APPROVAL SHEET

TITLE	**: SALTICAM SPECIFICATION**
DOCUMENT NUMBER	**: 3300AS0001 ISSUE : 1 ver 9 (Post-Review)**
SYNOPSIS	**:** This document describes the technical requirements of the SALTICAM Verification Instrument, Acquisition Camera and Science Imager of the Southern African Large Telescope (SALT).
KEYWORDS	**:** SALTICAM, Acquisition Camera, Commissioning Instrument, Imaging Camera
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DATE	: 6 September 2001

This issue is only valid when the above signatures are present.

ACRONYMS AND ABBREVIATIONS

μm	Micron
arcsec	Seconds of arc
CCD	Charge-coupled Device
COTS	Commercial off the shelf
EE(50)	Enclosed Energy is 50% of total energy
FoV	Field-of-View
FITS	Flexible Image Transport System: astronomical data format
FWHM	Full Width Half Maximum
I/O	Input/Output (Device)
ICD	Interface Control Dossier
IR	Infrared
MMI	Man-Machine Interface
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
nm	nano-metre
OEM	Original Equipment Manufacturer
PC	Personal Computer
PFIS	Prime Focus Imaging Spectrograph
PFP	Prime Focus Platform
PI	Principal Investigator (Astronomer)
RA, DEC	Right Ascension and Declination
RMS	Root Mean Square
SA	SALT Astronomer
SAC	Spherical Aberration Corrector
SALT	Southern African Large Telescope
SO	SALT Operator
SW	Software
TAC	Time Assignment Committee
TBC	To Be Confirmed
TBD	To Be Determined
TCS	Telescope Control System
UPS	Uninterruptible Power Supply
UV	Ultraviolet (light)

DEFINITIONS

Acquisition time	This is the length of time required to put the target at a desired position (a bore-sight), within the offset pointing requirement, from end-of-slew, until start of the integration
Offset accuracy	This is the ability to place a given point in the sky on the bore-sight once the telescope has acquired another object in the same FOV.
Target	This is a point in the sky. If the target is not visible to the acquisition imager, then the target is defined as an offset from a visible star that is within the focal plane field of view.
Technical Baseline	This is the design baseline that is required to fulfil the requirements of the SALT Observatory Science Requirements, Issue 7.1, and is the topic of this Specification.

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1 Scope

1.1 Identification

This document specifies the requirements for SALTICAM, the Verification Instrument, Acquisition Camera and Science Imager of the Southern African Large Telescope. For the remainder of this document, this instrument in all these modes will be referred to by its name: SALTICAM. Where applicable, the possible growth paths for later upgrades have been identified.

In general, the word “shall” is used to indicate mandatory requirements while descriptive statements are used to provide non-mandatory information.

1.2 System overview

The purpose of SALT is to collect light from astronomical objects, accurately focus it onto the telescope focal plane from where it will proceed into an optical instrument while tracking the relative movement of the target across the sky to maximise exposure time. The SALT system is comprised of the subsystems shown in Figure 1 below:

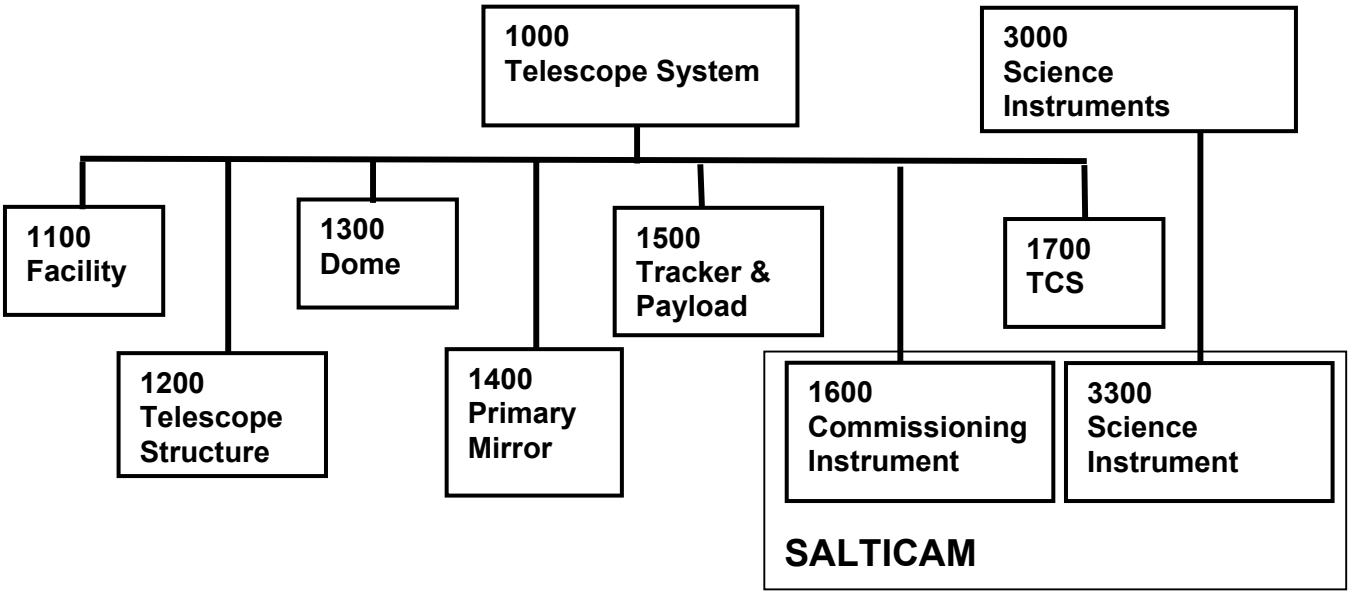


Figure 1. SALT Subsystems

This specification will focus on the SALTICAM. This entity is a science instrument but also incorporates the functionality of the “Commissioning Instrument”. It is numbered 3300 in the breakdown of Figure 1, but incorporates 1600, a number which it bore with dignity until version 1.9 of this specification.

Figures 2 and 3 below are schematic representations of the internal layout of the telescope, the facility and dome.

