

Introduction & Background

Why Measure the Speed of Light?

The speed of light (c) is a fundamental constant in physics, but measuring it is historically challenging because light travels *extremely* fast. Even over long distances on Earth, the transit time is so brief that early experiments struggled to detect any delay.

Early Attempts Galileo (1600s):

Galileo tried using human reaction times (flashing lanterns between hilltops) but found no measurable delay – light seemed “instantaneous” at that scale. This showed that more sensitive methods were needed.

First Successful Determination Fizeau (1849):

Hippolyte Fizeau used a rotating cogwheel to chop a light beam traveling to a distant mirror. At a certain wheel speed light passing through the teeth would be blocked on return by the following tooth, allowing an estimate of c . He measured about $3.13 \times 10^8 \text{ m/s}$, a bit higher than the true value, but it was the first successful experimental determination of c .

Foucault’s Rotating Mirror (1850s):

Léon Foucault built upon Fizeau’s experiment, using a spinning mirror instead of a wheel. In 1850 he showed light travels slower in water than in air. Later, in 1862 Foucault measured an absolute value of c with his rotating mirror apparatus. At $c = 2.98 \times 10^8 \text{ m/s}$, this comes within **0.6%** of the modern accepted value.

Theoretical Foundation

Indirect Time Measurement:

Directly timing light is impractical in a small lab so Foucault’s method measures the *time of flight* indirectly via a small angular deflection $\Delta\theta$.

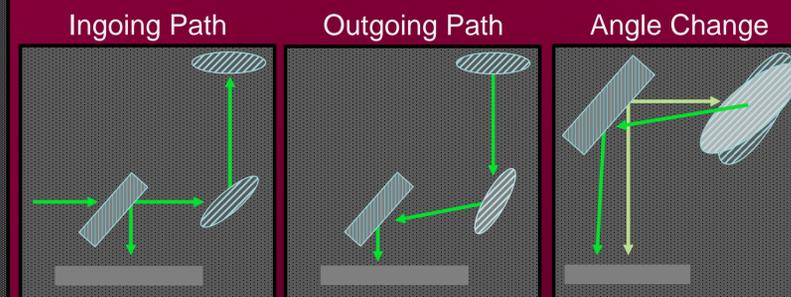
Principle of Operation:

When the mirror is stationary, a beam of light from the source reflects to the distant mirror and returns along the same path, so the returning beam overlaps the outgoing beam. But if the mirror is rotating rapidly, by the time the light comes back, the mirror has turned by a small angle $\Delta\theta$. The return beam is reflected off a shifted angle. This causes the returning light spot to appear displaced from its original position. The faster the mirror spins (higher angular velocity ω), the larger the angular shift.

Experimental Design

Geometric Relation:

The laser first passes through the beam splitter before reflecting off the rotating mirror and eventually heading towards the static mirror a distance (D) away. Upon its return, the new angle it makes with the rotating mirror face results in a different outgoing path from this element than the initial ingoing path. This angular difference is what we can relate to the change in the final position on the screen.



Derivation:

We relate the change in position on the screen to the change in angle via the rotational frequency of the mirror (f) and proportionality constant (α_c).

$$\Delta x = \alpha_c f$$

First, we determine the time difference (t) between the when the laser leaves the rotating mirror to when it returns. This is the same time that is elapsed over the mirror’s change in angle ($\Delta\theta$) due to its angular velocity (ω).

$$t = \frac{2D}{c} = \frac{\Delta\theta}{\omega} \longrightarrow \Delta\theta = \frac{2D}{c} \omega \quad (1)$$

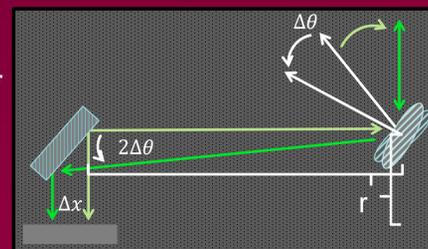
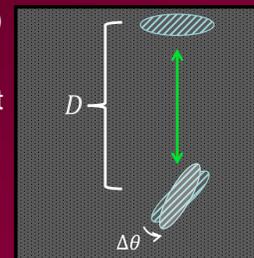
Relating this with screen displacement (Δx), the path length from the rotating mirror to the screen (r), and applying the small angle approximation:

$$\Delta x = r \tan(2\Delta\theta) \approx 2r\Delta\theta$$

Using equation (1):

$$\Delta x = \frac{4rD}{c} \omega \quad \& \quad \omega = 2\pi f$$

$$\Delta x = \frac{8\pi rD}{c} f$$



Rotating Mirror Construction

Rotating Mirror:

