To: Dr. Bales
From: Sanjay Seshan (seshan@mit.edu) & Cristine Chen (cchen117@mit.edu)
Date: December 14, 2024
Re: Final Project Report – Custom Strobed Ripple Tank

1 Summary

We designed and constructed a custom ripple tank. A ripple tank is a widely used physics demonstration tool that visually projects water wave patterns to explore wave mechanics. An example of a commercial ripple tank is shown in Figure 1. Additionally, we developed a multicolor, adjustable strobe array powered by an Arduino. This setup allows us to freeze the motion of ripples in various colors and simulate forward and backward wave motion. Using our apparatus, we also successfully demonstrated the double-slit experiment, showcasing interference patterns within the ripple tank which resemble those observed in Figure 2, where we borrowed a ripple tank from the MIT Physics Department to perform the same experiment.

Figure 1: Commercial ripple tank from Thermo Fisher Scientific

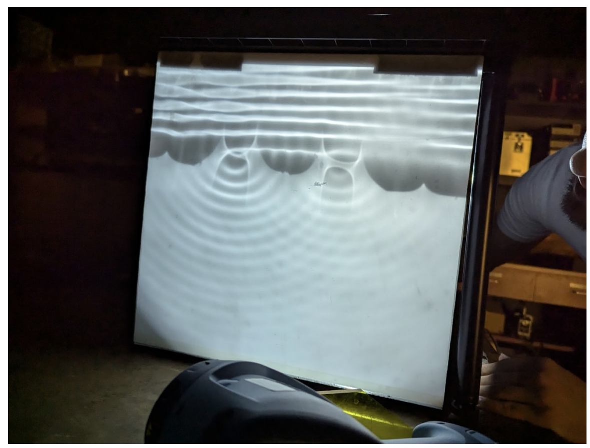

Figure 2: Interference pattern from double slit experiment

Hypothesis: We are able to build a ripple tank which we can use to demonstrate the interference patterns of a double-slit experiment model.

We recommend that our project be used as a guide to creating a ripple tank to teach students about interference patterns.

2 Background

Since we are building a ripple tank to demonstrate the double-slit experiment, we must understand a few concepts: waves, constructive/destructive interference, and stroboscopy.

The double slit experiment was conceived to prove the wave-particle duality of light. In essence, to prove that light can act as a wave, we create a model in which light is directed to two small pinhole slits, somewhat close together. The pattern on a projection screen should show an intensity pattern consistent with a wave. Figure 3 shows an example of this setup using electrons or light as well as an interference pattern for two point source waves (where they add or subtract). A common demonstration of this effect is in a ripple tank using water, where a planar wave is passed through a slit to generate two point sources. These sources in turn merge to demonstrate an interference pattern, similar to the light/electron beam source.

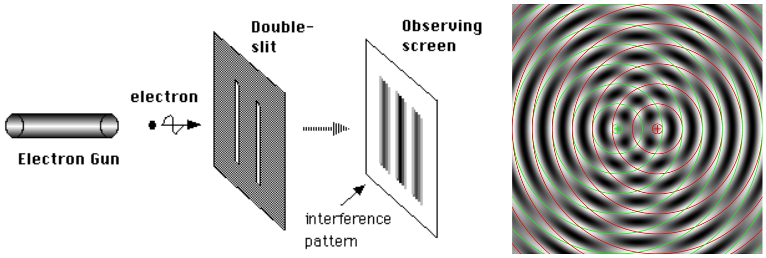

Figure 3: Sample double-slit experiment setup using electrons or light (left) and Constructive/Destructive interference example (right) (source: Wikipedia[1,2])

We must also understand the concept of stroboscopy. Strobosopy uses a continuously flashing light to control the perception of periodic processes to the human eye. This effect means that by controlling the rate at which a strobe flashes (including exposure time), and is therefore processed by the eye, we can analyze periodic motions, such as a motor spinning or ripples generating, in greater depth.

