LBT PROJECT
2 X 8,4m OPTICAL TELESCOPE

LBT672 On-axis Wavefront sensor #1
Lab Acceptance Test Report

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepared</td>
<td>Joar Brynnel</td>
</tr>
<tr>
<td>Approved</td>
<td>Simone Esposito</td>
</tr>
<tr>
<td>Released</td>
<td>Joar Brynnel</td>
</tr>
</tbody>
</table>
1. Revision History

<table>
<thead>
<tr>
<th>Issue</th>
<th>Date</th>
<th>Changes</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>31-May-06</td>
<td>Issue a</td>
<td>Joar Brynnel</td>
</tr>
</tbody>
</table>
| B     | 5-Jun-06   | Issue b
5.6.7: Added section
5.6.8: Added section
5.6.9: Added section
New Action Items: AI 31 - AI 34 | Joar Brynnel |
| C     | 14-Aug-06  | Issue c
Results from thermal and flexure testing added
3.1: Text added after Potsdam test
4: Text added after Potsdam test
5.8.1: Weight measurement added to text
New Sections
6: Added Action Items AI35-AI39 | Joar Brynnel |
| D     | 24-Oct-06  | Section 7: Corrected inconsistencies in Action Items Summary (numbering inconsistency)
Section 8: At the request from Arcetri, due dates for documentation was extended to Jan 2007. | Joar Brynnel      |
| E     | 25-July-08 | Repeat complete acceptance test                                         | Joar Brynnel      |
| F     | 27-July-08 | Updated report:
5.8.3: Updated table with correct results
5.7.2: Added section: Pupil Re-rotator
5.7.3: Added section: Tip-Tilt mirror
5.7.4: Added section: Camera lens
5.7.10: Updated section with results
5.8.1: Added comment
6: New Action Item AI24
6: Updated due dates for action items | Joar Brynnel |
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3. About this document

3.1. Purpose

Subsystems manufactured for the Large Binocular Telescope (LBT) shall be subjected to acceptance testing before leaving suppliers premises. The test constitutes a major milestone, and based on the test result the LBT Director may grant “Lab Acceptance” after which the equipment may be shipped to Arizona.

Two “W” On-axis Pyramid wavefront sensors are developed and built by Arcetri under the contract AO103 “WLBT On-Axis Wavefront Sensing Units”.

In May 2006 the W unit #1 was Lab Acceptance tested (see 687s001d). This test resulted in a relatively large number of Action Items. The unit has since then been upgraded and improved. For this reason it was mutually agreed to repeat the acceptance test.

This document describes test results from the repeated Lab Acceptance Tests of “W” unit #1, performed at Arcetri Observatory on May 28-30 2008.

3.2. Scope

In this document test results are documented. Performance test cases are documented in [RD2]. Performance, operation, interfacing, and inspection results, an executive summary and resulting Action Items are contained in this document.

3.3. Reference Documents

[RD1] LBTO Contract AO103  WLBT On-Axis Wavefront Sensing Units
[RD2] 687f002 W unit laboratory acceptance test specifications, S. Esposito, A. Tozzi, A. Puglisi, E. Pinna
[RD3] Tip-Tilt mirror test report (to be released)
[RD4] ADC Test Report (to be released)
[RD5] Optical de-rotator test report (to be released)
[RD7] 562s002 Telescope Cooling System Installation
[RD8] 670s001 Instrument Rotator and Cable Chain technical specifications
**4. Executive Summary**

The “W” pyramid wavefront sensors are key components for the LBT Adaptive Optics system. Overall system AO performance and reliability depends on how well the subsystems function. Therefore it is important that the “W” sensors are well characterized and debugged in advance of AO system tests in Arcetri and subsequent tests on the LBT.

An acceptance test of the on-axis sensor “W” #1 was carried out during summer of 2006 (see Issue “c” and “d” of this document). A relatively large number of issues were identified during this test, resulting in several action items. In the process of addressing those action items, the design was improved and modified. For this reason it was decided to repeat the full acceptance test. The results of testing of the improved design are contained in this document. A significant improvement is the addition of a remote controlled camera lens adjustment added to compensate for pupil displacement induced by the re-rotator.

