

#	Experiment:	Required Readings:
1	Time & Frequency Plots (Fourier Transforms)	Graphs p.25-26 Resonance Curves p.81-82 Analysis of Tones p. 115-118 <i>Bring 1 instrument per group</i>
2	Wave Tank	Properties of waves p.45-49
3	Resonant Flame Tube	Vibrating Air Columns p.63-68
4	Vibrating Chladni Plates	Vibrating Systems p.74-75; Percussion Inst. p.299-306
5	Wave Interference Lissajous Figures	Waves p.35-42 Properties of waves p.45-49

FREE-FORM LAB INVESTIGATION: Note, the last 5 labs of the semester are "free-form" rather than "cook-book" style. I provide you the equipment to investigate different phenomena, and you decide how you are going to explore the questions. Many of these labs (and equipment) are new, so I am looking for you to be creative and come up with interesting methods. I provide you with required reading assignments above, and (where available) with supplementary reading material in this packet. This material is only a suggestion—the final format of your lab investigation is up to you!

ROTATION OF LABS: Since the equipment for these 5 labs is specialized and expensive (please take good care of the equipment), I only have 1 set-up of each lab. This means that for week #1, 5 teams will be working on 5 different labs, and then we will rotate. There will be a sign-up sheet to determine the rotation.

EQUIPMENT WARNINGS: As I mentioned above, some of this equipment is hi-tech, and very expensive. Please be careful, pay attention to all equipment warnings, and if you have a question, please ask. Anyone who is electrocuted or explodes will receive a failing grade for that lab segment.

Lab 1: Time & Frequency Plots

EQUIPMENT WARNING: Make sure the cooling vents on the Scientific interface box are not blocked.

In this lab, we will use a PC computer to make time-domain and frequency-domain (Fast Fourier Transform FFT) plots of various sound waves. The plots can be made in real-time, and then you can freeze the plots so you can print them out.

The list of experiments below is just a suggestion. Feel free to experiment and come up with other interesting measurements.

- Play an instrument both soft and loud.
- Play different notes on a single instrument.
- Play the same note on two different instruments.
- Play one of the copper or PVC tubes used in Lab 3.
- Play two tuning forks that are almost (but not quite) in tune.
- Sing a note that is "good" and "bad." Can you use these plots to distinguish a "good" singer from a "bad" singer?
- Make up your own ...

For all of the above, compare plots of both the time-domain and frequency-domain. How do they differ? What patterns do you notice.

To save time, please hand in 1 set of plots per group, stapled together, and with notations on the plots so the TA can match each plot to the comments in your lab book.

Lab 2: Wave Tank

EQUIPMENT WARNING:

- The stand containing the Mechanical Strobe is very unstable--be sure this is balanced so that it does not fall over and break.
- The Mechanical Strobe is poorly designed (despite the fact that it is rather expensive). There is very little clearance between the spinning disk and the housing screws. Be sure that the disk is not scraping on the screws as this will damage the disk and the motor. Also assemble the disk so that the painted black surface is away from the screws.

This lab has 5 basic parts. The first 4 part will be to perform an experiment demonstrating the basic properties of waves (light/sound): reflection, refraction, interference, diffraction. The 5th part is to measure the speed of the water waves using the relation $v = f\lambda$.

I have given you (lengthy) supplementary reading materials with suggested experiments. You do not have to do all of these suggested experiments--just do one experiment of your choosing per segment. Again, part of your grade will be based on the creativity of the experiments you choose to do.

