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The Design of

Atmospheric Dispersion Correctors (ADCs)

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Background

This note describes some techniques for designing and tuning ADCs. It was prompted by the need for some high precision astronomical ADCs for the Z, J, H and K-bands (0.9 – 2.5 microns).

Some hitherto overlooked phenomena in the aforementioned waveband are discussed.

The material described here is referenced.

Optical Principles – ADC implementation

There are 3 types of ADCs (of which I am aware....):

1. pairs of doublet prisms counter-rotating around an optical axis;
2. a "Trombone" arrangement of a pair of prisms moving relative to each other along an optical axis; and
3. a lens moving laterally in a direction parallel with the zenith direction, thereby becoming "wedged" or prismatic relative to the optical axis.

Type 1 predominates in astronomical applications and is relatively neutral both mechanically and optically, at least in so far as imagery and magnification are relatively unaffected. This type can be used in collimated or non-collimated light.

Type 2 are far less common and require considerable space in front of a main focus. Astigmatic aberrations are the main drawback, as well as the amount of space required and the mechanical challenges presented by having to telescope the components through large displacements.

Type 3 are in use in a few instruments but require some serendipity in that there needs to be at least one lens element that is relatively insensitive to lateral displacement.

I much prefer the Type 1.

This type of ADC is based on a pair of Risley Prisms but I prefer to call them "Direct Vision Doublet Prisms" or DVDPs for short. In collimated light (for example, within a relay) the prisms can be identical because each DVDP is at an infinite conjugate. In non-collimated light some asymmetry is required because each DVDP is at a slightly different conjugate.

Its function is to counteract the effect of atmospheric dispersion as closely as possible down to a maximum zenith angle (ZAmax). It achieves this by counter-rotating the individual DVDPs around the optical axis through a maximum angle (Θ) of 90° given by:

$$\theta = \sin^{-1}\alpha$$

where

$$\alpha = \frac{\tan(ZA)}{\tan(ZAmax)}$$

Θ is measured relative to the normal to the plane (ADC group Local X) containing the local zenith (ADC group Local Y) and the optical axis. The local zenith is the direction that the zenith vector would point after transformation by the optical system at the DVDP location. The counter-rotation (-Θ) is measured relative to the opposite or negative normal. Maximum correction occurs at Θ = ±90° when both prisms align such that their combined dispersive power is maximised. Minimum or zero correction occurs at Θ = 0° when their combined dispersive power cancels.

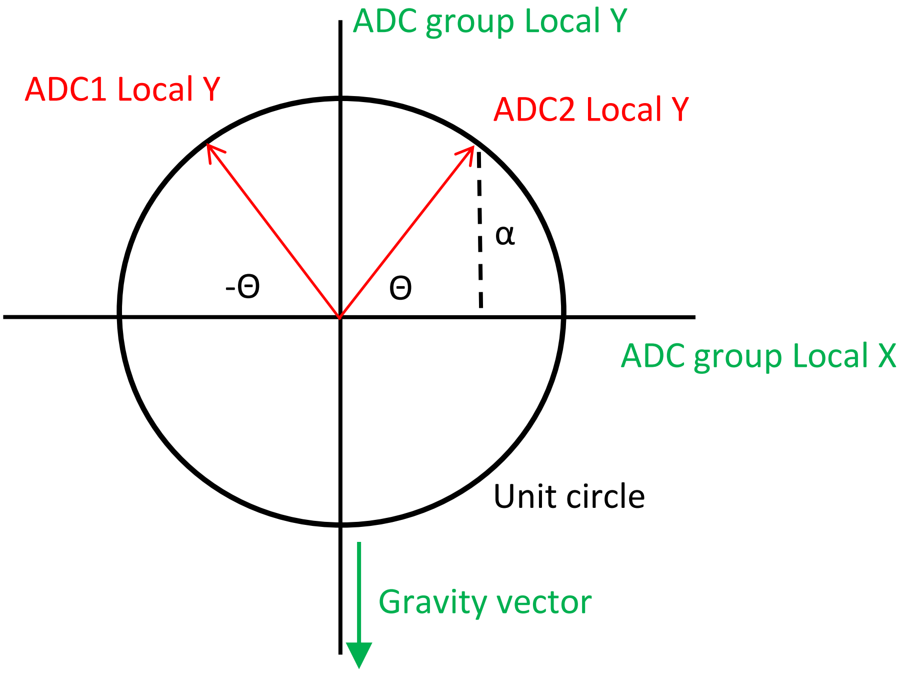

Figure: Looking through the ADC along Local Z, or the optical axis

The design procedure is to first of all select a waveband and then let an optimiser find the optimum prismatic tilts of selected surfaces in the DVDPs.