It is a pleasure to report that the revised design and implementation of the W sensor #1 unit meet expectations in most, if not all, areas. No showstoppers were identified; however some issues need further attention (see Action Item list). In particular the following is noted:

- Some components on the sensor optics board are warmer than ambient. This is critical since it is in the non-common optical path.
- Complete unit must be balanced around the instrument rotator axis
- Component failure at low temperatures

It is expected to re-visit the status of action items very soon, and review the official outcome of the test at that time.

The PO would like to thank the “W” team in Arcetri for excellent cooperation during the acceptance test, and also acknowledge the outstanding work in bringing the “W” unit #1 to this state of completion and performance.
Figure 1: On-Axis wavefront sensor optical table

Figure 2: AGw #1 front side
5. Test Results

5.1. Glycol cooling system inspection

The W unit will be connected to the LBT facility glycol cooling system. Cooling liquid is divided first between the AGw unit and the on-axis system, and then further divided for cooling of the various electronics boxes and CCD units. The on-axis system internal coolant distribution appears appropriate for the application.

5.2. Surface temperatures

To check for local hot spots and temperature distribution, IR images were acquired with the W sensor in full operation.

Figure 3: Thermal image of complete unit, front side

Figure 3 shows a thermal overview of the complete on-axis system. For the test, the system was supplied with a glycol/water mixture with a temperature of approximately 20 degrees. Ambient temperature was about 22C. The electronics boxes on the lower left and right are cooled by large cooling plates with extremely uniform surface temperatures of 20.5 degrees. The two CCD heads in between the large electronics boxes are also supplied with coolant. The optical bench is at a temperature of 23 degrees generally slightly warmer than ambient. Some hotspots are visible on the optical bench, most notably the re-rotator stepper motor and the XYZ stage motor encoders that have surface temperatures of around 25 degrees.
Figure 4: Re-rotator stepper motor

Figure 4 shows a close-up of the re-rotator motor. Maximum surface temperature is 26.5 degrees.

AI: Investigate reason for hot re-rotator motor.

Figure 5: Thermal image of filter wheel motor

The filter wheel motor, imaged in Figure 5, was running warm with a temperature of 43 degrees.

AI: Investigate reason for hot filter wheel motor.
The front side thermal image is shown in Figure 6. The large part in the upper part of the image is the base plate for the off-axis WFS. Clearly visible in the thermal image are the coolant supply and return hoses (blue=cold), and the calibration source enclosure on the lower left. In addition, the Camera Lens control electronics (right side of image) was running at a temperature of 27°C, in spite of being water cooled. At the time of testing, the Camera Lens electronics was not yet packaged in the system. Attention must be paid to thermal aspects when integrating the Camera Lens electronics in the system.

Figure 7: Calibration source enclosure
The calibration source enclosure contains motor control electronics and a light source. No active cooling is provided. Since the calibration source it not required for sensor operation, attention must be paid to minimize its duty cycle.

As mentioned already, the camera lens electronics were not packaged and integrated into the system at the time of testing. Although the electronics was mounted on a cold plate, the surface temperature was as high as 27°C.

AI: Improve cooling of Camera lens electronics

### 5.3. Glycol cooling system flow and pressure

During the test the W sensor was supplied with cooling liquid from a closed loop chiller. We measured the following flow and pressure. Note that this numbers are for the W sensor only, the off-axis cooling system was turned off.

Pressure in: 2.5 Bar  
Pressure out: 1.5 Bar  
Flow rate: 7.0 L/min  

A pressure test was done using compressed air. The cooling system was pressurized to 8 Bars. After 10 hours the pressure had dropped to 1 Bar. The leakage must be identified and corrected for.

AI: Pressure test complete cooling system at 10 Bar
5.4. Over-temperature protection

The coolant system flow was turned off, and the system was left in full operation. The over temperature sensor, located in one of the electronics enclosures was programmed for a switch-point of 42°C. After approximately one hour of operation the sensor triggered and the system shut down automatically.

5.5. Electrical power supply

The W unit uses one power supply connection 120VAC/60Hz. For the duration of this Lab Acceptance test a transformer-fed supply 110VAC/50Hz was used.

Test result:

All units on: 3.5A/118VAC/50Hz max current draw.

A surge protection is currently integrated in one of the electronics boxes. It was agreed to re-locate the surge protection to the power interface panel.

AI Relocate surge suppression unit at the power input port

5.6. General inspection

The unit was inspected for completeness and workmanship. The following was noted.

AI: The following parts do not have appropriate surface treatment: CCD cooler cover, re-rotator bracket.

AI: Main coolant connection not labeled.

