Atmospheric Dispersion Corrector for W unit (ADC)

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ABSTRACT

The ADC (Atmospheric Dispersion Corrector) is the device that compensates the effect of “differential atmospheric refraction”, that is a consequence of the wavelength-dependent index of refraction of the atmosphere. It is based on two couples of prisms.
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### Abbreviations, acronyms and symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>LBT</td>
<td>Large Binocular Telescope</td>
</tr>
<tr>
<td>ADC</td>
<td>Atmospheric Dispersion Corrector</td>
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1 The “ADC” unit:

The ADC (Atmospheric Dispersion Corrector) is the device that compensates the effect of “differential atmospheric refraction”, that is a consequence of the wavelength-dependent index of refraction of the atmosphere. There is a main requirement for an ADC: variable dispersion to compensate that of the atmosphere at a given zenith angle. For LBT telescope the zenith-angle range is between 0° and 70°. In most of the cases the dispersion correction has to keep a diffraction limited PSF in the wavefront sensor focal plane. This is to maintain the smallest PSF possible and so to use the pyramid sensor at the maximum sensitivity. The DL PSF at the sensor central wavelength of 0.75 micron is 11.25 micron. So the final PSF width has to be negligible with respect to this.

This requirement suggests counter rotating prisms with dispersion a maximum (minimum) when the apex angles of the prisms are in the same (opposite) directions.

*Figure 1:* on the left: a beam of light pass trough the ADC couples of glasses that are rotated with the apex angles in the same direction (maximum of dispersion). On the right: a beam of light pass trough the ADC couples of glasses that are rotated with the apex angles in the opposite direction (minimum of dispersion). The two images of the pictures are made by a simple with paper.
1.1 The ADC composition:

With an ideal ADC the image of a star shows no dispersion at any Zenith angle, as well as no large displacement from a nominal position on the detector. Thus there are two basic requirements for an ADC:

- variable dispersion to compensate that of the atmosphere at given zenith angle
- Zero-deviation at some mean wavelength, within the range of interest for all zenith angle.

The selection of the individual prism angles depends on the telescope and configuration in which the ADC is used. The ADC for LBT AGW unit 2 is composed by two couples of prisms with a diameter of about 12 mm and a thickness of about 4.5 mm. They are assembling inside a structure that is able to move by two motor one couple with each other.

1.1.1 Principle of ADC

Figure 2: scheme of ADC couple system

An ADC can consist essentially of Amici prism system. In its simplest form the Amici prism system consists of a cemented double of two prisms, one being of higher dispersion glass than the other, the prism angle being chosen so that, for some mean wavelength, a collimated light beam on traversing the prisms emerges parallel to the incident beam. In general, the beam will be displaced sideways, but will remain collimated. Collimated beams of longer or shorter wavelengths will be dispersed in opposite directions, and differently displaced, but will remain collimated. Amici prisms have their entrance and exit surface parallel if and only if the two glasses have identical refractive indices at the mean wavelength [3]. So, the two prisms have the same angle but different refraction indices, such that light of the mean wavelength is undeviated, while longer and shorter wavelengths are deviated to compensate the atmospheric dispersion.

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The condition for zero deviation of a pair of prisms at the mean wavelength is (for each couple):

$$\text{prism angle}_1 \times (n_1 - 1) = \text{prism angle}_2 \times (n_2 - 1)$$

(or: deviation by first prism = deviation by second prism @ mean wavelength)

Each of Amici prism system produces dispersion, over the required wavelength range around the mean wavelength, of half the atmospheric dispersion at the maximum zenith angle to be corrected. At smaller zenith angles, the two separate doublet prisms couple are rotated in opposite directions (these two prisms are to be mounted so that each can be rotated about the optical axis of the telescope) to reduce the net dispersion but maintain a vertical direction for this dispersion. So the two doublets must be free to rotate independently: when they are in opposite orientations they give null dispersion, while they give maximum dispersion when their orientation is the same. Optical oil can be used to fill the space between the two discs.

The rotation prisms system opening angle is proportional to the tangent of zenith angle [4].

