Scanning Interferometer Aimed at Characterizing Laser Coherence Lengths

Henry B. Wahhab,[1] Mariana Rojas-Montoya,[1] and Christopher L. Smallwood[1,*]

[1] *Department of Physics and Astronomy, San José State University, San Jose, CA 95192, USA*

[*] *christopher.smallwood@sjsu.edu*

Abstract: We report on the design and construction of a Mach-Zehnder Interferometer with an adjustable measuring arm aimed at quantifying the coherence lengths of lasers for use in undergraduate research projects and low-cost interferometers.

The coherence length of a beam of light is a measure of the phase continuity of the beam's oscillating electric and magnetic field components as it propagates through space [1]. In devices relying upon the interference properties of light, this quantity is of paramount importance because interference effects cannot be observed except at distances shorter than the coherence length. In spite of this fact, coherence lengths corresponding a wide variety of light sources—particularly low-budget laser pointers—are often poorly tabulated. In addition, many lasers have multiple modes, which is a feature often easily leading to confusion between the true definition of coherence length and the length scales associated with periodic beating between adjacent co-propagating laser modes [2, 3]. Here we report on the design and construction of a tailored interferometric device aimed at quantitatively characterizing the coherence lengths of different kinds of light sources. Goals include measuring the coherence lengths of low-cost diode lasers and lasers based on frequency-doubling the 1064 nm transition associated with Nd^{3+} ions embedded within host matrices like YAG, YVO_4, and glass.

Figure 1 shows a photograph of the optical setup and a schematic diagram of the relevant beam paths. The interferometer setup consists of a 632.8 nm He-Ne laser, seven mirrors, three polarizers, two photodetectors, a quarter and half wave plate, and lastly the retroreflector mounted on the collision cart placed on the track. The beam first passes through a polarizer aligned vertically before reflecting off two mirrors leading up to a non-polarizing beam splitter. The transmitted portion of the beam travels to the retroreflector on top of the cart strongly secured onto the track in order to reduce any vibrational noise. The retroreflector then sends the light back towards the same beam splitter where part of it gets transmitted and reflected again to their corresponding photodetectors. Both photodetectors have 45° polarizers in front of them, however one has an additional quarter wave plate which is used for the generation of quadrature signals. If the light is reflected the first time through the beam splitter, the path it takes is similar except that the polarization is now horizontal due to a well placed half wave plate. The design of the apparatus allows for this horizontally polarized light to be mixed with both vertically polarized light that has been phase shifted by a quarter wavelength and the original vertically polarized light. This occurs when

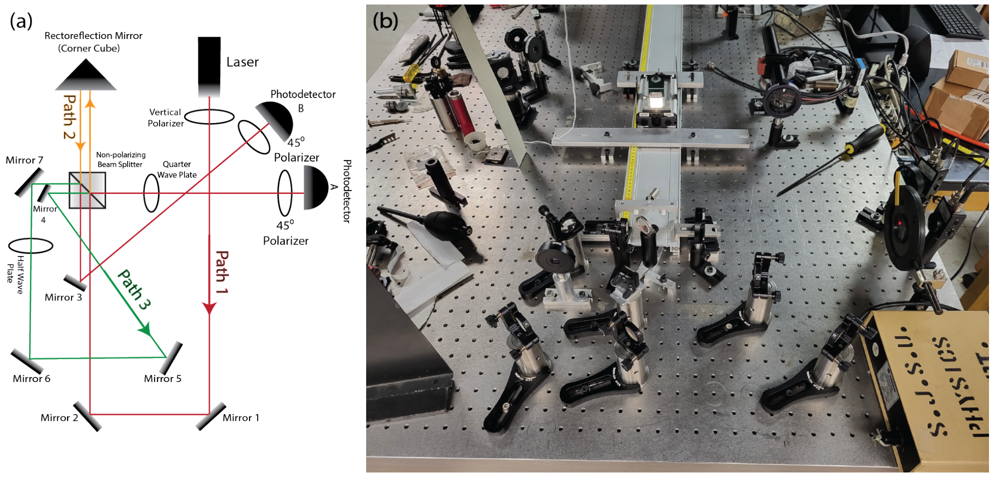

Fig. 1. Interferometer Experiment Setup.

the beams reach the beam splitter for the second time, creating a total of four path combinations (Transmitted-Transmitted, Transmitted-Reflected, Reflected-Transmitted, Reflected-Reflected). The 45° polarizers before each photodetector are also needed in order to obtain an equal contribution from both horizontal and vertical polarized light. Photodetectors A and B now can measure these quadrature signals as their intensities are out of phase by a 90° since only one path contains the phase shifted vertically polarized light. The signals were then analyzed utilizing a microcontroller programmed with CircuitPython which allowed for real time data analysis, proving that the setup was functional with a nearly perfect circular Lissajous figure of the photodetector voltages.

In terms of design elements related to the scanning interferometer arm, a particularly advantageous element of the system is a Pasco-brand collision cart, which is a common undergraduate lab appliance used for studying conservation of energy and linear momentum, and which slides upon an unusually long track length, making the setup's initial scaffolding ideally suited to the measurement of relatively long-coherence-length light source like helium-neon lasers. This collision cart was drilled in such a manner that allowed for a hollow retroreflector to be securely mounted on the center of the cart. Retroreflectors are typically composed of three perpendicular mirrors that allow for light to be reflected back at the source with only a transverse displacement. This special property is among the main centerpieces for this project as it allows for the cart's track to act as the interferometer measuring arm. After laying out these components, we used a helium-neon (HeNe) laser as an initial test case to verify that the system worked as expected.

The future goals of this project are to get an accurate measurement of the coherence length of the HeNe laser being operated as well as other less common, low-cost lasers. This is planned to be measured by moving the retroreflector cart in increments of five centimeters and recording the visibilty using the photodetector voltages since it is proportional to intensity. The cart track essentially acts as a two meter delay stage giving the ability to measure large coherence lengths like that of a HeNe laser. In addition, since a second photodetector is not needed, this output can be replaced with the CCD camera ensure alignment is constant while moving the cart. For other lasers that have a much shorter coherence length, the retroreflector and cart can be replaced with a smaller automated delay stage to measure the length more accurately. Ultimately, this project has been an extremely educational undergraduate experience for us and has the potential to be able to categorize and document the important property of coherence lengths for a variety of lasers and light sources.

References

1. F. L. Pedrotti, L. M. Pedrotti, and L. S. Pedrotti, *Introduction to Optics, 3rd ed.* (Cambridge University Press, 2018).
2. J. J. ten Bosch and M. J. A. de Voigt, "Interferometric Study of the Modes of a Visible-Gas Laser with a Michelson Interferometer," *Am. J. Phys.* **34**, 479–482 (1966).
3. Abdulaziz M. Aljalal, "Michelson interferometry with a diode laser," *Am. J. Phys.* **90**, 373–379 (2022).