To start, we know that if we flash the strobe at the same rate a periodic event completes one period, we will get the effect that it (e.g. a motor) is standing still. Any discrepancy in this frequency (lower for forward/clockwise, higher for counterclockwise) will cause movement to appear. We can generalize this phenomenon in Equation 1 where k is positive for forward motion and negative for backward motion, and N is for the number of different states. Note that this is for discrete states; continuous waves have a coefficient of < 1, 1, or > 1 for backward, still, or forward motion.

$$f_{strobe} = \frac{N}{N+k} f_s \tag{1}$$

Furthermore, since we capture periodic motions using stroboscopy, we must consider the Nyquist frequency (Equation 2). This equation means that as we double the sampling (strobe) frequency, our motion appears to be repeatable, creating a false effect that the experiment is operating at double the frequency. Therefore, we must sample below this limit. Note that sampling at half the frequency would produce the opposite effect, with the superposition of opposing points of the discrete positions on the motor wheel.

$$f_0 = 2f_s \tag{2}$$

We focus on freezing the periodic ripples in the ripple tank (i.e. making the ripples appear to be standing still or moving forwards or backwards). We can take advantage of the differences in refractive indices between air and water (~ 1.33) to generate distortions on the viewing screen from the ripples. In effect, the water acts like a lens, which bends a directed light when disturbed. Using this effect, we can visualize the waves through the shadows created from the water ripples.

3 Procedure

3.1 Set-up

We began by obtaining the components as shown in Table 1.

We made our final project setup as shown in Figure 4 and Figure 5.

3.1.1 Ripple Tank Board

We built our ripple tank (12" x 12" x 1") with 4 strips of acrylic (11.75" x 1" x 0.25"), cut with a bandsaw, on top of an acrylic base (12" x 12" x 0.128"), all glued together using a solvent-based acrylic adhesive at

