Fast Polarization Switch "Poincaré Switch"

Michelle Nguyen[1], David "Austin" Rich[2] and Joshua Hendry[2]

1. Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

2. Dept. of College of Optics and Photonics, University of Central Florida, Orlando, Florida, 32816

Abstract — The Fast polarization switch is a mechanical system that employs a birefringent optical crystal that will alter the path length of the light by rotating the crystal. When the axis of rotation is aligned with the fast axis of the crystal and is off axis by 45° in reference to the incoming light's polarization. We can achieve orthogonal polarization states with small degrees of variance in the total path length. The project's sponsor, ASML, is looking to use this system to assist in semi-conductor metrology. ASML will use this project to explore the viability of a mechanical system designed to achieve orthogonal states with a Polarization Extinction Ratio of 100:1 with a switch time of at most 5 ms and it needs to work utilizing visible light frequencies.

I. Introduction to Fast Polarization Switch

This project was based on a research paper done in Korea in the department of physics at KAIST (Korea Advanced Institute of Science and Technology) titled **"Double-pass rotating z-cut quartz plate as a rapidly variable waveplate."** by Byungjin Lee, Kiryang Kwon, and Jae-Yoon Choi. This paper was provided to us by our sponsor ASML. The paper gave good theoretical and experimental findings, and research avenues to establish more background and study the history of these types of devices. Your basic Polarizers that you find in the lab can be adjusted by rolling the crystal in reference to the path of the light and follow a similar working principle to the project. However, this device takes it to the next level of precision and timing. By employing a cross-flexure galvanometer motor controlled by software built in LABVIEW, we can precisely control the position of our crystal and the timing it takes to get there. By utilizing GTPs or Glan-Taylor Polarizers in adjustable mounts we were able to create a system that meets the PER (Polarization Extinction Ratio) of 100:1**.** We supported the results of our system with mathematical and theoretical simulations that can be used to fine tune the system or even explore how changes to the system will affect the output. Then map the results of the math to the "Poincaré Sphere". Showing the polarization state. We hope that our work will provide a good background and launchpad for ASML or other teams to improve this system or utilize it as a part of their product line.

II. Features and Functionality

The main functionality of our project is to take in light and change its polarization to a desired one. This is done by utilizing the birefringent crystal property of having 2 different refractive indices. By rotating this crystal, we can adjust the optical path length of the light that goes through it. This will allow for the ordinary and extraordinary axes of the light to experience different retardation which will change the polarization of the output light. As we rotate our crystal, the polarization of our light, if mapped onto the Poincaré, will form a great circle that p1asses through two linear states and both circular states.

This system can also be used as an extremely sensitive power modulator. By placing a polarizer in the path of the light exiting the crystal, we can modulate power simply by changing the polarization of the light. This means as we approach the polarization of our polarizer, we will have an increase of optical power and as we move the polarization closer to the orthogonal polarization, we will have less.

This polarization modulation method produces a system with an extremely high extinction ratio, 100:1 demonstrated by the scientists in the paper stated earlier, and a system that can be modulated quickly as the only thing needed is to rotate the crystal to a specified degree.

ASML has tasked us with being able to hit three goals which are achieving a polarization extinction ratio (PER) of 100:1, having the system function with any wavelength in the visible spectrum, and achieving a switching speed of under 5ms.

A. PER

The extinction ratio of our system is defined as the number of photons measured with the desired polarization vs the number of photons in the orthogonal polarization. This value can be easily determined using the output polarizer of our system. By setting the output polarizer of our system to the polarization of the light leaving our crystal, we can measure the maximum optical power. By then rotating the polarizer to the orthogonal state, we measure a minimum power. The ratio of these two powers directly correlates to the extinction ratio of our system.

B. Wavelength

The wavelength of light that our system is compatible with is directly determined by our optical components and the crystal itself. The wavelength of the light will affect the degree needed to turn the crystal to achieve a desired polarization state. This means we need a program to adjust the degree needed to rotate the crystal based on the wavelength of the input light. We will also be using uncoated optical components, in the case of the crystal, or components coated to accept the visible spectrum of light to ensure that our system will work with any wavelength within this spectrum.