AI: Control electronics for camera lens not packaged.

AI: Labeling of connectors and cables is incomplete and need improvement

AI: Replace defect encoder on Z stage motor.

AI: AGW internal baffling shall be designed and implemented.

AI: Temperature sensor “BCU39 not working.

AI: CCD39 grounding not properly implemented

AI: No filters inserted in filter wheel 2
5.7. Performance

Performance was tested according to test procedure [RD2]. The following was noted during test.

5.7.1. Pupil Images optical configuration

Measurement was performed according to Section 4 of [RD2], with the goal to verify pupil diameters to 30 +/-0.1 pixels on the WFS CCD, and pupil center distances to 36 +/-0.1 pixels.

Figure 9: Pupil configuration

Conclusion: Pupil diameters (average) are in specification. Center distances are not in specification. Center distance can be adjusted independently from pupil diameter by adjusting focus of the WFS board.

AI: Adjust focus on WFS board to correct pupil image geometry
### 5.7.2. Pupil Re-rotator

The pupil re-rotator stage performance was verified.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Requirement</th>
<th>Measured</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSF total displacement</td>
<td>0.5 arcsec</td>
<td>0.08 arcsec</td>
<td>Pass</td>
</tr>
<tr>
<td>PSF displacement during integration</td>
<td>9 µm (2.5 deg rotation)</td>
<td>6 µm</td>
<td>Pass</td>
</tr>
<tr>
<td>Pupil image total center displacement</td>
<td>+/- 2 pix&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.7 pix</td>
<td>Pass</td>
</tr>
<tr>
<td>Pupil image displacement during integration</td>
<td>0.1 pix (2.5 deg rotation)</td>
<td>90: 0.07 px, 180: 0.03 px, 270: 0.1 px, 360: 0.1 px</td>
<td>Pass</td>
</tr>
</tbody>
</table>

<sup>1</sup> Requirement changed after addition of remote controlled camera lens

### 5.7.3. Fast Tip-Tilt mirror

Test of tip-tilt mirror unit performance: available amplitude vs. modulation frequency.

<table>
<thead>
<tr>
<th>Modulation Freq</th>
<th>Requirement</th>
<th>Measured</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Hz</td>
<td>500 urad</td>
<td>9000 urad</td>
<td>Pass</td>
</tr>
<tr>
<td>200 Hz</td>
<td>420 urad</td>
<td>8000 urad</td>
<td>Pass</td>
</tr>
<tr>
<td>400 Hz</td>
<td>250 urad</td>
<td>5700 urad</td>
<td>Pass</td>
</tr>
<tr>
<td>600 Hz</td>
<td>170 urad</td>
<td>4200 urad</td>
<td>Pass</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>90 urad</td>
<td>1900 urad</td>
<td>Pass</td>
</tr>
</tbody>
</table>
5.7.4. Camera lens translation

Measurement of available stroke in X and Y of the camera lens stages.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Requirement</th>
<th>Measured</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>4 pix</td>
<td>7.2 pix</td>
<td>Pass</td>
</tr>
<tr>
<td>Y</td>
<td>4 pix</td>
<td>7.3 pix</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Measurement of positioning accuracy and stability in X and Y of the camera lens stages.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Requirement</th>
<th>Measured</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0.1 pix</td>
<td>&lt;0.05 pix</td>
<td>Pass</td>
</tr>
<tr>
<td>Y</td>
<td>0.1 pix</td>
<td>&lt;0.05 pix</td>
<td>Pass</td>
</tr>
</tbody>
</table>

5.7.5. X stage absolute repeatability

The stage was homed, and moved to an absolute position. The final position was measured with an electronic dial gauge with a measurement resolution of 1 um. Requirement for X stage repeatability is 28 um.

<table>
<thead>
<tr>
<th>Measurement #</th>
<th>Position</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.771 mm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.770 mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.770 mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.770 mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.771 mm</td>
<td></td>
</tr>
</tbody>
</table>

X stage PtV = 1 um Pass

5.7.6. Y stage absolute repeatability

The stage was homed, and moved to an absolute position. The final position was measured with an electronic dial gauge with a measurement resolution of 1 um. Requirement for Y stage repeatability is 28 um.