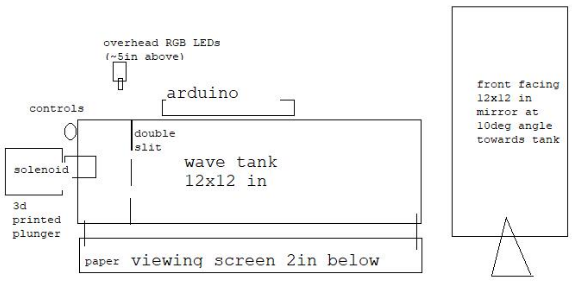

Figure 4: Cross-section drawing of final project setup for ripple tank

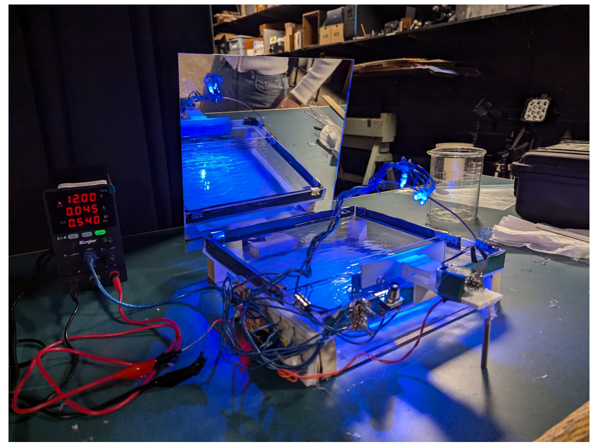

Figure 5: Final setup as implemented

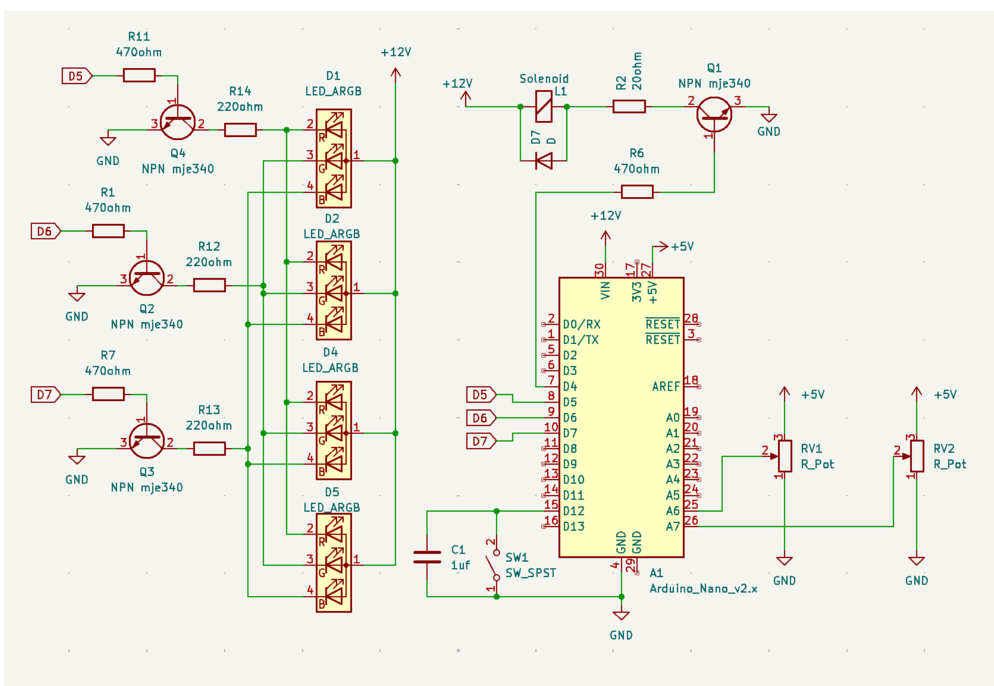

Figure 6: Schematic of electronics used in the ripple tank

Table 1: Equipment used for the ripple wave tank system

Quantity	Item	Manufacturer	Model
1	Acrylic Mirror Sheet	PTSGCAI	12" x 12" with with 1/8" Thickness
1	Acrylic Transparent Sheet	CALPALMY	12" x 12" with with 1/8" Thickness
1	Acrylic Transparent Sheet	DNR	1/4" Thickness
1	Laser Cutter	Glowforge	DNR
1	Hot Glue	Adhesive Technologies	N/A
20	Binder Clips	N/A	N/A
1	Foam Strips	N/A	N/A
1	Assorted Wood Pieces	N/A	N/A
1	Solenoid	Yaxin	AU0837S
1	3D Printed Solenoid Attachment	N/A	N/A
1	Arduino	Arduino	Nano
1	Acrylic Solvent Glue	Weld-on	N/A
1	Variable Power Supply	Kungber	Set to 12V

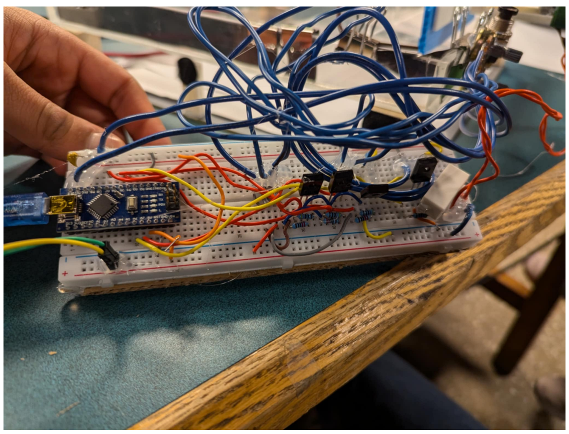

Figure 7: Ripple tank circuitry (V_{in} on left, solenoid+LEDs+inputs to right)

Figure 8: Created an acrylic 12" x 12" tank

the seams. The sides were held together using clamps while the glue was applied at the edges as seen in Figure 8. After a few days, the glue is able to hold the box together at full strength. The final product is fully waterproof and leakproof.