*Figure 3:* pictures of the single prism composing the ADC’s couple

The two couples of the ADC’s prisms are composed of two glass types.

Nominal glass properties of each prisms couple:

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C04-64:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index n(_d)</td>
<td>1.633507</td>
</tr>
<tr>
<td>Abbe V(_d)</td>
<td>63.401916</td>
</tr>
<tr>
<td>Dioptric Power</td>
<td>0.003800</td>
</tr>
</tbody>
</table>

BAM23:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index n(_d)</td>
<td>1.637167</td>
</tr>
<tr>
<td>Abbe V(_d)</td>
<td>40.263150</td>
</tr>
<tr>
<td>Dioptric Power</td>
<td>0.000800</td>
</tr>
</tbody>
</table>

- Prisms apex angle of couple #1 (C=C04-64, B=BAM23):
  - Glass 3C → 29.21830°
  - Glass 1B → 29.21000°
- Prisms apex angle of couple #2 (C=C04-64, B=BAM23):
  - Glass 7C → 29.21660°
  - Glass 5B → 29.21000°

*Figure 4*: scheme of the ADC single prisms couple

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1.2 The ADC position inside the whole system:

The ADC is located on the optical board system, after L1 lens:

*Figure 5: ADC location in the optical system*
In the next figure there is the mechanical design of the ADC support:

*Figure 6: the mechanical support of the ADC*

![Mechanical Support Diagram]

We are able to move the two couples of prisms thanks to a computer control: we set the angle degree for each wheel that moves the prism single couple. The accuracy of rotation angle is one hundredth of degree.

2 **Behavior of the ADC:**

In order to evaluate the behavior of ADC correction, we put it inside a Zemax simulation of the whole LBT board optical system, setting all the parameters of the two couple of prisms (apex angles, refraction index…). By this simulation we can evaluate as the behavior as the possible sources of errors.

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2.1 The refractive index of ADC glasses:

As first, we could have seen that putting as required the nominal refraction index (the values are in section 1.1) inside this simulation system, we had different results between the simulation and the laboratory measures. Particularly this happened because a different values of refractive index means a different Zero-deviation at some mean wavelength, so we obtain a different distribution of the spot displacement for each wavelength (1) rotating each couple of prisms in opposite direction. With this new values of refractive index for each prism’s glass, we obtained the same displacements for each wavelength as in the laboratory measures.

<table>
<thead>
<tr>
<th>Glass</th>
<th>Index nd</th>
<th>Abbe Vd</th>
<th>Dpgf</th>
<th>Temperature</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>C04-64</td>
<td>1.6033031</td>
<td>63.401916</td>
<td>0.006300</td>
<td>20.00 C</td>
<td>1.00 ATM</td>
</tr>
<tr>
<td>BAM23</td>
<td>1.606021</td>
<td>40.263160</td>
<td>0.000800</td>
<td>20.00 C</td>
<td>1.00 ATM</td>
</tr>
</tbody>
</table>

We can examine the previous values of refraction index towards these new values:

<table>
<thead>
<tr>
<th>Glass</th>
<th>nd_old value</th>
<th>nd_new value</th>
<th>Δvalue</th>
</tr>
</thead>
<tbody>
<tr>
<td>C04-04</td>
<td>1.603507</td>
<td>1.603931</td>
<td>4.24E-04</td>
</tr>
<tr>
<td>BAM23</td>
<td>1.607167</td>
<td>1.606821</td>
<td>3.46E-04</td>
</tr>
</tbody>
</table>

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In the next spot representation found by Zemax simulation we can see that the zero-lambda value is different between the old nominal index value and the new index value.

Figure 7: on the left: the old refractive glass index, and the lambda-zero system (no deviated from the glass system) is nearer 0.800 micron. On the right: the new refractive glass index, and the lambda-zero system is now nearer 0.700 micron.

