APOLLO Fiducial Diffuser

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1 Diffuser angular spread measurement

In our ranging experiment, we essentially have two signals. There is a 'fiducal' signal, which signals the firing of the laser beam, and effectively starts our stopwatch. The fiducial signal comes from light reflected by a corner cube mounted on the seconday mirror of the telescope. And there is a 'lunar' signal, which signals the return of the photons form the moon, and effectively stops our stopwatch. To minimize any bias in our measurement, the fiducial signal needs to illuminate the APD array in the same way that the lunar signal does. A glass slab with a quadrant that is frosty should match the uniform illumination pattern of the lunar signal. A spacial mask is also needed to create a central obstruction for the fiducial photons in the same way that the secondary mirror is a central obstuction to the incoming lunar photons. So, we will have a rotating optic. When the lunar photons return, they will travel through the transmissive quadrants. When the fiducal photons return, they will travel through the frosty quadrant.

Not all fiducials will be sent through the frosty glass. For various reasons, we will sometimes send the fiducial photons unmolested into the APD array. But the intensity of the fiducial return needs to match in both cases. Thus, a quadrant of the glass will be neutral density. Every other shot the fiducual photons will travel through the frosty quadrant. And every other shot the fiducial photons will travel through the neutral density quadrant. We will choose a neutral density to match the number of received photons in both cases.

Our goal is to determine what fraction of incident light reaches the APD array through the diffuser. Then we can choose an matching attenuation for out neutral density quadrant. To do this, we measure how our diffuser spreads incident light out over angles with a photodiode. The data is adequately fit by a Gaussian. We can calculate the fraction of incident light that reaches the APD array when it travels through the diffusing quadrant. In other words, we want to calculate the effective attenuation of incoming light by the frosty glass. We want this to be the same as the attenuation of incoming light when it travels through the neutral density quadrant.

We used a HeNe laser of wavelength 632.8 nanometers as a light source. To measure the transmitted light we used a calibrated Melles Griot photodiode. The photodiode puts out a current, that is a function of the incident power on the photodiode. A 2.41 mm aperture was placed in front of the photodiode. The photodiode aperture was placed 125.4 mm away from the frosty side of the glass diffuser. The frosty side of the glass diffuser was pointed away from the laser, and towards the photodiode. The photodiode aperture was roughly concentric with the laser aperture, so that a level laser beam fully enters the aperture. All measurements were taken with the room lights out.

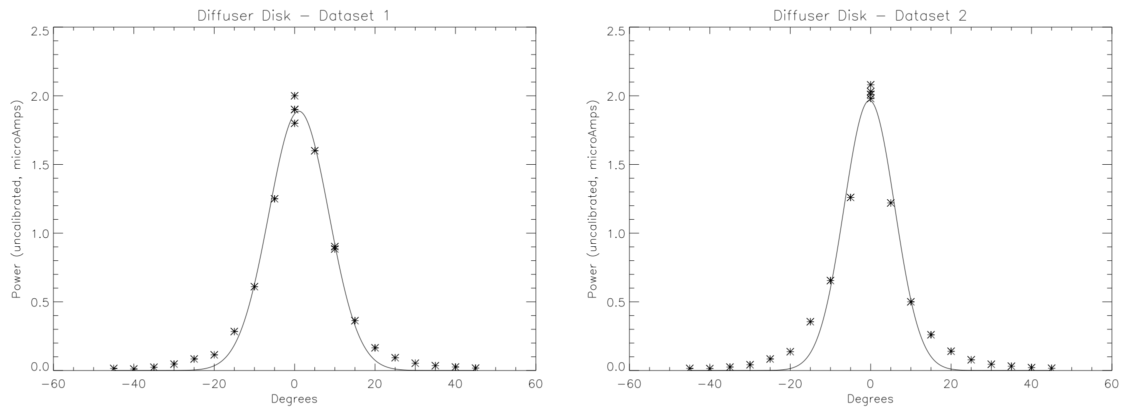

Figure 1: Two datasets, fit Gaussians. The current read out of the photodiode can be converted into a power in Watts.