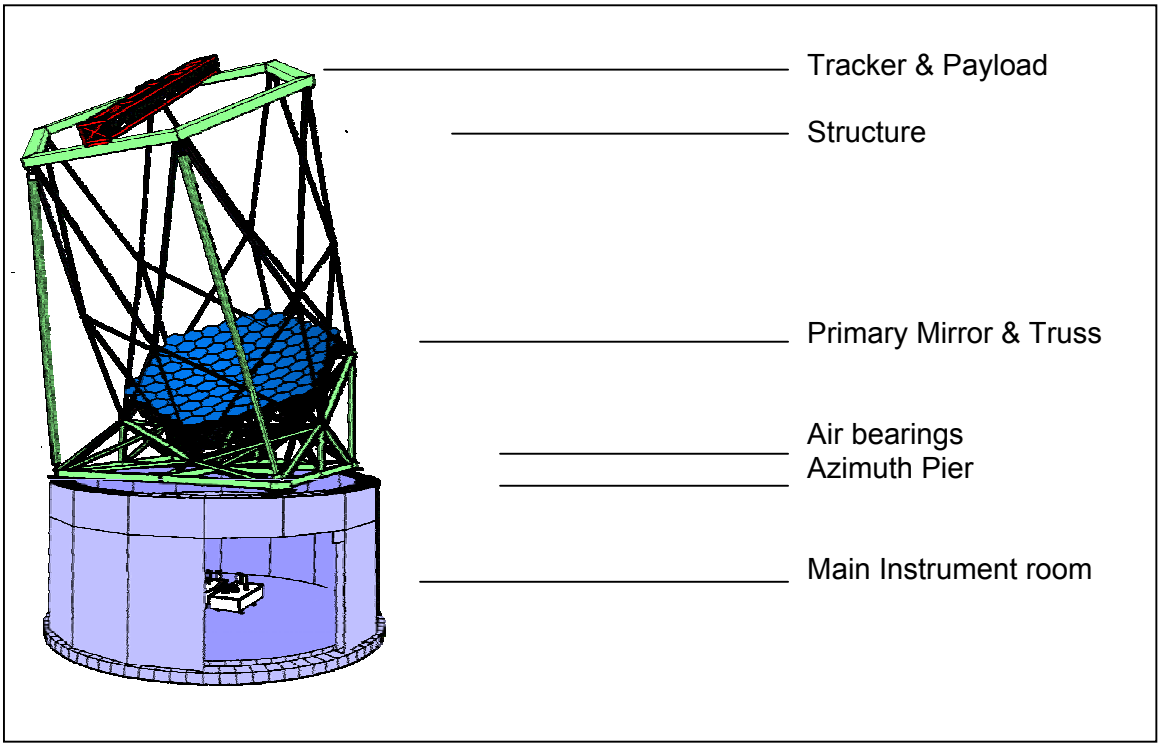


Figure 2. SALT Pier, structure, primary mirror and tracker

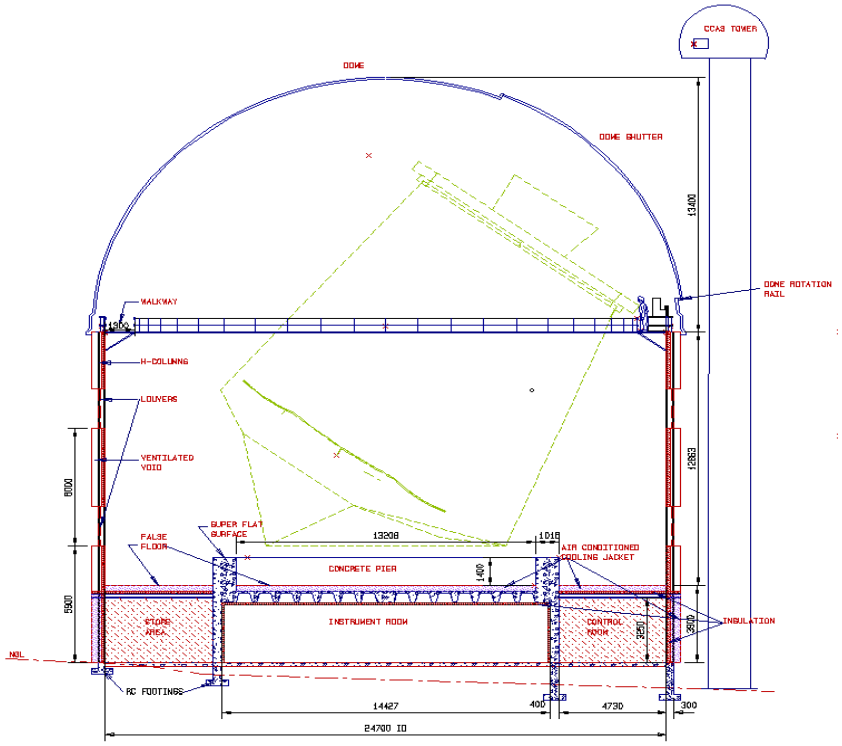


Figure 3. Facility and Dome

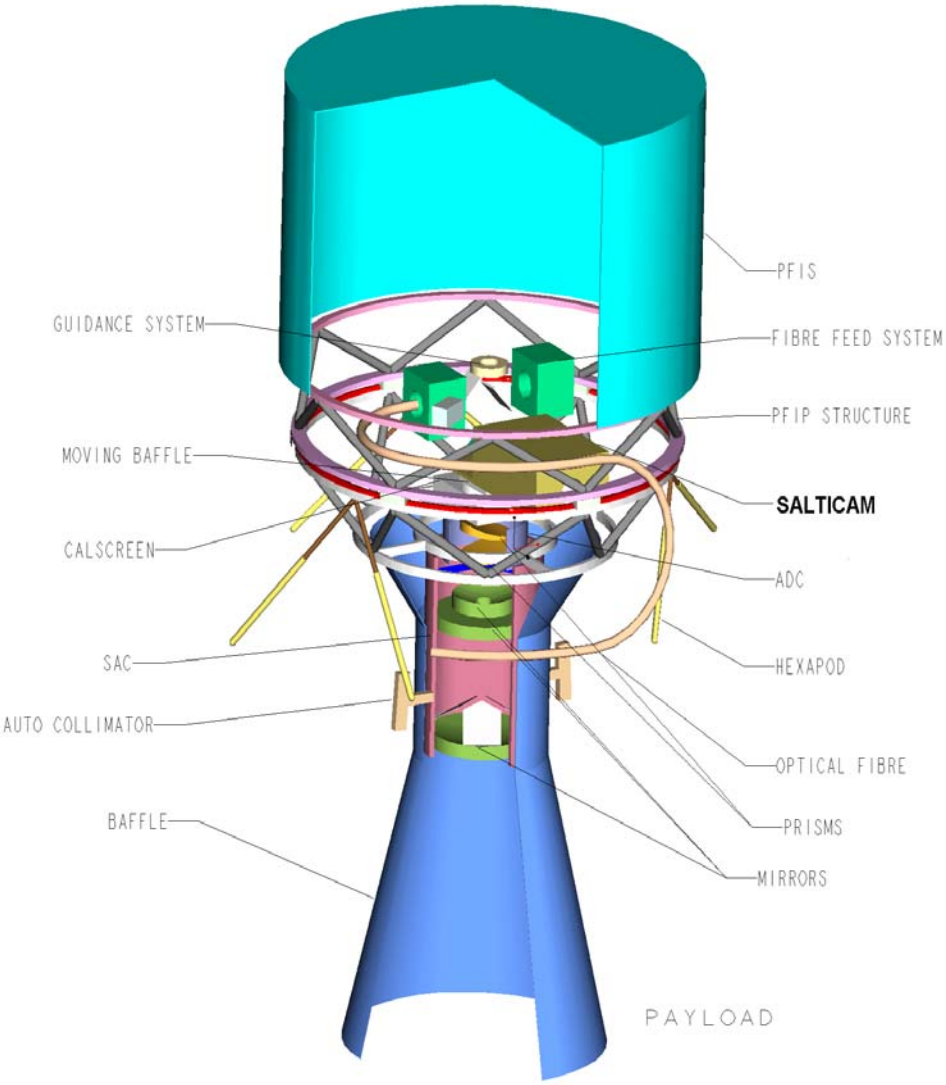


Figure 4. Payload

SALTICAM will be positioned on the payload, as depicted in Figure 4.

2 Referenced documents

SALT DB000531	SALT Observatory Science Requirements, Issue 7.1, D.A.H. Buckley, dd. 31 May 2000
	SALT Commissioning and Acquisition Instrument Requirements, Draft 4.0, D.A.H. Buckley, dd. 19 February 2001
HET Tech Report #44	HET Error Budget, April 94
	Science with SALT, DAH Buckley, March 1998
	SPIE proceedings (various)
SALT-1000AS0029	Specification for the SALT Prime Focus Instrument
SALT-1000AS0049	SALT Data Interface Control Dossier
SALT-1000AS0013	SALT Electrical Interface Control Dossier
SALT-1000AS0014	SALT Physical Interface Control Dossier
SALT-1000AA0030	SALT Safety Analysis
SALT-1000AA0017	SALT Error Budget
SALT-1000BS0021	SALT Requirements for Built-in Testing
SALT-1000BS0010	SALT Software Standard
SALT-1000BS0011	SALT Computer Standard
SALT-1000AS0032	SALT Electrical Requirements
	SALT Report of Interim Project Team, April 1999
SALT-1000AS0033	SALT Support Requirements
SALT-1000AS0040	SALT Operational Requirements
	Applicable South African Legal Requirements
	Safety, Health and Environment Act
SALT-1000AS0007	SALT System Specification

3 SALT Project Furnished Equipment and Responsibilities

The cooler box/es for housing all electronics on the payload shall be supplied by the SALT Project.

4 Functional Requirements

4.1 Main Purpose and Overview

The purpose of SALTICAM in SALT is threefold:

(I) To provide telescope verification capability:
SALTICAM shall enable the Project Team to demonstrate that the telescope meets the System Specification. In this mode, a “bare” detector system will be placed at the focal plane of SALT and obtain images of point sources, thereby showing that properties of the telescope (e.g. image quality, throughput, flatness of the focal plane etc.) comply with the System Specification.

(II) To provide the functionality of an acquisition camera:
In this mode, SALTICAM will enable the telescope operators/resident astronomers to acquire science targets quickly and efficiently and position them for observation in the entrance apertures of the scientific instruments

(III) To provide scientific imaging capability:
SALTICAM shall provide scientific imaging capability which means the ability to deliver images of celestial targets in a wavelength range, and with time and spatial resolution to be agreed by the SALT Science Working Group and SALT Board.

Functions (I) and (II) fall under the name “Commissioning Instrument”, numbered 1600 in Figure 1. Function (III) lies outside the responsibility of the SALT project, but is to be delivered by SAAO and is subject to the approval of, and under the control of, the SALT Science Working Group and SALT Board.

For all three roles played by SALTICAM, its primary purpose is to produce high quality images. This will be achieved using a science grade CCD camera, comprising one or more scientific grade CCD chips (although a technical solution will almost certainly entail butting two or more CCDs, for the purpose of this specification we shall conceive of the detector as one CCD). The CCD shall be a scientific grade 1 CCD, thinned and back-illuminated to provide adequate blue sensitivity.

The CCD shall be housed in a cooled cryostat and controlled by low-noise electronics which are nevertheless capable of reading out the CCD at high speed and low readout noise. The CCD should be sealed from light unless the instrument’s shutter is opened under instrument control. Functions (I) and (III) (and possibly (II)) require the light reaching the detectors to be bandpass filtered; this shall be achieved by the provision of a filter unit operating under instrument computer control, capable of accommodating at least 8 optical filters.

In particular, the capability is described under headings (I-III) below:

I. **Verification Instrument:** In this mode, the instrument shall comprise the filter wheel, the shutter, and the cryostat. There shall be no optical components in the optical train from the telescope to the detectors, other than an optically flat window which is necessary to seal the cryostat vacuum from the external environment. The instrument shall be mounted at the focal plane of SALT (where the entrance aperture(s) of the PFIS are to be located); it shall be mounted on a manually adjusted X-Y-Z stage to enable it to acquire images over the

entire science and guide star Field of View (FoV) of SALT, as well as limited focussing capability. (It is assumed that the SALT Project Team will provide a suitable mounting point so that the camera is “squared-on” to the incoming light). The filter wheel and shutter shall be remotely operable, and the instrument shall be capable of providing a continuous sequence of images, at high time resolution if necessary, covering the full sensitivity range of the CCD (320-1000 nm). (*The Verification Instrument will be capable only of testing the telescope over the optical range up to 1000 nm. If testing of the telescope in the infrared is required, other test equipment will be necessary).*

II. **Acquisition Camera:** In this mode, the instrument shall comprise the filter wheel, the shutter, and the cryostat. In addition, there shall be suitable optics in front of the detectors which effectively re-image the 8 arcmin science FoV of SALT on to the chosen CCD(s). The instrument shall be fed by a folding flat mirror mounted just after the exit pupil of the telescope optical system (though this is the responsibility of the SALT Project Team). All such additional optics should, as far as possible, avoid degradation of the image quality provided by the telescope. The filter wheel and shutter shall be remotely operable, and the instrument shall be capable of providing a continuous sequence of images, at high time resolution if necessary, covering the full sensitivity range of the CCD (320-1000 nm). The acquisition camera will also need to communicate with the guiding system to perform closed-loop guiding using its CCD when it is fed by a pellicle instead of the fold mirror.

III. **Scientific Imager:** In this mode, the instrument will be capable of operating as for the Acquisition Camera in (II), and with additional capability stipulated by the SALT Science Working Group. In particular, the Instrument Computer must maintain Universal Time to at least millisec accuracy for time-stamping scientific images. In addition, controlling the exposure time to millisec accuracy is also required for the scientific images. Closed-loop guiding will be needed and may be achieved using either of two methods: (i) in high time resolution imaging, centroids of point sources on the science frames can be extracted and used to correct the guiding of the telescope; (ii) a guide star pick-off mirror may be used to sense the position of a guide star and correct the guiding of the telescope.

In all three modes, capability will be needed to store images, display images, and provide simple image processing functions to assess the shapes and brightnesses of objects in the image.

A schematic layout of the instrument in its various modes is shown in Figure 5.

