

ECE445
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Adaptive Light-Filtering Glasses

Team 7

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Abstract

This document proposes a pair of adaptive light-filtering glasses designed to (a) detect potentially hazardous flickering light and (b) reduce the exposure and risk the conditions pose to individuals with photosensitive epilepsy or other light-sensitive conditions. The system makes use of three photodiodes to monitor ambient, directional, and behind-lens light intensity to identify flickers. Based on the flicker frequency and magnitude, the system identifies a risk level, with potentially hazardous flicker frequencies being within the range of 3 to 60 Hz, and dynamically controls the LCD light valve lenses to attenuate the incoming light. A behind-lens photodiode provides a closed feedback loop adjustment of the optical attenuation. The proposed system targets at least 80% hazardous flicker detection accuracy, a false positive rate below 10%, an attenuation response time below 0.5 seconds, and over 8 hours of battery lifespan.

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1. Introduction

1.1. Problem

Photosensitive Epilepsy or PSE is a form of epilepsy in which seizures can be triggered by visual stimuli consisting of flashing lights, repetitive patterns, rapid changes of colors, etc. Such stimuli can be found in both natural and artificial environments such as while driving down the road or even while watching films. The likelihood of provoking a photosensitive response depends on several characteristics ranging from its frequency, intensity, color, percentage of the visual field occupied, etc. Typically, flicker frequencies occurring between 3 to 60 Hz are counted as potentially hazardous and higher sensitivity is found between 15 to 20 Hz. As such, our **problem statement** is defined as:

“Individuals with photosensitive epilepsy are vulnerable to unexpected exposure to hazardous flickering light in everyday environments. Existing passive protection methods cannot identify and respond to these triggers in real-time.”

Although photosensitive epilepsy is estimated to affect approximately 1 in every 4,000 people where photosensitivity is found the most amongst children and adolescents. The scale of this exposure can be seen in the case of the 1997 Pokémon incident in Japan. During an episode of Pokémon, there was a sequence of rapidly red and blue flashing imagery where about 685 children experienced seizures and hospital visits.

Cases like this show us that photosensitive epilepsy poses both public-health and personal-safety concerns in the current age. Modern environments contain several potential sources of flickering visual stimuli including displays, videos games, social-media content, and artificial lighting. Individuals are left unarmed against these challenges and cannot predict when such hazards will appear. Beyond just seizure effects, unexpectedly losing awareness or motor control adds additional safety concerns depending on where an individual is placed.

1.2. Solution

All in all, the problem addressed by this project is unpredictable exposure of individuals with photosensitive epilepsy to potentially hazardous flickering light. An effective solution is one that can identify potential hazardous flickers and reduce the user's exposure without obstructing vision during normal lighting conditions. We propose a pair of adaptive light-filtering glasses that will continually monitor incoming light and dynamically adjust the attenuation of the lenses based on the detected risk level.

The glasses will make use of 3 photodiodes to measure the incoming light intensity. Two of these photodiodes will be front-facing with one of them having a narrow field of view to measure directional light and the other having a wider field of view to measure ambient lighting conditions. These photodiodes will be connected to a microcontroller [PCB Box - Figure 3 in Visual Aid] which will process these incoming signals to identify both the frequency and the magnitude of a specific flicker. When a potentially hazardous flicker is detected, the LCD light valve incorporated into each lens increases its attenuation and thereby reduces the intensity of the light that reaches the user. The last of the three

aforementioned photodiodes will be positioned either (a) behind the lens or (b) in the middle of the two lenses depending on the shape of the LCD light valve available. This third photodiode will provide feedback that allows the system to continuously adjust the light valve based off of the remaining exposure, making a closed feedback loop [Photodiodes - Figure 1 in Visual Aid]. The glasses will be connected by a cable to the main PCB [PCB Box - Figure 3 in Visual Aid] and clippable power pack [Clippable Power Pack - Figure 4 in Visual Aid], which can be attached to the user's pants. Separating the processing and power components from the glasses reduces the weight and number of components that must be worn on the user's head.

1.3 Visual Aid

Here are pictorial representations of the proposed solution in the context of the user. The user will wear the light-filtering glasses using an extendable band. The band will contain a PCB enclosure housing the pertinent circuitry, positioned behind the user's head. This placement avoids obstructing the user's field of view while improving the weight distribution of the glasses.