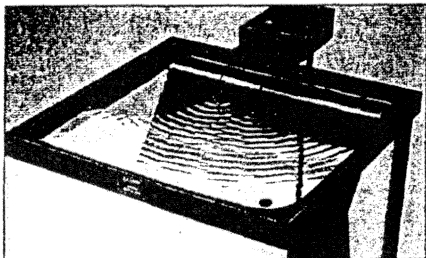
- **REFLECTION:** Perform 1 experiment demonstrating reflecting.
- **REFRACTION:** Perform 1 experiment demonstrating refraction.
- **INTERFERENCE:** Perform 1 experiment demonstrating interference. Be sure to investigate how the interference changes with 1) different separations (**d**) of the wave source, and 2) with different wavelengths (λ).
- **DIFFRACTION:** Perform 1 experiment demonstrating diffraction. Be sure to investigate how the diffraction changes with 1) different apertures (**a**) of the wave source, and 2) with different wavelengths (λ).
- **WAVE SPEED:** Perform 1 experiment to compute the speed of the waves in water using the relation $v = f\lambda$. Explain how you determined each quantity. 0

For each measurement above, comment on how the phenomena you observed for water waves applies to sound waves.

Experiments

Interference Patterns

Two point sources create a classic interference pattern. Note the gray bands, or nodal lines, where the waves destructively interfere. Between the gray lines are antinodal lines, where they constructively interfere.



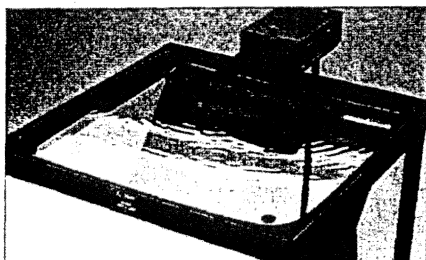
Two Point Source Experiment Setup



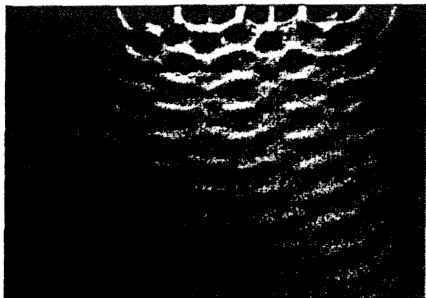
A two point source experiment generates clean nodal and antinodal lines.

Multiple Point Source

The plane wave actuator bar allows your students to study the wave interactions generated by plane waves or by multiple point sources—up to eight.



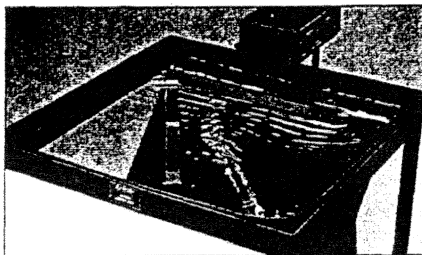
Four Point Source Experiment Setup



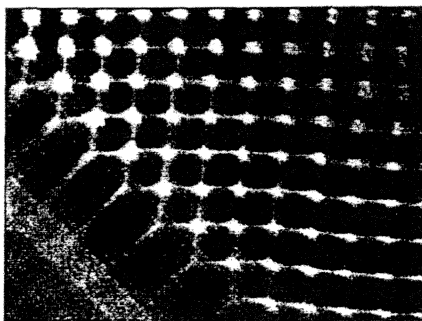
Four point sources moving in unison produce the above pattern.

Reflection

Use the barriers to study wave interference due to reflection. The crests and troughs show up as bright and dark bands. Notice points of constructive and destructive interference.



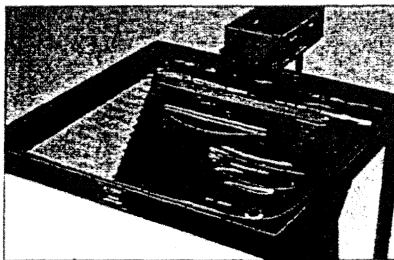
Reflection Experiment Setup



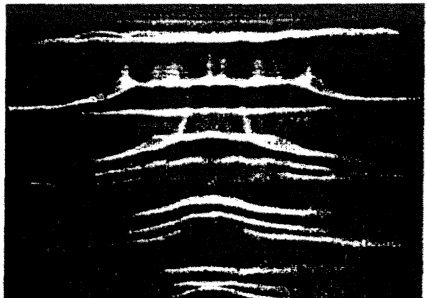
Waves reflected off the large rectangular barriers create the above criss-crossing wave pattern.