(1) Remember that for a single prism of index ‘n’ the deviation = prism angle*(n-1). So the condition for zero deviation of a pair of prisms is: \( \text{prism angle}_1\times(n_1-1) = \text{prism angle}_2\times(n_2-1) \)

2.2 The ADC dispersion

In the laboratory tests we are not able to check the right behavior of the ADC for each Zenith angle, but we have tested the displacements for some wavelength at zero zenith angle. We have compared the laboratory measures with the Zemax results. So by checking that the behavior of the ADC inside the simulation of the whole system for zero zenith angle is the same of the laboratory measures, we could
deduced that the real dispersion correction at each zenith angle is also the same as expected from zemax simulation results.

**Table 1:** in the table below there are the displacement values (micron), of laboratory measures and of Zemax simulation results, for each ADC rotating angle @ zero° zenith angle.

<table>
<thead>
<tr>
<th>ADC rotation angle (degree):</th>
<th>0°</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB 0</td>
<td>92.7471</td>
<td>201.025</td>
<td>304.638</td>
<td>409.287</td>
<td>503.932</td>
<td>564.843</td>
<td>micron</td>
</tr>
<tr>
<td>ZMX 0</td>
<td>111.018</td>
<td>217.568</td>
<td>317.907</td>
<td>409.214</td>
<td>487.452</td>
<td>550.731</td>
<td>micron</td>
</tr>
<tr>
<td>LAB 1</td>
<td>66.5033</td>
<td>147.365</td>
<td>215.635</td>
<td>278.242</td>
<td>330.502</td>
<td>373.839</td>
<td>micron</td>
</tr>
<tr>
<td>ZMX 1</td>
<td>72.6911</td>
<td>142.622</td>
<td>209.507</td>
<td>268.496</td>
<td>319.215</td>
<td>362.571</td>
<td>micron</td>
</tr>
</tbody>
</table>

**Figure 8:** the plot of the results of table 1.
3 Deflection measures of the ADC

We measured the displacement of the beam for each Zenith angle, by, are showed Zemax simulation, and we found the corresponding contro-rotation angle of the ADC that is able to correct the dispersion. We evaluated as the dispersion between the wavelengths for each zenith angle (the spot are evaluated respect to the centroid of the beam), as the dispersion of the beam respect to the mechanical axis of the ADC.

3.1 Dispersion between wavelengths

Figure 9: spot diagram @0° zenith-angle and @0° ADC rotation angle, by Zemax simulation system, using like reference the centroid of the beam.

The zemax reference wavelength for the centroid reference is 0.700 micron
AIRY DIAM is the diameter of PSF @ 0.700 micron.

Table 2: values of ADC rotation angle, Xcentroid, Ycentroid, RMS radius, GEO radius (@lambda reference of 0.700 micron), for each zenith angle. All these values are calculated respect to centroid.

<table>
<thead>
<tr>
<th>Zenith angle (degree)</th>
<th>ADC rotation Angle (degree)</th>
<th>X coordinate Centroid (micron)</th>
<th>Y coordinate Centroid (micron)</th>
<th>RMS radius* (micron)</th>
<th>GEO radius* (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>5.8e-06</td>
<td>0.6</td>
<td>10e-08</td>
<td>5.68</td>
<td>9.57</td>
</tr>
<tr>
<td>10°</td>
<td>3.42</td>
<td>0.6</td>
<td>18</td>
<td>5.73</td>
<td>10.35</td>
</tr>
<tr>
<td>20°</td>
<td>7.08</td>
<td>0.6</td>
<td>37</td>
<td>5.85</td>
<td>11.33</td>
</tr>
<tr>
<td>30°</td>
<td>11.27</td>
<td>0.6</td>
<td>59</td>
<td>6.19</td>
<td>12.44</td>
</tr>
<tr>
<td>40°</td>
<td>16.50</td>
<td>0.5</td>
<td>85</td>
<td>6.72</td>
<td>13.79</td>
</tr>
<tr>
<td>50°</td>
<td>23.77</td>
<td>0.5</td>
<td>120</td>
<td>7.64</td>
<td>15.55</td>
</tr>
<tr>
<td>60°</td>
<td>53.80</td>
<td>0.5</td>
<td>170</td>
<td>9.39</td>
<td>18.08</td>
</tr>
<tr>
<td>70°</td>
<td>67.45</td>
<td>0.2</td>
<td>280</td>
<td>13.36</td>
<td>22.15</td>
</tr>
</tbody>
</table>

*RMS radius: is the distance between the centroid and the center of image for each wavelength.
*GEO radius: is the distance between the centroid and the center of image for the extreme wavelength.