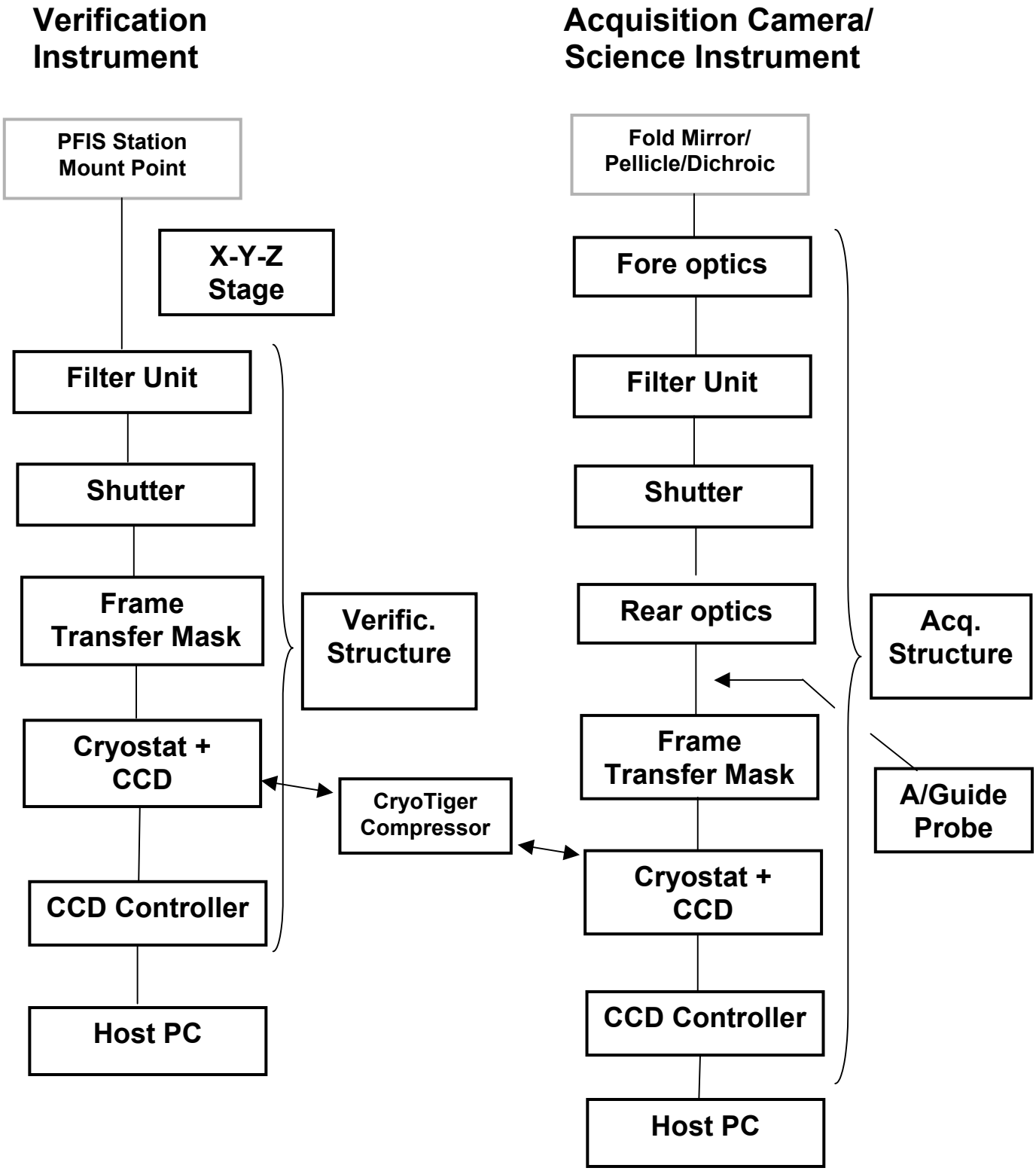
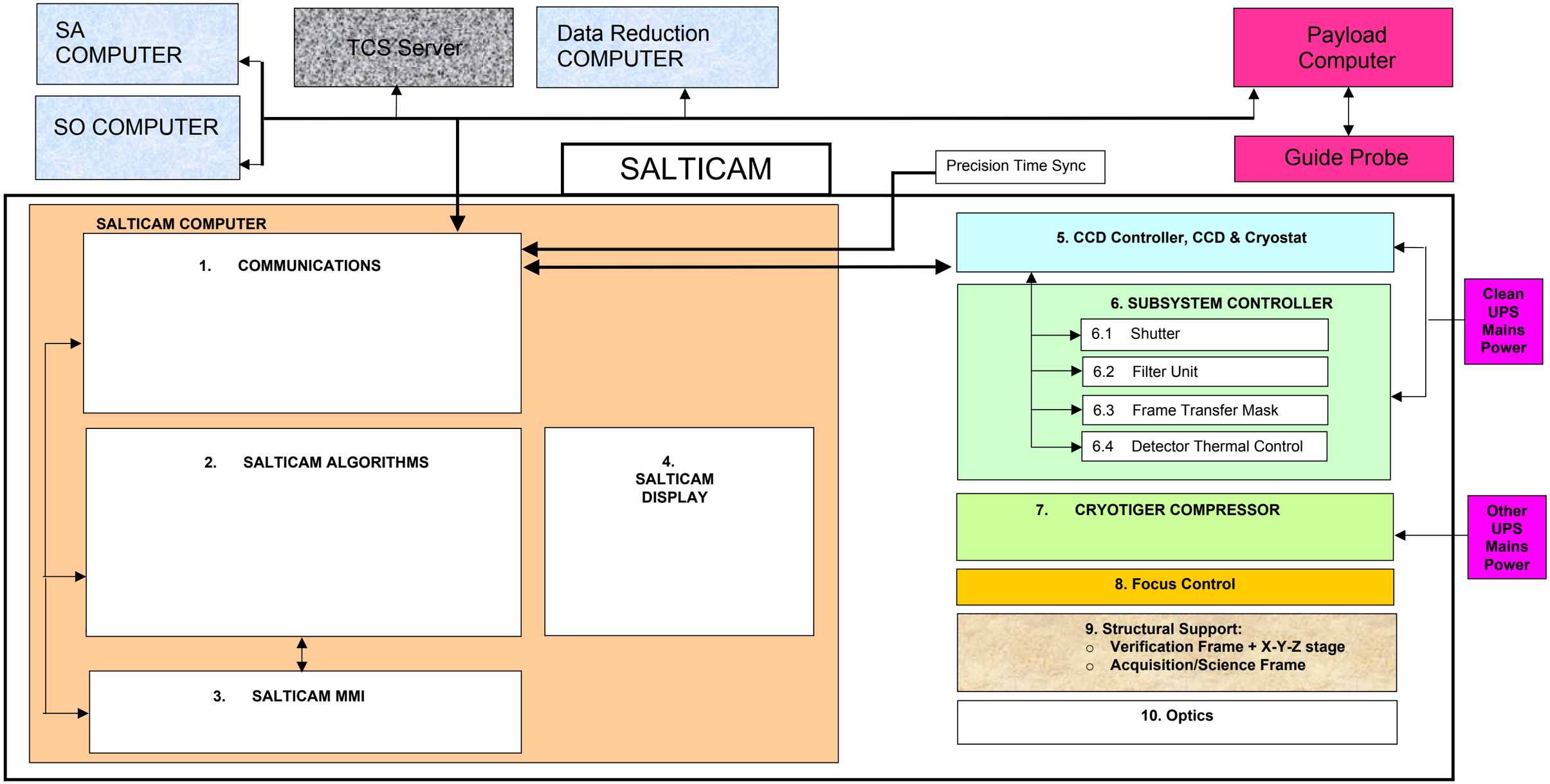


Figure 5. Instrument Layout

4.2 Functional description

4.2.1 Functional Flow Diagram

The following diagram describes schematically all the functions to be performed by SALTICAM per subsystem and its interaction with the rest of the Telescope.



4.2.2 Descriptions of Functions in Section 4.2.1

4.2.2.1 COMMUNICATION WITH SO/SA COMPUTERS

The SALTICAM computer will display the images extracted from its detector on its display which will be located close to the SO and SA. It will receive control signals from the SO/SA computers which will permit the SO/SA to interact with the display: place marks/boxes/windows on the display, select objects on the display, overlay catalogues on the display etc. Small quantities of data are involved.

The SALTICAM computer will also receive setup information for the next image(s) to be obtained with the camera: exposure time; prebinning, frame transfer state, windows (if any), filter, gain (if programmable), repeat count and any other information that the camera needs to define its imaging. Small quantities of data are involved.

The SALTICAM computer will also transmit compressed versions of its images (no larger than 600 x 600 pixels) over a network to either or both of these machines. Data rates of 1 Mbyte/sec will be necessary for this latter functionality.

4.2.2.2 COMMUNICATION WITH TCS SERVER/PAYLOAD COMPUTER

The SALTICAM computer will solicit information from the TCS server including the Right Ascension and Declination, Hour Angle and zenith distance of the pointing of the telescope. Small quantities of data are involved.

The SALTICAM computer will also send the TCS server/Payload computer X and Y offsets which will: (i) place objects in the entrance apertures of the scientific instruments; (ii) function as guiding corrections during closed loop guiding. Small quantities of data are involved.

4.2.2.3 COMMUNICATION WITH DATA REDUCTION COMPUTER

At low priority so as to avoid interference with SALTICAM's normal operations, the SALTICAM computer may be requested to transmit one or more images to the data reduction computer. SALTICAM images may be as large as 17.6 M pixels (of 2 bytes/pixel) but will usually be no larger than 4.2 M pixels. Data rates to be determined by the data reduction requirements.

4.2.2.4 COMMUNICATION WITH PRECISION TIME SOURCE

The Precision Time Source will ensure that the SALTICAM computer keeps Universal time to 1 millisec accuracy or better at all times by providing suitably coded GPS-referenced time to the computer.

4.2.2.5 COMMUNICATION WITH CCD CONTROLLER, SUBSYSTEM CONTROLLERS & CRYOTIGER

This communication takes place between the SALTICAM computer and the CCD controller which also permits control of other subsystems:

- Bi-directional communication. Control & status, and CCD Read out data - data

rate (on internal optical fibre) up to 64Mbits/sec (equates to 1M pixels/second, theoretical maximum speed). Image size up to 17.6 M pixels, but usually 4.2 M pixels.

- The SALTICAM computer will control the filter unit, the frame transfer mask, the shutter and the detector temperature via instructions to the subsystem controller (which is part of the CCD controller).
- No communication with the Cryotiger is possible.

4.2.2.6 SALTICAM MMI

The SALTICAM MMI will be used to set up the camera (filter, frame transfer mode, prebinning, windowing, exposure time), initiate closed-loop guiding if necessary, initiate the acquisition and readout of one or more images, control data display and storage (in FITS format), and manage interaction with the displayed image. The MMI functionality shall be exportable to the SO/SA MMI computers.

4.2.2.7 SALTICAM ALGORITHMS

The SALTICAM control program shall have at its disposal suitable algorithms for interacting with objects in any displayed image, and for closed loop guiding.

Closed-loop guiding algorithms shall include determining centroids of guide objects and deducing offsets for transmission to the guiding system in the TCS. In high time resolution mode, guide star centroiding may be achieved from the scientific images; communication with the TCS to correct the telescope pointing will be needed.

Display interaction shall include:

- Image Display: images obtained by the instrument shall be displayed with adequate resolution on a large monitor in the SALT Control Room. Control of brightness and contrast shall be part of the display algorithms. Displaying the image in any orientation of RA and Dec is required (**TBD1**).
- Image Manipulation: simple image manipulation shall be provided including:
  i. Marking the image with boxes, crosses or other suitable markers.
  ii. A read out of pixel position, RA and Dec of a mouse-type pointer.
  iii. Fitting of Gaussian functions to point sources.
  iv. 2-d line plots of image brightness in any direction across the image.
  v. Simple aperture photometry to estimate magnitudes of objects.
  vi. Simple image processing function such as background subtraction, smoothing or median filtering.

