

# **Final Project: Lumen**

Mount Sinai BioDesign & The Cooper Union

ECE394 Junior EE Projects II

Professor Shlayan

Anna Konvicka, Sara Yacoub, Xue Ru Zhou

May 2022

# Contents

<b>1</b>	<b>Background</b>	<b>2</b>
1.1	Photobiomodulation As a Neuroprotection Strategy . . . . .	2
1.2	Applications of PBM: Long-Term and Post-Operative . . . . .	2
<b>2</b>	<b>Current Prototype at Mount Sinai</b>	<b>2</b>
<b>3</b>	<b>Our Prototypes</b>	<b>3</b>
3.1	Prototype 1: Small LEDs . . . . .	3
3.2	Prototype 2: Optical Fiber . . . . .	5
<b>4</b>	<b>Voltage Regulator</b>	<b>7</b>
4.1	Purpose of Voltage Regulator . . . . .	7
4.2	Overall Circuit . . . . .	7
4.2.1	Voltage Division Feedback Resistors . . . . .	8
4.2.2	Inductance . . . . .	8
4.2.3	Output Capacitance . . . . .	9
4.2.4	Diode and Input Capacitance . . . . .	9
4.2.5	Components Selection . . . . .	10
4.3	Simulation Results . . . . .	10
4.4	Experimentation Results . . . . .	11
<b>5</b>	<b>Test Protocol</b>	<b>12</b>
5.1	Procedure . . . . .	12
5.2	Establishing Penetration Baselines . . . . .	13
5.3	Assessing Light Transmittance . . . . .	13
<b>6</b>	<b>Conclusion</b>	<b>14</b>
6.1	Future Work . . . . .	14
6.2	Final Thoughts . . . . .	14
<b>7</b>	<b>References</b>	<b>15</b>

# 1 Background

## 1.1 Photobiomodulation As a Neuroprotection Strategy

Photobiomodulation (PBM) is the process of exposing damaged cells to light of wavelength of their high absorption peak to induce wound healing and tissue repair. Neural-PBM is the focus of PBM to induce neuroprotection by exposing neural tissues to near-infrared light. It is established that light exposure from PBM has no negative effects itself, and that this exposure can be an effective therapy for promoting neural healing and ameliorating brain dysfunction.

## 1.2 Applications of PBM: Long-Term and Post-Operative

There are several forms of disease and injury that lead to reduced brain function. For the purposes of this report, we will consider two instances of brain dysfunction: Alzheimer's Disease and post-operative recovery from neurosurgery.

Though the fundamental goal is the same in both instances (intracranial exposure to specific light wavelengths), there are several critical differences. As Alzheimer's Disease has no established cause and no known cure, the goal with treatment is palliative rather than curative. While all parts of the brain are affected by Alzheimer's, perhaps the most painful effect is the loss of self that accompanies the associated memory loss; for this reason, we wish to use PBM to target the hippocampus region of the brain (the locus of memory) preserve neuron function as much as possible.

Conversely, post-operative recovery lasts for a period of days (rather than years) in which there is an acute need to reduce promote tissue healing and prevent swelling and inflammation. While the target of therapy will change on a case-by-case basis, we are choosing to focus on this temporary application over producing a permanent implant at this stage due to the lessened invasiveness of this device (class II, rather than class III), the decreased need for biostability, and elimination of a charging circuit in favor of creating a battery-powered device.

# 2 Current Prototype at Mount Sinai

Transcranial BPM (tBPM) is a non-invasive administration of BPM where the light source is positioned outside of the skull. The current prototype at Mount Sinai utilizes this. It consists of an LED mounted on a PCB, all of which is covered by a sheath and inserted through the skull of the patient (but not past the dura).



Figure 1: Jared Lam’s prototype of ILE (intracranial light emitter) [3]

In tBPM, studies show that only 0.2% – 10% of light is transmitted to the most critical parts of the brain due to significant loss when penetrating the brain matter, bones, etc. Our project, which attempts to deliver intracranial photobiomodulation, seeks to close the gap in effectiveness by introducing the light source within the ventricles of the brain. There are mainly two issues that we need to address for entry to the ventricles: size, stability (and catheter deployment). See next section for our prototypes.

