EC601 Project Literature Review
Grover Coins and Interferometry

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I. Introduction

Recent work in Dr. Alexander Sergienko's laboratory in the Boston University Department of Physics has experimentally shown advancements in interferometer technology that allows for significant upgrades in sensitivity by over an order of magnitude [1]. This experiment was done by upgrading a Michelson interferometer, using what is known as a Grover Coin to create a Grover-Michelson interferometer. Additionally, the sensitivity of this device was theoretically shown to be tunable across a wide range based on phase [2]. These recent advancements are extremely exciting, as interferometers are used heavily across a wide range of optical applications, and, by implementing Grover enhanced interferometers, the capabilities of these applications could be significantly upgraded. However, the current hardware available has limited the experimental applications explored to only Grover-Michelson interferometers; the group is chiefly interested in exploring Grover-Sagnac interferometers as well, as Sagnac interferometers are more ubiquitous than Michelson interferometers in application.

II. Interferometry

A. Michelson Interferometer

The Michelson interferometer was initially developed by Albert Michelson in 1887 for the famous Michaelson-Morley Experiment, shown in Fig. 1, which ultimately disproved the concept of the "luminiferous aether," which was the leading hypothesis at the time for how light propagated through the universe [3].

The interferometer functions by measuring the interference patterns introduced when the light is reflected into itself. A change in the phase can be detected when a disturbance is introduced to the system, allowing the user to measure several different phenomena based on the experimental setup and propagation medium [5]. Modern applications of traditional Michelson interferometers include optical filters, and optical dispersion and distance measurement devices [6]. Notably, the U.S. National Science Foundation's Laser Interferometer Gravitational-wave Observatory (LIGO) is also a Michelson interferometer at an extremely large scale [7]. The interference pattern of traditional Michelson interferometers follows a $cos^2(\phi)$ plot, where $\Delta\phi$ translates directly to a change in intensity, ΔI. Therefore, the higher the slope, the greater ΔI will be for the same $\Delta\phi$ measured, which directly translates to a greater sensitivity of whatever the desired measurement is [2].

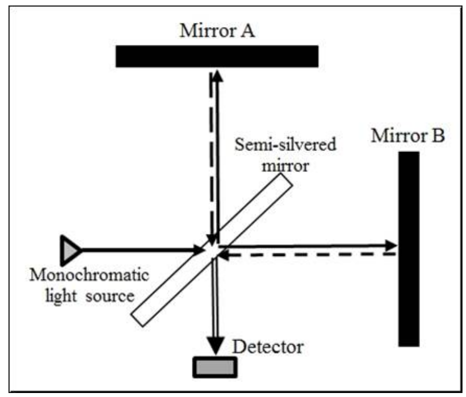

Fig. 1: Experimental setup of the Michelson-Morley Experiment. This setup is mostly the same as the modern day Michelson interferometer, though it has been upgraded using modern technology, substituting the semi-slivered mirror for a polarizing beam splitter [4].

B. Sagnac Interferometer

The Sagnac interferometer was initially developed by French physicist Georges Sagnac in 1913 as a method to detect rotation relative to stationary stars in space [8]. The original experiment utilized an interferometer shown in Fig. 2, with an extremely large square cavity utilized. Modern day recreations of Sagnac interferometers use optical fiber as opposed to an open cavity to easily increase the length of the cavity and, therefore, its sensitivity.

Though initially created to measure the rotation of the Earth, the enhanced sensitivity of the fiber optic Sagnac interferometer allows it to measure a wide range of phenomena. It is most commonly used in aerospace applications as a gyroscope, but can also be used for electrical current and acoustic sensing to name a few [9].

Similar to the Michelson interferometer, the Sagnac interferometer measures a change in the intensity of the light based on a change in phase across a $cos^2(\phi)$ plot where the points of greatest slope have the greatest sensitivity. However, despite being functionally very similar, it differs in the types of measurements it is capable of doing, because of the rotational aspect that is not present in the Michelson interferometer [9].

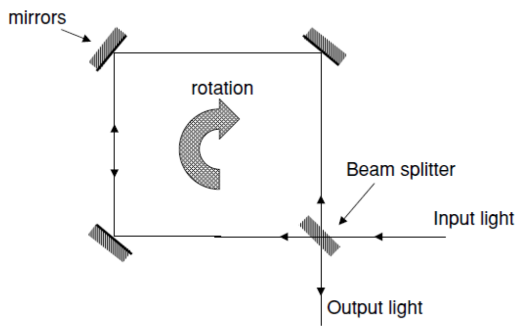

Fig. 2: Experimental setup of Sagnac's original experiment to measure rotation. The phenomenon that makes this measurement possible has now been titled "The Sagnac Effect." [9].

III. Advancements Using the Grover Coin

The Sergienko group has shown extensive progress to Michelson interferometers by implementing what is known as a Grover Coin in place of the polarizing beam splitter (PBS) at the center of the interferometer. The primary physical difference in the system is that the Grover Coin allows equivalent output from all four directions whereas a traditional PBS only allows optical output from two directions; this is shown visually in Fig 3. Mathematically, the Grover Coin can be represented by the 4x4 matrix [1],

$$G = \frac{1}{2}\begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \tag{1}$$

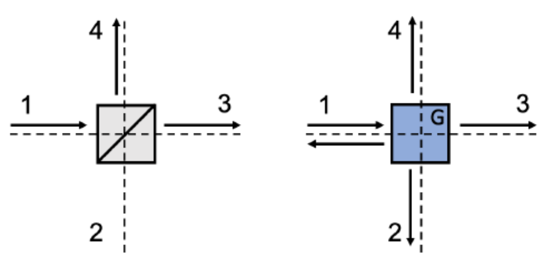

Fig. 3: Visual representation of physical difference between optical outputs of polarizing beam splitter (Left) and Grover Coin (Right) [1].

When implemented into the cavity and manipulated with specific arm phases, the intensity vs. phase relationship in the traditional Michelson interferometer that was discussed in section IIA, $I = cos^2(\phi)$, is shown to transform into the relationship seen in the black line in Fig 4. The slope in this transformation is dramatically steeper which, as discussed in section IIA, provides a significant increase in device sensitivity [1].

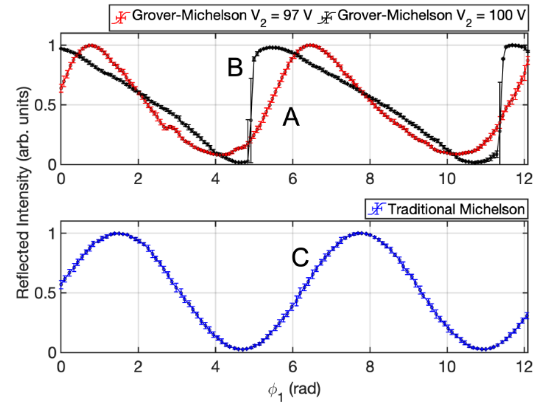

Fig. 4: Intensity vs Phase relationship of Grover-Michelson interferometer shown experimentally by the Sergienko Group (Top) compared to traditional Michelson Interferometer relationship (Bottom). The voltage shown correlates to a piezo-electric device controlling the arm phase in the Grover Coin [1].

References

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