C. Timing

To measure switch timing, we utilize a DET100A2 photodiode this combined with a TIA circuit allows us to measure the timing between orthogonal polarization states, or on and off states of our system. By measuring the time, it takes to move between them when we rotate our crystal between two pre-determined locations. Our goal is to see a change between a maximum and a minimum that happens in under 5ms. MATLAB will produce the waveform and sends this waveform to LabView to be displayed to the user in the GUI, allowing us to directly compare the results of our sim to the results of the system. Our demo of functionality will work the same as our timing test. However, it will only utilize the broadband LED as that is the light source we use to replicate the incoming light of ASML's system.

D. Overall Functionality (Demo)

Our demo will replicate as closely as the NDA allows the system in which ASML will integrate our project. It uses a broadband source with a spot size of 10 mm and a wavelength range with a bandwidth of 30 nm.

III. Subsystem Components

A. Lasers

To ensure that our project works with the entire visible spectrum, we will be using two different lasers across this spectrum. We will be using a PL205 and PL202 from Thorlabs. These are red and blue lasers, both ends of the visible spectrum, so that we can ensure that if the device works for these two light sources it will work with any source also in the visible spectrum.

To ensure safety in our system, we chose low power lasers, only having an optical power of 0.9mW. We will also be using beam blocks anywhere in our system where we may have stray beams including polarizer and beam splitter waste.

B. Polarizers

Polarizers play a crucial role in our system as they will help us determine the overall PER of our system. These polarizers will act as the ceiling to our extinction ratio, so we need to ensure we have polarizers with a much higher extinction ratio than 100:1. This led us to choose a polarizer type, being the Glan-Taylor polarizer. This type of polarizer features such a high extinction ratio because it uses two crystals with an air gap specifically designed to reflect any polarization that is not the desired one. The polarizers we chose are the GT5s from Thorlabs. These will allow us to have an extinction ratio ceiling of 100,000:1 which is much higher than our desired PER of 100:1. This will allow us to see the true PER of our crystal and not be limited by our polarizers.

C. LED

The LED in our system will work with our TIA to determine switching speed. Also, to closely mimic the design that this type of system will experience as told to us by our sponsor, we have chosen an LED with a bandwidth of 30nm. For this bandwidth property, we chose the M470L5 from Thorlabs. This device is a high-power blue LED with a bandwidth of 28nm. This will clearly demonstrate to our sponsor how this type of system will react in combination with their other systems that use a broadband source. This source has a central wavelength of 470nm and an average power of 1161.7mW

Since this is an LED, it is a diverging beam which means to pass through our system we will need a collimating lens. For this lens we chose the ACL25416U from Thorlabs. This lens has an extremely high numerical aperture, meaning it will accept a large area of emission. To calculate the divergence of the beam after collimation, we use the focal length of the lens, which is 16mm, and the emission area of the LED, which is 1mm. We use the formula:

$$\theta = \frac{d}{f} \qquad \text{Eq. 1}$$

Where theta is the divergence angle after the lens, d is the diameter of the emitter, and f is the focal length of our lens. Using our numbers from earlier we get theta is equal to 3.6 degrees. Since this is a relatively small divergence angle and the LED is a Lambertian source, we will consider this zero for now. The amount of captured light is determined by the lens numerical aperture which is 0.79. Using the equation:

$$1 - \cos(\theta) \qquad \text{Eq. 2}$$

Where theta is the half angle corresponding to the NA, which is 52 degrees, we get a collection efficiency of 38%.

The beam from this source while high powered will also experience the samebeam blocks as the laser to ensure safety for any bystanders that may experience harm from this LED.

D. Birefringent Crystal

We chose Calcite for our birefringent crystal because it has very high birefringence sans the non-linearities to prevent frequency conversion and improve PER (Polarization Extinction Ratio). This allowed us to use an incredibly small crystal reducing weight and strain on the motor and improving the switch speed while still being able to stop and hold within the given time frame. Our calcite is 0.1 x 10 x 10 cm. If we had chosen a thicker calcite, we would have needed to design a motor system that would have to be even more precise. If we had chosen another material, i.e. Quartz, we would have needed a crystal almost 10 times the size. Such as the one used in the reference paper provided by ASML. To help us decide our crystal and compare between the possibilities we utilized our MATLAB simulation to determine the angles of rotation needed and to predict the possible PER of the system when utilizing the crystal. As well as what may happen giving any inconsistencies with the crystal alignment. Then mapped the results onto the Poincaré sphere to determine the polarization state.