## 3 Our Prototypes

### 3.1 Prototype 1: Small LEDs

The first prototype is similar to the current prototype in that the LED is directly inserted into the brain. However, instead of soldering the LED and the circuit wires (to charging circuit) to a PCB, the LED will be directly soldered to the wires to reduce the space needed.

Originally, we considered using a similar setup with the LED and the wires soldered on a small PCB, as seen in the figure below.

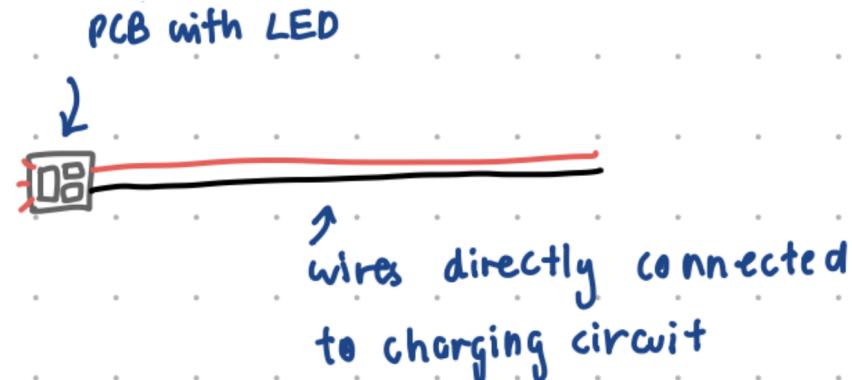


Figure 2: LED and wires soldered onto small PCB (1 cm x 1 cm)

LED Name	Specifications	Link
15404085BA420	850 nm, 0.5 x 0.5 x 1 mm	<a href="https://tinyurl.com/2kp4h9m5">https://tinyurl.com/2kp4h9m5</a>
SML-P12U2TT86R	615 nm, 1 x 0.2 x 0.6 mm	<a href="https://tinyurl.com/ycx42dp2">https://tinyurl.com/ycx42dp2</a>
SML-D12D8WT86C	605 nm, 1.2 x 0.8 x 0.65 mm	<a href="https://tinyurl.com/2p94e646">https://tinyurl.com/2p94e646</a>

For external protection and stability, the wires will be fitted into a catheter (ones that are commonly used by surgeons to enter the ventricles) and the PCB will be covered by a 3D printed sheath.

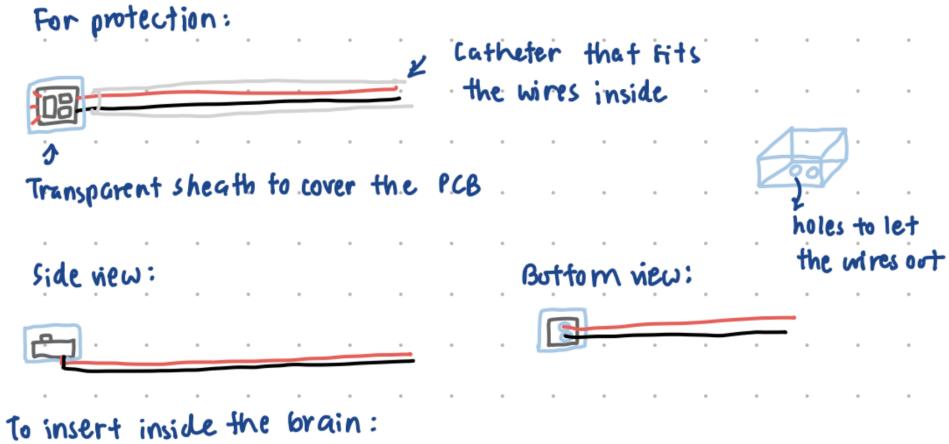


Figure 3: Sheath and catheter on prototype 1

This may not be practical because the wires are too large in diameter for the catheter we want to use (the Ommaya catheter). There are other types of catheters, but they are inflexible and very large in diameter. To resolve the size issue, we found three different types of small LEDs, as shown in the table below.