One usually finds that the state of correction runs along a parabolic-like curve of varying steepness with a minimum somewhere in the band. Generally speaking, no two glasses will ever be a perfect match for the atmosphere.

For this exercise the waveband of operation runs from the near IR (0.9 microns) to the short-wave IR (2.5 microns), an important astronomical window.

In this case, where high precision is vital, a better match is required within sub-bands, but not simultaneously across the entire waveband of 0.9 – 2.5 microns.

The astronomical sub-bands are:

- Z-band: 0.9 – 1.1 microns
- J-band: 1.0 – 1.4 microns
- H-band: 1.4 – 1.8 microns
- K-band: 1.8 – 2.5 microns
- HK-band: 1.65 – 2.5 microns

The trick now is to “de-tune” the ADC in all but one of the sub-bands so that the residual atmospheric dispersion is minimised in each band.

An extensive review of the literature reveals several pairs of materials that work well over the whole band. These are ZnS/ZnSe, OHARA BAL42/S-NPH2 and OHARA S-FPL51Y/S-LAH71. It does appear as if these pairs have been found through a largely experimental approach rather than with a more subtle understanding of the effects taking place.

Fortunately, we have developed a tool that can be used to explore the differential dispersive properties of any optical glass.

A description can be downloaded here.

The next Figure shows some plots for a selection of glasses including the pairs listed above.