4.2.2.8 CCD CONTROLLER & CRYOSTAT, AND SUBSYSTEM CONTROLLER FUNCTIONS

The SALTICAM computer shall send the following commands to the CCD controller:

- Request for controller status
- Download CCD-specific control/executable code
- Filter selection and positioning
- Set full frame or frame transfer mode
- Frame Transfer mask in/out

- Set pre-bin factor
- Set window/s
- Start/stop exposure
- Shutter open or close
- Shift image to store area
- Read out CCD data
- Focus control (there is a remote possibility that camera focus will be controllable via the instrument computer: **TBD2)**
- Various test functions such as charge pumping, noise testing etc.

4.2.2.9 THERMAL CONTROL FUNCTIONS

- CCD detector temperature monitoring and control
- CCD controller internal temperature monitoring
- SALT Project-supplied temperature monitoring of thermal control enclosures

4.2.2.10 CRYOTIGER FUNCTIONS

The cryotiger cooler supplies cooling to the CCD cryostat. The compressor shall be mounted either on the top hex of the telescope in a SALT Project-supplied thermal enclosure on a suitable anti-vibration mount, or in a suitable enclosure on the telescope behind the primary mirror (to be supplied by the SALT Project)(**TBD10)**. It requires two high pressure gas lines to run from the compressor to the CCD cryostat.

4.2.2.11 STRUCTURAL SUPPORT FUNCTIONS

All the components of the instrument shall be mounted on frames with preferably a single mounting interface to the payload platform. Two frames will be needed: one for mounting the instrument in Verification mode at the Prime Focus Spectrograph focal station, another for mounting the instrument (including optics) in Acquisition Camera/Scientific Instrument mode and fed by the SALT Project-supplied folding flat mirror located immediately after the telescope exit pupil.

The Verification mode framework will have a manually adjustable X-Y-Z stage which will allow traversal of the CCD detector to cover the centre of the FoV to the edge of the science FoV simultaneously, as well as positioning the CCD detector so that its centre is co-incident with that of the centre of the science FoV. Limited focussing capability of +/- 10 mm in Z shall be provided (where Z is along the optical axis of the telescope) (**TBD9**).

4.2.2.12 OPTICS FUNCTIONS

Suitable optics shall be supplied so as to re-image the entire science FoV, and as much of the guide star FoV as possible, on to the CCD detectors. Such optics shall, as far as possible, avoid degradation of image quality or light throughput over the range 320 to 1000 nm.

Capability to focus the instrument will be provided, but it is envisaged that this will be carried out infrequently: when checking the simultaneous focus of SALTICAM and the Prime Focus Imaging Spectrograph. Thus, manual adjustment of the focus on the

payload is planned, rather than motorized and under computer control.

4.2.3 Modes, States and Events

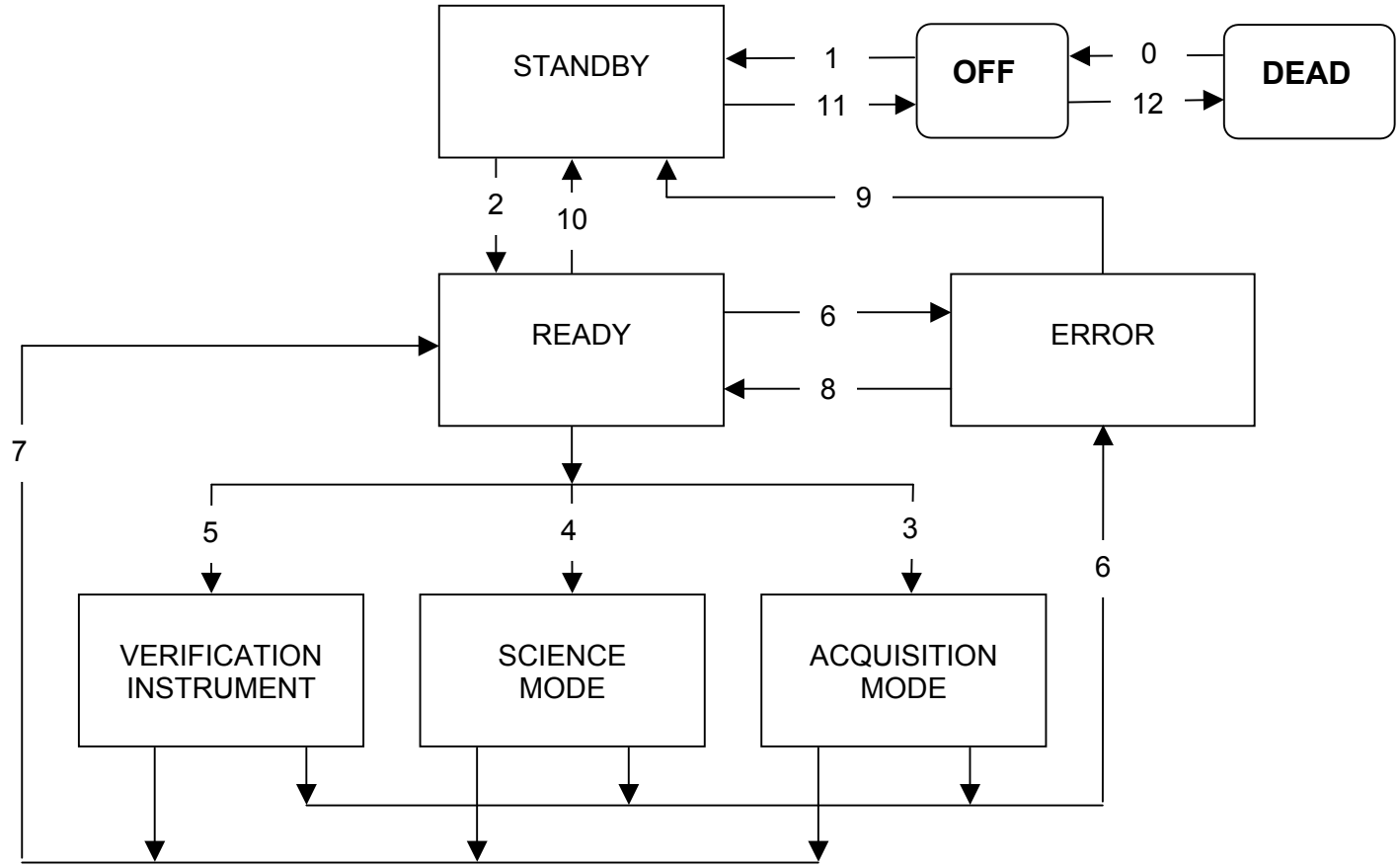


Figure 6. System Modes

See Table 2 for a description of mode transition events

Table 1 Description of System Modes

Mode	Description	States
Dead	Power to Salticam Computer, CCD and Subsystem Controller, and Cryotiger compressor is switched off.	
Off	Power to Salticam Computer is switched off; power to CCD and Subsystem Controller, and Cryotiger compressor is switched on.	CCD Controller, Subsystem Controller and Cryotiger Compressor switched on.
Standby	Power to Salticam computer, CCD and Subsystem Controller, and Cryotiger Compressor is switched on. In this state the Salticam Computer is running.	SALTICAM computer switched on.
Ready	All subsystems powered up and initialised: • Detector controller active with default (acquisition mode) setup • Detectors at set point temperature • Shutter closed. • Filter unit to default position. • Frame Transfer Mask out of beam. • Focus (**TBD2**)	Controller code downloaded. System health checked: • Filters to default position • Shutter closed • FT mask out of beam CCDs reached operating temperature.
Verification	Verification mode: exposing and read out.	Image format parameters updated: Pre-bin factor Window/Frame Xfer Exposure time Readout speed updated Filter selected. New setup downloaded.
Acquisition	Acquisition mode: exposing and read out.	Image format parameters updated: Pre-bin factor Window/Frame Xfer Exposure time Readout speed updated Filter selected. New setup downloaded.
Science	Science mode: exposing and read out.	Image format parameters updated: Pre-bin factor Window/Frame Xfer

		Exposure time Readout speed updated Filter selected. New setup downloaded.
Error	Any errors, which affect the capability of the instrument to perform as designed, will put the Salticam system in this mode. Sensor readings and status reporting will continue in this mode as it is possible to do so. In this mode error reporting must be sufficient to guide the telescope operator to the source of the problem.	

Table 2 Description of mode transition events

EVENT	From Mode	To Mode	SENSOR/INPUT
0	DEAD	OFF	Button – Cryotiger Compressor Button – CCD Controller Button – Subsystem Controller
1	OFF	STANDBY	Button – Salticam Computer
2	STANDBY	READY	On successful power up and initialisation sequence
3	READY	ACQUISITION	Acquisition mode setup downloaded. Operator initiated.
4	READY	SCIENCE	Science mode setup down-loaded. Operator initiated.
5	READY	VERIFICATION	Verification mode setup down-loaded. Operator initiated.
6	READY/ ACQUISITION/ SCIENCE/ VERIFICATION	ERROR	Error conditions • Problem with subsystems: Filters, Shutter, Frame Transfer Mask. • Problem with detector temperature • Problem with controller over-temperature • Problem with fibre data comms. • Operator initiated – on detecting problems with CCD data
7	ACQUISITION/ SCIENCE/ VERIFICATION	READY	Image acquisition, readout, display and storage. Operator initiated.
8	ERROR	READY	Error conditions resolved, software initialisation sequence. Operator initiated.
9	ERROR	STANDBY	Error conditions not resolved.
10	READY	STANDBY	Software/operator initiated shutdown sequence
11	STANDBY	OFF	Button – Salticam Computer
12	OFF	DEAD	Button – Cryotiger Compressor Button – CCD Controller Button – Subsystem Controller

5 SALTICAM Technical Requirements

5.1 Schematic diagram

Figure 7 below shows another perspective of the major components of the Salticam Instrument, and the communication interfaces.