Here is a picture of the LEDs soldered to very thin wire with 0.1 mm diameter (<https://www.adafruit.com/product/3522>).



Figure 4: Small LEDs soldered to very thin copper wire

These new sizes mitigates the issue of having too big of a device inside the ventricles. More generally, the advantages of Prototype 1 (compared to Prototype 2) are:

1. More light is scattered in the brain because the light source is directly placed in the ventricles rather than through another medium (optic fiber).
2. Multiple LEDs can be stacked on top of one another for more illumination.
3. Light penetration tests are easy to perform (See test protocol in Section 5.1 for more details).

However, lack of stability is still an issue, especially with these small fragile components. The overall setup is not rigid and the solder joints are delicate enough to break easily. These disadvantages can be offset by careful handling of the materials and a sturdy, protective catheter.

### 3.2 Prototype 2: Optical Fiber



Figure 5: Sketch of connection point of prototype 2

This diagram of the second design is similar to the first in that it is an LED connected to a power supply. The key difference is that the LED is located outside of the skull, which eliminates the size constraint of inserting a light source into the brain directly. The optical fiber(s) will be cut to length after the distance to the ventricles is determined, then inserted through a catheter. The length of fiber protruding from the skull will be attached to the

connector (a plastic or rubber enclosure for the LED to direct light into the fiber). The LED within the connector will then be connected to the external power source (coin battery).

We expect that this prototype will be easier to insert and resize than prototype 1, however it remains to be seen whether the advantage of using a larger LED offsets the cost of transmission through an optical fiber without total internal reflection. Likewise, we are unsure whether it is preferable to use several small fibers or one larger one to transmit the light. There will be invariably be more light leakage with multiple fibers, but we are uncertain whether or not a single fiber will scatter light sufficiently within the ventricle. This will ultimately be determined by the test on the artificial brain where the images taken by the IR camera will indicate the level of scattering achieved.