Refraction

Place the convex lens in the tank and cover with water. Observe that the section of the wave on top of the lens travels more slowly than the waves along the side of the lens.



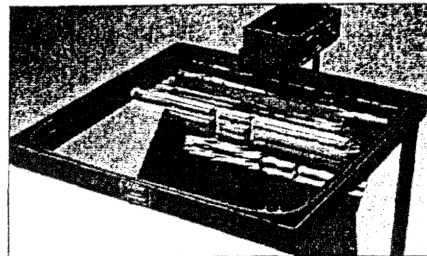
Refraction Experiment Setup



A convex lens, with the straight side facing the top of the screen, generates the above wave patterns.

Double-Slit Diffraction

The large and small rectangular barriers can be used to form a double slit, simulating two point sources.



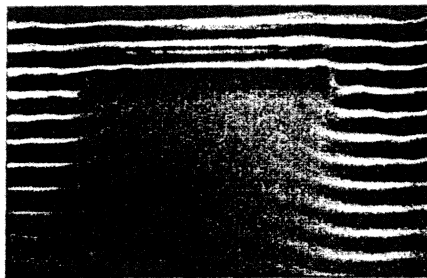
Double-slit Experiment Setup



The plane wave actuator bar and one small and two large rectangular barriers can be used to form a double slit that generates the above pattern.

Diffraction Around Objects

Observe how waves spread around the rectangular barrier placed in the tank.



Use the plane wave actuator bar to produce plane wave forms, and a rectangular barrier to produce the above wave pattern.

6 EXPERIMENTS:

* With Teacher's Guide and Sample Data:

1. Reflection.
2. Refraction.
3. Diffraction.
4. Interference.
5. Image Formed by a Plane Mirror.
6. Dependence of Wave Speed on Water Depth.

Experiment 1: Reflection

EQUIPMENT REQUIRED

- Ripple Tank (WA-9773)
- straight barrier (triangular refractor)
- curved barrier (concave refractor)
- clear metric rule
- 50W Halogen Point Light Source (WA-9776)
- Ripple Generator (WA-9777)
- plane wave actuator bar
- protractor
- drawing compass
- paper (40 cm x 40 cm)
- rod stand (90 to 120 cm long)

Purpose

To study the reflection of a plane wave from different shaped barriers.

Theory

When a ray reflects off a surface, the angle of incidence is the angle between the incoming (incident) ray and the normal. The angle of reflection is the angle between the outgoing (reflected) ray and the normal. The normal is a line that is perpendicular to the surface. See Figure 1.1. Wave fronts are perpendicular to the rays.

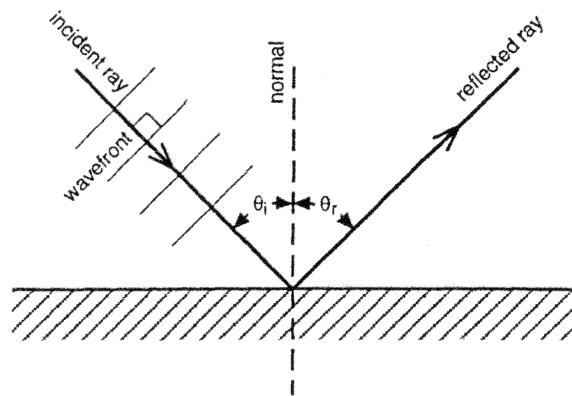


Figure 1.1: Definition of Angles

Setup

Type of Actuator: Plane Wave Actuator Bar
Water Depth: 5mm
Actuator Depth: touching water surface
Frequency: 5-10Hz
Amplitude: maximum

- ① Fill the tank with water to a depth of about 5 mm so the water is just above the step in the rubber gasket. The depth of the water must be less than the thickness of the plastic barrier.
- ② Level the tank.
- ③ Put the plane wave actuator bar on the ripple generator. Adjust the height of the ends of the bar so the bar is level with the surface of the water. Then lower the whole ripple generator until the bottom of the bar is submerged about half way down.
- ④ Loosen the phase lock knob, set the phase setting to zero, retighten the phase lock knob.
- ⑤ Set the amplitude to the maximum setting.
- ⑥ Set the frequency to setting "C".
- ⑦ Plug in the ripple generator and the light source.