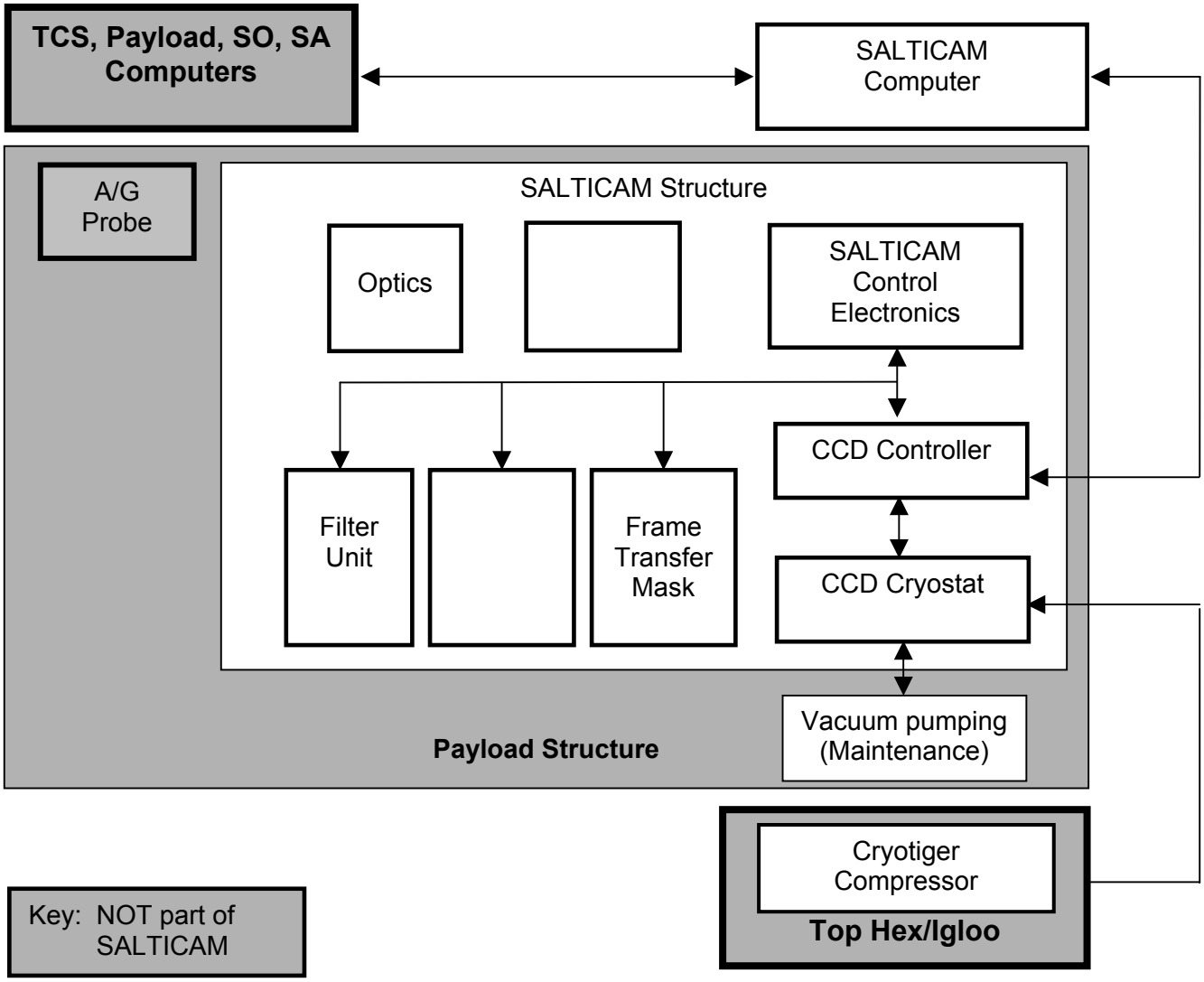


Figure 7. SALTICAM Schematic

5.2 SALTICAM Interfaces

5.2.1 SALTICAM External Interfaces

Details of these interfaces are to be supplied for inclusion in the SALT Electrical, Physical and Data Interface Control Dossiers which take precedence.

Table 3 Salticam external Interfaces

No.	Subsystem 1	Subsystem 2	Type	Direction	Interface description
1	SALTICAM	Payload	P		Physical attachment of instrument to payload structure
2	SALTICAM	Autoguider probe	P		Physical attachment of autoguider probe to SALTICAM
3	SALTICAM	Payload	P		Optical fibre cables to connect SALTICAM computer and CCD controller
4	SALTICAM	Payload	E	Input	Electrical power cables. Clean UPS mains to CCD controller
5	SALTICAM	Payload	C	Input	Liquid cooling lines and cooler boxes
6	SALTICAM	Payload	C	Input	Cryotiger coolant lines
7	SALTICAM	Payload	C	Input	Vacuum pumping (maintenance)
8	SALTICAM	Payload	O	Input	Starlight fed by fold mirror/ pellicle/ dichroic
9	SALTICAM computer	Payload/TCS Computers	D	Both	Communication: data, commands, status for autoguiding
10	SALTICAM computer	Time synchronisation source	D	Input	Communication: Time data
11	SALTICAM computer	TCS, SO, SA computers	D	Both	Network connection. Data, command, status

The following SALTICAM sub-systems shall require cooling by the SALT-furnished cooler boxes:

- SDSU II Controller
- SDSU II controller power supply
- SALTICAM controller unit
- Shutter unit solenoid and its electronics (**TBC5**, depends on design)
- **NOTE** that the proposed autoguider probe mounted at the SALTICAM focus will probably also require cooling

5.2.2 SALTICAM Internal Interfaces

Table 4 SALTICAM Internal Interfaces

No.	Subsystem 1	Subsystem 2	Type	Direction	Interface description
1	SALTICAM Computer	CCD Controller (SDSU II)	D	Both	Optical fibre: Command, Status, Data.
2	Cryostat	Instrument frame	P		Physical attachment of cryostat to frame shall be earthed.
3	Cryostat	Cryotiger coolant lines	P	Both	Pipe connections shall be insulating type
4	Shutter unit	Instrument frame	P		Physical attachment of shutter to frame.
5	Filter unit	Instrument frame	P		Physical attachment of filter unit to frame.
6	Frame Transfer mask	Instrument frame	P		Physical attachment of F.T. mask unit to frame
7	Optics	Instrument frame	P		Physical attachment of optics to frame
8	Focus Mechanism	Instrument frame	P		Physical attachment of focus mechanism to frame
9	CCD Controller	Cryostat	D	Both	Communication cables. CCD power, data, temperature control. **NOTE LENGTH LIMIT ON CCD CONNECTION CABLE (<400mm, TBC2)**
10	CCD Controller	SALTICAM computer	D	Both	Optical fibre. Command, status, data.
11	SALTICAM control	Shutter unit, Filter unit, Focus unit (**TBD2**), Frame Transfer mask.	D	Both	Communication cables. Command, status

In above tables: P: Physical; D: Data; O: Optical; C: Cooling; E: Electrical.

NOTE ITEMS 2 AND 8 IN ABOVE TABLE – CRYOSTAT TO INSTRUMENT FRAME – MAY BE REPLACED BY TWO INTERFACE DEFINITIONS :

i. CRYOSTAT TO FOCUS MOUNT

ii. FOCUS MOUNT TO INSTRUMENT FRAME

5.3 SALTICAM Characteristics

5.3.1 Performance Characteristics

The characteristics of SALTICAM that are required to perform the functions above are described below:

5.3.1.1 DETECTORS

The CCD detector shall cover an area of at least 54 mm in diameter, and with a minimum of 1920 pixels (of at least 28.2 microns each). (4096 x 15 micron pixels is also acceptable).

The largest commercially available CCDs with the required attributes for the instrument are roughly 30 x 60 mm. It is thus clear that for the detector to cover a diameter of 54 mm, two butted CCDs will be required. Scientific grade 1, thinned and back-illuminated devices will be required with excellent UV sensitivity (as specified in Table 5), and low noise readout amplifiers. The overall instrument sensitivity (inclusive of all camera optics and the detector, but exclusive of the telescope optics) shall also comply with the specification in Table 5.

Table 5 Instrument Sensitivity (Numerical values TBC3)

Wavelength	CCD DQE	Instrument Efficiency
B band (440 nm)	>50%	>40%
V band (550 nm)	>75%	>60%
R band (650 nm)	>75%	>60%
I band (850 nm)	>50%	>40%

At least 5 per cent instrument efficiency at 320 nm is also required.

With these efficiencies, and taking into account the efficiency of SALT, empirical scaling of the count rate measured with an excellent CCD on the SAAO 1-m telescope for a star with V = 18 yields predicted photon counting rates for a 1 second exposure through a V filter with SALTICAM and the full primary mirror of SALT of:

1800 photons / sec from a star with V = 20
288 photons / sec / arcsec^2 from sky (assuming V = 22 / arcsec^2)
S/N of 34 in 1 arcsec seeing (EE50) and 2x2 prebinned CCD readout

For highest time resolution performance, frame transfer mode (in which half the frame is masked from light) and/or sub-array mode (in which a number of small rectangles across the chip are read out) will be required.

5.3.1.2 CRYOSTAT

The CCDs will have to be mounted in an evacuated cryostat and cooled by the Cryotiger compressor so that Poisson noise on any dark current pedestal is far less than readout noise: a

value of 1 e^-/pix/hr is achievable with the chosen CCDs at an operating temperature of 170 K. The cryostat should be sealed by an optically flat window (still to be specified: **TBD4**)**.**

In frame transfer mode, half of the detector must be masked. A movable mask shall be placed immediately in front of the cryostat.

If the cryostat vacuum is lost and condensation forms on the outside, this condensation should be gathered using a drip tray or other means to prevent it falling onto other parts of the payload (e.g. the ADC or the SAC) or the primary mirror.

5.3.1.3 READOUT NOISE

In the slowest readout mode, the readout noise must be less than 5 electrons per pixel.

5.3.1.4 READOUT SPEED

In the slowest and therefore lowest noise readout mode, the CCD controller must be able to read out the CCD in a minimum of 5 sec (for 1920 x 1920 pixels) **(TBD5)**. Faster readout will be achieved with frame transfer readout, sub-array readout, or higher noise (or some combinations of these).

5.3.1.5 PREBINNING

The CCD controller should allow variable prebinning (from 1 x 1 to 9 x 9). Choice of prebinning should be under software control.

5.3.1.6 SHUTTER

The Instrument shall be provided with a shutter under computer control to define exposures not taken in frame transfer mode. An iris type shutter is acceptable provided it has an open or close time of100 msec or less (any requirement for equalising exposure time across the frame to be met by modelling). The shutter should have a mean time between failures of at least 0.5 million openings. Replacement of the shutter *in situ* within 2 hr must be feasible (**TBC9**).

5.3.1.7 FILTERS

The instrument will be provided with a filter unit operated remotely by the SALTICAM computer and containing at least 8 filter positions. UBVRI (or possibly Sloan) filters will be provided as standard.

5.3.1.8 FOCAL CONVERSION OPTICS

For Acquisition Camera and Scientific Imager mode, focal conversion optics are required which will re-image the f/4.2, 8 arcmin field of view on to the detector (at approximately f/2, or 107 microns/arcsec [depending on the pupil size chosen for the telescope]). These optics should not degrade the efficiency of the instrument more than specified in Table 5, and should provide images of point sources with image quality of (**TBD6**). This value should include all degradation due to optical and mechanical performance of the system, and variations in the environment (especially temperature changes) of the kind listed in Tables 6-8.