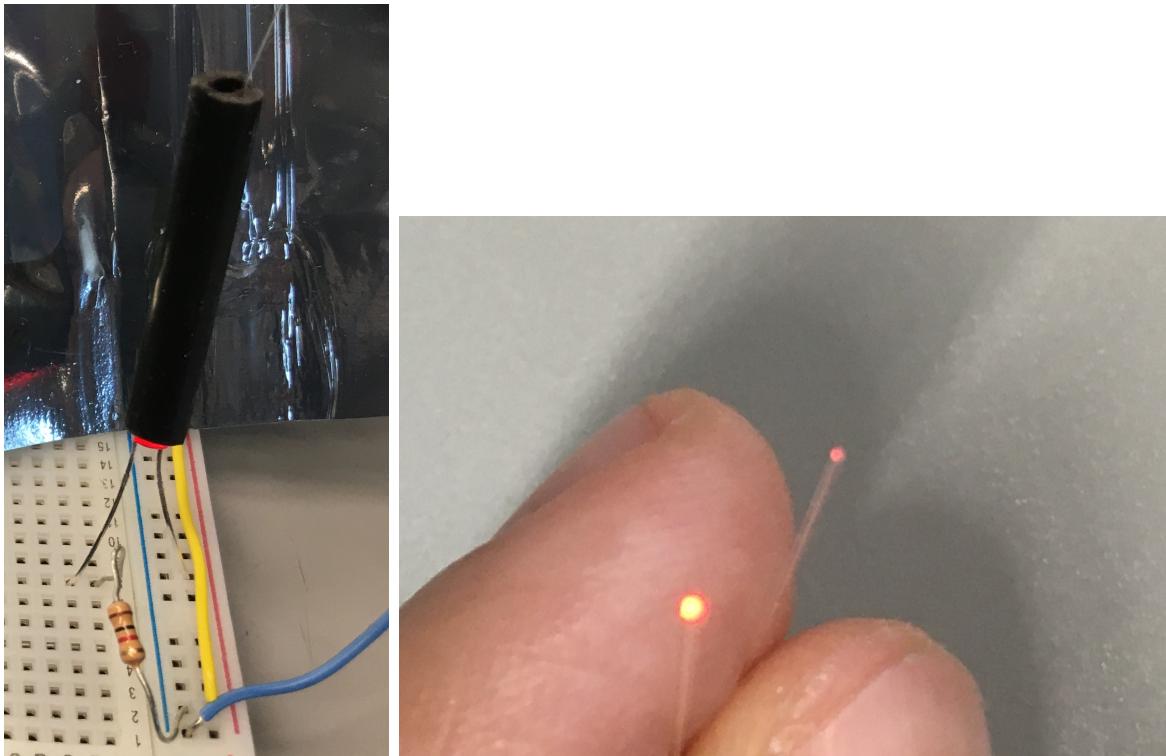


Figure 6: Thin Fiber Optics connected to LEDs and transmitting light

A test to show the fiber optics as they function, for this prototype, multiple very thin fiber optics will bundle together to disperse light in many directions.

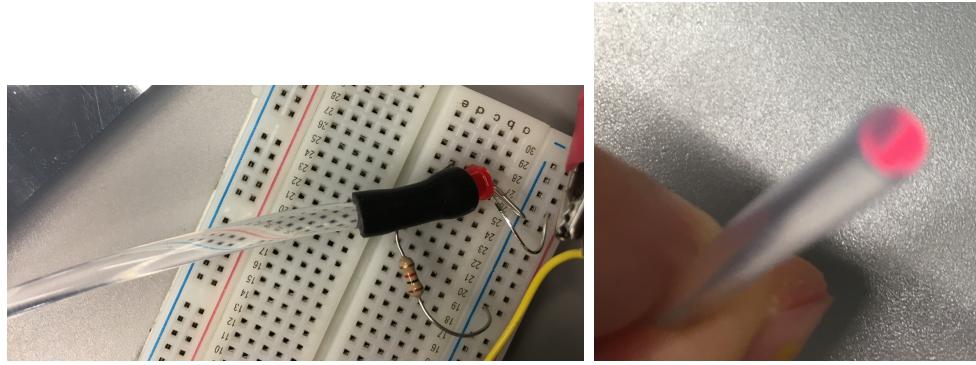


Figure 7: Bigger Fiber Optics connected to LEDs and transmitting light for demonstration

This demonstrates the functionality of the prototype with a much bigger fiber optic.

## 4 Voltage Regulator

### 4.1 Purpose of Voltage Regulator

While Lumen 1 focused on building a wireless receiver to light up the LEDs inside the brain for transcranial PBM, the scope of our project is to regulate the output voltage of their circuit. Wireless charging can also be used for our purpose of intracranial PBM, so instead of creating another version of a wireless receiver (or any other charging circuit), we built upon Lumen 1's idea.

Since Lumen 1 did not use a charging circuit, it is assumed that the patient will undergo light therapy whenever they connect the wireless transceiver to their head. With reasonable assumption, we can say that movement of the patient may cause fluctuation of the output voltage. Since Lumen 1 implemented induction charging, it's also reasonable to assume that the resulting voltage output is bidirectional. To solve this problem, we build a voltage regulator.

### 4.2 Overall Circuit

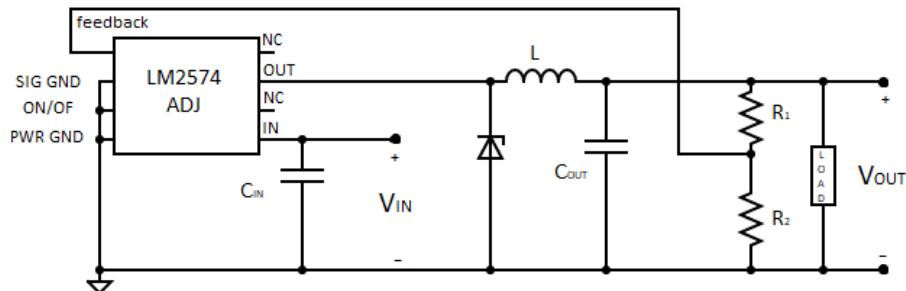


Figure 8: Schematic of the regulator circuit

An adjustable switching voltage regulator is designed for this purpose as shown in the previous schematic. The LM2574N is chosen for this application as it's output voltage can be regulated to a DC value low enough to power an LED without burning it or causing it to overheat.

