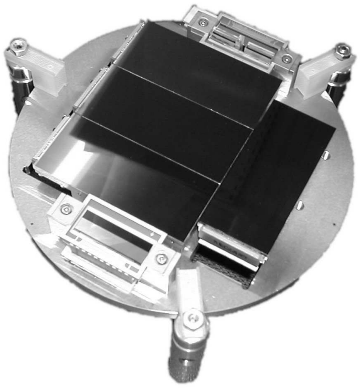

Fig. 1. LBC Red focal plane. Note the frame transfer e2v 4210 devices at the bottom-left and at the top-right in the picture.

Fig. 2. LBC Red cryostat with vacuum sensor valve

2. Cryomechanics

The LBC camera hubs are barrels of about 1m diameter and 1.5m tall. The hub contains correctors, rotator and filter wheels mechanics. The cameras themselves are mounted on the rotator flange and are composed by cryostat and shutter.

2.1. Focal Plane

Two separated cameras are sharing each LBC channel focal plane: an array of four E2V 42-90 (4.6K×2.5K) chips cover the corrected field (ϕ = 27arcmin) with a sampling of 0.23arcsec/pixel providing the scientific image, while two E2V 42-10 lay on opposite sides of scientific plane and are one on focus for guiding and the other slightly out of focus for pupil checking on active optics operations. Hereafter these two arrays are called *scientific* and *technical* respectively (see Fig. 1).

Being the focal ratio of the camera a very fast one (F#=1.45), the alignment of the detectors is a crucial point. To maintain a good optical quality the surface of the detectors have to be placed within the dimension of the pixel, i.e. 13.5μm. Using a laser based measuring machine provided by Mitutoyo it was possible to measure the height of the chips without touching the surface and with a precision of $\pm 1\mu$m.

The four 4290 chips, once mounted on the invar plate, have a peak to valley planarity value of 19μm (+8μm, -11μm).

2.2. Cryostat

Each channel cryostat is composed by three independent modules: a stainless steel rotator interface flange, a bimetallic (copper-nickel) nitrogen vessel and a housing made of aluminium (see Fig. 2). This configuration allows to separate the electrical part (detector flange, cables, etc) from the cryogenic assembly, allowing an easy maintenance and upgrade of the two parts independently. The liquid nitrogen vessels have been designed with a spherical shape both to minimize the radiative thermal inlet and to make a quite compact instrument. The spherical geometry of the vessel also guarantees the best volume to surface ratio, minimizing the thermal input with respect to the available volume of LN2. The current performance is of nearly 36 hours per refill (Pedichini & Speziali 2004).

The building phase was carried on at Forestal s.r.l. experiencing new mechanical technologies based on electroforming processes to produce the bimetallic spheres (copper-nickel for the blue channel, alluminium-nickel for the red one).

A cilindrical cryogenic pump filled with zeolith is applied on the copper flange with the aim to adsorb the outgassing and to keep the vacuum level at 10^{-6}mbar.

The rotator flange is made of a stainless steel (AISI 4130). It holds the baseplate with the detectors and it interfaces the cryostat with the the prime focus hub.

2.3. Shutter

Three main constraints drow the project of the shutters for the cameras: 1) a wide unvignetted shutterable aperture with a diameter greater than 12cm; 2) maximum allowed thickness of 20mm for the most of the area; 3) exposure uniformity on the whole field better than 1/100mag at 1sec exposure time. Others secondary constraints were the need for a RS232 control interface to program the shutter control electronics at the telescope and the readout of the real exposed time. To satisfy all the listed constraints, we designed LBC shutter using the concept of the dual blade shutter as the ones used on 35mm Reflex cameras. To allow a closed loop control of the blades motion we have selected an 2 axis DSP controller with linear drivers and Faulhaber D.C. motors model 1725 equipped with digital magnetic microencoder with a resolution of 512step/turn. The diameter of this motor with its encoder is only 17mm. Embedded magnets in teflon cursors and Hall-effect sensors give the zero positions of the blades and the exact exposure time.