5.3.1.9 STRUCTURE

The Verification and Acquisition/Science frameworks shall support the sub-systems of SALTICAM during operation and shall be sufficiently rigid so as to maintain the image quality requirement for the instrument.

The structure shall provide a means to align the camera with the optical axis of the telescope.

5.3.1.10 SAFETY

The following should be read in conjunction with the SALT Safety Analysis, SALT-1000AA0030, listed in section 2.

All single point failures that can lead to loss of life, serious injury to personnel or damage to equipment shall be identified and the design modified to prevent such failures.

In no case shall it be possible for any component of the instrument to detach and drop from the Payload.

Motor overload protection, fusing and sensing shall be implemented and monitored by the control system to ensure that failure mode criteria are met.

Where tools must be used on-telescope for servicing and maintenance, they shall be secured by lanyards to the servicer's tool belt or man lift.

All fasteners, cover panels and other components which can be accessed while the tracker is on telescope shall be captivated by the use of ¼ turn captured fasteners, wire loop, bails, threads or some other similar means to prevent accidental injury to personnel below as well as damage to primary mirror.

No lock washers shall be used for on-telescope accessible fasteners, chemical locking compounds or aircraft-type locking nuts shall be used instead.

A safety analysis and design shall be presented and implemented to satisfy all safety requirements.

Software development process to be commensurate with the safety implication of software failure (see SALT1000BS0010)

5.3.2 Physical Characteristics

5.3.2.1 ENVELOPE

In Acquisition mode, no part of the instrument shall protrude beyond a radius of 1.5 m from the optical axis of the telescope. Likewise, no part of the instrument shall protrude beyond a radius of **TBD??** from the optical axis of the camera.

5.3.2.2 MASS

The SALTICAM mass on the payload shall be less than 25 kg (**TBD7**).

5.3.2.3 MAXIMUM & MINIMUM SURFACE TEMPERATURES

All the SALTICAM related electronics shall be located in the instrument envelope on the payload in a cooled enclosure. The SALTICAM computer shall be located in the computer room (70m from Top Hex). The cryotiger compressor shall be located in a cooled enclosure on the Top Hex, as a second option directly underneath the Primary Mirror (25m from Top Hex) in a cooled enclosure (**TBD10**).

Any gradient in the air temperature within the optical path will have a negative influence on the image quality produced by SALT. In order to minimise this effect, the following constraints are imposed. Relaxation of these constraints may be allowed on a case-by-case basis, subject to meeting the overall seeing objectives. These constraints shall be met for the 99th percentile of operation ambient conditions (see 5.3.3.1).

Section 5.5 provides further guidance in this regard.

5.3.2.4 OBJECTS IN THE OPTICAL PATH

All items of equipment that are within 1m of the telescope optical path *or within a vertical cylinder defined as a vertical extension of the pier to the highest point of the top hex*, shall comply with the following:

(a) No item exposed to the ambient air, regardless of its size, shall have a surface temperature of more than 8ºC above ambient.
(b) No item having forced-air cooling shall blow the exhausted air into the ambient air.
(c) No item exposed to the ambient air, regardless of its size, shall have a surface temperature cooler than 2ºC below ambient to prevent condensation on surfaces.
(d) No item shall blow exhausted cool air into the ambient air.
(e) Items with a surface temperature of more than 2ºC above ambient shall have a Thermal Factor (TF) of less than 0.6 m^{2}C, where TF is defined as follows:

$TF = A \cdot \delta T$

Where A = Exposed surface area of the item in m^2
δT = Temperature difference between the items exposed surface and the ambient air temperature in ºC

NOTE: In practice, these constraints mean that many items may require cooling jackets or cooled enclosures. As an example, an item measuring 0.4x0.4x0.4m emitting more than about 4W of heat continuously, will need to be insulated and cooled otherwise its surface temperature will go above the allowed limit.

5.3.2.5 OBJECTS OUTSIDE THE OPTICAL PATH

All items of equipment that are within 1 m of the telescope optical path, but not included in

5.3.2.4 shall comply with the following:
No item exposed to the ambient air, regardless of its size, shall have a surface temperature of more than 8ºC above ambient.
No item having forced-air cooling shall blow the exhausted air into the ambient air.
No item exposed to the ambient air, regardless of its size, shall have a surface temperature cooler than 3ºC below ambient.
No item shall blow exhausted cool air into the ambient air

Items with a surface temperature of more than 3ºC above ambient shall have a Thermal Factor (TF) of less than 2 m^2C (with TF defined in 5.3.2.4).

NOTE: In practice, these constraints mean that many items may require cooling jackets or cooled enclosures. As an example, an item measuring 0.4x0.4x0.4m emitting more than about 6.5W of heat continuously, will need to be insulated and cooled otherwise it's surface temperature will go above the allowed limit.

5.3.2.6 COMPONENT/MODULE REPLACEMENT

All major components that might need removal, must provide for interfaces suitable for using the dome crane as lifting device (capacity 1 ton).

Any special lifting or handling fixtures for modules by their nature or orientation require such fixtures for safe lifting and positioning. Any individual module of the camera shall weigh less than 15 kg so that a single person can manhandle individual modules without strain.

5.3.3 Environmental Requirements

5.3.3.1 NORMAL OPERATIONAL ENVIRONMENT

SALT shall meet all the requirements specified in this document when operated in the night-time outside ambient condition defined in Table 6 below:

Table 6 Normal Operational Environment

Parameter	Value	Notes
Minimum Temperature	0ºC	
Maximum Temperature	20ºC	
Maximum nightly temperature range	8ºC	
Maximum rate environment cooling	-1.5ºC/h	
Maximum rate of environment warming	+0.5ºC/h	Estimated value
Minimum Humidity	5%	
Maximum Humidity	97%	Non-condensing
Maximum wind velocity (outside)	16.8 m/s	Gusts up to 22 m/s
Maximum wind velocity (at dome opening)	6m/s	
Site altitude	1798m	
Solar radiation	0 W/m^2	Twilight to dawn

5.3.3.2 MARGINAL OPERATIONAL ENVIRONMENT

The degradation of system performance as a result of the ambient environment specified in Table 7 below, shall not exceed 10% of the nominal values in paragraph 5.3.1

Table 7 Marginal Operational Environment

Parameter	Value	Notes
Minimum Temperature	-10ºC	
Maximum Temperature	25ºC	
Maximum rate environment cooling	-2.0ºC/h	
Maximum rate of environment warming	+1ºC/h	Estimated value
Minimum Humidity	5%	
Maximum Humidity	97%	Non-condensing
Maximum wind velocity (outside)	21 m/s	Gusts up to 25 m/s
Maximum wind velocity (inside)	8m/s	
Solar radiation	0 W/m^2	Twilight to dawn

5.3.3.3 SURVIVAL ENVIRONMENT

SALT shall survive when exposed to the day or night ambient environment specified in Table 8 below. Note that the dome and louvers will be closed under these conditions and therefore the tracker does not have to be designed for this wind loading, but all tracker subsystems must be able to survive the temperature profile.

Table 8 SALT Survival Operating Environment

Parameter	Value	Notes
Minimum Temperature	-20ºC**	
Maximum Temperature	45ºC**	
Maximum Humidity	100%	Occasional exposure to condensing conditions
Maximum wind velocity (outside)	61 m/s**	
Rain	Note 1	
Snow	Note 1	
Hail	Note 1	
Icing	Present	Low temperatures after condensation or rain are common.
Solar Radiation	Note 1	
Other	Note 1	
NOTES: Environmental conditions not specified shall be obtained from the appropriate building/civil standards suitable for Sutherland. **: Use the worst case of these figures and those specified in the appropriate building/civil standards.		

5.4 Operation and Maintenance Requirements

5.4.1 Packaging, handling, storage

Packaging, handling and storage requirements will be determined for each individual type of component, taking into account the specific requirements of the component, the method of shipping and interim storage locations. Storage at SALT will be in the SALT Store Room, in dry, air-conditioned conditions. Containers shall be sufficient for one return shipping only, unless otherwise specified.

5.4.2 Product Documentation

The SALTICAM instrument shall include operating manuals, maintenance manuals, calibration procedures and component level documentation.

Full size copies of as built component specifications, drawings and CAD files.

Acceptance test documentation

Build History document.

All documentation shall be in English.

5.4.3 Personnel and Training

5.4.3.1 OPERATION

SALTICAM will be operated from the control room at the telescope. A SALT operator (SO) and

a SALT Astronomer (SA) will be on duty during the whole night, for every operational night. Any ad hoc repair work will be performed by the SAAO standby maintenance staff, to be called by the SO when required. The SO will have a National Diploma (N6/S3) or equivalent qualification in electronic or mechanical engineering or have adequate experience. The SA will be a PhD astronomer.

5.4.3.2 MAINTENANCE

SALT will be maintained by the SAAO staff at Sutherland and Cape Town. Personnel will be trained in the maintenance of SALT, and be granted a "SALT – license" upon completion of training. All maintenance work carried out on SALT will be supervised/signed off by a SALT licensed person. It is anticipated that the following people will be required to maintain SALT:

<u>At Sutherland:</u>	
Mechanical Technician:	2
Electronic Technician:	1
Electrical Technician:	1
<u>In Cape Town:</u>	
Mechanical Engineer:	1
Electronic Engineer:	1
Software Engineer:	1

These positions should not be SALT only, i.e. these personnel must be part of the SAAO technical staff, who will also work on the other SAAO telescopes. Thus, two Electronic technicians, each working 50% on SALT, can constitute the one full time Electronic Technician listed above.

One mechanical and one of the electrical/electronic technician will also be required to be on standby during every night of operations. These standby personnel will form part of the normal SAAO standby team.

In the above requirements, "Technicians" require a N6, T3 or equivalent qualification, and "Engineer" means an S6 or Bachelors degree in Engineering and/or Computer Science.

The SALTICAM Instrument system shall be designed to be operated and maintained by the personnel mentioned above.

5.4.4 Availability

5.4.4.1 SCIENCE EFFICIENCY

The table below specifies the required SALT efficiency for various operational aspects.
The values are percentages of the total time allocated to science, and exclude bad weather, engineering time and instrument commissioning. A Problem Reporting and Corrective Action System (PRACAS) shall be implemented from system testing onwards, to monitor the growth in efficiency to achieve these values after ten years of operation. How the SALTICAM Instrument effects will be incorporated, forms part of this specification.

The HET values shown are for information only, and are the measured average for the period October 1999 to June 2000.

