Southern African Large Telescope
High-Resolution Spectrograph

SALT HRS

3200AP0031 Acceptance Testing Plan

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Issue History

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3200BP0031 ATP	PLC	1.0	23 Feb 2005	First draft
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1 Scope

This document provides a series of tests and calibrations that will lead to the acceptance of the SALT High Resolution Spectrograph (HRS) consistent with its Functional Performance Requirements Document (FPRD: 3200AE0015).

As well as a table that defines each of the requirements in the FPRD and how pre- and post-delivery tests and calibrations will be undertaken, detailed descriptions of each of these will be given.

2 SALT HRS FPRD requirements matrix

FPRD req.	Description	Acceptance test		
		section	Pre-delivery	Post-delivery
2.1	Resolving power	3.1	Lab test at UC	Telescope test
2.2	Wavelength coverage	3.2	Lab test at UC	Telescope test
2.3.1	Fixed object & sky	3.3.1	Lab test at UC	Telescope test
2.3.2	Nod & shuffle	3.3.2	Partial lab test at UC	Telescope test
3.1.1	Fibre input	4.1.1	FIF spec	Telescope test
3.1.1	Fibre output	4.1.2	Lab test at UC	
3.1.2	Image slicers	4.1.3	Lab test at UC	
3.1.3	Collimator	4.1.4	Lab test at UC	
3.2	Dispersive elements	4.2	Manufacturer's spec	
3.3	Cameras	4.3	Manufacturer's spec	
4.1	Blue detector	5.1	Manufacturer's spec	
4.2	Red detector	5.2	Manufacturer's spec	
5.1	Image quality	6.1	Lab test at UC	
5.2.1	Radial velocity precision	6.2.1		Telescope test
5.2.2	Line profile stability	6.2.2	Lab test at UC	Telescope test
5.3	Scattered light	6.3	Lab test at UC	
5.4	Ghosts	6.4	Lab test at UC	
6	Throughout	7	Manufacturer's spec	Telescope test
7.1	Mechanical stability	8.1	Lab test at UC	Test at SITE
7.2.1	Thermal isolation	8.2.1	Lab test at UC	Test at SITE
7.2.2	Vacuum	8.2.2	Lab test at UC	Test at SITE
8.1	Instrument control	9.1	Lab test at UC	Test at SITE
8.2	Reduction software	9.2	Lab test at UC	Test at SITE

3 Science Requirements

3.1 Resolving power

FPRD- 2.1: SALT HRS is designed to operate in three different resolving power configurations: an internally mounted fibre giving R=16,000 plus two image slicers giving R=37,000 and R=65,000 respectively. SALT HRS will deliver spectra that exceed 90% of each of these as-designed resolving powers at the blaze wavelength for each order.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
Lowest resolving power: Wavelength calibration lamp will be injected directly into spectrograph using a set of 500 μm fibres.

Higher resolving powers: A test pair of fibres will be mounted on each of the image slicers and wavelength calibration lamp injected into the spectrograph.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
UC procedures will be repeated once SALT HRS is installed in the Spectrograph Room at SALT. A wavelength calibration lamp test using the ThAr lamp installed in the FIF will then be undertaken to confirm the laboratory test resolving powers.

Note: The resolving power for all modes will be defined by the FWHM of a single emission line located near the blaze wavelength of each order. The emission line will be converted into a one-dimensional profile before the FWHM is measured.

3.2 Wavelength coverage

FPRD 2.2: The spectrograph will be capable of wavelength coverage from 370 to 890nm, but with a blind spot of ~10nm at the dichroic crossover wavelengths.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
Wavelength calibration lamp and the direct injection fibre will be used to confirm the wavelength coverage.

Post-delivery compliance will be verified by laboratory and telescope test in the Spectrograph Room at SALT.
Procedure:
UC procedure will be repeated once SALT HRS is installed in the Spectrograph Room at SALT and then confirmed using the wavelength calibration lamp from the FIF.

3.3 Observing modes

3.3.1 Fixed object and sky

FPRD 2.3.1: In this mode a single object and adjacent background field will be observed simultaneously.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
A test pair of fibres will be used to inject a flat-field calibration lamp in each mode to ensure that the spectrograph complies with the above requirement.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
UC procedure will be repeated once SALT HRS is installed in the Spectrograph Room at SALT and then confirmed using the flat-field calibration lamp from the FIF.