E. Photodiode

The chosen photodiode needs to have a couple of specifications. It needs to be fast enough to sense our switching time, be able to read the full visible spectrum, and measure our max to minimum power. For these specifications, we chose the DET100A2 detector to measure the switching time and the S120C paired with the PM100D to measure the extinction ratio. The DET100A2 will be paired with our transimpedance amplifier to read a clean current graph of our optical power converted to current. With the DET100A2's fast rise time of 35ns we should easily see a switching speed on the order of milliseconds. We will use the other device to easily read the optical power of our system. With the S120C's low minimum power reading of 50nW and maximum power reading of 50mW, we will be able to see the minimum and maximum power of our system using the laser. This comes from the PER of our system being 100:1 and the formula:

$$P_{min} = \frac{P_{max}}{PER} \qquad \text{Eq. 3}$$

With our max power being 0.9mW our minimum power should be 0.9μW. This will be a power range acceptable for the S120C.

F. Motor

For our project, it was decided to utilize a galvanometer motor for its fast-switching speed, closed loop feedback system for precise motor movement, and its small step angle. ThorLabs Cross-Flexure 1D galvanometer motor was chosen as the motor for our system due to its availability and advertised cost. When researching different galvanometer motors on the market, it was difficult to find a galvanometer motor that was currently readily available as other galvanometer motors could take months to arrive. Another issue was the cost of the galvanometer motors as other motors on the market did not advertise their cost and instead, the customer had to reach out to the company for the cost. Thus, it was decided that the Cross-Flexure 1D galvanometer motor would be the motor for our project since it was readily available, which would help with the time constraints of the project and the cost was advertised which would help with keeping the project under the given budget.

G. Motor Control

For our project, it was important to determine how to control the motor. For the motor driver, the Cross-Flexure 1D galvanometer motor came with its own motor driver. Thus, the motor driver that comes with the galvanometer motor will be utilized to control the motor which ensures the compatibility between the motor driver and the galvanometer motor along with assisting with the workload of the project as the motor driver PID control comes configured to work best with the motor.

Next was to determine how to tell the motor the degree movement to rotate. It was decided to utilize a DAQ card based on the recommendations of Thorlabs to generate the voltage that would tell the motor driver the desired degree movement of the motor. It was then decided that the USB-6002 would be the DAQ card utilized in our project due to its cost and update rate of 5,000 samples per second. The USB-6002 was one of the cheaper options for the DAQ card on the market, which helped with keeping the project within the given budget. The 5,000 samples per second update rate is a high enough update rate that would permit the motor to have a switching time within 5ms.

H. Microcontroller

For the microcontroller, the ESP32 was chosen to be utilized in our project for its low power consumption, cost, and its compatibility with the Arduino IDE. The Arduino IDE is a development environment that is beginner friendly, uses a simple C programming language, has an extensive library, and a large community support which helped with the development time and labor of the code for the microcontroller. The ESP32-S3 development board was chosen as the development board in our project due to its dual core capabilities which ensure certain tasks in the microcontroller code would not interfere with each other. The development board was utilized specifically in our project to assist with the testing of the code for the microcontroller, which helps with debugging issues with the PCB to determine if it was a hardware or software issue.

I. Operational Amplifier (Op-Amp)

For our project, OPA354 was the op-amp chosen to be utilized in the TIA circuit. The reason OPA354 was chosen was due to its rail-to-rail output type, 100 MHz gain bandwidth product, and 3 pA current input bias. The rail-to-rail output type allows the op-amp to be operated on a single power supply rail. This helped with the development of the TIA circuit since it prevented the need to create a negative power supply for the negative rail. For the TIA circuit, it was calculated that the op-amp would need to have a gain bandwidth product of at least 50 MHz. The OPA354 gain bandwidth product of 100 MHz meets this requirement with headroom as well which ensures that the op-amp is not the limiting factor of the TIA circuit. Last of all, the 3 pA current input bias ensures that the op-amp is accurately measuring the current from the photodiode to provide an accurate output voltage to ensure that we have an accurate reading of the switching time of the motor.

