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LBT First Light AO system laboratory acceptance test specifications

S. Esposito, A. Riccardi

INAF – Osservatorio Astrofisico di Arcetri
Largo E. Fermi, 5 - 50125 Firenze - ITALY
http://www.arcetri.astro.it/adopt

ABSTRACT

The document reports the list of the tests to be completed during the laboratory acceptance test of the first light AO system of the LBT telescope. The required HW subsystems and SW to perform the considered tests are listed too. Specifications for successful test completion are given. The LBT AO system to be tested includes the adaptive secondary mirror as system deformable mirror and the W unit as the wavefront sensing unit. The acceptance test will be done in the refurbished solar tower.

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a	21 Feb 2005	S. Esposito		First release of the document
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Abbreviations, acronyms and symbols

Symbol	Description
LBT	Large Binocular Telescope
MMT	6.5m MMT telescope
AGW	Acquisition, Guiding and Wavefront sensing unit
AO	Adaptive Optics
W	On axis Wavefront sensing unit
LBT672a	First Adaptive secondary unit of LBT telescope
PSF	Point Spread Function
ARNICA	ARcetri Near Infrared CAmera
GUI	Graphical User Interface
TCS	Telescope Control System
ROI	Region Of Interest
FoV	Field of View
RTR	Real Time Reconstructor
RON	Read Out Noise
DM	Deformable mirror
SNR	Signal to Noise Ratio
WFS	WaveFront Sensor
SR	Strehl ratio
ADS	ADS International SRL
IM	Interaction Matrix

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1 Introduction

The present document is listing the tests to be done in order to validate the performance of the First Light AO system for LBT. This test will be done in the Arcetri Solar Tower that has been refurbished for this purpose. The test set-up for the overall AO system is based on testing the elliptical secondary illuminating it from the long focus and reflecting the light back in the short focus. A first list of tests to be done was outlined in the AO progress meeting held in Florence in February 2005 [1].

2 Requirements before AO system testing

The AO system test in the solar tower requires several subsystems to be integrated in the solar tower. Moreover different control software packages have to be installed and working. A detailed list of both items (required HW and SW) is reported below:

1. The adaptive secondary mirror of LBT namely LBT672a has to be installed at the top of vertical optical bench in the solar tower. The LBT672 functionalities have to be checked in the LBT672a acceptance test ("flattened secondary shell, ready for AO test" milestone has been reached). This will include the mirror flattening and the identification of mirror modes [2].
2. The W unit has to be mounted in the AGW frame. The W unit functionalities have to be checked in the W acceptance test ("W system ready for System test" milestone has been reached). The AGW frame has to be attached to the bottom end of the vertical optical bench in the solar tower. A proper device for AGW handling is under development in ADS [3].
3. An optical interferometer has to be mounted in the W unit to provide an external metrology. This instrument is used to measure the LBT672 optical shape during the entire performed test including mirror flattening and mirror modes identification. The interferometer will be aligned with the secondary mirror and with the W unit. A 4D single shot interferometer has been foreseen for this task. This unit will be tested in the optical laboratory to check for functionalities, measurement range and accuracy. The control software needed to operate the interferometer using the engineering GUI of the AO supervisor will be developed during the mentioned laboratory test.
4. An infrared camera will be used for the Solar Tower test to measure closed loop Strehl Ratios. The actual baseline for this camera is the Arcetri ARNICA infrared array. This camera will be placed at the bottom of the AGW frame in the simulated f/15 focal plane. On axis long exposure PSF in J, H and K bands will be measured using this camera. This camera is based on a 256x256 NICMOS engineering chip provided by Arcetri Observatory. The camera plate scale is approx 20mas/pix. The camera can provide ROI frame rate of 25 fps with a 16X16 sub-array. This feature could be useful for time critical PSF sampling.
5. The hexapod will be mounted in the secondary hub. The hexapod has to be operational. It will be used to align the secondary with the W unit. Offload of tip tilt and defocus from AO system to the telescope will be tested using the hexapod. Control software for the hexapod has to be operational trough TCS.
6. TCS software needed to test the AO system functionalities has to be installed and running. Specifically the TCS AO GUI (at least the TCS commands/procedures triggered by the TCS AO GUI), the mode-offloading control software (i.e. alignment & collimation arbitrator, at least for the offloading-to-hexapod part)
7. The retro reflector used at the secondary short focus has to be integrated and the overall optical system LBT672a, wavefront sensor, interferometer and retro reflector will be aligned [5]. The following two measurement configurations will be used:
    a. Illumination of Adaptive Secondary using the external metrology interferometer. This configuration will be used for mirror flattening, mirror influence functions measurements, mirror modes identification.
    b. Illumination of Adaptive Secondary and W sensor. This is done using the interferometer light source. The use of a polychromatic source is required for IR closed loop test. An optical design of the retro reflecting unit that uses only mirrors has been already completed. This reflective unit will be used for IR testing of the AO system.
8. The AO system supervisor software has to be installed and running on the AO system workstation [4].