Now for calculating/estimating the values of the components used for this design.

#### 4.2.1 Voltage Division Feedback Resistors

The resistance for the feedback voltage division resistors are determined by the following equation, as per the datasheet:

$$V_{out} = V_{ref} \cdot \left(1 + \frac{R_1}{R_2}\right) \quad (1)$$

$V_{ref} = 1.23V$  and we are aiming for  $V_{out} = 2V$ . If  $R_1$  is selected to be  $R_1 = 1k\Omega$  then from equation (1) we can estimate  $R_2$  to be  $R_2 = 600\Omega$ .

#### 4.2.2 Inductance

To select a reasonable inductance, we have to first calculate the inductor Volt  $\times$  microsecond constant,  $E \times T$ . The datasheet provides the following equation for the Volt  $\times$  microsecond constant:

$$E \times T = (V_{in,max} - V_{out}) \times \frac{V_{out}}{V_{in,max}} \times \frac{1000}{f} \quad (2)$$

Where,  $V_{out}$  is the desired regulated voltage  $V_{out} = 2V$ ,  $V_{in,max}$  is as recommended by the datasheet capped at  $V_{in,max} = 40V$  and  $f$  is the switching frequency of the regulator in kHz, also as recommended by the datasheet  $f = 52kHz$ . The inductor Volt  $\times$  microsecond constant,  $E \times T$  has units  $V \times \mu s$ . From equation (2) we get  $E \times T = 36.5V \times \mu s$ . Knowing the maximum load current to be significantly small for an LED to be  $I_{load,max} = 20mA$ , then the datasheet provides in figure 32 a guide on choosing the proper inductance value.

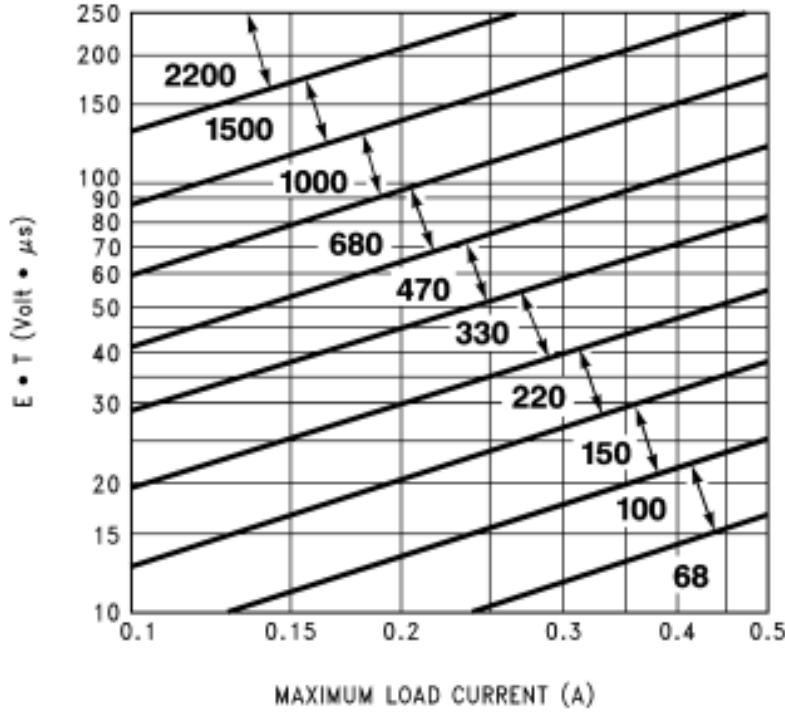


Figure 9: Adjustable LM2574HV Inductor Selection Guide in  $\mu H$  - Also Figure 32 in the Datasheet

From here, we can see that  $L = 470\mu H$  is the proper value.