J. Digital-to-Analog Converter (DAC)

The ESP32-S3 lacks DAC functionality and thus, an external DAC component must be utilized in our system to output the voltage value from the TIA circuit to the DAQ card to be displayed to the user. The DAC6311 was chosen as the DAC component for our system due to its SPI data interface and 50 MHz output frequency. When choosing a DAC component, the choice had to be made between using an I2C and SPI data interface. An SPI data interface was chosen as the DAQ has an input voltage sampling rate of upwards to 50 kHz. The I2C has a slower output frequency rate than the SPI and may not be able to keep up with the DAQ card. Thus, the SPI data interface was chosen and the DAC6311 was chosen for its output frequency of 50 MHz which can keep up with the input analog sampling rate of the DAQ Card.

K. Power Supply

In our system, there are three main components that need to be powered: the motor, the LED, and the ESP32.

The motor will be powered by the GPWR15 DC Power Supply as it is recommended by the motor company (ThorLabs) to utilize this power supply with the motor.

The LED requires an LED driver to power the LED. The LED driver chosen was the LDDS-1000HW due to its voltage output of 2 V to 45 V and its max current output of 1 A. The LED company (ThorLabs) recommends choosing an LED driver that can provide the forward voltage needed of 3.8 V and does not exceed the max input current of the LED which is 1 A. Thus, the LDDS-1000HW was chosen as the LED driver for our system.

An external power supply is needed to power the LED driver. The LED driver takes an input voltage of between 12 V to 56 V and needs a current of at least 820 mA to be able to supply 1 A to the LED. It was decided to utilize the wall outlet as our power supply to the LED driver since the DC power supply for the motor already uses the wall outlet as its power source. To convert the AC power of the wall outlet to DC power to be utilized by the LED driver, a power adapter must be selected. The 16-00216 power adapter was chosen as the power adapter for our system due to its 12 V output voltage and 3 A output current. The 12 V output voltage meets the requirements needed to power the LED driver while the 3 A current gives extra room for the LED driver to function.

The ESP32 takes an input voltage of 3.3 V to power on and can draw upwards of 500 mA depending on the complexity of the code. Thus, a voltage regulator needs to be selected to power the ESP32. The LM2575 voltage regulator was chosen as the voltage regulator in our system due to its lower power dissipation as a switching regulator, 4 V to 40 V input voltage, 3.3 V output voltage, and max output current of 1 A. Due to the LM2575 taking an input voltage of 4 V to 40 V, the power adapter can be utilized as the power source for the voltage regulator. The LM2575 is also compatible with the ESP32 since it can output a voltage value of 3.3 V and provide upwards to 1 A which is enough current for the ESP32 to function. Last of all, utilizing the TI WEBENCH program for the circuit design of the LM2575, the total power dissipation can be as high as 651.99 mW which negates the need to have a heat sink for the voltage regulator on the PCB.

IV. HARDWARE DETAIL

A. Optical Setup

Our optical setup will consist of two components: the optical combiner and the crystal plus analyzer. The optical combiner will consist of two sources being one of our lasers and the LED, two mirrors, the lens, and a beam splitter. The LED will be fed into our lens which will then reflect from a mirror angled at 45 degrees to feed into a beam splitter. The laser will shine directly into the beam splitter. This process will create two outputs from the beam splitter that are both sources going in the same direction. One of these outputs is considered waste and is blocked with a beam block to protect the eyes of the users. The other output will reflect off the second mirror and o into the crystal and analyzer setup. A diagram of this setup is shown here:

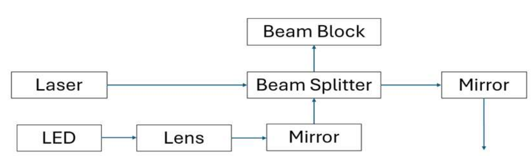


Fig.1. Diagram of optical combiner design

The crystal plus analyzer setup consists of the polarizers, crystal, lens, and detector. The first polarizer will determine the two places that the great circle, traced by the polarization states on the Poincaré Sphere, will intersect the sphere on the equator correlating to the two linear polarization states achievable by this setup. The crystal will then change the polarization of the light. The final polarizer and detector will be used to determine PER. The detector will be easily swapable so we can use either of our two detectors. The final lens is used to focus the light onto the photodiode. A diagram of this setup is shown below:

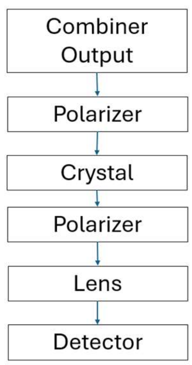


Fig. 2. Diagram of the crystal plus analyzer setup

B. PCB Setup

For this project, there are a total of three PCB boards: voltage regulator, TIA circuit, and the main board.