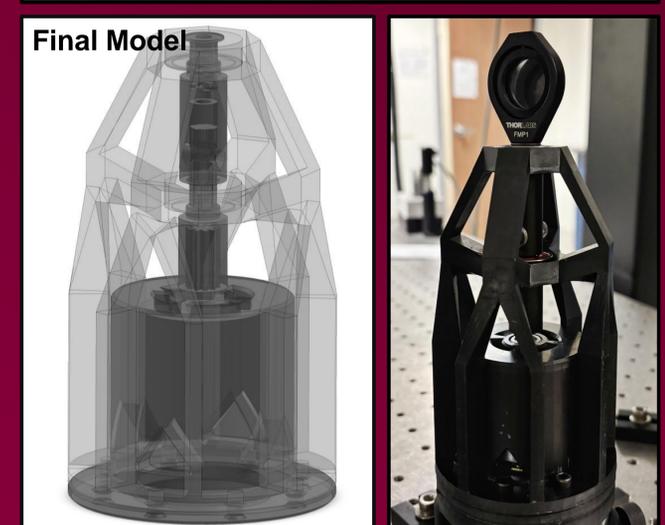
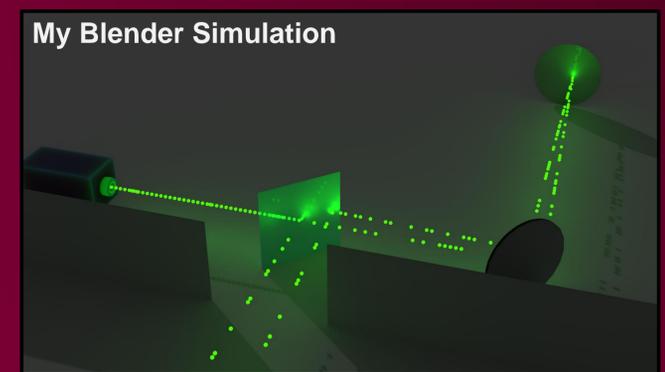
Despite leveraging these optical techniques, the rotating mirror needs to meet high frequency demands. The upper range of the desired frequency is **~600Hz** or **36,000 rpm**. Even far below this frequency, the vibrational effects can be catastrophic if the parts are not structurally sound, as was discovered in testing.

Modeling and Printing:

Without readily available equipment in the lab capable of meeting this demand, it was necessary to construct this part from scratch. Aside from the motor and mirror, each part that housed the motor and mirror was modeled in SolidWorks and 3d-printed in Chitu Systems’ Conjure Rigid Resin.

Solutions:

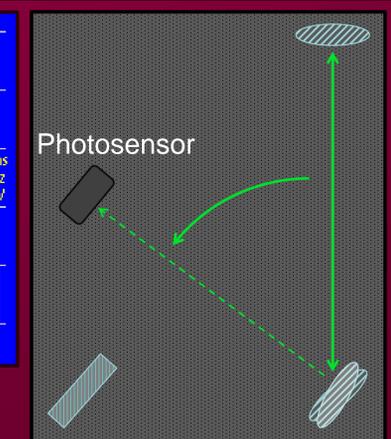
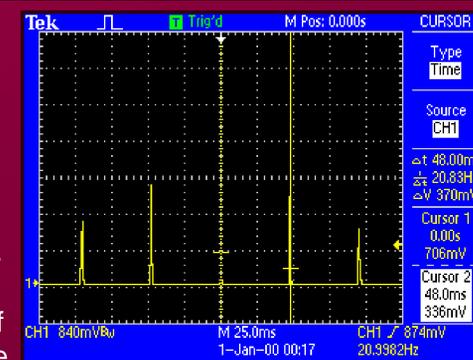
After several iterations, a reliable structure was found. The structure consists of three main components; the motor case, the central axle, and the stabilization structure. The axle is comprised of three separate components, each clamping onto stabilizing bearings which are inset into the stabilization structure. They are spun by the motor gear and interface with each other via toothed joints.



Experimental Setup

Measuring Rotational Frequency:

To measure the frequency of the rotating mirror, a photosensor connected to an oscilloscope was placed in the lasers path. During each rotation of the mirror, the laser sweeps across the sensor for a fraction of a second. The frequency can be read off the oscilloscope by measuring the time between the peaks in the signal.



Next Steps:

- Folded Optical Path using Multiple Mirrors
Using a series of well-aligned mirrors to “fold” the laser path within the available space can increase the effective optical path length without needing a long straight-line distance.
- Lens Pair Configuration
Incorporating a converging lens to focus the initially divergent beam, followed by a collimating lens that reshapes the beam into a parallel form will help minimize dispersion over the extended path.