3.1.2 Ripple Tank Electronics

To build our system's electronics (i.e. an Arduino controlled strobe and electromagnetic oscillator), we designed the schematic shown in 6. This approach uses bipolar junction transmitters (BJTs) to allow high power consumption for the light-emitting diodes (LEDs) (> 40mA for each color on each LED) and the solenoid (> 600mA), all while being controlled by the Arduino, which only provides 5V at 20mA. The implemented version is shown in Figure 7. The system is connected to a 12V power supply, and limited to 2A current.

We include 3 input methods: one solenoid controls the solenoid frequency, another solenoid controls the difference in frequencies between the solenoid and the LEDs, and a push-button controls the LED color channels (each push cycles through a color channel combination – B/G/R/W). The frequencies can range between about 5 and 80 Hz. The light frequency can be changed within 15Hz of the solenoid's frequency.

Figure 9: Two slit drawing used to laser cut

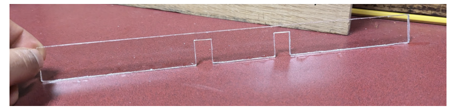

Figure 10: Printed slits affixed to ripple tank

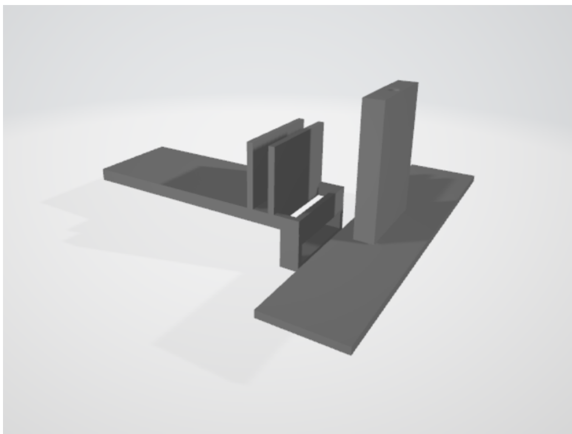

Figure 11: Plunger model assembly made in SolidWorks

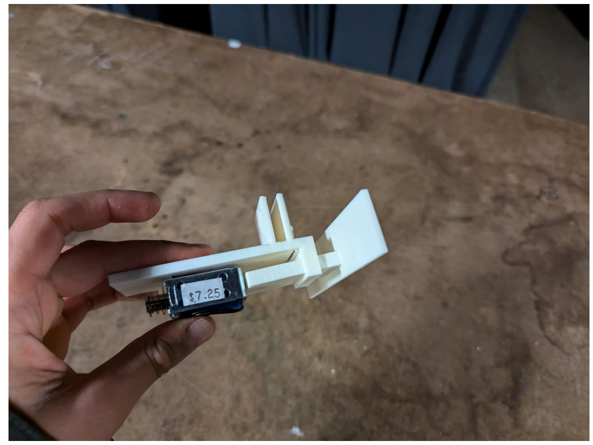

Figure 12: 3D printed assembly of the plunger

3.1.3 Double Slit

The double slit experiment was recreated using 0.5” slits that are 2.5” apart. The design was made in Inkscape and printed on a transparent acrylic sheet. The sheet was then mounted between a foam holder approximately 1” away from the plunger. Figure 9 and Figure 10 show the model and assembled double slit attachment that is clipped onto the main board.

3.1.4 Plunger

The plunger used to generate the ripples was designed in SolidWorks to be 3D printed. It hosts a solenoid resting on a 0.25” mount and is connected to a moving assembly ($\sim$5”). A moving plastic piece (5” x 0.5”) pushes the water in a forwards and backwards motion to generate the ripples. We show the plunger assembly model and completed design in Figure 11 and Figure 12.

3.1.5 Assembly

We assembled the experiment platform consisting of a base acrylic plate, layered with a piece of paper on top, and wooden mounts used to elevate the ripple tank. The tank is then lined with foam padding which are clipped to its edges to absorb the ripples generated.