<table>
<thead>
<tr>
<th>Measurement #</th>
<th>Position</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.260 mm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.265 mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.266 mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.264 mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.267 mm</td>
<td></td>
</tr>
</tbody>
</table>

Y stage PtV = 7 um Pass
5.7.7. Z stage absolute repeatability

The stage was homed, and moved to an absolute position. The final position was measured with an electronic dial gauge with a measurement resolution of 1 um. Requirement for Z stage repeatability is 100 um.

<table>
<thead>
<tr>
<th>Measurement #</th>
<th>Position</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.618 mm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.617 mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.617 mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.615 mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.620 mm</td>
<td></td>
</tr>
<tr>
<td><strong>Z stage PtV</strong></td>
<td><strong>5 um</strong></td>
<td><strong>Pass</strong></td>
</tr>
</tbody>
</table>

5.7.8. CCD39 Performance test

Readout noise of the CCD39 WFS camera was measured at various readout speeds and ambient temperatures (-20C, -10C and +20C).

<table>
<thead>
<tr>
<th>Pixel rate</th>
<th>RON -20C</th>
<th>RON -10C</th>
<th>RON +20C</th>
<th>Req. RON</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>12 e-</td>
<td>11.9 e-</td>
<td>20.1 e-</td>
<td>8.4 e-</td>
<td>Fail</td>
</tr>
<tr>
<td>890</td>
<td>8 e-</td>
<td>7.6 e-</td>
<td>12.7 e-</td>
<td>5.8 e-</td>
<td>Fail</td>
</tr>
<tr>
<td>400</td>
<td>4.5 e-</td>
<td>4.1 e-</td>
<td>4.6 e-</td>
<td>4.5 e-</td>
<td>Pass</td>
</tr>
<tr>
<td>150</td>
<td>6.5 e-</td>
<td>5.5 e-</td>
<td>5.1 e-</td>
<td>3.5 e-</td>
<td>Fail</td>
</tr>
</tbody>
</table>

AI: CCD39 detector readout noise partially not meeting specifications.

5.7.9. CCD47 Performance test

Readout noise of the CCD57 acquisition camera was measured at various readout speeds. Detector temperature -27C.

<table>
<thead>
<tr>
<th>Pixel rate</th>
<th>Measured RON</th>
<th>Requirement RON</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>18 e-</td>
<td>8.4 e-</td>
<td>Fail</td>
</tr>
<tr>
<td>250</td>
<td>12 e-</td>
<td>5.8 e-</td>
<td>Fail</td>
</tr>
</tbody>
</table>

AI: CCD47 detector readout noise not meeting specifications.
5.7.10. Reference Star Acquisition

The accuracy of the automatic reference star acquisition was tested using an artificial reference source.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Required accuracy</th>
<th>Measured accuracy</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centering accuracy</td>
<td>40.2 um in focal plane</td>
<td>3.3 um in focal plane</td>
<td>Pass</td>
</tr>
</tbody>
</table>

5.8. Interface verification

5.8.1. Mechanical Interface

Complete AGW unit (Off-axis + On-axis + AGW structure): 684Kg

According to [RD6] the AGW weight requirement is 600Kg.

Note: While this nominally violates the maximum weight requirement, it is not considered critical. Given the situation, the unit shall be weighed again after addressing the rotational balance problem (see section 5.8.2). If counterweights are added to balance the unit, this could push the AGW total weight into an unacceptable range.

AI: Weigh unit after balancing.

5.8.2. Rotational imbalance

Imbalance around the rotator axis was measured to 382 Nm without the off-axis CCD controllers installed. According to [RD8] the maximum compounded imbalance for AGW and instrument (here: Lucifer) is 200Nm.

AI: Reduce AGW imbalance to less than 50 Nm.
5.8.3. **Optical Interface**

XY stages travel ranges:

<table>
<thead>
<tr>
<th>Direction</th>
<th>Measured range</th>
<th>Requirement</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>X positive</td>
<td>2.1 arcmin</td>
<td>2.2 arcmin</td>
<td>Pass</td>
</tr>
<tr>
<td>X negative</td>
<td>-1.1 arcmin</td>
<td>-1.05 arcmin</td>
<td>Pass</td>
</tr>
<tr>
<td>Y positive</td>
<td>+78 arcsec</td>
<td>+84 arcsec</td>
<td>Pass</td>
</tr>
<tr>
<td>Y negative</td>
<td>-60 arcsec</td>
<td>-62 arcsec</td>
<td>Pass</td>
</tr>
</tbody>
</table>

It appears that the W bench is well centered in X and Y.