#### 4.2.3 Output Capacitance

The inductance and output capacitance together determine the dominant pole-pair of the switching regulator. So for stable operation the output capacitance must satisfy the following:

$$C_{out} \geq 13300 \times \frac{V_{in,max}}{V_{out} \times L} \quad (3)$$

Where  $L$  is in  $\mu H$  and the output capacitance is in  $\mu F$ . For our desired values the output capacitance has to be  $C_{out} \geq 566\mu F$ . However, for a smooth output ripple, it needs to be significantly larger than this. We will pick something on the order of  $1000\mu F$ .

#### 4.2.4 Diode and Input Capacitance

The zener-diode current rating must be at least 1.5 times greater than the maximum load current. A bypass input capacitor is also needed for stable operations. The values needed for these 2 components are dependant on physical and geometric properties of these components. Table 1 in the datasheet shows values/models for which these components are recommended.

#### 4.2.5 Components Selection

Even though, we calculated exact values suitable for operation for these components, a value within a reasonable range of our calculations is sufficient for good performance. We are also limited by the availability of these components in jLab and whether or not exact values as such are manufactured at all (such as with the inductor), so the values chosen to actually perform the lab differ from our calculations slightly. They are represented in the following table:

Component	Value
$R_1$	$1k\Omega$
$R_2$	$500\Omega + 120\Omega$ in series
L	$370 \mu\text{H}$
$C_{in}$	$22\mu\text{F}$
$C_{out}$	$1000\mu\text{F}$
Zener Diode	1N5226

### 4.3 Simulation Results

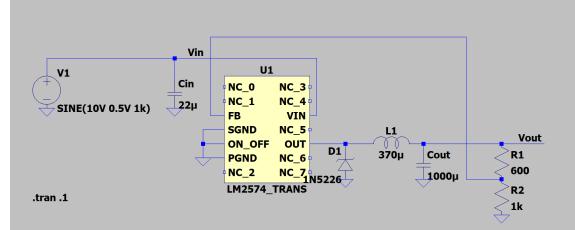


Figure 10: LTSpice simulation of the regulator circuit schematic

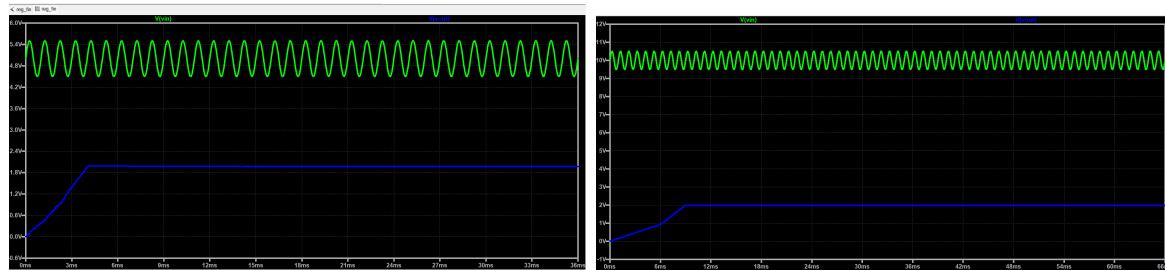


Figure 11: LTSpice simulation of the regulator circuit (a) plot at DC level input = 5V (b) plot at DC level input = 10V

The figure above shows the performance of the circuit on LTSpice simulation. The regulator eliminates any perturbations or AC elements of the signal and steps down the DC value to 2V regardless of the input signals' DC value as long as it is higher than the 3.3V breakdown voltage of the zener diode.