The input devices were clipped to the sides of the tank, and the Arduino breadboard was mounted to the set-up using velcro. The LEDs are mounted above the system on a metal beam facing towards the tank.

The plunger is mounted at the center of the two slits. A 3D-printed 0.25” clip on a stable wood block is used to allow the mirror to be held at a slight downward angle (about 10° from vertical) as a visual aid.

We used clips on almost every component to allow for easy disassembly and reassembly, which makes our system more portable.

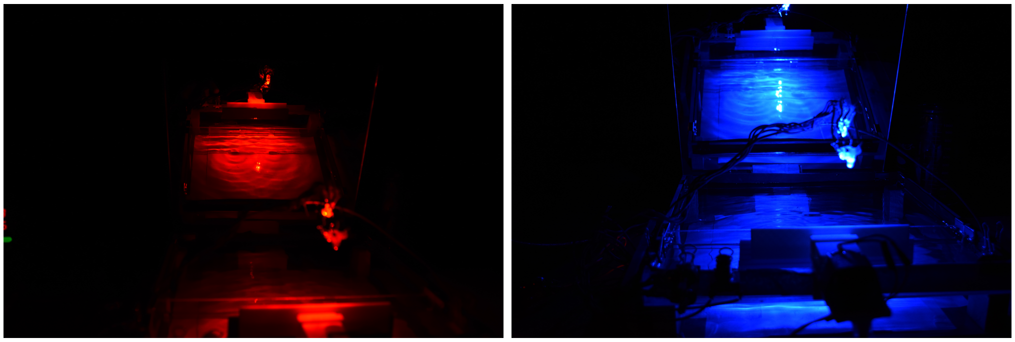

Figure 13: Experiment results for freezing in Red and Blue strobes

Figure 5 shows our completed assembly.

3.2 Data Collection

We used the code shown in Section 8.1 to control the LEDs and the solenoid at 50% Duty Cycle for Pulse Width Modulation (PWM) at the frequency chosen using the potentiometer. The LEDs are pointed towards the ripple tank, as the waves are generated. We can adjust the frequency of the flashing of the LEDs to be the same as the frequency of the ripples generated to freeze the ripple patterns or create forwards/backwards motion. Without the LEDs, we can see the real-time ripple movement. The color channels can also be adjusted as desired.

We present some sample images that we took using this setup. In real life, we can see forward or backward motion as well by adjusting the potentiometers.

4 Results

We used a potentiometer to adjust the ripple tank's frequency, ensuring synchronization with the LEDs, which were set to operate at the same frequency. Using this approach, we were able to freeze the ripples generated by the solenoid and plunger setup at variable frequencies. The result is shown in Figures 13 and 14 for White, Green, and Red configurations. We demonstrate the double slit experiment in this system as seen through the patterns in Figure 15. Figure 16 identifies the positions of constructive and destructive interference in the ripple patterns generated with the two-slit apparatus.

These pictures were captured on a Nikon D5300 with ISO 800, f/4 aperture, and 1/500 shutter, except Figures 15 and 16, which were captured on a Google Pixel 7.

5 Discussion

From our results, we conclude the feasibility of our project. We were able to successfully generate ripples in our handmade custom acrylic wave tank and strobed the ripples by using LEDs fired at the same frequency as the solenoid. We were able to properly visualize forward and backward ripple movement by adjusting the LED frequency relative to the solenoid's frequency. Note that low frequencies have better ripple intensity, but high frequencies have better interference as well as are easier to see. This effect is because at low frequencies, there is more time to change the solenoid position, but we generate more ripples at higher frequencies. Also, the persistence of vision with the LED strobing is better with high frequencies.