Some of the values are determined by Instrumentation efficiency and Operator efficiency, which fall outside the scope of this document.

Table 9 SALT Efficiency

Activity	SALT spec	HET at present
CCD exposure and readout	66%	34%
Move and set*	20%	29%
Instrument Calibration	5%	3%
Primary Mirror Alignment	5%	24%
Down-time	2%	8%
Other	2%	1%
TOTAL	100%	100%

The above requirement is expanded into specific numbers for Reliability (allowable Mean Time Between Failures, minimum "up" time, maximum data error rates, allowable "false-alarm" rate) and Maintainability (allowable Mean Time To Repair, specific maintenance provisions to be built into items, Built-in Testing, error logging) in the document “SALT Support Requirements”, referred to in Section 2.

5.4.4.2 RELIABILITY

Unscheduled SALTICAM down time during operation shall not exceed 10 hr / year in its role as Verification Instrument, and 1 hr/yr in its role as Acquisition Camera (**TBD8**).

5.4.4.3 SALTICAM MAINTAINABILITY

Scheduled maintenance shall be performed during the day.

Spares shall be provided for components critical to operation of the instrument the failure of which will lead to a downtime of more than 10% of the specification in 5.4.4.2.

SALTICAM’s vacuum should be able to be pumped down without removing the cryostat from the telescope. Pump-downs should be necessary at intervals of 3 months or more.

5.4.4.4 MEASURES TO ACHIEVE EFFICIENCY

SALTICAM Subsystems shall be organized into modules for ease of mounting/dismounting and servicing.

COTS equipment will be used as far as possible to reduce spares holding requirements. A float level of standard spares will be kept in the SALT Store.

As far as possible local support for all subsystems/components is required

Special tools and equipment required for system operation and maintenance shall be kept to a minimum, and will be provided with each subsystem.

All normal maintenance actions will be able to be completed within one working day, unless otherwise specified. Where maintenance actions take more than a day and happen regularly (e.g. primary mirror coating), enough spares will be held to ensure that the operation of the telescope system is not affected.

5.5 Design and Construction constraints

5.5.1 General design guidelines and constraints

The following guidelines and constraints apply to SALT (where these general guidelines contradict specific requirements in other parts of this document, the other requirements shall have precedence):

Preference will be given to material with low thermal inertia and open section (e.g. I-beam rather than tube) for anything above the telescope chamber floor.

The telescope chamber shall have the same temperature as the ambient air during observing, i.e. it shall be cooled during the day, to match ambient temperature at the start of observing

No warm air will be exhausted into telescope light path.

Commercial, off the shelf (COTS) equipment will be used unless specifically stated otherwise. All computer hardware will be COTS equipment, using “mainstream” equipment and vendors. Computer operating system and application software will be COTS, using “mainstream” packages and vendors

Optical fibres will be used for any digital communications travelling more than 30m

The Metric measurement system will be used.

All surfaces inside the telescope chamber should follow the ambient temperature as closely as possible, the effect of a positive delta being air turbulence, causing bad seeing, and a negative delta being the risk of condensation, damaging mirrors and equipment.

5.5.2 Materials, Processes and Parts

All components will be protected against corrosion by proper surface treatment (e.g. anodising), painting, etc.

Wherever a component is mounted in an optically sensitive area, it shall be painted with a non-fluorescing, non-radioactive paint.

All components mounted in the optical path will be non-reflective, non radiating in the spectrum 320 to 1500nm

All custom components will be marked as follows:

Table 10 Part identification

SALT
Supplier name
Product name
Product number
Serial number (where applicable, e.g. mirror segments, mirror mounts)
Version number (where applicable, e.g. controllers/computers with embedded software)
Hazard/danger/poison warning (where applicable)

No special markings are required on COTS equipment.

The normal operation of any component/subsystem shall have no negative impact on the environment, and shall comply with the Montreal Protocol.

5.5.3 Electromagnetic Radiation

The normal operation of any component or system will not affect the normal operation of any other system or component, or any other equipment at the Observatory at Sutherland and has to comply with the FCC standards as per Section 2.

The SALTICAM design should incorporate measures to shield its sensitive electronics from electrical noise.

5.5.4 Workmanship

Workmanship specifications will be specified per type of component, but will not be higher than required to fulfil the overall SALT performance specification.

5.5.5 Interchangeability

Interchangeability will be maximised by using COTS equipment wherever possible, and exceptions will be specified.

5.5.6 Safety

5.5.6.1 SAFETY-CRITICAL FAILURES

All single-point failures that can lead to loss of life, serious injury to personnel or damage to equipment shall be identified and the design modified to prevent such failures.

A preliminary safety analysis to identify such potential failures is contained in the SALT Safety Analysis referred to in section 2.

5.5.6.2 SOFTWARE SAFETY

Where the malfunction of software alone could cause a safety-critical failure, alternate means shall be provided to prevent the occurrence of such a failure. This would typically take the form of electrical interlocks designed in a fail-safe manner.

5.5.6.3 SAFE INITIALISATION

All systems, when initialising from power-up or when reset, shall be in a safe, non-active state (e.g. equipment stationary, drives off). It shall take a specific command from the TCS (by exception) or the operator via the TCS, to proceed with potentially unsafe actions (such as rotating the structure or dome, moving the tracker or opening/closing the shutter).

5.5.7 Special commissioning requirements

5.5.7.1 SUBSYSTEM MMI'S

There shall be monitors/keyboards plus good human interface SW at the subsystem computers, for use during system commissioning. These controls must include facilities for overriding automatic functions and monitoring of information communicated to/from the TCS.

5.5.7.2 TEST POINTS

Means shall be provided to measure electrical signals and interpret data transferred between subsystems and major electronic items within each subsystem.

5.5.7.3 TEST DATA

Each subsystem shall send to the TCS the values of all internal variables that may need to be interrogated during commissioning and testing, but would not normally be needed for telescope control by the TCS. A list of typical variables required is provided below, but details will be provided in the SALT Electrical Interface Control Dossier:

5.5.8 Software

Each subsystem shall comply to the requirements defined in SALT Computer Software Standard referred to in Section 2.

This document addresses the following:

Software must separate H/W interfaces with functional software, so that I/O devices can be replaced later without having to modify all the software

The acceptable languages and operating systems will be specified per computer plus general interfacing requirements

Specific practices and documentation/design requirements for the software will be defined

Protocols for interfacing between computers will be defined (detail will be in ICD)
Format for PLC software

Each computer shall report the health status of itself and all it's input/output devices to a higher level computer, such that the TCS will be notified all major failures.

TCS shall monitor communication health to all systems (ping test?)

The SALTICAM Computer shall use, as far as possible, Labview running on Linux on a PC.

5.5.9 Computer Hardware

Each subsystem shall comply to the requirements defined in SALT Computer Hardware Standard referred to in Section 2.

This document addresses the following:
Hardware must be selected such that it is possible to upgrade the PC's at a later stage

5.5.10 Electrical Design

5.5.10.1 UPS

"Clean" UPS power will be available for the CCD/Subsystem Controllers on the Payload.

A *separate* UPS power source will be available for the Cryotiger compressor.

5.5.10.2 CABLE SIZING

All electrical power cables shall be sized such that their outside surface temperature does not rise above ambient by more than 0.5ºC under worst-case operating loads.

5.5.10.3 GENERAL ELECTRICAL REQUIREMENTS

All subsystems shall comply with the SALT Electrical Requirements. This document will address the following:

Earthing and bonding of electrical equipment

Measures to minimise electrical interference

General principle to follow for electrical parts of each subsystem

5.5.11 Future growth

The following potential growth areas shall be borne in mind during the design process and accommodated where this does not have an impact on the achievement of the immediate performance, schedule and cost requirements.

5.5.11.1 REMOTE OBSERVING

The control room of SALT may be required to be duplicated at the SAAO in Cape Town, to allow remote operating of SALT.

6 Major Component List

The major suggested components and subcomponents with their respective functional allocations are detailed in the following table. The selection and design of these components will be finalised in the design phase.

6.1 SALTICAM Major Components

Table 11 SALTICAM Major Components

No	Major Component	*Sub Components*	Function
1	SALTICAM Computer System	*Computer Hardware* *Software Suite* *Power Switches*	1. Communication 2. SALTICAM Algorithms 3. SALTICAM MMI
2	SALTICAM Structure	*Verification mode frame/optical bench* *Acq./Science mode frame/optical bench*	1. Rigid backbone of instrument.
3	Optics	*Three optical lens assemblies*	1. f/4.2 to f/2 focal reducer
4	Shutter	*Shutter mechanism* *Solenoid* *Control circuits*	1. Detector exposure control
5	Filters	*Eight glass filters* *Filter mechanism* *Control circuits*	1. Instrument bandpass control
6	Frame Transfer Mask	*Mask plate* *Slide mechanism/motor* *Control circuits*	1. Switch instrument between full-frame & frame transfer mode
7	Cryostat	*Cryotiger cooler cold end* *CCD detectors*	1. House CCD detectors in evacuated cryogenic environment
8	SDSU controller power supply		1. Various power supplies necessary for the SDSU controller
9	SDSU CCD controller		1. Control CCD readout, data conversion, etc.
10	SALTICAM controller	*Shutter controller* *Filter controller* *Focus controller* *Frame Transfer controller*	1. Control circuits for all SALTICAM sub-units
11	Focus Mechanism	*Focus motion* *Control circuits/Mechanical solution*	1. Control position of camera to focus instrument.
12	Cryotiger Compressor		1. Supply coolant to the cryostat.

6.2 Major Component Characteristics

All systems & subsystems shall comply with the requirements of Section 2 documents.

6.2.1 SALTICAM Computer System

The computer system shall be located in the computer room in the Facility. The maximum wire length between the Computer Room and the top of the Telescope Structure will be less than 80m.

This room will be maintained at temperatures between 5 to 25 degrees C and relative humidity 5% to 95%.

The SALTICAM Computer System shall perform all functions reliably in this environment.

COMPUTER HARDWARE:

At least a Pentium III class machine, shall comply with SALT Computer hardware Standard (Section 2).

The selection of hardware should not limit future upgrading with advances in technology.

SOFTWARE SUITE

Operating system : Real Time Linux
Communication Software shall include TCP/IP Protocol
SALTICAM software development environment : LabVIEW MMI and Real Time C Module.
SALTICAM Software : Comply with standard as in section 2 (SALT Software Standard)
SALTICAM should be fully commanded from either the TCS or SALTICAM Computer with the SALTICAM MMI fully available at TCS level

POWER SWITCHES

Functionality must be provided to power up SALTICAM subsystems in an orderly fashion either fully or selectively. The details will be finalised in the design phase. A typical grouping of these manual switches may be as follows:

- Cryotiger, CCD Controller and Subsystem Controller
- SALTICAM Computer

6.2.2 Structure

(a) Shall consist of a rigid beam/framework on which all the major components of the instrument will be mounted. Any flexure should not degrade the optical performance so that the required image quality is not met.
(b) The structure for the instrument in Verification mode will be different from that in Acquisition or Scientific mode.
(c) A manually operated X-Y-Z stage will be provided for the Verification mode structure (**TBD9**).
(d) Space to accommodate the guide probes will have to be provided in the Acquisition and Science modes.

