Effective Focal-Plane Tilt with Linear ADC

Andrew Phillips (UCO/Lick Observatory), 08jan03

We demonstrate that linear ADCs — or any "zero-deviation" system that translates beams — will produce an effective tilt of a spherical focal surface. Implications for the Keck telescope and LRIS ADCs are discussed.

It has been claimed that Linear ADCs do not produce a tilt of the focal plane (eg, Avila, Ruppretch & Beckers, 1997). This statement is found to be inaccurate in the case of a curved focal surface, as is generally true for two-mirrored telescopes such as the typical RC design.

The curved focal surface is approximated by a parabola described by

$$z(x) = \frac{-x^2}{2R},$$

where R is the radius of curvature of the surface. The displaced focal surface is simlarly described by

$$z(x+d) = \frac{-(x+d)^2}{2R},$$

where d is the displacement. Thus, the difference in height, Δz, is

$$\Delta z = \frac{-(2xd + d^2)}{2R}.$$

The radius of curvature for the Keck telescope focal surface is approximately 2180mm, while the maximum ADC displacement is roughly 30mm for the current "strawman" ADC design. At $x = \pm 10' = \pm 435$mm, we see that the focal surface is effectively tilted by ±6.2mm, or 0.82°.

Note that this tilt scales linearly with the displacement of the beam, which in turn is directly proportional to the prism separation.

The long dimension of the LRIS field is about 2×167mm in the focal plane; this means that, if we focus for the center of the field, we are never more than ±2.4mm out-of-focus, leading to a maximum image blurring of ~160μm. *(Note that this is worst-case for the LRIS field, but the offset TV field will be even more affected.)* This image blur is of the same size order as the aberrations introduced by the prisms, so the actual effect on image size will need to be modeled. However, it seems likely that this amount of additional image blur will be acceptible for LRIS. It is also clear that the telescope will need to be refocused as the rotator angle changes in order to remove the tilt effects, that is, to keep the images focused at the center of the LRIS field.

By extension, a linear ADC would probably not provide adequate image quality over the entire 20-arcmin Keck field unless some sort of compensation could be provided to reduce the beam displacement. Since the ADC prisms taken together form a thick plate, it should be possible to reduce the displacement by tilting the prisms as the separation is increased, but the feasibility of this needs to be explored further before this could be seen as a viable optical design option. Given the relatively small thickness of the combined prisms, it seems likely that the reduction will be small over practical tilt angles, and will probably come at the expense of increased aberrations.

Considerations of Internal Reflections in the ADC

Andrew Phillips (UCO/Lick Observatory), 15jan03

Simple calculations of likely "ghost" reflections in the linear ADC are discussed.

There are 4 surfaces (referred to as S1, S2, S3 and S4, in the prder that light passes though the two prisms), leading to 6 surface pairs that could produce ghosts. In the following, α is the prism angle of the individual prisms, and we assume 70mm total thickness for the combined prisms. We consider each surface pair:

- **S1/S2:** Internal to the first prism. Using the design orientation of the prism, light entering this prism vertically (approximately true) is emitted at an angle $\alpha(n-1)$. Light reflected off surfaces S1 and S2 is emitted at an angle of $\alpha(3n-1)$, that is, different by $2n\alpha$ from the direct pass. For prism angles of 5 degrees, this angle is over 14°. Since angles over about 4° completely miss the grating/mirror, this surface pair is deemed inocuous for ghosts.

- **S1/S3:** Since surfaces S2 and S3 are parallel, this pair behaves the same as S1/S2 except that there is additional defocus due to the increased pathlength of prism separation.

- **S3/S4:** equivalent to S1/S2

- **S2/S4:** equivalent to S1/S3

- **S2/S3:** These are the parallel inner surfaces of the prisms, and are the most problematic. The difference in pathlength ($2\Delta z$) results in a defocus depending on prism separation. For an order-of-magnitude effect, we consider the defocus spot size compared to a 0.5-arcsecond disk in estimating an intensity difference. The ghost/parent contrast (per given area) is then

  $$(\frac{d}{0.5''})^2 r_1 r_2$$

  or

  $$(\frac{2\Delta z/15}{0.363})^2 r_1 r_2$$

where $d = 2\Delta z/15$ is the defocused spot diameter, r_1 and r_2 are the reflectance at each surface, and Δz is measured in mm. We adopt reflectance of 0.01 for each surface. For a minimum separation of 4 mm, we see a maximum value ghost/parent ratio of 6×10^{-5}; at 10 mm, this becomes 10^{-6}.

The location of this ghost will be somewhat offset from the primary image. The rays will be parallel to the parent beam, so the offset is simply the translation of the rays,

$$\Delta x = 2\Delta z \tan(\theta)$$

where θ ranges from about 0.5 – 1.3 degrees. Thus, at 10mm prism separation, the offset is 0.64 arcsec at maximum – this will still be in the wings of the PSF.

- **S1/S4:** This is equivalent to S2/S3, but with the overall addition of $2 \times (70/n)$ mm of defocus. Thus, surface pair S2/S3 will dominate over this pair (except at large prism separation where ghost effects are negligible from either pair).

In conclusion, only the inner surface pair is of any concern. The maximum contrast of ghost/parent is given by $r_1\dot{r}_2$ (at which point the ghost falls on top of the parent) and rapidly declines as the prisms separate.