The voltage regulator PCB houses the LM2575 with the necessary inductor, capacitor, and diode needed in the circuit for the voltage regulator to function. The voltage regulator PCB also has an LED indicator to assist with the debugging process.

The TIA PCB houses OPA354 with the necessary resistors and capacitors needed for the TIA circuit to function along with a BNC connector to connect with the photodiode as the input to the TIA circuit. A total of three op-amps were utilized to build two amplifiers and a filter that are cascaded in the circuit. The first amplifier is the transimpedance amplifier that converts the current from the photodiode into voltage. The second amplifier is the unity buffer amplifier to assist with the impedance of the circuit. The last op-amp cascade is an active low pass filter with a cutoff frequency of 25 kHz. The TIA PCB's power supply comes from the voltage regulator PCB since the ESP32-S3 can only read a voltage value of upwards to 3.3 V. If the ESP32 reads a voltage value greater than 3.3 V, it can damage the ESP32-S3 and make it unusable.

The main board PCB houses the voltage regulator PCB, TIA PCB, ESP32-S3-WROOM-1U-N8 module, USB Type A connector, screw terminals (for connections to the DAQ card, LED driver, and LED), CP2102-GMR USB to UART bridge, and two buttons along with various resistors and capacitors. The main board PCB functionality acts as the central hub for low level processing and sensing to turn on or off the LED based on the user's input and to collect the data needed to determine the switching time of the motor.

The Type A USB connector, CP2102-GMR chip, and buttons are utilized to upload code onto the ESP32. One of the buttons is the Reset button for the ESP32 and the other button is the Enable button for the ESP32. An LED indicator will be utilized for debugging purposes in which if the proper code has been uploaded, the LED indicator will start blinking.

For the ESP32-S3 to receive the user input of wanting to turn on the LED, the ESP32-S3 has a dedicated pin to reading digital voltage signals from the DAQ card and another dedicated pin to output a digital voltage signal to the LED driver to turn on the LED. A second LED indicator will be utilized to determine if the DAQ card is outputting a digital voltage signal to the ESP32-S3. A third LED indicator will be utilized to determine if the ESP32-S3 is outputting a digital voltage signal to the LED driver.

For the switching time data collection, the ESP32-S3 is assigned a dedicated analog-to-digital converter (ADC) pin to read the voltage output from the TIA PCB. The ESP32-S3 then utilizes SPI communication with the external DAC component to output the voltage value to the DAQ card to be read by the user. The first LED indicator will stop blinking and stay on to indicate that the ESP32-S3 is reading the voltage value and is communicating with the DAC.

C. Motor

The motor requires four total wires to function. The first wire goes from the DC power supply to the motor driver to power the motor driver. The second wire goes from the motor driver to the motor to power the movement of the motor. The third wire goes from the DAQ card to the motor driver in which the DAQ card outputs the voltage value for the motor driver to process for the desired motor movement. The fourth wire goes from the motor driver to the motor in which the motor driver outputs the voltage and current needed to achieve the desired motor's movement.

V. Software Detail

A. Microcontroller Programming

The ESP32-S3 is programmed to blink an LED indicator and continuously check if it reads a digital voltage value from the DAQ card. If the ESP32-S3 reads a digital voltage value from the DAQ card, the ESP32-S3 keeps the LED indicator on, outputs a digital voltage value to the LED driver, and starts to continuously read the output voltage value from the TIA PCB. The ESP32-S3 then utilizes SPI communication with the DAC to output the voltage value that is then sent to the DAQ card to be read by the user.

The FreeRTOS library is utilized in the microcontroller code to assist with the division of tasks. Two main tasks are in the program, a task for the ADC reading and a task for the DAC output. The DAQ card can sample voltage values upwards to 50,000 samples per second and thus, the ESP32-S3 will have to read voltage values at a rate of 50 kHz and output voltage values at a rate of 50,000 samples per second. Thus, to ensure the two tasks do not interfere with each other, the two tasks are pinned onto two separate cores of the ESP32-S3. Queues are utilized to transfer data between the two tasks safely. The ADC task sends the voltage value reading to the DAC task. The DAC task then reads this voltage value and utilizes SPI communication with the external DAC component to output this voltage value.

