Southern African Large Telescope
SALTICAM
Preliminary Design Review

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Operational Concepts Definition Document

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1 Scope

This document is the Operational Concepts Definition Document for the preliminary design review of SALTICAM, the verification instrument, acquisition camera, and scientific imager of the Southern African Large Telescope (SALT). It will describe the various operational modes of the instrument.

2 Operational Concepts Overview

In all modes, the basic operation of the instrument is to acquire one or more images. Prior to image acquisition, the following operations must take place:

- Slewing of the telescope and tracker to point the telescope at the desired celestial target
- Selecting the desired starting tracker rho and commanding the tracker to rotate to that position
- Updates for all user-specified parameters such as the desired filter, frame transfer mode (or not), prebinning, windowing, gain, exposure time etc.

An image of the field of view is then obtained (further discussed below) and displayed on the SALT Operator's and/or SALT Astronomer's MMI. Recognition of the field then takes place after which a small refinement of the telescope's pointing is needed, either to place the target(s) in the entrance aperture(s) of another instrument, or if further operations by SALTICAM are required, to refine the match between the instrumental field of view and one or more celestial targets. At this point, one or more further images may be obtained by SALTICAM if it is performing science imaging or closed loop guiding.

3 Detector Management Overview

Operational complexity resides exclusively in the management of the detector, involving interactions between readout speed, readout noise, pixel windowing and prebinning. It is planned that prior to the acquisition of each image, any one of the set of image parameters associated with each image can be updated. These parameters include window dimensions, readout speed and gain, prebinning, frame transfer mode (or not) etc. (see below).

Images are obtained by exposing the CCD detectors to light and reading them out. CCD readout proceeds by clocking the charge in each pixel towards the readout amplifier where it is measured, digitized and sent to the control computer. The readout proceeds by first clocking each row of the CCD towards the readout register by one row. The row of pixels that was formerly closest to the readout register is then transferred into the readout register. The pixels in the readout register are then clocked towards the readout amplifier where their charge is measured and digitized one pixel at a time.

The charge measurement process has readout noise associated with it resulting in a compromise between readout speed and noise: the faster the readout the higher the readout noise. Readout speed is increased if the pixels are combined before being fed through the readout amplifier which is where most time is required. Pixel combination, or prebinning, effectively combines 2 or more pixels into one with the combined charge. Windowing is also a possible means of speeding up readout in which pixels in the readout register which lie outside the desired window are "skipped" rapidly.

Frame transfer operation is another way to reduce readout time further. When operated this way, half of each chip closest to the readout register is masked from light. At the end of an exposure, a frame transfer takes place (in 0.10 sec) transferring the image formed in the half of the chip furthest from the readout register to behind the mask. Readout of the masked region proceeds as the next exposure is accumulating. In addition to reducing the amount of data to be read out, this technique has the advantage that there is no "dead time" during read out. The shutter is open throughout this sequence. The field of view is, of course, halved with frame transfer operation.

3.1 Performance Goals

With the CCD chips to be used in for the instrument, and the performance expected from the SDSU CCD controller, it is desired that the following readout rates and noise values will be attained. These values should **NOT** be regarded as specifications until confirmed in the lab (**TBC8**):

- Vertical (row) transfer time of 50 μsec/row
- Readout rate of 3.0 μsec/pix with 5 e^-/pix readout noise
- Readout rate of 10.0 μsec/pix with 3.3 e^-/pix readout noise
- Prebinning overhead of 1.0 μsec for each prebinning in the horizontal register
- Pixel skip times of 0.8 μsec/pix or better

The CCD chips to be used have 2k x 4k x 15 micron pixels. The readout register is on the short dimension and contains 2 readout amplifiers (split readout register) so that each amplifier will be responsible for reading out 1k x 4k sections of the detector. The amplifiers are read out simultaneously and although the detector will likely be a 1 x 2 mini-mosaic of chips, readout of each chip (2 amplifiers per chip, 4 in total) proceeds simultaneously.