With the diffuser removed from the system, we measured the raw power out of the laser with the photodiode. The photodiode read out 1 mA.

We measured the power that entered the photodiode at various angles, from +45 degrees to −45 degrees. The photodiode was always aligned so that its aperture was normal to the line connecting the photodiode and the diffuser. Zero degrees has the photodiode looking straight on at the diffuser and the laser. Positive angles are counter-clockwise from zero. We performed the same experiment twice, producing “Dataset 1” and “Dataset 2”.

The data is shown in Figure 1. It was fit to a Gaussian:

$$P(\theta) = P_0 e^{-\frac{(\theta-\theta_0)^2}{2\sigma^2}}$$

For Dataset 1, the fit gives $P_0 = 1.89\ \mu A$, $\theta_0 = 1.06°$, $\sigma = 7.45° = .130$ radians. For Dataset 2, $P_0 = 1.97\ \mu A$, $\theta_0 = -.303°$, $\sigma = 6.29° = .110$ radians.

We are interested the incident power per solid angle $I(\theta)$ where we have assumed $\theta_0 = 0$. Since our photodiode aperture was small compared to the distance to the frosty glass, $I(\theta)$ is simply

$$\frac{P(\theta)}{\Omega} = I_0 e^{-\frac{\theta^2}{2\sigma^2}}$$

where Ω is the solid angle area of the photodiode aperture. If D is the diameter of the photodiode aperture, and R is the distance between the photodiode aperture and the frosty glass.

$$\Omega = 4\pi \frac{\text{(Area of aperture)}}{\text{(Area of sphere)}} = 4\pi \frac{\pi (D/2)^2}{4\pi R^2} = \frac{\pi D^2}{4R^2}$$

As stated, D = 2.41 mm, R = 125.4 mm, so $A = .290 * 10^{-3}$ rad^2. Thus, for Dataset 1, $I_0 = 6.52 * 10^{-3}$ A/rad^2. For Dataset 2, $I_0 = 6.79 * 10^{-3}$ A/rad^2.

Now we know the power per solid angle transmitted by the diffuser. We would like to know how much power gets through a circular aperture that is concentric with the source,

P_{aper}. The aperture has diameter d, and is a distance r from the frosty glass. Thus, the aperture has an angular width $d/r = \theta_0$

$$\begin{aligned} P_{aper} &= \int I(\theta) d\Omega \\ &= \int_0^{\theta_0} \int_0^{2\pi} I(\theta) \sin\theta d\theta d\phi \\ &\approx \int_0^{\theta_0} \int_0^{2\pi} I(\theta) \theta d\theta d\phi \\ &= 2\pi I_0 \sigma^2 \left[1 - \exp\left(-\frac{\arctan^2(d/2r)}{2\sigma^2} \right) \right] \end{aligned}$$

In our system, d = 18 mm, and r = 146.1 mm. Thus, for Dataset 1, $P_{aper} = 73x10^{-6}$ A, and for Dataset 2, $P_{aper} = 75x10^{-6}$ A. Remember, we measured the total incident power to be 1 mA. So, the fraction of incident power that gets to through our aperture $\frac{P_{aper}}{P_{input}} = 73x10^{-3}$ and $75 * 10^{-3}$, respectively.

The light that passes through the diffusing quadrant also passes through a spacial mask. The mask has an aperture of diameter 14 mm and a central obstruction of diameter 3.2 mm. Thus, only 94.8 percent of the light gets through the mask to the APD. So, $\frac{P_{APD}}{P_{input}} = .948 \frac{P_{aper}}{P_{input}} = 69x10^{-3}$ and $71x10^{-3}$, respectively. This corresponds to a neutral density of -1.16, and -1.15, respectively.

Thus, if we want the same amount of light to reach the APD array in the diffser and ND case, the neutral density quandrant should have an attenuation of about ND 1.15.