3.3.2 Nod and shuffle

FPRD 2.3.2: In this mode the fibre will be moved (nodded) simultaneous with the charge being moved (shuffled) on the CCD, providing on-chip summing of source and two sky samples. Nod and shuffle will only be available for the lowest resolving power configuration.

Pre-delivery compliance will be verified by partial laboratory test at UC.
Procedure:
The CCD systems will be checked to ensure that they are able to shuffle charge appropriately in response to a specific command.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
UC procedure will be repeated once SALT HRS is installed in the Spectrograph Room at SALT and then confirmed using the whole FIF system to ensure that the FIF 'nods' in response to the signal that has 'shuffled' the charge on the CCD systems.

Note: Only the low resolving power fibre mode will be available for use in nod and shuffle.

4 Optical requirements

4.1 Fibre feed and collimator

4.1.1 Fibre input

FPRD 3.1.1: At the fibre input, the FIF will provide the user with the option of selecting separate object and sky fibres with variable separation at the centre of the focal plane (that is, close to on-axis). It is assumed that a 500μm fibre placed in the telescope focal plane will capture at least 80% of the energy from a point source given a telescope image quality of EE(80) = 2.1".

Pre-delivery (of SALT HRS) compliance will be provided by the FIF passing all its acceptance tests and by verification of telescope image quality.

Post-delivery (of SALT HRS) compliance will be verified by telescope tests.
Procedure:
A procedure for determining the FIF operation and the fibre throughput will be developed in consultation with the FIF PI.

4.1.2 Fibre output

FPRD 3.1.1: The fibres will introduce no more than 20% focal ratio degradation for telecentric input at the telescope focal plane.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
Various fibres to be used in SALT HRS will be tested using standard laboratory techniques for measuring fibre FRD. Only fibres that comply with this requirement will be selected.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
UC procedure will be repeated once SALT HRS is installed in the Spectrograph Room at SALT and when the fibre assembly is complete. The fibres will then be installed in FIF and the tests repeated.

Note: Tests of the fibre FRD installed in FIF will require the use of on-axis point sources (e.g. stars) with a fully illuminated SALT pupil.

4.1.3 Image slicers

FPRD 3.1.2: Provide two dual-fibre image slicers delivering resolving powers of at least 90% of their targets, R=37,000 and R=65,000.

Pre-delivery compliance will be verified by laboratory test at UC following acceptance tests at the manufacturer.
Procedure:
Each image slicer pair will be provided with light from a pair of test fibres and the light output imaged onto a test CCD and the width of each transmitted sub-slit measured to ensure that it will be capable of providing the higher resolving powers required.

Once mounted in SALT HRS fibre selector each pair of image slicers will be tested at the slit plate and at the focal plane of the cameras to ensure that they deliver the required resolving powers. This test may be identical to 3.1 above.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The test will be identical to 3.1 above.

4.1.4 Collimator

FPRD 3.1.3: The collimator will accept and collimate 95% of the light exiting the fibres and/or image slicers assuming 10% focal ratio degradation.

Pre-delivery and post-delivery compliance follows from measurements of the fibre focal ratio as per section 4.1.2 above.

4.2 Dispersive elements

FPRD 3.2: Provide sufficient two-dimensional dispersion to achieve the resolving power, wavelength coverage, operational modes and background and sky subtraction. There will be at least 5 rows on the CCD between each order for the removal of background light from the two-dimensional images.

Echelle grating:

Pre-delivery compliance will be verified by acceptance tests at grating manufacturer and laboratory test at UC.
Procedure:
Test information from echelle grating manufacturer will be reviewed at UC to ensure that it meets the agreed specification in quotation prior to approval being given to the grating manufacturer supplier to ship the grating.

The dispersion of the echelle grating and effective resolving power will be determined as part of the compliance tests for wavelength coverage (3.1) and resolving power (3.2) described above.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The above tests will be repeated using both laboratory and telescope sources.

VPH gratings:

Pre-delivery compliance will be verified by acceptance tests at VPH grating manufacturer and laboratory test at UC.
Procedure:
Test information from VPH grating manufacturer will be reviewed at UC to ensure that the gratings meet the agreed specifications in quotation prior to approval being given to the grating manufacturer supplier to ship VPH gratings.