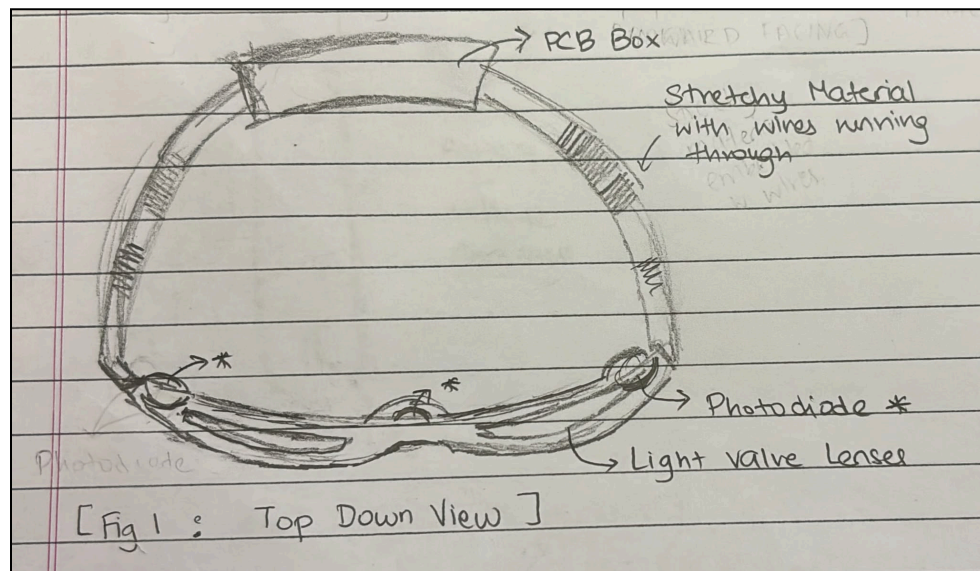


Figure 1: Top Down View

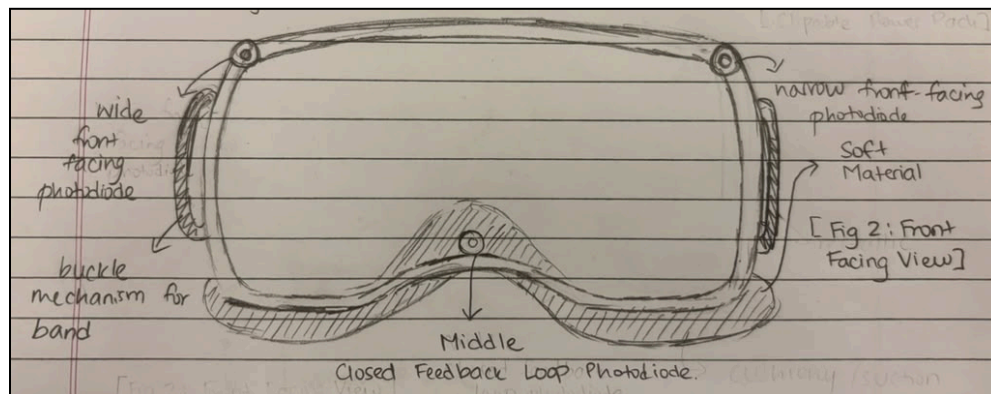


Figure 2: Front Facing View

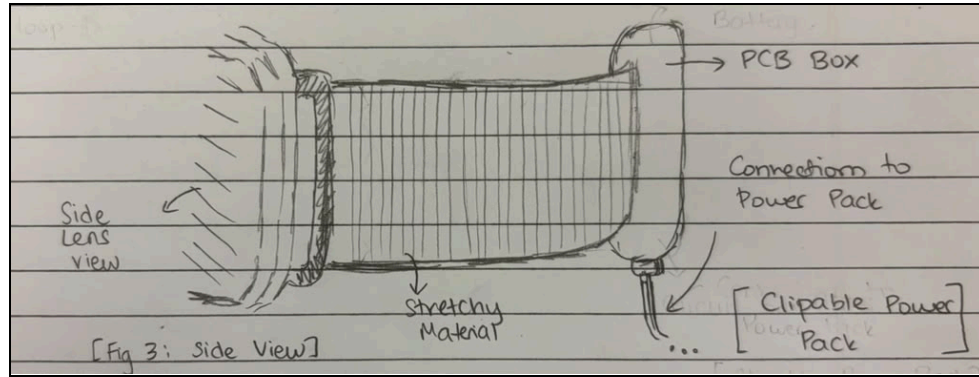


Figure 3: Side View

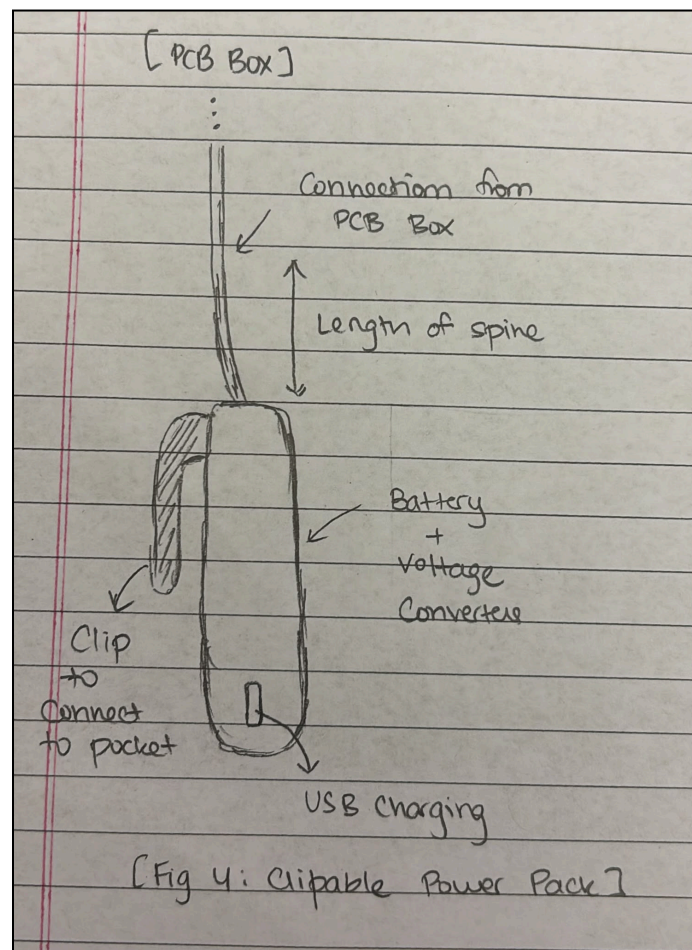


Figure 4: Clipable Power Pack

There are no external systems required for the base proposed solution. As a stretch goal, if time permits, an emergency response subsystem may be incorporated into the glasses. An IMU would monitor for abnormal movements that may indicate seizure activity and, if detected, communicate with an external device to alert the user's emergency contact or potentially contact emergency services.

1.4 High Level Requirements List

Here's a list of 3 quantitative characteristics the project must exhibit in order to solve the problem:

- A. The system must detect hazardous flickering light within the frequency range of 3 to 60 Hz with an accuracy of at least 80%. It must also maintain a false positive rate below 10% for non-hazardous changes in intensity.
- B. The system must detect a hazardous flicker and activate the optical attenuation system within 0.5 seconds of first detection of the hazardous input.
- C. The system must operate continuously for at least 8 hours on a single full battery charge under normal operating conditions.