In a an ideal ripple tank experiment, alternating bright and dark stripes should emerge as a direct result of constructive and destructive interference. When two wave sources are in-phase, their crests and troughs align

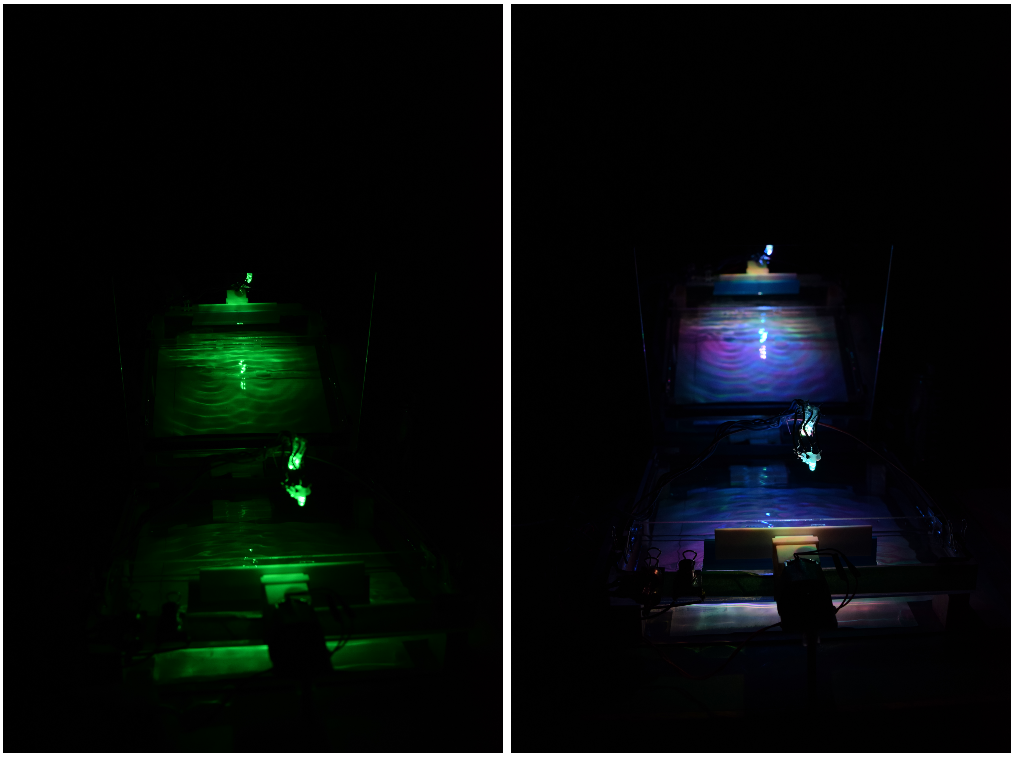

Figure 14: Experiment results for freezing in Green and White strobes

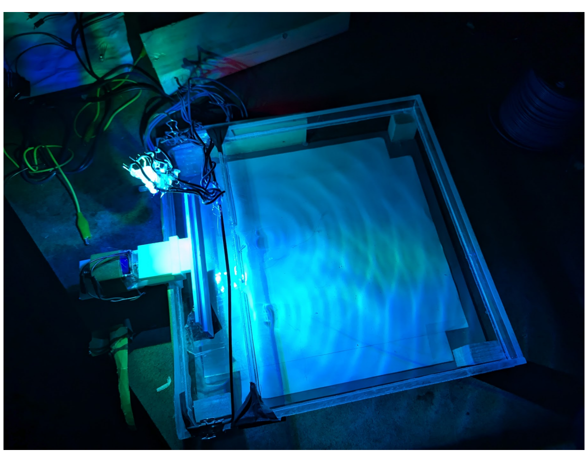

Figure 15: Frozen double slit images from strobing LEDs

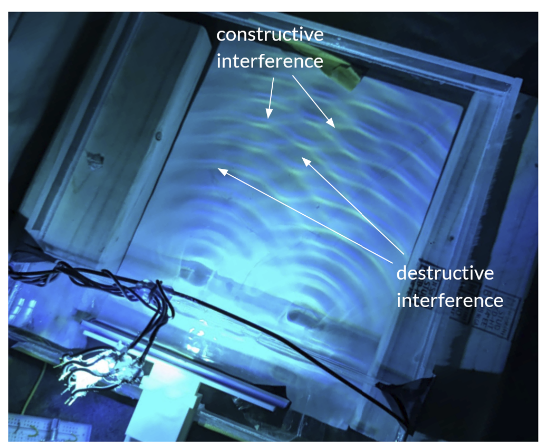

Figure 16: Frozen ripple tank waves from strobing LEDs with interference patterns identified