9. The engineering interface software has to be installed and running on the AO system workstation

3 Real Time loop functionality

The functionality of the real time loop chain of the AO system [6] will be checked before closed loop performance test. These tests require connecting the W unit and LBT672 using the real time fiber link only and so can be performed before units integration in the solar test tower. In other words the test is performed in optical open loop.

1. Real Time chain up and running. The correct real time HW and SW initialization will be checked.
2. Real time chain data flow check and computations validation. Correct implementation of closed loop algorithm will be checked for consistency. The diagnostic lines will be used to download wavefront sensor CCD frames, computed slopes, and computed mirror commands. Numerical computations for some particular CCD frame cases (i.e. bias of a single CCD quadrant is increased) will be checked using off line computation.
3. Electronic dependant time delay. The time delay of the real time chain is defined as the time elapsed between the end of the CCD exposure and the start of actuation of the LBT672 actuator commands. This delay time depends on CCD frame read-out time and parallel slope computation time, slope transmission to LBT672 RTR, commands computing time on LBT672 DSPs. The delay time will be measured checking the time elapsed between the CCD end of frame signal and the LBT672 update mirror position flag. Expected electronic time delay due to read out time should be less than the nominal value reported in the following table. The fixed contribution of slopes transmission and RTR computations is 160 microsecond (see R. Biasi presentation February 05). Total expected time delay is the sum of read out time and computation time.

<u>Table Legend</u>	**Frame rate / Bin factor**	**100**	**200**	**400**	**600**	**1000**
Pixel rate [KHz] / RON[e-] Read-out time [ms]	**1x1**	**400/4.5 4.86**	**400/4.5 4.86**	**850/5.8 2.37**	**2500/8.4 0.916**	**2500/8.4 0.916**
	2x2	**150/3.5 6.11**	**400/4.5 2.36**	**400/4.5 2.36**	**850/5.8 1.17**	**2500/8.4 0.474**
	3x3	**150/3.5 3.2**	**150/3.5 3.2**	**400/4.5 1.25**	**400/4.5 1.25**	**850/5.8 0.642**
	4x4	**150/3.5 2.36**	**150/3.5 2.36**	**150/3.5 2.36**	**400/4.5 0.939**	**400/4.5 0.939**
	5x5	**150/3.5 1.68**	**150/3.5 1.68**	**150/3.5 1.68**	**400/4.5 0.685**	**400/4.5 0.685**

4 AO system Calibration

The AO system calibration test has to demonstrate the possibility of measuring all the calibration data needed to operate the AO system at the telescope. The entire test mentioned in this and in the following sections will be performed in the Solar Tower.

1. LBT672 flattening procedure. The flattening procedure will produce the set of commands that place the adaptive secondary in a position having a minimal wavefront optical quality of 65nm rms. A goal of 30nm wavefront rms is considered [1].