The dispersion of the VPH grating will be determined as part of the compliance tests for wavelength coverage (3.1). The order separation will be determined using the low, medium, and high resolving power fibre injection modes with laboratory light sources.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The above test will be repeated using both laboratory and telescope sources.

4.3 Cameras

FPRD 3.3: The cameras are required to ensure at least 2 pixel Nyquist sampling of the smallest slit-limited resolution element and be capable of the wavelength coverage given in FPRD 2.2.

Pre-delivery compliance at camera manufacturer and at UC.
Procedure:
Will be verified by acceptance tests at the manufacturer as per Prime Optics tests specified in Section 6 of document 3210AA0007, dated February 23, 2005.

The sampling and wavelength coverage of the cameras will be determined as part of the compliance tests for wavelength coverage (3.1) and resolving power (3.2) described above.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The above test will be repeated using both laboratory and telescope sources.

5 Detector requirements

Specifications for the CCD Camera vendor for the SALT HRS are given in SALT-3290BPXXXX.

5.1 CCD system for blue camera

E2V Technologies 44-82, Grade 0
Thinned, back illuminated CCD
Astro BB antireflection coating
2k x 4k x 15micron square pixels
2 readout amplifiers per chip

For charge shuffling in the direction of cross-dispersion, the CCD must be aligned with the columns in this direction.

The CCD will have the following parameters:
CTE: The charge transfer efficiency shall be better than 99.999 per cent.
Full well: The peak charge storage shall be greater than 150,000 e^-/pix.
Sensitivities, quantum efficiency: The CCD QE, as a function of wavelength, shall equal or better the values shown in the table below:

Wavelength (nm)	Minimum QE (%)
350	>40
400	>70
500	>75

Dark current: The dark current shall be less than 1 e^-/pix/hour at a temperature of 160 K.
Readout noise: At a readout speed of 20 kpix/sec, the readout noise must be less than 3 electrons per pixel RMS.
Cosmetics: The CCD cosmetics shall equal or better the values shown in the table below:

Defects	Grade 0
Column defects (black or white)	6 or less
White spots	500 or less
Total spots (black or white)	1250 or less
Traps	30 or less

where the definition of the defects is as in the E2V Technologies data sheet, except that the definition of a black spot is a pixel which has 50 per cent or less responsivity.

CCD controllers: The CCD controller shall be appropriate for the CCD camera supplier's hardware.
Gain: At least two gain settings, under software control, shall be supplied.
Pre-binning: Pre-binning of 1 x 1 to 9 x 9, independently adjustable in each direction, shall be available.
Readout speed: The device will be capable of operating at readout speeds of up to 1 million pixels/sec.
Readout times: The time to read out the CCD array shall be less than or equal to the values shown in the table below:

Prebin/ Readout Speed	Readout Time (sec)	Readout Noise (e^-/pix)
1 x 1 Slow (100kHz)	50	4
2 x 2 Slow (100kHz)	15	5
1 x 1 Fast (400kHz)	18	9
2 x 2 Fast (400kHz)	6	10

Windowing: The CCD controller and software shall enable up to 5 windows to be selectable.
Software: The CCD controller software shall be in LabVIEW and/or C.

Pre-delivery compliance will be verified by laboratory tests at UC following acceptance tests at the blue CCD system manufacturer.
Procedures:
Test information from blue CCD system manufacturer will be reviewed at UC prior to approval to CCD system supplier to ship the blue CCD system. A series of compliance tests (for example, dark current, readout noise) will be repeated at UC when the blue CCD system is received.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The tests at UC will be repeated as a laboratory test at SALT.

5.2 CCD system for red camera

Fairchild Imaging CCD486 (data sheet, Rev 061804), Grade 1
Thinned, back illuminated CCD
Broad band antireflection coating
4k x 4k x 15micron square pixels
4 readout amplifiers per chip

For charge shuffling in the direction of cross-dispersion, the CCD must be aligned with the columns in this direction.