2. Design

2.1 Block Diagram

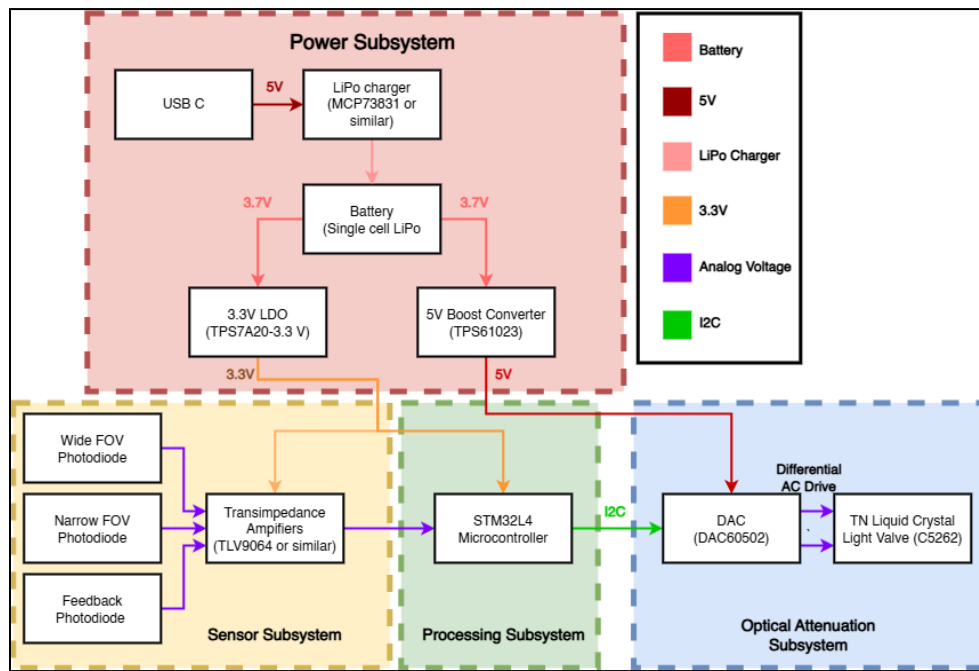


Figure 5: Block Diagram of Proposed Solution

Our proposed system consists of 4 subsystems: power, sensor, processing, and optical attenuation. The block diagram [Figure 5 - Block Diagram of Proposed Solution] represents the electrical interactions between these subsystems. The closed-loop feedback path between the optical attenuation and sensor subsystems occurs optically rather than electrically and as such is not drawn as an arrow within the figure. The feedback photodiode measures the light transmitted through the LCD light valve and this measurement is later processed by the microcontroller to continuously adjust the attenuation level. This optical interaction is separate from the above electrical interactions.

2.2 Subsystem Overview and Requirements

2.2.1 Power Subsystem

Functional Description:

The power subsystem is responsible for supplying power to the whole device. It consists of a single cell LiPo (~1000mAh, 1C) with TPS7A20-3.3V LDO [12] for stepping the battery voltage down to 3.3V which is required for the microcontroller and transimpedance amplifiers. A 5V Boost converter based on TPS61023 [13] will generate the 5V needed for the light valve [Section 2.2.4]. Finally, a LiPo charger based on the MCP73831 [8] to charge the battery with a 5V input from a USB C port.

Contribution to Overall Design:

The power subsystem contributes to the overall design by ensuring the glasses can stay operational for 8 hours. We have to use a battery since the glasses need to be portable. It provides charging functionality through the USB C port.

Interfaces:

This subsystem interfaces directly with the sensor, processing and optical attenuation subsystems as it supplies power to all three. It supplies 3.3V to the sensor and processing subsystems and 5V to the optical attenuation subsystem along with a common ground for all components which is important for signal transmission.

Requirements:

The power subsystem should:

- A. Provide a regulated 3.3V rail within 5% while supplying up to 100mA
- B. Provide a regulated 5V rail within 5% while supplying up to 20mA
- C. Charge the battery following the CC/CV profile at a max charge current of 500mA

2.2.2 Sensor Subsystem

Functional Description:

The sensor subsystem is responsible for detecting and measuring any flicker present in the user's field of view. It consists of 3 photodiodes: a wide FOV, a narrow FOV and a feedback photodiode. A set of 3 transimpedance amplifiers based on the TLV9064 [12] Op Amps set up in an inverting transimpedance amplifier configuration for each of the three photodiodes.

Contribution to Overall Design:

The sensor subsystem provides the processing subsystem with analog signals containing information about the lighting conditions around the user. The wide FOV photodiode will measure the ambient light intensity. The narrow FOV photodiode will measure light intensity directly in field of view of the user and the feedback photodiode will be placed behind the optical valve [Section 2.2.4] and will measure the received light intensity after attenuation, which can be used to evaluate the effectiveness of the design and

to provide feedback for the closed loop controller. The op-amps convert the currents from the photodiodes into a voltage in the range 0-3.3V such that it can be detected by the ADC on the microcontroller.

Interfaces:

The sensor subsystem receives 3.3V from the power subsystem along with a common ground reference for the photodiode signals. The op-amps will be powered with 3.3V single rail power supply which will then output 3 channels of analog voltages for the processing subsystem.