2. WFS pupil registration. Pupil images have to be registered to the pixel grid. Because the actuator patter is fixed with the pupil (the secondary mirror is the telescope pupil and the telescope DM) registering pupil image register the actuator grid too. Pupil registration repeatability is fundamental in order to use the measured interaction matrix at the telescope. Accuracy of pupil registration procedure has to be less than 1/10 of CCD pixel. The pupil position will be measured using the wavefront sensor CCD.
3. Interaction matrix measurements. The mirror modes achieved after the mirror flattening procedure (see LBT672 calibration plan). These modes will be used as orthonormal base to generate a given set of AO system modes. Possible choices are Karhounen-Loewe or mirror modes. The Interaction Matrix between LBT672 and W sensor will be measured. Two methods for interaction matrix acquisition will be tested namely:
   a) Classical push pull technique
   b) Sinusoidal modulation technique. This method will provide a better SNR and will reduce the measurement time. This technique will be used for on-sky measurement of the interaction matrix.
      The quality of acquired interaction matrices in terms of noise propagation coefficients and repeatability will be checked. However IM performance has to be finalized measuring the AO system performances in closed loop. Interaction matrices will be measured as a function of number of subapertures (CCD binning) and tip tilt modulation amplitude.
4. Slope null acquisition. The slope null represent the reference signal for the wavefront sensor. The AO closed loop will position the mirror in order to produce a pattern of slopes of opposite sign w.r.t. the slope null. This signal pattern has to be determined considering a particular focal plane detector and finding the adaptive secondary configuration delivering the best Strehl Ratio on that particular detector. This procedure of SR maximization will be done using phase diversity algorithms. The achieved unperturbed SR should be better than 0.75 in J band, 0.85 in H band and 0.9 in K band. This corresponds to 90nm residual rms at all wavelengths.

5 Closed loop performance

Three types of closed loop tests will be run during the AO system test:

1. Closed loop test with no input disturbance. This test will measure the goodness of the achieved slope null pattern. The closed loop SR is driven by the achieved flattening wavefront residual during the LBT672 optical acceptance test. Considering the specification on the flattening [1], SR value has to be better than 60% (goal 90%) at 633nm, 30x30 sampling, 1 kHz loop frequency, full-mode correction, bright reference and kept for 20 minutes.
2. Closed loop with digital input disturbance. This test is achieved using the feature of the LBT672 unit to add some pre loaded time history of commands to the commands computed using the sensor signal. This adding is done by the DSPs aboard the secondary unit. This test mode will provide the ultimate performance of the system because all the aberrations introduced are removable using the secondary. The H band SR should be better than [7][1]:
   i) 87%, equivalent reference star: 8 mag(R), median seeing conditions (r0=0.15m at 500nm, 15m/s wind speed)
   ii) 53%, equivalent reference star: 12 mag(R),median seeing conditions
   iii) 17%, equivalent reference star: 16 mag(R), median seeing conditions
3. Closed loop with phase screen. MMT rotating phase screen will be used for complete testing of the closed loop performance when input perturbation is no longer completely decomposed on the mirror modes. The H band SR should be better than [7][2]:
   i) 80%, equivalent reference star: 8 mag(R), median seeing conditions (r0=0.15m at 500nm, 15m/s wind speed)
   ii) 50%, equivalent reference star: 12 mag(R),median seeing conditions
   iii) 15%, equivalent reference star: 16 mag(R), median seeing conditions
   The SR values achieved in this test will be degraded by the chromaticity effect of MMT phase plates. This effect will be calibrated out measuring the achieved infrared SR in static (i.e. no-spinning phase plates) and

[1] Paper do not consider: read out time, RTR computation time and flattening error. These effects on SR are computed and added to paper result.
[2] Paper do not consider: read out time, RTR computation time and flattening error. These effects on SR are computed and added to paper result.

bright-source condition. The calibrated correction is obtained averaging SR values achieved on at least 10 (30 goal) patches of phase plates.

The considered three tests will be done measuring the SR at the sensor wavelength (0.7 micron) using the technical channel CCD and in the IR at J, H and K bands using the infrared test camera. The SR will be measured as a function of photon flux, integration time, binning mode, tip tilt modulation amplitude. The IR data will provide the basis for look up tables for AO system configuration to be used at LBT for on sky operations. Because of chromatic aberrations of the MMT phase screen high IR SR measurement will be better done using the test described in 2. The entire considered closed loop test will be done considering a least square type of reconstructor and a maximum likelihood reconstructor using prior information about the statistic of the input disturbance. Results of the two different approaches will be compared.

