

# The Design, Development, and Implementation of Fabry-Perot Interferometer

A SENIOR PROJECT SUBMITTED TO THE  
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Senior Project Approval Page

THE SENIOR PROJECT OF **DAVID M HOUSTON** FOR THE BACHELOR OF  
SCIENCE  
DEGREE WAS ACCEPTED BY THE EVALUATION COMMITTEE AND THE  
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TECHNOLOGY  
ACADEMIC SENIOR PROJECT ADVISOR APPROVAL:

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THE FOLLOWING PAPER PRESENTS A CONCISE DESCRIPTION OF THE SENIOR PROJECT FOLLOWING THE IEEE JOURNAL GUIDELINES. THIS ABBREVIATED REPORT EXCLUDES ALL CONFIDENTIAL INFORMATION AND IT IS THEREFORE ADEQUATE FOR PUBLIC DISSEMINATION

**Project Goal:**

The goal of the project is to design, build, test, and implement a scanning spherical mirror Fabry-Perot Interferometer (FPSI) to characterize the spectral frequency output of a laser beam. The device will the laser beam cascade it through a confocal mirror setup. The beam will be focused on the mirrors with an image no greater than 1x the size of the object. The constituting output will consist of the graph of the spectral frequency terms for the different wavelengths of the laser beam. These terms will be maximized by the correct calibration of the device within 1% of max expected values. This generated output will be digitally synthesized and made readily accessible to the user via multiple modes.

**Motivation:**

This project is interesting due to its increased application over a broad spectrum of applied fields in optics, spectrum analysis, DSP, microcontroller technology, and computer interfacing. The project takes down the bulk and size of the current FPSI design and makes a simpler and far more efficient model, which has twice the capabilities and less than half the real-estate. The FPSI is not only a diverse project, but it is highly utilized in many applications involving metrology, which has made many advances in the fields of medicine, astrophysics, and quantum physics.

A modification in the way data is taken and stored is key in understanding the system for which it is implemented. This is why the current FPSI coaxial interfacing needs to be expanded to a more versatile tool. Interfacing over a coaxial line has many issues involved with it (i.e. cross talk), which has to be taken into account when using such a device. The project takes the old coaxial approach to data transfer and converts to a medium of exchange using digital serial interface, which is explained in the fourth section. This is equipped for high-speed transfer of data with the accuracy of the data preserved. While this doesn't conserve the full form of the signal, the algorithms encompassing the ideas behind DSP are more than enough to overcome this small issue.

The DSP improvements, to which there are not current assignments, greatly accentuate the projects suitability. The data for the expressed output will now be more readily available and easily accessible and readable. Before, the data would have to be analyzed on an oscilloscope and then recorded, however, now it will be accessible in any ready-access digital transfer form on hand (i.e. thumb drive, direct computer connection, or Bluetooth connection) (This is explained in great detail in the fourth section of the paper). Overall this will not only improve the performance of the device but also make operations more smooth and efficient for both research and industry operations.

The FPSI project will change from its current state of consisting of a substantially large driver to a smaller more transportable module capable of the same basic operation. This module will consist of a single input, describing the behavior of the interferometer, and two outputs, one driving the interferometer and one of the digitally synthesized data of the output (discussed in section four). This will make it not only more

mobile, but also safer, reducing the overall voltage in the system. The current setup for the FPSI requires a driving voltage of 300V this however, will be brought down to a safer range of 0-30V. This is because of a modification in the piezo's used for the oscillation of the device. Making changes in the hardware structure of the FPSI, is a step that will be done in order to reduce inconsistencies and unnecessary redundancies within the project.

While the present setup for the FPSI interferometer will only have minor changes, the components encompassing it will, and overall, improve the devices functionality and feasibility in research and industry. A simple explanation of the benefits of the project was thus explained so far, and I hope that you can take the time to read over the details encompassing the vast expansion in section four of this project and provide feedback where necessary.

### **Background:**

The spherical mirror Fabry-Perot Interferometer (FPSI) is a device consisting of two partially reflective confocal mirrors and an oscillator. The oscillator modulates the mirror system by changing the distance between the mirrors by microns, which consequently changes the geometrical system of the FPSI. This gives its scanning profile because of its ability to move through many different resonant wavelengths.