Due to the need for the ADC reading to have a frequency of 50 kHz, the Arduino IDE ADC reading library cannot be utilized in the code as it does not have the functionality to read voltage values at that high of a frequency. Thus, the ESP-IDF ADC reading library needs to be utilized in the code to be able to read voltage values at the desired frequency.

B. Graphical User Interface (GUI)

The GUI will be created in the program LabVIEW which is a graphical programming environment that specializes in data acquisition and instrument control. LabVIEW has two components to its program, a front end and a back end. The front end is where the GUI is in which the user will input if they want the LED on or off, determine the type of motor movement, and verify the switching time of the motor.

The user will be able to select three different types of motor movement: holding, switching, and sweep. For each motor movement type, the user will input the desired degree that they want the motor to travel to. For the holding motor movement type, the motor will rotate to the desired degree that was inputted by the user. For the switching motor movement type, the motor will rotate to the first desired degree and then switch between the first desired degree and the second desired degree. For the sweep motor movement type, the motor will rotate from 0 degrees to 10 degrees in five seconds.

An LED indicator will be displayed at the bottom of each motor movement type to indicate when the motor movement type is ready to start. The user will click on the Start button under the motor movement type that is ready and the motor will begin moving based on the user's input. When the user wants to stop, the user will click on the Stop button.

The user will also be able to verify the switching time of the motor. LabView has the capability to communicate with MATLAB to exchange data or to have MATLAB run certain pieces of code. LabView will give MATLAB the voltage values that the DAQ card reads from the external DAC component. MATLAB will then plot these values onto a graph in which the x-axis is the time in milliseconds and the y-axis is the voltage values. MATLAB will then send the graph back to LabView for it to be displayed to the user in the GUI in which the user will be able to calculate what the switching time of the motor is.

C. Motor Control

In the back end of LabVIEW is the code of the program in which instead of the traditional coding with words, LabVIEW utilizes block coding; however, the same coding principes still applies. One such principle is "if else" statement in which LabView utilizes case structures to fulfill this coding principle. LabView also utilizes shift registers to pass one value of an iteration within a while or for loop into the next iteration. Through case structures and shift registers, a program can be created in LabView to select the type of motor movement to execute based on the user's input.

To control the motor's movement, LabView's Setpoint Profile VI functionality will be utilized. The setpoint profile uses two arrays: time and setpoint value. The time array will be utilized to assist with the timing of outputting the voltage value from the DAQ card to the motor driver. The setpoint value array will be used as the voltage value that will be sent to the motor driver. Instead of calculating the specific voltage values in between two time periods, the Setpoint Profile VI will do that calculation for us. The only values we need to give to LabView's Setpoint Profile VI are the time of when the motor should be at a certain degree and what degree the motor should be at given as a voltage value.

D. MATLAB Simulation

A simulation was created in MATLAB to help us predict the response of our system and to guide us in choosing the correct crystal and positions when it came to the degree of movement the motor had to move. ASML also requested us to do a deep dive into the math of the crystal we believed the best way to do that and the best resource to provide ASML in tandem to this system would be a mathematical simulation supporting this set up in both understanding how to get it to work, but also the pitfalls one must watch out for when fine tuning the system,. Which dimensions or alignments have the greatest effect on the output of our system, and how by altering other optical components you may be able to compensate for those issues. Included below are some of the key results from our simulation that were constantly referenced when fine tuning the system in the lab.

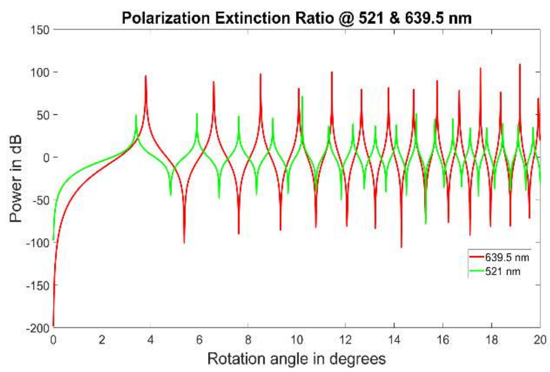


Fig. 3 Plot from MATLAB simulation shows the PER response of the system as the calcite crystal is rotated from 10˚ to 20 ˚.