## 4.4 Experimentation Results

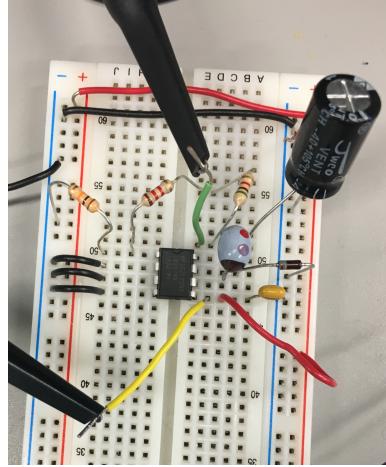


Figure 12: The regulator circuit built in lab

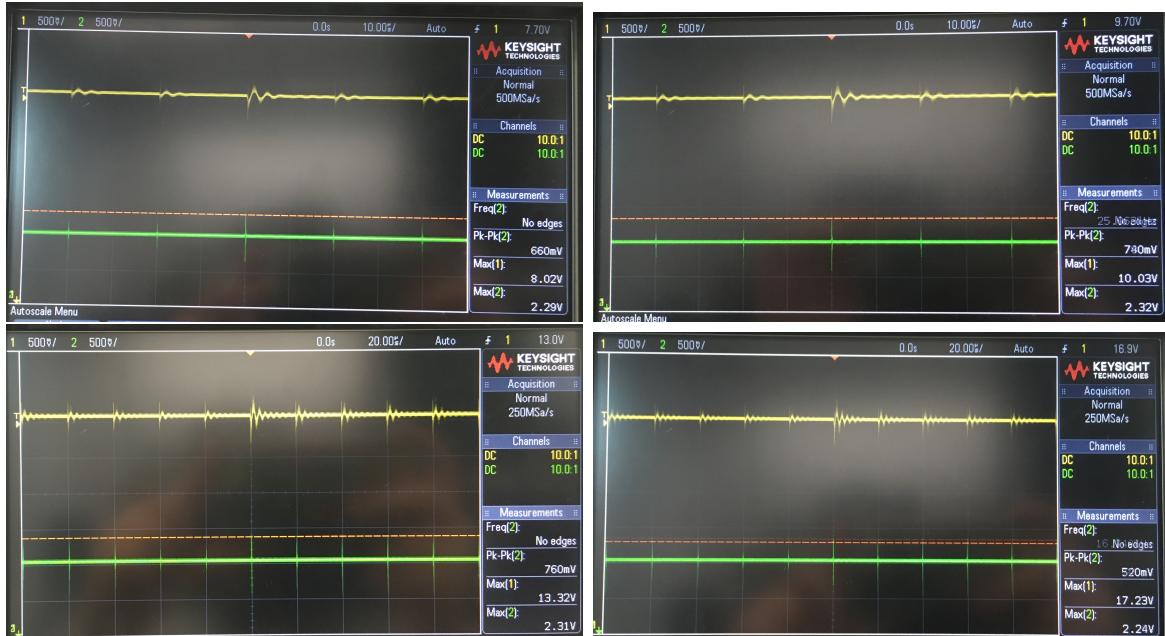


Figure 13: The regulator circuit oscilloscope plot, where yellow signal is the input and green signal is the output, at (a) input DC level = 8V (b) input DC level = 10V (c) DC level = 13V (d)input DC level = 17V

The figures above show the performance of the regulator circuit when built in lab. The input, which is shown in the yellow waveform, varies manually its DC level, as long as it's higher than the 3.3V breakdown voltage of the zener diode, and exhibits noise/perturbations. The output signal, which is shown in the green waveform, stays regulated at around 2.3V and with minimal noise, regardless of the varying DC input.

## 5 Test Protocol

The following test protocol is written in the case that the prototypes are easy to deploy into the ventricles (despite the fact that they are not, especially Prototype 1) and in the case that testing is not performed in a dark room.

The usage of photo sensor circuits is also included, but not necessary.

### 5.1 Procedure

1. Measure output voltage of a photo-sensor circuit in response to a nearby LED (without interference). The voltage will later be compared to the voltages measured from different parts of the brain.
2. Drill a hole for insertion as an opening for the IR camera.
3. Assemble the prototype.
  - Prototype 1: Cover the small PCB with LED with the transparent sheath (if not already). Insert the rod into brain to provide a path to ventricle and then insert prototype.
  - Prototype 2: Insert optic fiber into the stylet design. Glue the LED to the end of the optic fiber with UV glue. Cure using UV lamp. Cover the conjunction with a connector.
4. Drill a hole into the skull at the entry point. The entry point is at the top of the skull.
5. Drill two holes in the skull part from the entry point to allow the wires/optic-fiber to be connected to the charging circuit.
6. Insert the device into the ventricle. Note any inconveniences or issues with deployment.
7. Remove stylet and close the skull. Attach the device to the charging circuit.
8. Insert the photo transistor inside the drilled hole and cover with electrical tape if there are any gaps. Measure the output voltage of the sensing circuit and record the values.
9. Slice brain into two parts hemispherically (though not so far as to expose device). Use IR camera to capture light penetration of brain.