The driver applies a voltage ramp function, which in principle, cycles through all voltages from 0 to a set value. This max set value is usually set so that focusing on a specific wavelength can be achieved. Hercher explained in his paper that, "[s]ince the resonant wavelength of the interferometer is a linear function of the mirror spacing it is possible to obtain a linear plot of the source spectrum simply by recording the output from the detector as a function of the mirror separation." [1] This encapsulated the main idea behind the interferometer where a logarithmical scale of frequency can be taken and scale down to something that is linear and easily measureable.

This system differs from its predecessor, the parallel mirror Fabry-Perot Interferometer (FPPI), which was developed by Fabry and Pérot back in the early 20<sup>th</sup> century [1], in the fact that the light incident on surface on the mirrors is not collimated, but rather, focused on the first mirror allowing for a wider angle and range of distribution for the detector. The very first of the Fabry-Perot Interferometers had implemented a white light source and was driven by a series of pressured tanks, which displaced water accordingly. This allowed for the movement of the lens along an axis so as to observe the spectral fringes associated with that movement [2]. **(Talk more about this).**

This has been improved to scan over all wavelengths and to have a more exact form of measurement by means of electronic devices. The initial idea behind the scanning FPSI was to analyze specific modes of gaseous lasers to improve their performance in the field [3]. This idea was then expanded upon and now the scanning FPSI is not only used for laser mode analysis, but also for "pressure or mechanical scanning, fringe display, or tunable narrow band filtering" [1]. This idea was further expanded upon by using the FPSI actively to "control a tunable diode laser" for improved accuracy [5]. Further more, the use of the FPSI has been applied in interference

measurements. “The FPI is used to study the thermosphere by measuring the oxygen red line emission at 630.0 nm” [4]. It can be seen that the advancement of the FPSI has been growing over the decades, however control and measurement at high accuracy can only be truly achieved in a perfectly balanced system. While “Air-spaced FPIs... are more stable by 2 orders of magnitude and can be constructed for any desired wavelength” [5], the control of these devices can only be so exact due to flaws in analog control circuitry.

Due to the current setup of the FPSI being based solely on analog analysis and control drivers, accuracy to a degree can only be marginally achieved. In order to specifically obtain a truly balanced and accurate system one needs to know set specific values for the system to which measurements can be made and quantitatively known so as to reduce error within the system. In order to achieve this level of precision a switch from analog to digital control must be made.

[1] Hercher, M. (1968). *The Spherical Mirror Fabry-Perot Interferometer*. Applied Optics, 7(5): 951-966.

[2] Fabry, Ch. and Perot, A. (1901). *On A New Form of Interferometer*. University of Marseilles.

[3] Newell, J. W. (1965). *A Scanning Fabry Perot Interferometer for Laser Mode Analysis*. United States Naval Postgraduate School

[4] Ford, E. A. K. (2007) *High time resolution measurements of the thermosphere from Fabry-Perot Interferometer measurements of atomic oxygen*. Ann. Geophys., 25, 1269–1278

[5] Reich, M., et al (1986). *Internally coupled Fabry-Perot interferometer for high precision wavelength control of tunable diode lasers*. Applied Optics, Vol. 25, Issue 1, pp. 130-135

### **Proposed Plan:**

The plan for the design, development, and implementation of the Scanning Fabry-Perot Interferometer is based on a three-module design being:

1. The optical input
  - a. Fabry-Pérot Interferometer
  - b. Photo-detector
2. The black box
  - a. Driver
  - b. Processor
3. The digital output
  - a. ADC
  - b. DSP manipulation of two signals

These modules are described below in the following block diagrams indicating path of information and precedence in the system. The following key explains the module meanings and importance.

(Block diagram goes here)

### **Optical Input**

The optical input as shown in the diagram above will consist of the interferometer. This delicate structure is a active lens system which utilizes a focusing convex lens, two confocal mirrors, a peizo, and a photo-detector to send output. The lens system for the device is laid out in Fig. 1B. In order to determine the exact setup for maximum power transfer through the lens systems, a series of test will be constructed as to determine this setup. The first test will be to determine if the optimal distance between the lens and the first mirror. Table 1B lays out the tests and the results indicating the most desired setup for both measured and calculated values. Fig 2B outlays the setup for these calculations that were taken in OSLO, but also models the setup for the measurements that were taken.