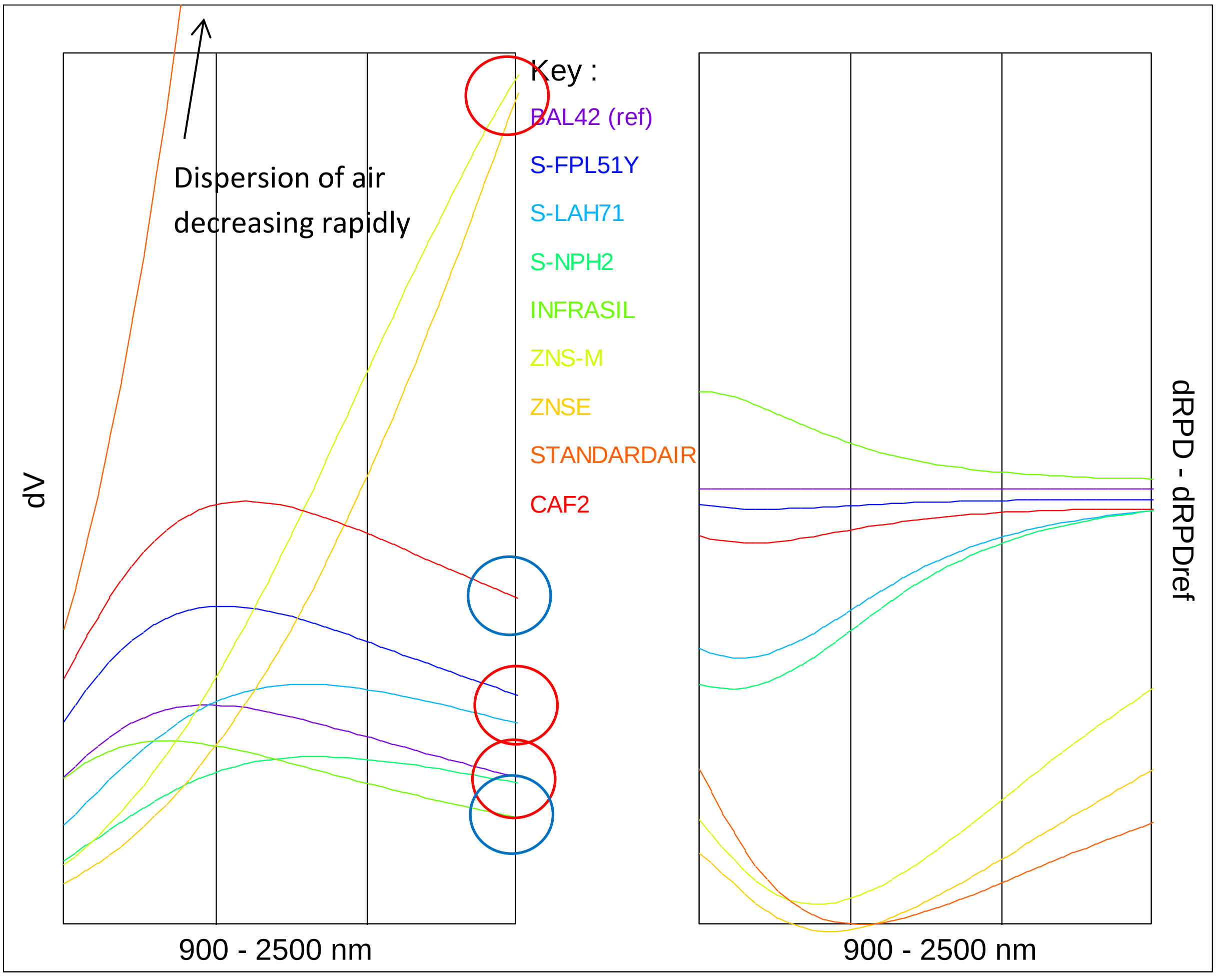

Figure: Differential dispersive properties of selected ADC glasses

In the “dV” plots the glass pairs found in the literature are observed to have some interesting properties. The red circles indicate these regions of interest. It can be seen that the dVs of the pairs steadily converge with increasing wavelength and in fact for the pair S-NPH2/BAL42 they almost meet. This implies that very little differential prismatic power would be available as one approaches the long end of the waveband. But this is precisely why these pairs work so well because at this end of the band the dV for AIR is increasing rapidly, or in other words it is becoming less-dispersive at an ever-increasing rate, and the need for prismatic power in the ADC is therefore falling just as rapidly. We can use this reasoning to predict that CaF2 and INFRASIL (blue circles) will make a very poor match and this is indeed found to be the case.

The converging dVs also imply that the strongest prismatic power will be required at the long end of the waveband and this effect underpins the design strategy.

The prismatic powers of the ADC prisms are optimised for the long wavelength band and differential counter-rotations are used to “de-tune” for shorter wavelength bands.

Unfortunately, the “tuning” comes at some cost. The differential counter-rotations cause the image centres at the sub-band central wavelengths to become mobile and this will require tracking by band and by zenith angle. My understanding is that the “coarse” tracking can be done algorithmically from the model, adjusted during commissioning; whilst “fine” tracking can be achieved as it would normally be done.

Z-Track and X-Track

Most ADC prisms are designed with zero external tilt.

This means that the ADC action will cause small lateral offsets of the image which will cause the image to “gyrate” during an exposure. The small offsets occur because the ADC prisms are separated longitudinally and act in image space (position), rather than in a collimated space (angle).

Some systems use small amounts of tilt on the leading and trailing surfaces of the ADC doublet to avoid this problem. However, these small external tilts are often within the tolerance range for these surfaces and therefore difficult to attain during fabrication. In other words, there would always be some image gyration.

Telescope tracking can handle these small image offsets.

The telescope tracking is broken down into “Z-track” in a direction along the (transformed – ADC group Local Y) zenith direction and “X-Track” in a direction perpendicular to this.

From the vector diagram we can infer that:

$$Ztrack \propto \frac{\tan Z}{\tan Z_{max}}$$

Thus, if we allow Z-track at Zmax to vary, then Z-track at all other Z can be calculated parametrically in proportion.

Again, from the vector diagram we can also infer that:

$$Xtrack \propto \cos\theta$$

The serial nature of the ZEMAX multi-configuration data means that it is quite awkward to vary the X-track value at Z = 0. Therefore, we let the X-track value at some median value of Z vary and adjust the other values parametrically in proportion.

In reality, the “tracking function” will need to be established during commissioning.

Remarks

Of course, it goes without saying that this is not the last word on ADC design. There are subtleties that will only become evident through much experience and it is not the intention here to deliver a complete guide.

And also, there is no substitute for hands-on design as a corroboration of this technique.