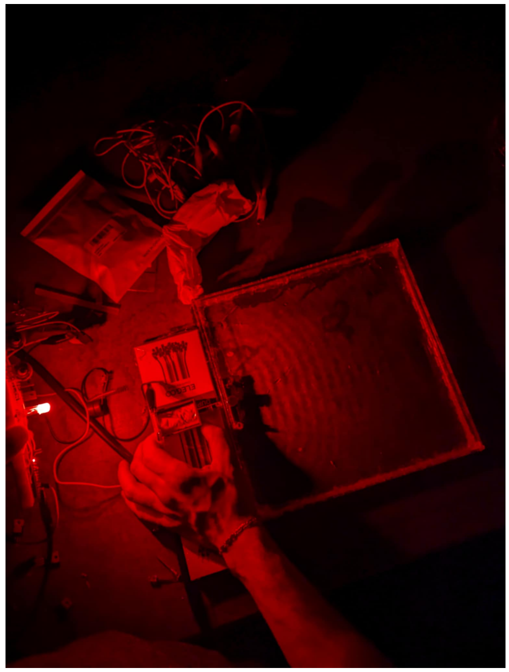

Figure 17: Mark I initial proof of concept

perfectly as they propagate. At points where the crests of one wave coincide with the crests of the other, or where the troughs coincide, the amplitude of the resulting wave is maximized. This additive interaction leads to regions of higher wave amplitude in the ripple tank, which appear as bright fringes under appropriate lighting condition. If two wave sources are out-of-phase (e.g., one emits a crest while the other emits a trough at the same point in time), their respective crests and troughs will cancel each other out. At points where the crest of one wave meets the trough of another, the amplitudes subtract, resulting in minimal wave amplitude or even complete cancellation. These regions are observed as dark fringes in the ripple tank.

Furthermore, we are able to demonstrate the interference patterns of a double slit experiment, which enables our project to be a helpful educational resource to be used for teaching about waves to students.

5.1 Process

We started our project with a rough draft prototype of a ripple tank. We laser cut acrylic panels and hot-glued them together to create a tank which turned out to be very prone to leakage. We also went through a few iterations of our electronics – we built a basic system on 5V that was able to be used for stroboscopy on a motor wheel, but the brigthness was rather dim. Now we are able to strobe with high brightness at 12V in RGBW. Our original prototype can be seen in Figure 17.

Once we built a new 12" x 12" box that was waterproof, we spent a few weeks working on creating ripples. Our initial approach was using an electromagnet to attract and repel a magnet on a spring to generate ripples, but this approach created rather weak ripples without enough amplitude. These low intensity ripples were not enough to clearly visualize the interference patterns in the double slit experiment. We eventually decided to switch to a mechanical approach, using a custom 3D-printed plunger attached to a solenoid. This approach allowed for much higher amplitudes than what we were previously getting.

After assembling all of the components together, we were able to attain very good results as mentioned earlier. We decided to add a mirror to permit easy viewing for users that may be further from our setup.

Overall the entire project took us many weeks to finalize since many of our initial attempts were underwhelming or took a while to bear fruit. In the end, we were able to achieve our goal of demonstrating the interference patterns created by the two slit experiment in a custom strobed ripple tank.

6 Future Work

In the future, we hope to improve our electronics by creating a printed circuit board (PCB), developing more stable holders for LEDs and inputs, adding an LCD screen for detailed settings, and creating better wiring for the electronics. We also hope to take advantage of our modular two-slit insert system to expand to other patterns such as one-slit, three-slit, etc. Additionally, we hope to improve the assembly by making it more stable and easier to remove the water. Some work can also be done to improve the robustness of the ripple generator.