(Fig 1B goes here)

(Fig 2B goes here)

The radius of curvature for the mirrors was measured to be  $40.2 \pm 2$  mm which puts the focal length at  $20.1 \pm 1$  mm. Fig 3B shows the layout for the previous measurement setup and the table for measuring these values can be found in Table 2B. This simply proves that the measured values for the mirrors were within the values for the expected radii.

In order to correctly determine the operation of the peizo, tests will be run with frequencies ranging from 0-300Hz in order to determine the functional impedance of the device and the proper admittance offset to properly stabilize the device.





The frequency will be controlled by the value from the analog input and will only change the amount of time the signal is on. Eq 1C explains the value of the frequency as a function of the active time. The signal has an off, or rest time, which stays constant regardless of the frequency. This however, will be tested with the new photo detectors to determine the discharge time so as to see how long they need to be turned off for. Fig. 2C shows the setup for this test. Fig. 3C describes the layout of the first part of this system and how they coincide with each other.

$$f_r = (t_{on} + t_{off})^{-1}$$

(Fig 2C)

(Fig 3C)

The output, which consists of a digitally synthesized analog saw-tooth signal, will be fed to an amplifier to boost the modulation signal in two stages. The first stage will provide a reference point so as to determine the spectral output of the photo detector. This voltage will be ranged from 0-5V so as to promote logical analysis via FPGA (this is discussed in Section 3). The second stage will amplify this signal to a maximum voltage, which will be determined by running specified tests on the peizo to determine ratios of voltage to vibration frequencies in correlation with spectral output. The specs for the ADS1115 microcontroller used are in Appendix B.

### ***The Processor***

The photo-detector will be mounted to an adjustable plate at the rear of the FPSI so as to allow for calibration of the FPSI. This will allow for maximum collection of the FPSI output and a better spectral reading on the output if the device is secure and stable. The output from the photo-detector will have to be amplified due to its small output signal. The amplitude output of a typical photo-detector is around 50mV. Based on the first design, it would be reasonable to assume that we would need an amplifier setup capable of producing a closed-loop amplification of 100. This will be created by a variety of OpAmps and magnitude resistors in order to maximize amplification in the system with a “tuning” resistor to focus on certain magnitudes of output. This will then be sent to an ADC on the Arduino, which will be processed and then sent as digital output to an FPGA, which will perform logical operations.

### **The Digital Output**

This type of output will be sampled from the output of the photo-detector through the processor, which will feed the corresponding data string via SPI interface to an FPGA or some other form of logical device. This will be determined by generating a logical layout of the process. This process is to take and create an output that will have the photo detector signal expressed as a function of the input voltage driving the piezo. This provides the output the ability to express the spectral frequency as a linear function of the change in the distance of the mirrors. Extensive reaserch and tests in this area will I need to be complete before an exact design of the process can be fully produced, due

to its complexity. Fig 1E shows the follow of data from the photodetector output to the master device.

(Fig 1E)

This data will then be interfaced to a external device (i.e. computer) in order to take the processed data and create a graphical representation as well as create a CVS with the associative data. This is be done via a GUI model with a language which posses the capabilities for a universal interfacing between master and slave device. Python will be used for the programming; however, other languages will be tested for interface and compared based on speed, cross-platform configuration, and simplicity.

### **Evaluation**

Overall the project will be able to take in the beam from a HeNe laser and deliver as output the modes of the laser. It will use a controllable driver, which will determine the range of wavelengths specified via attenuated input devices. This will be distributed by a microcontroller (Arduino Uno) and sent to a DAC (MCP4725) which will process the data and output the correct signal in accordance with the input signals. The tolerance will be measured to be within 1% of expected output for the driving voltage. Given the nature of the HeNe, we will measuring a two-mode system and, via the digitized representation of the output, will be able to correctly identify the two modes of the laser to within 5% of specifications. This will be done via FPGA logical design and computer interfacing for displace as well as the storage of the data. The GUI inferfacing output will provide specifications for the modes wavelength as well as amplitude and

Time Line (this layout will be more professional)