The CCD will have the following parameters:
CTE: The charge transfer efficiency shall be better than 99.999 per cent.
Full well: The peak charge storage shall be greater than 100,000 e^-/pix.
Sensitivities, quantum efficiency: The CCD QE, as a function of wavelength, shall equal or better the values shown in the table below:

Wavelength (nm)	Minimum QE (%)
550	>80
650	>80
800	>80
900	>50

Dark current: The dark current shall be less than 1 e^-/pix/hour at a temperature of 160 K.
Readout noise: At a readout speed of 50 kpix/sec, the system (CCD plus controller) readout noise must be less than 4 electrons per pixel RMS.
Cosmetics: The CCD cosmetics shall equal or better the values shown in the table below:

Defects	Grade 1
Column defects (total)	6 or less
Point defects (dark or hot)	200 or less
Cluster defects	25 or less

where the definition of the defects is as in the Fairchild Imaging CCD486 data sheet, Rev 061804.
CCD controllers: The CCD controller shall be appropriate for the CCD camera supplier's hardware.
Gain: At least two gain settings, under software control, shall be supplied.
Pre-binning: Pre-binning of 1 x 1 to 9 x 9, independently adjustable in each direction, shall be available.
Readout speed: The device will be capable of operating at readout speeds of up to 1 million pixels/sec.
Readout times: The time to read out the CCD array shall be less than or equal to the values shown in the table below:

Prebin/ Readout Speed	Readout Time (sec)	Readout Noise (e^-/pix)
1 x 1 Slow (100kHz)	50	4
2 x 2 Slow (100kHz)	15	5
1 x 1 Fast (400kHz)	18	9
2 x 2 Fast (400kHz)	6	10

Windowing: The CCD controller and software shall enable up to 5 windows to be selectable.
Software: The CCD controller software shall be in LabVIEW and/or C.

Pre-delivery compliance will be verified by laboratory tests at UC following acceptance tests at the red CCD system manufacturer.
Procedures:
Test information from red CCD system manufacturer will be reviewed at UC prior to approval to CCD system supplier to ship the red CCD system. A series of compliance tests (for example, dark current, readout noise) will be repeated at UC when the red CCD system is received.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The tests at UC will be repeated as a laboratory test at SALT.

6 Instrument performance requirements

6.1 Image quality

FPRD 5.1: A minimum image quality of 80% encircled energy within 25μm diameter must be obtained at 90% of all blaze wavelengths.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
The image quality for each camera will be verified by acceptance tests at the manufacturer as per Prime Optics tests specified in Section 6 of document 3210AA0007, dated February 23, 2005. Integrated image quality will be verified at UC using the 100μm high resolving power reference fibre and laboratory calibration sources.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
Image quality will be determined using the 100μm high resolving power reference fibre and either laboratory or telescope wavelength calibration sources.

6.2 Stability

6.2.1 Radial velocity precision

FPRD 5.2.1: The minimum requirement is for 30 m s^{-1} radial velocity precision for observations of sharp-lined G, F or K dwarfs and taken with a signal to noise S/N > 100 in the medium resolving power mode.

Pre-delivery compliance will be verified by partial laboratory test at UC.
Procedure:
A series of tests with a wavelength calibration lamp and the 100μm reference fibre will be undertaken to ensure the requisite repeatability of the positions of the emission lines.

Post-delivery compliance will be verified by telescope tests.
Procedure:
The UC test will be repeated at SALT and then telescope tests undertaken using a series of observations on selected sharp-lined G, F and K dwarf radial velocity standards observed with a S/N greater than 100 through the medium resolving power image slicer.

6.2.2 Line profile stability

FPRD 5.2.2: Minimum requirement of less than 1% change in the wavelength calibration lamp line profile over a 12 hour period for a fully illuminated pupil. The calibration lamp line intensity must remain stable to within 10% over 12 hours.

Pre-delivery compliance will be verified by partial laboratory test at UC.
Procedure:
A series of tests with the wavelength calibration lamp will be undertaken to ensure that the repeatability of the positions of the emission lines will introduce less than a 1% change in the wavelength calibration lamp line profile over a 12 hour period.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The UC test will be repeated at SALT and then again with telescope tests undertaken using a series of observations with the FIF and fully illuminating the pupil with the wavelength calibration lamp.

6.3 Scattered light

FPRD 5.3: The level of stray light is to be less than 5% of the local continuum averaged over the orders centred on the blaze wavelength.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
Stray light will be estimated using various continuous laboratory light sources.

Post-delivery compliance will be verified by reconfirmation laboratory test.

Procedure:
The level of stay light will be confirmed using stellar observations.