It is further assumed that the normal operating mode of SALTICAM will use at least 2 x 2 prebinning; at a plate scale of ~0.14 arcsec/pix, such prebinning runs no risk of undersampling the images and in fact higher prebinning can be contemplated with readout time reduction. (No prebinning will also be provided for the few applications where highest spatial resolution is necessary.)

The above information leads to the readout times discussed in 3360AE0001 detector.pdf, summarized in the Functional Performance Requirements Document (3300AE0004 FPRD.pdf) and reproduced in the table below:

Mode	Prebin	Readout Speed (μsec/pix)	Readout Noise (e^-/pix)	Readout Time (sec)
Full Frame	2x2	10.0	3.3	11.2
Full Frame	2x2	4.0	5	4.6
Frame Transfer	2x2	10.0	3.3	5.7
Frame Transfer	2x2	4.0	5	2.4

Readout times can be reduced by reading out a small window on the chip containing a star (as in autoguiding for example). The time needed to read out a 100 x 100 pixel window (~15 arcsec square) is:

- (4096*50 μsec/row) + (50*50*4.0 μsec/pix) + (100*924*0.8 μsec/pix)
  = 0.21 sec + 0.010 sec + 0.08sec
  = **0.30 sec** : 2 x 2 prebinning and fast readout to give 5 e^-/pix readout noise.

Note that this time is dominated by the time needed for row transfers and pixel skips.

Frame transfer readout time is as short as 2.4 sec. Thus, a continuous sequence of 2.6 sec exposures could be obtained (allowing 0.2 sec for overhead such as displaying the data) with no dead time. It should be noted that the image is smeared during the 0.10 sec needed to transfer it into the masked region.

It cannot be emphasized too strongly that the performance figures given in this section are goals, **NOT** specifications.

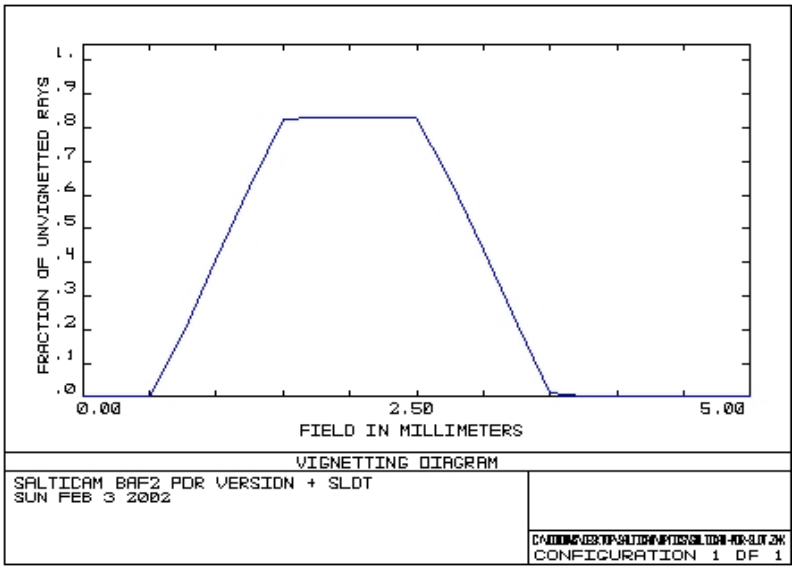


Figure 1. Vignetting as a function of field position perpendicular to the frame transfer boundary for a 2 mm wide chip positioned 2 mm above the FT boundary.

3.2 Slot Mode

For highest time resolution, so-called "slot mode" is proposed. In this mode, a 2 x 30.4 mm^2 slot in the frame transfer mask is positioned just above the frame transfer boundary of the detectors. The slot will be 2 mm above the surface of the chip. With a f/2 final

focus, this means that there will be a 1 mm region of no vignetting and a 1 mm wide region on either side which will be partially illuminated. This has been modeled in Zemax and the vignetting diagram is shown in Fig. 1.