Requirements:

The sensor subsystem should:

- A. Generate voltage proportional to the current output of the photodiodes with a constant gain within a variance of 5%.
- B. Detect light intensity with a stable frequency response between 3-60Hz with no more of 1% variance in response between 3Hz and 60Hz
- C. Use the full ADC range of 0-3.3V over expected range of light intensities without clipping

2.2.3 Processing Subsystem

Functional Description:

The processing subsystem is responsible for sampling and analysing signals generated by the sensor subsystem, calculating the level of flicker hazard, and output to the optical attenuation subsystem in case an intervention is needed. It consists of the STM32L432KC [10] microcontroller that samples the output from the 3 amplifiers using its onboard 12 bit ADCs at 1kHz. It then performs DSP in order to determine the level of hazard and adjust the attenuation of the light valve by sending appropriate commands to the DACs via I2C.

Contribution to Overall Design:

The processing subsystem acts as the decision making component of the overall system. It receives the signals from the sensor subsystem to determine the presence and intensity of flicker. By analysing the flicker it determines the level of attenuation required and it then commands the optical attenuation subsystem to realize the level of attenuation. It then reads the output of the feedback photodiode in order to compare the required attenuation to its realized value and uses a PI controller to adjust for any discrepancies.

Interfaces:

The processing subsystem interfaces directly with the power subsystem to receive a 3.3V power supply along with a common ground reference shared with the sensor subsystem. It receives three analog voltages from the sensor subsystem, which are connected to the microcontrollers ADCs. Finally it interacts with the optical attenuation subsystem through I2C to the DACs, sending commands to generate the required differential signal needed to drive the TN optical valve.

Requirements:

The processing subsystem should:

- A. Sample all 3 sensors at a rate of 1kHz per channel
- B. Identify dominant flicker frequencies within the 3-60Hz range with an accuracy of 1Hz
- C. At least 80% detection rate for hazardous flicker.
- D. Have a false positive rate of less than 10%.
- E. React to hazardous conditions within 0.5s

2.2.4 Optical Attenuation Subsystem

Functional Description:

The optical attenuation subsystem is responsible for controlling the intensity of light transmitted through the glasses to the user's eyes. It consists of a DAC60502 [11] dual-channel DAC and a TN liquid crystal light valve. The DAC receives I2C commands from the processing subsystem which allows it to generate the AC drive signal across the light valve according to [7]. By changing the amplitude of the differential signal the level of optical attenuation can be changed.

Contribution to Overall Design:

The optical attenuation system is the output of the device, that provides the physical intervention needed to reduce flicker exposure to the users. When hazardous flicker is present, it is detected by the sensor subsystem, the level of hazard is determined by the processing subsystem which finally outputs to the optical attenuation subsystem to protect the user. It also acts as the actuator changing the light levels for the feedback photodiode in the sensor sub-system so that the processing subsystem can fine-tune the attenuation.

Interfaces:

The optical attenuation subsystem interfaces directly with the power subsystem which provides the DAC with the 5V needed to drive the optical valve. It interfaces with the processing subsystem through I2C, where the microcontroller sends commands to two channels of the DAC which are connected across the TN light valve to provide the differential drive signal needed for attenuation. The light valve interfaces with the feedback diode through the intensity of light that passes through the glasses

Requirements:

The optical attenuation subsystem should:

- A. Generate the differential AC drive signal needed for the light valve with an adjustable amplitude between 0-5V and 0 DC bias (since that can damage the light valve).
- B. Adjust the attenuation and settle within 500ms of receiving the attenuation command from the microcontroller.

2.3 Tolerance Analysis

One of the major risks for the sensor subsystem is saturation of the transimpedance amplifier under bright ambient conditions. We currently plan on using the BPW34 photodiodes [16].