3. CCD Controllers

The actual version of LBC CCD controllers, a project developed at SkyTech by F. Pedichini of INAF-OAR and A. Carbone manager of SkyTech itself, uses only two half eurocard boards (see Fig. 3) and a separate 40W power supply. Two identical CCD controllers manage scientific and technical focal plane arrays.

The core of the system is a programmable Xilynx FPGA used to accomplish several different task as: interface the optical fibers (OF) data link, manage the telemetry, generate the control waveforms toghether with the ccd supply biases, process the video data flux and execute the control commands. The actual configuration uses only the 30% of the FPGA's gates leaving a huge space for future expansion of the system like the use of IR and optical CMOS detector and advanced "on controller" data reduction/processing.

Fig. 3. LBC CCD controller electronics box

Noise performances of the order of 10e- at 500kpix/s/channel are achieved directly connecting to the cryostat using cables not longer than 50cm despite the lack of a video preamplifier. The 6 + 6 optoisolated lines of clock drivers yelding a 2A surge current per phase are optimized to drive, by means of trapezoidal waveforms, vertical charge transfer also in huge ccd detectors. The video board with its 16 low noise biases (less than 2e-) fully programmable between -23V and +23V can supply up to 4 separated detectors and process 4 video streams digitized at 16bits and 1Mpix/s/channel. The video analog layout can accomplish also digital reset level correlation and full d.c. video processing (CMOS detectors) with minimal changes in the FPGA firmware or in the front end components.

The typical gain of our controllers is about 2e-/adu and when running at 500kpix/s/channel, the video board, has a RON of $3 \div 4$e-; this result is obtained despite the compactness of the controller thanks to the syncronicity of the whole system, indeed this syncronicity is extended also to the serial data link when downloading pixels during the array read-out. Up to 4 video boards could be installed in the controller allowing its usage in extremely demanding applications like large arrays of NIR detectors.

4. Control Software

Both LBC channels are controlled by a single Linux PC (called CMU) relying on 4 more Windows PCs to drive the CCD Controllers (Di Paola et al. 2004).

On a general level, all the operations, except from images retrival and processing, are performed by the CMU. The CMU hosts all drivers and software to control the about 45 devices composing LBC and also an HTTP server to supply the user interface to a remote network client. The Windows machines, driven by CMU commands, acquire data and store the FITS format images they generate in a local temporary archive and directly upload the same files to the LBC archive machine. In this architecture images never reach CMU.

4.1. Hardware Control

The LBC control software is a hierarchical structure. The very low level modules (typically hardware interfaces) are accessible by all the *system modules*. Five *system modules*, that control scientific camera and shutter - filters - rotator - housekeepings - tracking and active optics using technical camera, are only accessible from a higher level module called *channel manager*. Two *channel managers* (one for the blue and onother for the red LBC channel) are controlled by an *instrument manager* that is directly interfaced with the telescope control software and the user interface.

All the configuration options are maintained inside text configuration files. The log messages are managed by a custom library that collects information from the whole instrument and writes them on a text file.

Smooth operations and optimized *open shutter time* are obtained by means of heavy use of multithreading techniques in a monolithic executable.

4.2. User Interface

The user interface has been designed to allow access to the highly automated operations of the *instrument manager*. It is possible to power on and off only the housekeepings or the full instrument in a click, as well as perform a complete dithering sequence using both channels simply loading and executing an Observing Block (OB). Both a web based and a standalone interface are supplied for OB files generation.

Instrument status and Active Optics operations are controlled through dedicated pages, as well as the log viewing interface that easily allows system specific messages searching.

5. Conclusions

During more than 5 years of work we developed a very versatile and reliable generation of CCD controllers that are both used for scientific and guiding cameras on LBC and are being moved also to other projects.

At the same time we deeply interacted with industry leading the development of bimetallic structures by mean of electroforming techniques as stated by LBC vessels.

About the control software a fully automated system to be completely controlled by the astronomer has been developed basing on a web interface that has also been used to perform remote observations.

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