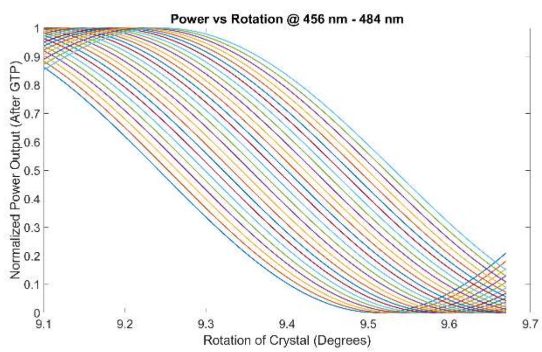


Fig. 4 Plot from MATLAB simulation showing the response from our system as we go between a minimum and maximum point for our broadband source. GTP (Glan-Taylor Polarizer).

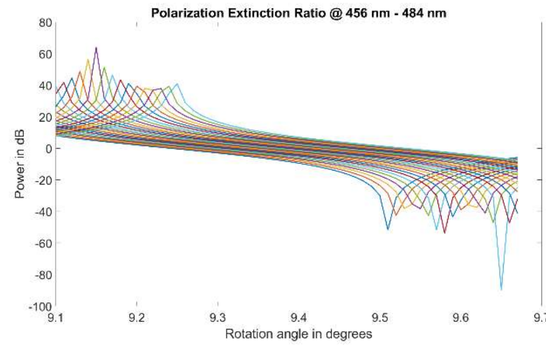


Fig. 5 Plot from MATLAB simulation showing the PER response of the system using the broadband source, each line corresponding to one of the constituent wavelengths of our system.

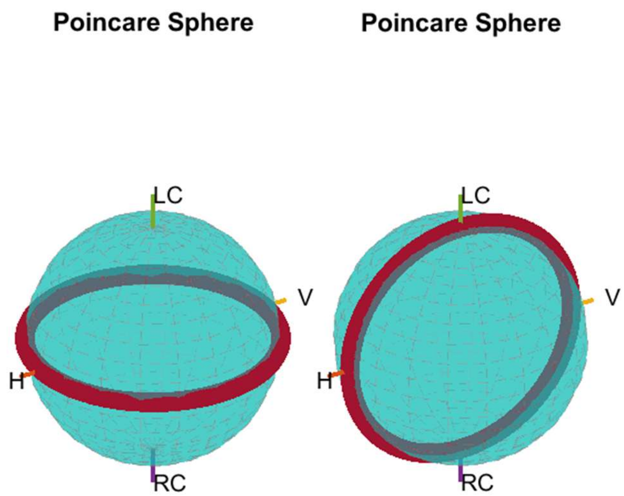


Fig. 6 Poincaré Spheres showing the achieved polarization states of our system when we include a static QWP(Left) and without the QWP(Right)

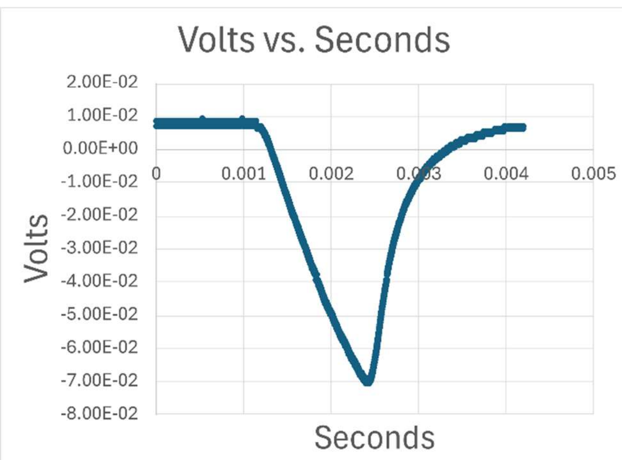
VI. System Performance And Characterization

A. Optoelectronics Feasibility Study

The Fast polarization switch project utilizes a photodiode to measure the efficacy of our system. With a target 30 dB difference between the off and on states of our output power. The photodiode will be combined with a transimpedance amplifier to offer an analog measurement of the output providing high enough fidelity of measurements to clearly see any vibrational effects and accurately compare the experimental results to the simulated results, the photodiode we are using is a biased Si detector from Thorlabs the DET100A2 with a detector size of 75.4 mm^2 , 35 ns Bandwidth of 10Mhz. Taking the output of our sources both the beam size and the overall optical losses due to the absorption and scattering cause by the optical components we can simulate the intensity incident on the detector.