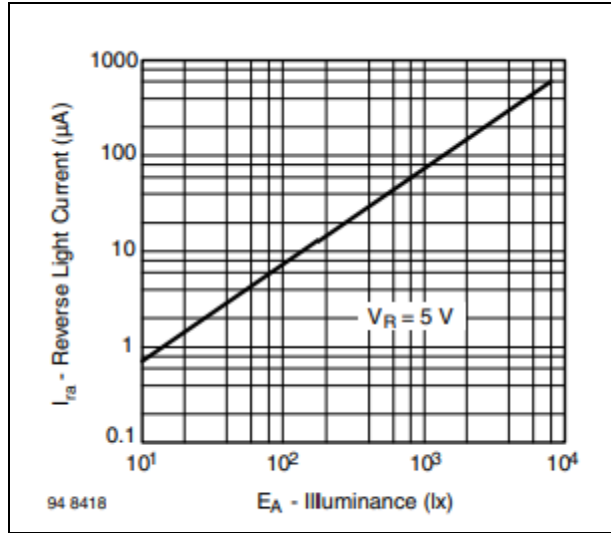


Figure 6: BPW32 Reverse Light Current as a Function of Illuminance

For indoor use with displays we expect a usable range between 10 and 1000 lux, which corresponds to dim indoor conditions to soft overcast conditions. This gives a photodiode current range of ~0.7 to 70uA.

Considering a basic TIA implementation [9]:

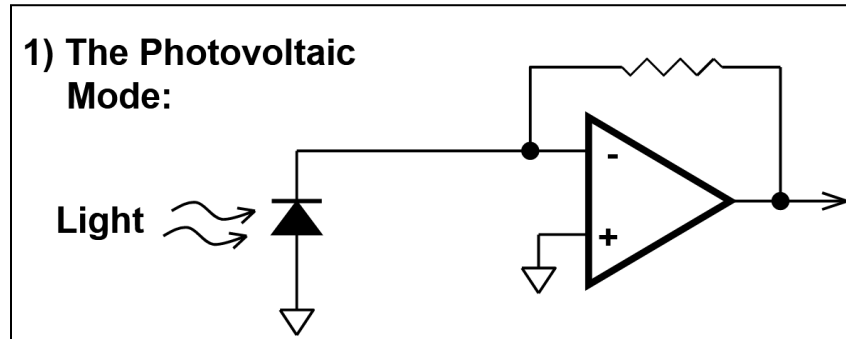


Figure 7: Photodiode TIA circuit

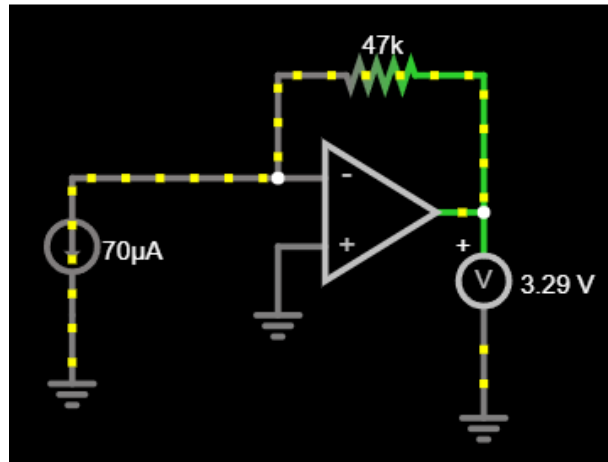
We can calculate what feedback resistor value we need to use to make full use of the 0-3.3V range for the ADC.

$$\begin{aligned}
 V_{out} - V^{-} &= I_{PD} R_{FB} \\
 V^{+} &= 0V = V^{-} \\
 \Rightarrow R_{FB} &= \frac{V_{out}}{I_{PD}}
 \end{aligned}$$

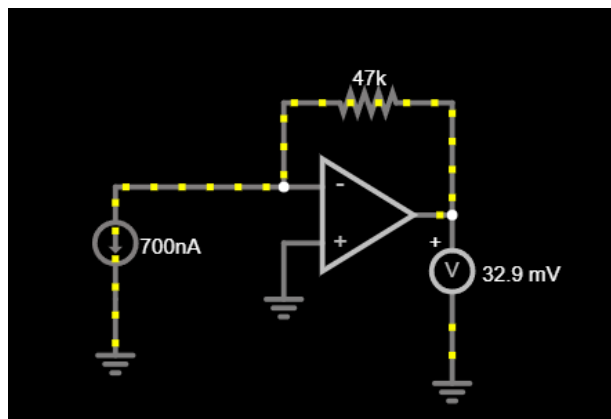
Figure 8: TIA Feedback Resistor Derivation

Plugging in the max and min values of output voltage (0-3.3V) and photodiode current (0.7-70uA) we get a range of resistor values 0-47.142k Ohms. Thus by choosing the largest resistor in this range ensures our output stays within ADC limits.