We also hope to get better captures of our system, by creating a more robust procedure to get videos and images. We hope to use high speed videography to capture only bright frames, allowing us to present captures of forward and backward motion.

7 References

[1] Wikipedia contributors. (n.d.). Double-slit experiment. Wikipedia, The Free Encyclopedia. Retrieved November 2, 2024, from https://en.wikipedia.org/wiki/Double-slit_experiment

[2] Wikipedia contributors. (n.d.). Interference. Wikipedia, The Free Encyclopedia. Retrieved November 2, 2024, from https://simple.wikipedia.org/wiki/Interference

All images are taken by Sanjay Seshan or Cristine Chen. The drawings in the Background (Figure 3) are from Wikipedia. All other drawings are made by the students. Content is derived from lectures. All setup pictures are captured on a Google Pixel 7 or a Nikon D5300.

We also want to thank Dr. Bales, Mark, Ed, and Christian for their support, advice, and help throughout this process.

8 Appendix

8.1 Arduino Code

```
void setup() {
  pinMode(7, OUTPUT);
  pinMode(6,OUTPUT);
  pinMode(5,OUTPUT);
  pinMode(4,OUTPUT);
  pinMode(A6,INPUT);
  pinMode(A7,INPUT);
  pinMode(12, INPUT_PULLUP);

  Serial.begin(9600);
}
int changeTime = 0;
auto pinmode = LOW;
int changeTimeLED = 0;
auto pinmodeLED = LOW;
int lastbtn = 1;
int state = 0;

void loop() {
  int currentTime = millis();
  int sensorValue = analogRead(A6);
  int delayval = sensorValue>>3;
```

```
  int sensorValue2 = analogRead(A7);
  int tmp = sensorValue2 >> 4;
  int delayval2;
  if (tmp < 32 && delayval - tmp >= 0) delayval2 = delayval - tmp;
  else delayval2 = delayval + tmp;

  int btn = digitalRead(12);

  if (btn == 0 && btn != lastbtn) state = (state + 1) % 4;
  lastbtn = btn;

  if ( (currentTime - changeTime)>=delayval){
      changeTime = changeTime + delayval;
      pinmode=(pinmode==LOW)?HIGH:LOW;
  }

  if ( (currentTime - changeTimeLED)>=delayval2){
      changeTimeLED = changeTimeLED + delayval2;
      pinmodeLED=(pinmodeLED==LOW)?HIGH:LOW;
  }

  if (delayval == 0) pinmode = HIGH;
  if (delayval2 == 0 || sensorValue2 > 1020) pinmodeLED = HIGH;

  int led3 = (state == 0 | state == 3);
  int led2 = (state == 1 | state == 3);
  int led1 = (state == 2 | state == 3);

  digitalWrite(7, pinmodeLED&led1);
  digitalWrite(6, pinmodeLED&led2);
  digitalWrite(5, pinmodeLED&led3);
  digitalWrite(4, pinmode);

}
```

9 Lab Notes

Figure 18: Old prototypes

Figure 18 shows some early experiments freezing a motor motion or building a wave tank.

Figure 19 illustrates an initial concept idea for the ripple tank.

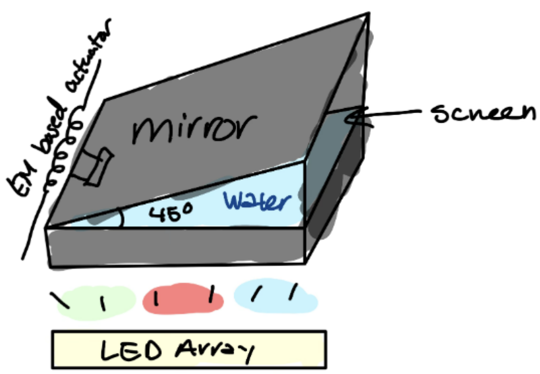

Figure 19: Original setup attempt