To avoid all contamination of one image by the next, it is clear from Fig. 1 that a 3 mm movement over the frame transfer boundary is required. However, this application is likely to be carried out only on very bright targets (by SALT standards) and as relative photometry only is required, contamination of one frame by a little sky background (or even faint stars if the target is located in a crowded region) may be tolerable. If so, 1 mm vertical transfers will be adequate, allowing even shorter sampling times. Time lines will be discussed below.

4 Operational Timelines

With the results of the previous section in mind, it is then possible to define operational time lines. In all examples, 2x2 prebinning is assumed (it is likely that prebinning up to 4x4 will produce no degradation of the image which is apparent to the SALT Operator's eye).

4.1 Normal, Shuttered Operation

For normal, shuttered operation of SALTICAM (i.e. not frame transfer or autoguiding), operating the instrument for acquisition will entail:

- Clearing the detector prior to exposure in: **0.21 sec**
- Shutter opening in: **0.10 sec**
- Exposure (time set by SO)
- Shutter closing in: **0.10 sec**
- Readout of the detector in: **11.2 sec** (3.3 e^-/pix readout noise)

OR

- Readout of the detector in: **4.6 sec** (5 e^-/pix readout noise)
- Data display

4.2 Frame Transfer Operation (including slot mode)

Frame transfer operation enables a continuous sequence of exposures, frame transfers and readouts (while the next exposure is accumulating). The shutter is open throughout the sequence:

- Clearing the detector prior to the first exposure in: **0.21 sec**

- Shutter opening in: **0.10 sec**
- Exposure
- Frame transfer in: **0.11 sec**
- Row transfers during readout: **0.10 sec**
- Readout of the detector in: **2.4 sec** (5 e^-/pix readout noise).
- Data display

with repetitions of frame transfer, readout and display for as long as desired. The minimum exposure time should be longer than the sum of the readout time and the time for row transfers (0.21 sec total) plus the time for overhead such as data display, say **2.8 sec** in the above example.

Slot mode was described in Section 3.2 above. Times for this kind of observing were discussed in the 3360AE0001 detector.pdf. Time lines for this mode, in which both 960 micron and 2880 micron strips are imaged (1 and 3 mm on the detector respectively – see the discussion in Section 3.2), would include:

- Clearing the detector prior to the first exposure in: **0.21 sec**
- Shutter opening in: **0.10 sec**
- Exposure for up to 0.095 or 0.245 sec.
- 960 and 2880 micron sub-Frame transfer in: **0.0032** or **0.0096 sec**
- Row transfers during readout: **0.0032** or **0.0096 sec**
- Readout of the detector in: **0.069 or 0.206 sec** (2 x 2 prebin: 5 e^-/pix readout noise).
- Data storage: **0.020 sec**

Total time is ~**0.10** or ~**0.25 sec**.

4.3 Autoguiding Using The SALTICAM CCDs

During autoguiding with the SALTICAM CCDs, normal, shuttered operation may be required if the guide star selected would be in the masked half of the detector. Windowed readout is most efficient. The timeline is:

- Clearing the detector prior to exposure in: **0.21 sec**
- Shutter opening in: **0.10 sec**
- Exposure (time set by SO)
- Shutter closing in: **0.10 sec**

- Readout of the detector in: **0.32 sec** (5 e^-/pix readout noise)(see the Detector document: 3360AE0001 detector.pdf)
- Data display?
- Guide star centroiding
- Error signals transmitted to the TCS/Payload computer

If the guide star is located in the image section of the chip, frame transfer operation saves on detector clearing and shutter operating time; exposure time is combined with readout time:

- Clearing the detector prior to the first exposure in: 0.21 sec
- Shutter opening in: 0.10 sec
- Exposure
- Readout of the detector in: **0.32 sec** (at 5 e^-/pix readout noise and including time for frame transfer and row transfers during readout of the 100 x 100 pixel window).
- Data display?
- Guide star centroiding
- Error signals transmitted to the TCS/Payload computer

with repetitions for as long as desired.