This is confirmed by simulation on Falstad:



***Figure 9:** Stimulation for max brightness*



***Figure 10:** Simulation for min brightness*

Thus giving a usable range between $[0.0329, 3.29]\text{V}$.

3. Ethics and Safety

Ethical & Societal Standpoint:

The development of the adaptive light-filtering glasses present several ethical considerations due to the intended application of the device for individuals with photosensitive conditions. As such, the prototype must not be represented as having the capabilities that have not been (a) either experimentally proven or (b) clinically established. Although the proposed system can measure flickering light and respond by controlling an LCD light valve, it does not demonstrate that the glasses can prevent seizures or provide clinically effective protection. Therefore, during development our tests will only evaluate measurable engineering traits such as flicker-detection accuracy, false positive rate, response time, and optical attenuation rather than making medical claims.

The development will also require consideration on how potentially hazardous visual stimuli are tested. Because the system is designed to detect flickering light associated with photosensitive responses, testing will be primarily conducted with photodiodes. Individuals with photosensitive epilepsy will not be intentionally exposed to hazardous flickering stimuli for the purpose of demonstrating the effectiveness of the prototype.

Ethical considerations may also arise from the accidental or intentional misuse of the prototype. A user may incorrectly interpret the glasses as a medical validated form of seizure protection and consequently expose themselves to visual stimuli that they would otherwise avoid. Similarly, individuals can be falsely misled to provide the prototype to other individuals while claiming that it provides medically validated protection. This could create a false sense of security and increase rather than decrease the user's exposure to risk.

To reduce the likelihood of misuse, the intended use, tested operating conditions, and limitations of the prototype will be explicitly documented. The device will be presented as an assistive proof of concept rather than as a replacement for established preventive practices or medical treatment.

Safety Standpoint:

Similarly, the development of the proposed system may introduce several physical safety concerns as well. The system makes use of a rechargeable lithium-polymer battery which introduces potential hazards associated with improper charging, short circuits, physical damage, and overheating. As such, the battery and the power circuitry will be physically separated from the user's head via a clippable power pack. The power subsystem will make use of appropriate charging, voltage regulation, and protective measures.

The optical attenuation subsystem also includes another hazard in the case of unexpected activation of the LCD light valve. False positive cases may temporarily restrict the wearer's visibility. As such, testing of this subsystem will occur in controlled environments where an unexpected change in attenuation cannot place the wearer or surrounding individuals in danger such as viewing media on a computer or TV. It is not intended for use while driving or walking near traffic. Intentional misuse could include operating the glasses during these restricted activities despite the documented limitations or even modifying the glasses to operate outside of its tested attenuated range. Even misusing the proposed system despite a hardware malfunction can be considered as an accidental misuse.

Generation of flickering light for testing the sensor subsystem will similarly be performed under controlled conditions and will primarily use instrumentation rather than photosensitive individuals again as test subjects.

IEEE Code of Ethics:

IEEE Code of Ethics	Relation to our Project	How will we avoid ethical breaches?
1.1 - Public Safety, Health, and Welfare	The glasses directly modify our user's vision. The unexpected attenuation or accidental / intentional misuse of them can endanger the user and surrounding others.	We will test attenuation in controlled environments, document unsafe operating scenarios such as driving, and even evaluate failure cases that can unexpectedly restrict the user's vision.
1.2 - Understanding technological capabilities and societal implications	Any user of the proposed system will be required to understand the concept of adaptive light filtering. The users will need to understand the scope that this filtering offers and how it cannot act as a medical grade device for photosensitive conditions.	We will clearly document the intended use and examples of accidental misuse of the glasses. We will note down the limitations, potential failure modes, and examples of appropriate operating cases for the prototype.
1.5 - Honest and Realistic Technical Claims	The successful detection or attenuation of flickers does not establish that glasses can or will clinically prevent seizures.	We will reduce our claims for the proposed system to measure the experimental engineering performance. We will not make claims of diagnosis, treatments, or seizures.
1.6 - Technical and Competence and Disclosure of Limitations	The project will involve battery safety, optical systems and considerations related to medical conditions. The clinical effectiveness is outside of the project scope.	We will continue to use and consult technical standards and disclose aspects of the system that have not been experimented or clinically validated.

Table 1: Relevant IEEE Code of Ethics

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