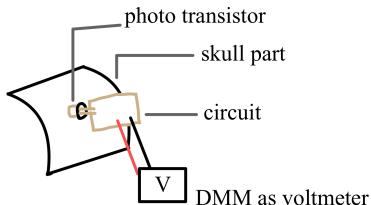


Figure 14: Photo sensing circuit connection to skull

Based on research strategy paper [2], in transcranial PBM (or tPBM) light transmission is attenuated through dura and brain matter resulting in only 0.2%–10% of light penetration to important regions of the brain. This intracranial method is expected to give higher than 10% light transmission to succeed.

## 5.2 Establishing Penetration Baselines

The following protocol is for testing the illumination of the three small LEDs through various brain tissue of different lengths. The result of this test will determine the LED that will be used for Prototype 1.

1. For all three LEDs, a baseline will be established in the absence of any material. This will allow determination of which LED is the brightest and should be used for further testing. Sensor and LED will be positioned directly facing each other.
2. The brightest LED will be tested at the three established distances (1 cm, 2 cm, 5 cm). *These distances should be discussed and modified*
3. This procedure is to be repeated with brain substitute and cadaveric brain tissue:
  - (a) Produce slices of brain tissue and brain substitute of established test thicknesses.
  - (b) Position LED directly against the surface of testing material and light sensor directly opposite the LED (ensuring appropriate planar alignment).
  - (c) Some transparent casing or plastic wrap is to be placed over the light sensor for ease of cleaning and to avoid damaging the device.

## 5.3 Assessing Light Transmittance

In the case that photosensing with photodiodes is done during testing, this is the protocol for determining the light penetrance by hand.

1. In section 5.1, the output voltage of the photosensor was measured in response to a nearby LED without interference (for example in an isolated black box). This measurement,  $V_{ideal}$  corresponds to the ideal light transmittance of the photosensor without any loss.
2. For every distance, the measured voltage is  $V_{tran,i}$
3. The light penetrance is found by:

$$I_{trans,i} = \frac{V_{trans,i}}{V_{ideal}} \cdot 100\% \quad (4)$$

## 6 Conclusion

### 6.1 Future Work

In the coming weeks, we will perform a series of trials as outlined above. First we will use cadaveric brain tissue to establish which LED selected for prototype 1 produces optimum penetration. This will inform which iteration we pursue, which we will then fabricate in a finalized prototype.

We will then use the two assembled prototypes to perform testing on simulated brain tissue in order to determine which transmits the most light to pursue further for future tests. In particular, we expect insertion of prototype 1 to be more difficult, but we are unsure whether optical fibers will be able to produce the same level of light dispersion as the LEDs. Our decision as to which to pursue will incorporate expected degrees of difficulty in inserting the respective devices, as it remains to be seen whether either can feasibly be implanted.

Using these results, we will then construct a test protocol for further tests, including on a live animal model (sheep or pig).

### 6.2 Final Thoughts

Overall, this six-week project has been an informative exercise in compartmentalization, rapid prototyping, and parallel development of multiple feasible products at once, all while working in a lab setting. By creating a test protocol alongside the device(s) themselves, we were able to consider what constitutes success from a medical as well as a scientific standpoint. We hope this process has yielded meaningful results for the team at Sinai BioDesign, and are excited to see how the project develops.

## 7 References

- [1] Texas Instruments, “LM2574x Simple Switcher 0.5-A Step-Down Voltage Regulator,” LM2574, LM2574HV datasheet, June 1999 [Revised May 2020].
- [2] Mount Sinai BioDesign, Lumen Research Strategy Paper, <https://tinyurl.com/3bja664a>
- [3] Lam, Jared. ”Lumen – Summer Internship”, <https://tinyurl.com/4xm7rmky>