4.4 Drift-scanning Using The SALTICAM CCDs

This will require the rows of the detector to be clocked at a tunable rate (from 27 to 107 rows/sec), and the readout register to be readout in a time much shorter than this vertical clock rate. The rho stage needs to be commanded so that the detector's vertical rows are aligned to local east-west on the sky.

Detector subsystem operations will include:

- Clearing the detector in: **0.205 sec**
- Shutter opening (time irrelevant)
- Performing one vertical transfer every **9.346 - 37.037 millisec** (a function of target declination). The time needed for the vertical transfer is 0.050 millisec.
- Readout register readout in: **5.37 millisec (2 pix prebinning, 3.3 e^-/pix readout noise)** (unprebinned slow readout is too slow for the vertical transfer repeat time).

OR

- Readout register readout in: **3.22 millisec (no prebinning, 5 e^-/pix readout noise)**.

OR

- Readout register readout in: **2.15 millisec (2 pix prebinning, 5 e^-/pix readout noise)**.

with repetitions of vertical transfers and readout register readouts for as long as desired.

5 Calibrations

In traditional CCD imaging, three kinds of calibrations are required: bias subtraction, flat-fielding, and standardization using standars stars.

5.1 Bias subtraction

Bias subtraction for the SALTICAM CCDs can be achieved by obtaining a sufficient number of zero length exposures to beat down the readout noise, or using the overscan region to measure the bias from every frame. Investigations of both approaches will be undertaken during commissioning and a suitable management scheme put in place. There is nothing unusual about SALTICAM bias measurement and subtraction compared to that used on any standard astronomical CCD camera.

5.2 Flat-fielding

Two components of flat-fielding can be measured: on short and long pixel scales. The former is required to make (hopefully) small adjustments to the pixels within and close to point sources. The latter is appropriate for correcting for non-uniform response over the field of view and is properly deferred to the next subsection.

Short pixel scale flat-fielding can be achieved either using sky flats (in the twilight sky and with the tracker on-axis) or by observing the calibration screen. Problems with the former are likely to arise from saturation of the CCDs or contamination of the flat fields by stars. Nevertheless sky flats will faithfully represent the response of the instrument to a uniform light source on the sky.

Observations of the calibration screen can be made when conditions are non-photometric (thus excluding sky flats). If standard incandescent lamps are used as the light source, there may be a problem with obtaining sufficient UV light for U band flat fields.

5.3 Standardization

Photometric standardization will require a set of standard stars at all Right Ascensions with reliably known magnitudes and sufficiently faint so as not to saturate the SALTICAM CCDs. In cases where absolute photometry is required, observations of standards will need to be made.

Observations of any given field of stars will suffer from the following telescope or instrument-induced sensitivity variations on large pixel scales and in time. These effects will make absolute calibration or relative calibration within a field more complex than on a conventional astronomical telescope:

- The entrance pupil of the telescope moving off the primary mirror. Because the entrance pupil of SALT (11-m) will **never** be filled (the primary mirror array is smaller than an 11-m circle), the amount of light reaching the focal plane will be a sharply peaked function of Tracker position.
- Variable reflectivity of the primary mirror segments.
- The vignetting of the Spherical Aberration Corrector as a function of field angle

Fortunately, the first and third effects are constant with time and will need to be measured once and checked infrequently (say once a year). Measurement of the first and third effects can be simultaneously achieved by observing in photometric conditions a crowded region which fills the field of view of the telescope and obtaining repeated images as the Tracker moves from its eastward extreme position (when it “picks up” the field) to its westward extreme position (when the field passes out of the Tracker range). The calibrations derived can then be applied to another field and the accuracy assessed.

The second effect will require regular monitoring involving tracking one or more standard stars from one end of the Tracker range to the other in photometric conditions and comparing the apparent brightness to the map already made from the first and third effects.