6 TCS mode offloading

We assume to offload Zernike modes up to Z11 in Noll ordering. Mode offloading to the telescope trough the TCS will be tested at the level of correct command transmission. The particular case of offloading modes to Hexapod can be physically tested. For instance a quasi-static tilt error can be introduced during AO closed loop moving the wavefront sensor board with the translation stages. The AO loop keeps the PSF locked on the W pyramid and the corresponding counter-tilt is applied by the adaptive mirror. The accumulated static mirror tilt command is sent to TCS. TCS has to react commanding the hexapod to null the static mirror tilt. At the end of the TCS offloading the accumulated static mirror tilt command should be reduced by 90%. Similar test can be performed for focus offloading.

7 AO supervisor diagnostic lines

The diagnostic lines test will be devoted to assess the correctness of the diagnostic data provided by the W control software. Two types of data are stored for diagnostic, W unit status, LBT672 staus and AO loop data. AO loop data will be checked operating the diagnostic lines during closed loop. The following time tagged data will be logged on files at a minimum frequency of 40 Hz. The dataset includes:

- WFS CCD frames
- WFS computed slopes
- LBT672 actuator commands/positions/forces

8 System Observing modes

The AO supervisor will act like a sequencer to control the AO system HW in order to perform the AO system observing modes. A list of the observing modes to be checked is reported below. The aim of the test will be to verify the correct execution of the following four operating modes.

1. Fixed mode (FM). Adaptive secondary mirror is holding a fixed shape for a given time. The optical shape of the secondary can be selected from a set of pre-defined shapes. This mode will be used basically for seeing limited observations.
2. Tip Tilt Mode (TTM) . In this mode only tip-tilt is corrected using the W sensor tilt measurements. This mode will support external tip-tilt signals. TCS will notify the correction signal to AO supervisor that in turns will drive the AO tip-tilt loop.
3. Auto-configured Adaptive mode (AAM). In this mode the reference star co-ordinates and magnitude are required. In this mode the AO supervisor will select the AO system configuration in order to achieve the best SR. Basic configured parameters will be, integration time, number of sensor subapertures, number of corrected modes, tip-tilt modulation amplitude. AO supervisor will configure the AO system using some pre-computed look-up tables.
4. Auto-configured Interactive Adaptive mode (AIAM). In this mode the reference star co-ordinates and magnitude are required. The AO supervisor will configure the AO system. However the user can change some configuration parameters among pre-defined values. Main adjustable parameters are:

- Integration time
- Number of Subapertures
- Number of corrected modes
- Tip-tilt Modulation amplitude

9 Documentation

A beta version of the AO system documentation will be provided at least one month before the AO system acceptance test in Arcetri. The final documentation version will include all the necessary modifications accordingly to the acceptance test. Final documentation will be delivered one month after the completion of the acceptance test. The documentation will include the following documents:

1. AO system user manual. This manual is intended as a tool to properly configure and operate the AO system once it is installed and aligned on the LBT telescope. The documents will include relevant data sheet, AO system configurations templates, performance list and look up tables.

2. AO system engineering documentation. This second part of documentation is aimed to provide a tool for a quite complete check and configuration of all the AO subsystem. The main issues of this set of documents are:

   - Adaptive secondary unit mechanics [ADS]
   - Adaptive secondary electronics [MicroGate]
   - Adaptive secondary embedded software[MicroGate]
   - Adaptive secondary test configuration and diagnostic software [Arcetri]
   - Wavefront sensor opto-mechanics [Arcetri]
   - Wavefront sensor auxiliary optics [Arcetri]
   - Board positioning stages [Arcetri]
   - W unit electronic boxes [Arcetri]
   - Board CCDs head and control electronic [Arcetri/MicroGate]
   - Real time control electronic and SW [MicroGate]
   - AO system supervisor SW[Arcetri]

10 References

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