5.8.4. **Electrical Interface**

See section 5.5.

5.8.5. **Software Interface**

Since the W unit is a subsystem of the AOS (Adaptive Optics Supervisor) software, there is no direct software interface to the TCS.

5.8.6. **Network Interface**

Two optical fiber connections are required:

- Ethernet: Instrument control, CCD39 controller, CCD47 controller
- Fiber Fast Link to Adaptive Secondary

AI: Fast Fiber Link to Adaptive Secondary not installed

5.9. **Software**

During the test, the W engineering software was used to control the W unit, and to acquire measurement results. The engineering software worked flawlessly during the test and seems complete. The engineering GUI’s appear complete and logically structured.
5.10. Functional test at varying ambient temperature

The W sensor was tested for functionality at different ambient temperatures. Tests were carried out in a climate chamber in Arcetri. The W sensor was integrated in the AGw structure together with the complete off-axis unit.

Chamber temperature was set to 0, -2, -11, and -20 degrees C. Each time the AGW was allowed to stabilize thermally, and the W system was operated to verify functionality at different temperature.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>+18C</td>
<td>Full system test before test. System fully functional.</td>
</tr>
<tr>
<td>0C</td>
<td>• Z stage positive limit switch stopped working (limit signal always active).2</td>
</tr>
</tbody>
</table>
| -20C        | • Problem with re-rotator controller. Tried to re-start, but it appears that the unit is stuck mechanically. Fixed by reducing re-rotator rotation speed from 12 to 4 units.  
              • Camera lens X and Y adjustment motion does not move properly.  
              • Some vignetting observed on CCD39, caused by slight misalignment of beamsplitter cube, likely from thermal effects in the cold. Cube angle was re-adjusted by 0.2 degrees which removed vignetting.  
              • Z stage limit switch issue (see above) |
| -11C        | • Re-rotator issue (see above).  
              • Camera lens X and Y adjustment issue (see above)  
              • CCD39 vignetting issue (see above). 0.2 degree position adjustment.  
              • Z-stage limit switch issue (see above) |
| -2C         | • Re-rotator working normally again.  
              • Camera lens X and Y adjustment issue (see above)  
              • CCD39 vignetting issue (see above). 0.1 degree position adjustment.  
              • Z-stage limit switch issue (see above) |
| +18C        | Full system test after test. System again fully functional. |

AI: Investigate reason for Z stage limit switch failure  
AI: Investigate reason for Re-rotator failure  
AI: Investigate reason for Camera lens failure  
AI: Investigate reason for optical mis-alignment at low temperatures

2 Workaround implemented in SW allowed for continued test.
6. Action Items Summary

Action Items are summarized, and completion date for individual action dates are assigned:

- AINT: Action Item must be completed before AO system integration and test in the Test Tower
- MTN: Action Item must be completed before delivery to the mountain.

<table>
<thead>
<tr>
<th>AI#</th>
<th>Ref</th>
<th>Issue</th>
<th>Status</th>
<th>Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.2</td>
<td>Investigate reason for hot re-rotator motor</td>
<td>Open</td>
<td>AINT</td>
</tr>
<tr>
<td>2</td>
<td>5.2</td>
<td>Investigate reason for hot filter wheel motor</td>
<td>Open</td>
<td>AINT</td>
</tr>
<tr>
<td>3</td>
<td>5.2</td>
<td>Improve cooling of Camera lens electronics</td>
<td>Open</td>
<td>AINT</td>
</tr>
<tr>
<td>4</td>
<td>5.3</td>
<td>Pressure test complete cooling system at 10 Bar</td>
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<td>5.5</td>
<td>Relocate surge suppression unit at the power input port</td>
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<td>6</td>
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<td>The following parts do not have appropriate surface treatment: CCD cooler cover, re-rotator bracket.</td>
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<td>7</td>
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<td>Main coolant connection not labeled</td>
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<td>8</td>
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<td>Labeling of connectors and cables is incomplete and need improvement</td>
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<td>9</td>
<td>5.6</td>
<td>Replace defect encoder on Z stage motor</td>
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<td>AGW internal baffling shall be designed and implemented</td>
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<td>CCD39 grounding not properly implemented</td>
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<td>Adjust focus on WFS board to correct pupil image geometry</td>
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<td>Reduce AGw imbalance to less than 50 Nm</td>
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### 7. Documentation

The following list of documentation was agreed upon, including delivery dates for a draft version of the document.

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