3.2 Dispersion of the beam

Figure 9: spot diagram @0° zenith-angle and @0° ADC rotation angle, by Zemax simulation system, using like reference the vertex last glass surface of the ADC.
Table 3: values of ADC rotation angle, X centroid, Y centroid, RMS radius, GEO radius (@lambda reference of 0.700 micron), for each zenith angle. All these values are calculated respect to centroid.

<table>
<thead>
<tr>
<th>Zenith angle (degree)</th>
<th>ADC rotation Angle (degree)</th>
<th>Real ray X coordinate (micron)</th>
<th>Real ray Y coordinate (micron)</th>
<th>RMS radius* (micron)</th>
<th>GEO radius* (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0°</td>
<td>0.6</td>
<td>0</td>
<td>5.71</td>
<td>9.86</td>
</tr>
<tr>
<td>10°</td>
<td>3.29°</td>
<td>0.6</td>
<td>17</td>
<td>19.32</td>
<td>29.51</td>
</tr>
<tr>
<td>20°</td>
<td>6.80°</td>
<td>0.6</td>
<td>35</td>
<td>38.50</td>
<td>51.86</td>
</tr>
</tbody>
</table>

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30°  10.84°  0.5  56  60.65  67.38
40°  15.85  0.5  82  87.91  108.66
50°  22.81  0.5  116  124.64  150.70
60°  34.23  0.4  169  180.77  214.73
70°  62.65°  0.2  266  285.43  333.41

*RMS radius: is the distance between the centroid and the vertex for each wavelength.
*GEO radius: is the distance between the centroid and the vertex for the extreme wavelength.

3.3 Atmospheric dispersion and ADC angle correction [5]
Parameters of the previous plot formula: [5]

\[
n_{\ldots1} @ 600 \text{ nm} \\
n_{\ldots1} @ 950 \text{ nm} \\
\text{rate1 è calcolato per il prisma 'BAM23'} \\
\text{rate2 è calcolato per il prisma 'C04-04'} \\
f= \text{focal length of telescope} \\
d=\text{couple prisms separation (} = 1.0 +/\!/-0.05 \text{ mm)} \\
z=\text{zenith angle} \\
\delta_\text{angle} = \text{difference between: angle of first prism of couple 1 - angle of first prism of couple} \\
(\text{we suppose that: angle of second prism of couple 1 - angle of second prism of couple 2, it's the same of first prism angle difference).} \quad (*)
\]

\[
\text{rate} = \frac{n_{\text{atm}_1} - n_{\text{atm}_2}}{(n_{\text{adc1}_1} + n_{\text{adc2}_1}) - (n_{\text{adc1}_2} + n_{\text{adc2}_2})}
\]

\[
\text{ang} = \frac{f}{d} \cdot \left(\tan\left(\frac{z \cdot 10 \cdot 3.14}{180}\right)\right) \cdot \text{rate} - \delta_\text{angle}
\]

\[
(*) \quad \text{if angle of first prism of couple 1 is equal to angle of first prism of couple 2, then } \delta_\text{angle}=0
\]

### 3.4 Atmospheric dispersion and residual values after ADC correction

This plot represents the residual values of ADC dispersion after the ADC correction. So for each zenith angle we found an ADC controrotating angle of correction and we check about the residual dispersion values for each wavelength (in the range between 0.600-0.950 micron).
The maximum residual dispersion between the wavelength range measured on image plane f/45 is:

<table>
<thead>
<tr>
<th>Delta_lambda (mm) (value_600_ok-value_950_ok)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° 10° 20° 30° 40° 50° 60° 70°</td>
</tr>
<tr>
<td>0.008 0.009 0.004 0.006 0.006 0.007 0.010 0.015</td>
</tr>
</tbody>
</table>