6.4 Ghosts

FPRD 5.4: Ghost images are to be less than 1% of the local continuum averaged over the orders centred on the blaze wavelength.

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
The ghost intensities will be estimated using a combination continuous and emission laboratory light sources.

Post-delivery compliance will be verified by reconfirmation laboratory test.
Procedure:
The above test will be repeated.

7 Spectrograph throughput requirements

FPRD 6: The SALT HRS (from the entrance to the fibre instrument feed to the CCD detector inclusive) will deliver throughput as a function of wavelength, resolving power and observing mode of at least 75% of the target throughputs in the following table, assuming the telescope delivers EE80 of 2.1" at the focal plane and with focal ratio degradation of 10%.

Resolving power (nominal)	Mode	Throughput (%) excl telescope	
		480 nm	650 nm
16,000	Fixed/N&S	21.5	29.2
37,000	Fixed	15.1	20.3
65,000	Fixed	9.6	12.9

Pre-delivery compliance will be verified by partial laboratory test at UC.
Procedure:
The absolute efficiency of all optical components will be determined either by the manufacturer or by tests at UC.

Post-delivery compliance will be verified by telescope tests only.
Procedure:
The throughput of SALT HRS (including the telescope) will be determined using standard spectrophotometric stars. Each star will be observed in the low, medium and high resolving power mode. The telescope image quality must meet the requirements stated above and the telescope pupil must be fully illuminated (or an appropriate correction made).

8 Mechanical requirements

8.1 Mechanical stability

FPRD 7.1: The spectrograph will be mechanically stable and isolated from the telescope facility such that any external sources of vibration will not resonate with natural frequencies of the spectrograph.

Pre-delivery compliance will be verified by partial laboratory test at UC.
Procedure:
The completed SALT HRS will be tested for its mechanical isolation by a series of vibration tests at a range of frequencies undertaken in the vicinity of the spectrograph.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The UC tests are to be repeated at SALT.

8.2 Thermal and pressure stability

8.2.1 Thermal isolation

FPRD 7.2.1: The operating temperature will be in the range 15 to 20 °C over a 12 month period, and the temperature will be stable to within 1 °C over a 1 day period.

Pre-delivery compliance will be verified by tests at SALT.
Procedure:
From late-2005 a six-month long temperature monitoring programme will be undertaken in the Spectrograph Room at SALT and simultaneously in a small scale insulated room to be placed in the Spectrograph Room.

The results will be used to assess whether the scaled insulated room complies with the requirements set in FPRD 7.2.1 and if not to use active temperature control to bring the insulated room to this requirement.

Post-delivery compliance will be verified by on-going monitoring at SALT.
Procedure:
Temperature monitoring will continue both inside and outside the enclosure to track compliance with this requirement.

8.2.2 Vacuum enclosure

FPRD 7.2.2: The spectrograph will be in an enclosure and maintained at pressures between 1 and 4 hPa.

Pre-delivery compliance will be verified by laboratory test at UC.

Procedure:
The completed SALT HRS will be tested for its ability to hold a vacuum in the range specified in the FPRD.

Post-delivery compliance will be verified by on-going monitoring.
Procedure:
The UC tests will be repeated at SALT.

9 Instrument control and reduction software requirements

9.1 Instrument control

FPRD 8.1: There will be software provided for:
- *Control of fibre feed selector;*
- *Control of target and calibration exposures, exposure meter, shutter and CCD;*
- *Control of the camera focus and monitoring of the temperature and pressure environment.*

Pre-delivery compliance will be verified by laboratory test at UC.
Procedure:
The control software will be tested to ensure that all functions of SALT HRS are operational.

Post-delivery compliance will be verified by laboratory and telescope tests.
Procedure:
The UC tests will be repeated to ensure that this requirement is satisfied.

9.2 Reduction software

FPRD 8.2: There will be software provided for:
- *Quick-look extraction for monitoring by SALT Astronomer;*
- *Science-quality extraction and calibration of spectra.*

Pre-delivery compliance will be verified by laboratory tests at UC.
Procedure:
The software will be tested to ensure that both quick-look extraction software and science-quality extraction and calibration software is operational.

Post-delivery compliance will be verified at SALT.
Procedure:
The UC tests will be repeated to ensure that this requirement is satisfied.