B. Switching Speed of Motor

The switching speed of the motor is verified by use of our TIA Circuit and will send a packet of data after the completion of a run to our MATLAB simulation which will plot the waveform produced by our system over time. This will show how much time it takes to switch between the two points provided. The timing tests take place over the course of a couple of seconds, so there are myriad data points to compare and analyze to prove the systems' capabilities and consistency. Below you will See The plot of the timing. Showing the change of 0.5 degree's and back. Proving the capabilities of our system to achieve a sub 5 ms switch time. The timing and consistency of the motor movement have been one of the more reliable parameters of our system. The PER in comparison took more fine tuning to meet the criteria.



C. Polarization Extinction Ratio & Wavelength

To test our wavelength, we set up our optical system and used a red and green laser. We ran both sources through our optical system and found that in each case we were able to change the polarization of the light. To test our PER, we crossed our polarizers and started sweeping through angles of our crystal. Doing this allows us to see several max optical powers and minimum optical powers. We recorded going between several maxes and minimums and took the ratio of their powers. With this setup we were able to achieve a mean PER of 200:1 with the red laser and 160:1 with the green laser. To increase those values to the desired 100:1 we plan on using specialized mounts for our polarizers to more accurately adjust the output analyzer.

Wavelength	Max	Min	PER
639.5 nm	471 uW	2.31 uW	200
521 nm	449 uW	2.8 uW	160

D. Transimpedance Amplifier

The TIA circuit was simulated in LTspice to determine what the output voltage should be based on the input current from the photodiode. To test the accuracy of the TIA PCB, the PCB was tested on a breadboard with a DC power supply and various resistors to achieve the desired input current. The output voltage of the TIA PCB was measured with a digital multimeter, and the measurement was compared with the simulation.

TABLE I
TIA PCB TESTING RESULTS

Input Current	Simulation	Experiment	Error Percentage
1 mA	332.01 mV	352.205 mV	6.08265%
2 mA	664.0 mV	676.32 mV	1.85542%
3 mA	996.0 mV	1.03621 V	4.03715%
4 mA	1.3279 V	1.39701 V	5.20446%
5 mA	1.6599 V	1.68734 V	1.65311%
6 mA	1.9920 V	1.98154 V	0.5251%
7 mA	2.3240 V	2.37353 V	2.13124%
8 mA	2.6560 V	2.94888 V	11.0271%
9 mA	2.9880 V	3.02710 V	1.30857%

Based on the results and averaging error percentage, the average error percentage of the overall TIA PCB is about 3.758312%. Thus, it can be concluded that the TIA PCB is accurate and precise, which means it can be utilized in our system to determine the switching time of the motor.

VII. Conclusion

The Fast Polarization Switch or Poincaré Switch was a fantastic project that pushed the boundaries of our skills and expertise as well as challenging our teamwork and time management abilities. Throughout these two semesters we were able to accomplish our goals in the best way we could with our biggest constraint being time. Time severely limited the options for key components of our system. namely the motor and crystal. We got the crystal we wanted but it came in later than we would have preferred and the motor was the only one with an appropriate lead time. However, it required us to write our own software to operate and was calibrated for a certain load requirement forcing us to keep the mirror that came with the motor attached. We could see some major improvements regarding the long-term reliability of this system if the motor that is procured is calibrated for that specific load and operating state of the motor. Or other crystals/set ups involving different orientations of the motor are implemented.

BIOGRAPHIES

Michelle Nguyen is currently a Senior at the University of Central Florida and will receive her Bachelor of Science in Electrical Engineering in May 2026. She is currently working as an undergraduate research assistant for Dr. Troung Nghiem and has plans to work at TRC as a Power Distribution Intern during the Summer of 2026.

David "Austin" Rich is a senior at the University of Central Florida and will recieve a Bachelor's degree in Optics and Photonics. After graduation he has plans to join the workforce applying his knowledge to bettering the future of Photonics.

Joshua Hendry is a Senior at the University of Central Florida and will receive his Bachelor of Science and Engineering in Optics and Photonics in May of 2026. After graduation he will be completing an internship at "Phase Sensitive Innovations", an RF & Photonics company in Delaware, before hopefully moving onto the University of Delaware. To pursue a Doctorate in Computer and Electrical Engineering with a concentration in Electromagnetics and Photonics.

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