University of New Hampshire
College of Engineering and Physical Sciences

Faraday Rotation Ammeter

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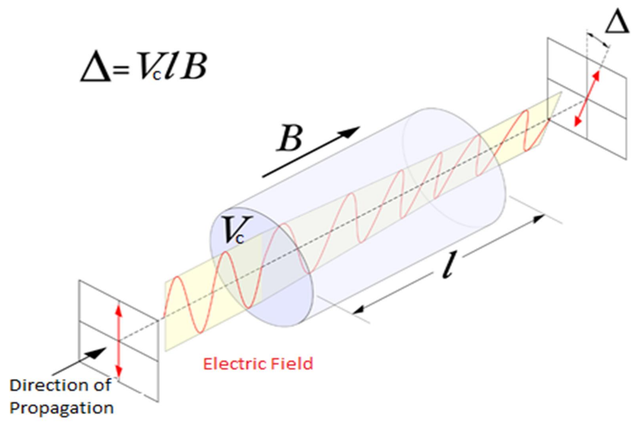
Problem Statement:

The need for a direct, non-intrusive measurement of space plasma current densities is required to determine critical currents at which the ionospheric plasmas become unstable. Observations show that current densities within the aurora are on the order of 10-100uA/m^2. Previous attempts at creating an instrument 20 years ago were able to achieve a sensitivity of 4mA/m^2. This project investigates ways to increase the sensitivity further to meet the expected values.

Introduction:

The Faraday Rotation Ammeter (FRA) experiment uses a linearly polarized laser source that is coupled to into a fiber optic cable to measure current density. When the device is placed in the desired environment, a present magnetic field (B) changes the angle of polarization of the propagating electric field via the Faraday Effect. The change in polarization angle is given by the Verdet constant (Vc), which describes material properties of the fiber relating to angular change and provides a measurement of current density. The strength of the magnetic field and length (l) of the fiber also affect the angular change of the as seen in the diagram and equation below.



Visual Demonstration of the Faraday Effect

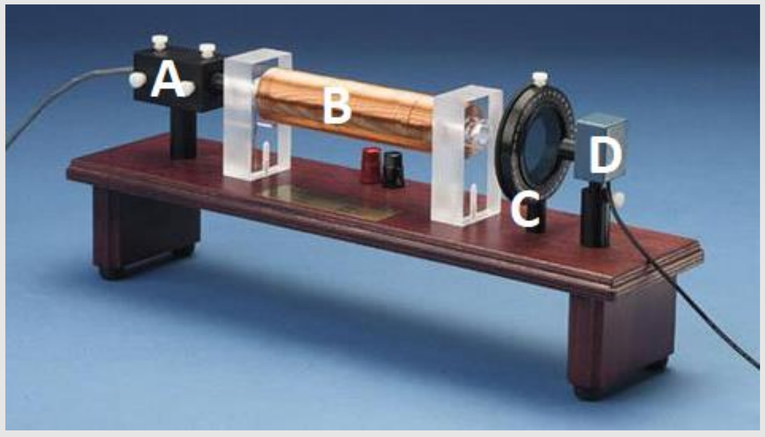
Objectives:

- Simulate a linearly polarized light source traveling through the system
- Measure and analyze the Verdet Constant of medium
- Rebuild the previous design
- Test the rebuilt design to verify the ability to measure the current
- Suggest improvements that will increase the sensitivity to be able to measure the expected values

Analyzing the Verdet Constant:

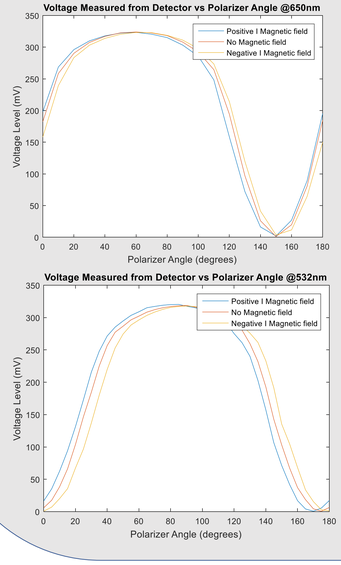
Faraday Rotation Experiment -

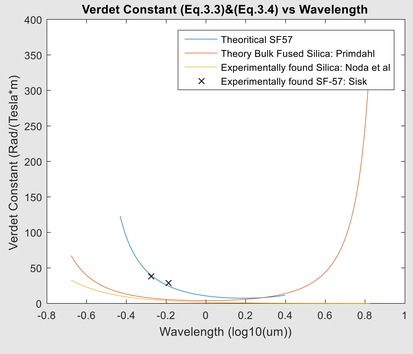
- A linearly polarized laser source (A) was powered and the polarizer (C) was rotated as the light exited the SF-57 glass to analyze the polarization angle as the signal entered the photodiode detector.
- Voltage levels given by the photodiode detector (D) when a constant magnetic field was or wasn't present in the solenoid (B) allowed the Verdet Constant of the SF-57 glass to be measured using Malus's Law.
- The detected Vc value of a laser source seen at a wavelength 650nm was 28.7 rad/mT while the expected was 23 rad/mT.
- Switching to a laser source with a wavelength of 532nm the detected Verdet Constant was increased to 37.34 rad/mT with the expected value for SF-57 glass seen to be 38 rad/mT.



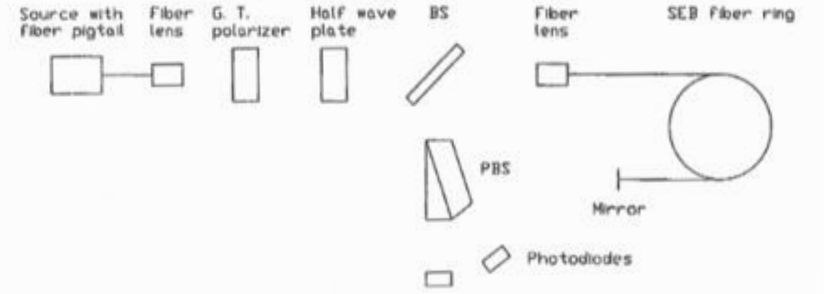
Faraday Rotation Setup used to measure the Verdet Constant

Measured Verdet Constant Data -





Original FRA Design:



$$\Delta = \mu_0 V_c \pi r^2 J$$

Equipment -

- Near-IR Laser diode (λ = 830nm)
- Polarizer to completely polarize the Laser source.
- Half Wave Plate to rotate the polarization state.
- Non-polarizing Beam splitter where 50% of the wave continues through (50% wasted).
- Fiber Lens/Coupler to focus the transmitted wave into the SEB fiber ring.
- Mirror to reflect the transmitted wave to increase the traveled length.
- Polarized Beam Splitter to split the rotated linearly polarized light wave down toward the photodiodes.
- Photodiodes to output the detected polarization state

Results:

Accomplishments -

- Created a functional MATLAB simulation to show how the Faraday Effect impacts the Electric field and determine the angle of rotation
- Verified that the Faraday Effect is real and that the Verdet Constant is a function of the wavelength of the laser source.
- Functional Laser Source, polarizer and half wave plate mounted.
- Mounted Beam splitter and fiber coupler with installed fiber chunk.
- SEB fiber from previous project intact. Talking with fiber companies on improving the fiber design and attenuation.
- Responsive Photodiodes and angle detection circuit

Future Improvements -

- Changing the wavelength of the laser source in order to take advantage of a higher Verdet Constant in the medium.
- Change the type of material used in the Fiber ring to obtain a larger Verdet Constant.
- Improve the fiber used in the Fiber Ring to minimalize the attenuation values in order to maximize the total length usable.
- Acquire photodiodes or polarimeter with greater sensitivity in order to detect smaller changes in polarization angle.

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