6.2.3 Optics

Optics will be provided to convert the f/4.2 focal ratio of the output of the SAC to f/2 or faster and provide image quality as specified (**TBD6**).

6.2.4 Shutter

(a) The shutter shall be an iris type
(b) The shutter shall have an open or close time of not more than 100 msec (**TBC4**)
(c) The shutter solenoid and its electronics will probably have to be cooled (**TBC5**)

(d) The mean no of cycles between failure of the shutter will be 500000 (**TBC7**)
(e) Replacement of the shutter *in situ* within 2 hr must be feasible (**TBC9**)

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6.2.5 Filters

The filter unit shall have provision for up to eight filters. UBVRI (or possibly Sloan) filters will be provided as standard.

6.2.6 Frame Transfer Mask

The frame transfer mask shall be a retractable mask as close to the focal plane as possible, of such a size as to cover half the CCD detector array.

6.2.7 Cryostat

(a) The cryostat is an evacuated container to house the CCD detectors.
(b) The detectors shall be mounted perpendicular to the optical axis of the instrument.
(c) The cryostat shall withstand a pressure differential of $>10^6$ mbar.
(d) The cryostat shall be provided with a drip tray or other means to gather any condensation forming on its outer surfaces should the vacuum be lost when it is cold.

6.2.8 SDSU Controller Power Supply

(a) The SDSU power supply is a COTS unit
(b) Mains power to the power supply shall be controlled by the SALTICAM computer
(c) The power supply will have to be cooled

6.2.9 SDSU CCD Controller

(a) The SDSU CCD controller is a COTS unit
(b) The controller will have to be cooled.

6.2.10 SALTICAM Subsystem Controller

(a) The Salticam controller shall house the control circuits for the various sub-systems: shutter, filters, F.T. mask, focus control (**TBD2**).
(b) Mains power to the controller shall be controlled by the SALTICAM computer.
(c) The controller will have to be cooled

6.2.11 Focus Mechanism

The focus mechanism shall provide a method of adjusting the instrument focus position by moving the entire instrument. This focus mechanism is currently conceived to be a manual adjustment but could be a remotely controlled motorized adjustment (**TBD2**).

6.2.12 Cryotiger Compressor

The Cryotiger compressor shall supply coolant to the cryostat. It is a COTS unit. It shall be located in a cooled enclosure on the top hex, or in an igloo at the base of the telescope.

6.2.13 Component positions within telescope Facility

As shown in Figure 6, all components of SALTICAM shall be placed on the payload except for two: (i) the SALTICAM computer shall be placed in the SALT Computer Room; (ii) the Cryotiger compressor shall be placed on the top Hex or in an “igloo” at the base of the telescope. (**TBD10**)

7 Operational Concepts

7.1 Overview

This section describes the operating modes of SALTICAM as an acquisition camera.

In all modes, the basic operation of the instrument is to acquire one or more images. This is achieved 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 and there is 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.

7.2 Performance Goals

With the CCD chips currently envisaged for the instrument, and the performance expected from the SDSU CCD controller, it is hoped 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 e^-/pix readout noise
- Pixel skip times of 1.0 μsec/pix or better

The CCD chips currently envisaged 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.

With the above information, it is straightforward to calculate readout times for the entire detector:

- (4096*50 μsec/row) + (512*2048*10.0 μsec/pix) = 0.21 sec + 10.49 sec = **10.7 sec** :
  2 x 2 prebinning and slow readout to give 3 e^-/pix readout noise.
- (4096*50 μsec/row) + (512*2048*3.0 μsec/pix) = 0.21 sec + 3.15 sec = **3.4 sec** :
  2 x 2 prebinning and fast readout to give 5 e^-/pix readout noise.

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*3.0 μsec/pix) + (100*924*1.0 μsec/pix)
  = 0.21 sec + 0.008 sec + 0.09 sec
  = **0.31 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 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 0.11 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. Frame transfer readout time is:

- (4096*50 μsec/row) + (512*1024*3.0 μsec/pix) = 0.21 sec + 1.57 sec = **1.78 sec** : 2 x 2 prebinning and fast readout to give 5 e^-/pix readout noise.

Thus, a continuous sequence of 2.0 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 0.11 sec needed to transfer it into the masked region.

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

7.3 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 SO’s eye).

7.3.1 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: **10.94 sec** (3 e^-/pix readout noise)

OR

- Readout of the detector in: **3.6 sec** (5 e^-/pix readout noise)
- Data display

7.3.2 Frame Transfer Operation

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: **0.1 sec**
- Readout of the detector in: **1.57 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 (0.45 sec total) plus the time for overhead such as data display, say **2.5 sec** in the above example.

7.3.3 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: **0.31 sec** (5 e^-/pix readout noise)
- 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: **0.31 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.

8 Test Requirements

8.1 Verification cross-reference Matrix

Per paragraph in sections 4, 5 and 6, the kind of testing of the product's compliance with the requirement is indicated in the Table 12 below.

Note that compliance to a requirement may be proven at the "system" (S) (i.e. SALT), "subsystem" (SS) (i.e. SALTICAM) or component (C) level, depending on the particular requirement (e.g. the mass of the total product can be proven by weighing all the components, it needn't be in the assembled state).

The "Test Method" may be any one of the following:

- Review (R) - the design is reviewed and it is obvious to all whether or not the item complies (e.g. whether or not the system has a particular mode).
- Inspection (I) - the completed item is inspected and compliance can be easily observed. This is normally used for physical characteristics such as colour, dimensions and mass.
- Testing (T) - this entails a technical effort whereby the system is stimulated in a certain fashion and its response compared to the required response.
- Analysis (A) – compliance of the design to the requirement is proved by mathematical analysis.
- Observational test (O) – it is anticipated that some properties of SALTICAM will be tested by mounting the cryostat on an existing SAAO telescope, obtaining data and analysing the results.

Where it is considered important, reference to the detail of the test method should be provided in the "Details" column of the table.

Table 12 Verification Cross-Reference Matrix

Sect.	Requirement	Test Method	Test Level	Test Detail Ref.
4	**Functional Requirements**			
4.1	**Main Purpose and Overview**	**R**		
4.2	**Functional Description**	**R, T**		
4.2.1	Functional Flow Diagram	R		
4.2.2	Description of Functions	R, T		
4.2.2.1	Communication with SO/SA Computers	R, T		
4.2.2.2	Communication with TCS Server	R, T		
4.2.2.3	Communication with Data Reduction Computer	R, T		
4.2.2.4	Communication with Precision Time Source	R, T		
4.2.2.5	Communication with CCD/Subsystem Controller	R, T		
4.2.2.6	SALTICAM MMI	R, T		
4.2.2.7	SALTICAM Algorithms	R, T		

Sect.	Requirement	Test Method	Test Level	Test Detail Ref.
4.2.2.8	CCD Controller & Cryostat, Subsystem Controller	R, T		
4.2.2.9	Thermal Control Functions	R, T, I		
4.2.2.10	Cryotiger Functions	R, T, O?		
4.2.2.11	Structural Support Functions	R, T		
4.2.2.12	Optics Functions	R, T, O		
4.2.3	Modes, States and Events	R, T		
5	**SALTICAM Technical Requirements**			
5.1	**Schematic Diagram**	**R**		
5.2	**SALTICAM Interfaces** (5.2.1-5.2.2)	**R, I**		
5.3	**SALTICAM Characteristics**			
5.3.1	Performance Characteristics	R, T, O		
5.3.1.1	Detectors	R, T, O		
5.3.1.2	Cryostat	R, T		
5.3.1.3	Readout noise	R, T		
5.3.1.4	Readout speed	R, T		
5.3.1.5	Prebinning	R, T		
5.3.1.6	Shutter	R, T, O?		
5.3.1.7	Filters	R, T		
5.3.1.8	Focal Conversion Optics	R, T		
5.3.1.9	Structure	R, T		
5.3.1.10	Safety	R, A, T		
5.3.2	Physical Characteristics	R, T, A, I		
5.3.2.1	Envelope	R, I, A		
5.3.2.2	Mass	R, T		
5.3.2.3	Maximum and Minimum Surface Temperatures	T, A		
5.3.2.4	Objects Inside the Optical Path	T, A		
5.3.2.5	Objects Outside the Optical Path	T, A		
5.3.2.6	Component/Module Replacement	R		
5.3.3	Environmental Requirements	R, T, A		
5.4	**Operation and Maintenance Requirements**	**R, T, I**		
5.5	**Design and Construction Constraints**	**R, I**		
6	**Major Component Characteristics**	**R, T, I**		
8	**Test Requirements**	**R**		

8.2 Detailed Test Methods

APPENDIX A: List of TBD and TBC Items

TBD	Place In Document	Description
TBD1	4.2.2.7	Display image in any orientation of RA/Dec, or just N at top, E at left?
TBD2	4.2.2.8 Table 1 6.2.10 6.2.11	Manual focus by lockable lead screw, or remotely-controlled motorized adjustment?
TBD4	5.3.1.2	Specification on flatness of cryostat window so as not to affect the verification of telescope performance.
TBD5	5.3.1.4	Minimum read out time for CCDs
TBD6	5.3.1.8 6.2.3	SALTICAM image quality specification. (To be specified by the science requirement).
TBD7	5.3.2.2	Mass limit for SALTICAM
TBD8	5.4.4.2	Unscheduled and scheduled SALTICAM down time permissible
TBD9	4.2.2.11 6.2.2	Z-stage for SALTICAM verification structure
TBD10	4.2.2.10 5.3.2.3 6.2.12 6.2.13	Location of Cryotiger compressor: on top hex or in igloo at base of telescope
TBD11	5.3.2.1	Envelope for SALTICAM in any direction away from the camera's optical axis

TBC	Place In Document	Description
TBC2	Table 4	400 mm length limit on cable connecting CCD controller to cryostat.
TBC3	Table 5	CCD DQE and instrument efficiency specification: numerical values
TBC4	6.2.4	Shutter open or close time limit of 100 msec
TBC5	6.2.4	Shutter solenoid needs to be cooled?
TBC7	6.2.4	Mean number of cycles between failure of shutter: 500000 cycles
TBC8	7.2	Readout rate, readout noise, pixel skip and vertical transfer time for CCDs

TBC9	5.3.1.6 6.2.4	2-hr replacement time for shutter *in situ*