Part I: Reflection Using a Straight Barrier

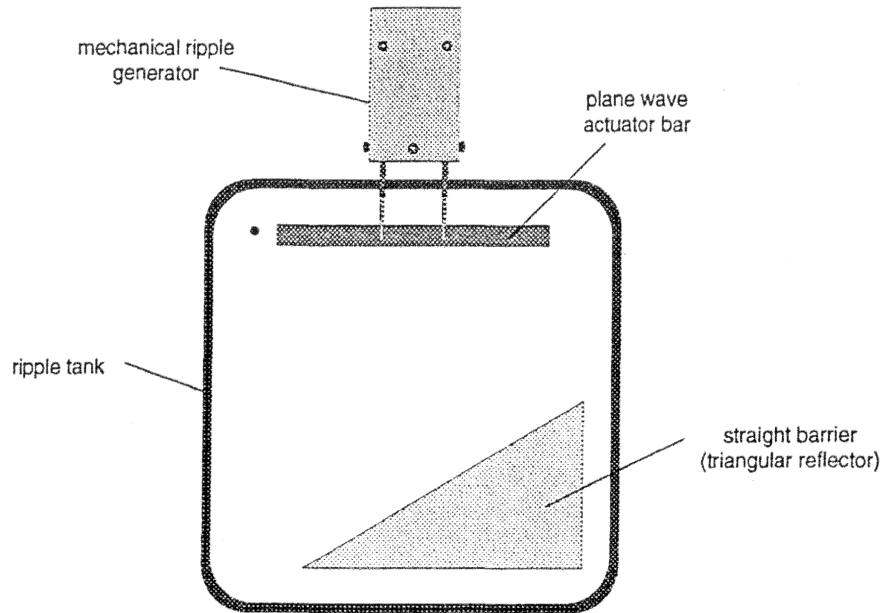


Figure 1.2: Position of Straight Barrier

Procedure

- ① Place the straight barrier in the water at an angle to the incoming plane waves. See Figure 1.2.
- ② On the paper below the tank, place the metric rule parallel to the plane waves that are incoming to the barrier. Make a line to show the incoming wave front.
- ③ Align the rule with the reflected wave and make a line to show the reflected wave.
- ④ Trace the position of the straight barrier.
- ⑤ Turn off the light source and ripple generator.
- ⑥ Draw a line that is perpendicular to the incoming wave front. Extend it to the straight barrier. This represents the incoming ray so draw an arrow on it pointing toward the barrier.
- ⑦ Draw a line from the point where the incoming ray strikes the barrier so it crosses the reflected wave front at a right angle. This represents the reflected ray so draw an arrow on it pointing away from the barrier.
- ⑧ Draw the normal (perpendicular) line at the point of reflection on the barrier.
- ⑨ Measure the angle of incidence, θ_i , and the angle of reflection, θ_r . What is the relationship between these angles? Record the results in Table 1.1.

Table 1.1 Reflection Results

	Trial #1	Trial #2
Angle of Incidence		
Angle of Reflection		

Experiment 2: Refraction

EQUIPMENT REQUIRED

- Ripple Tank (WA-9773)
- triangular refractor
- concave refractor
- convex refractor
- clear metric rule
- 50W Halogen Point Light Source (WA-9776)
- Ripple Generator (WA-9777)
- plane wave actuator bar
- 9 identical coins (to adjust the height of the triangular refractor)
- paper (40 cm x 40 cm)
- rod stand (90 to 120 cm long)

Purpose

The purpose is to show how waves bend as they pass from one medium to another.

Theory

As a wave passes from one medium to another, it changes speed. If it slows down, the wave will bend toward the normal as shown in Figure 2.1. This bending is called refraction.

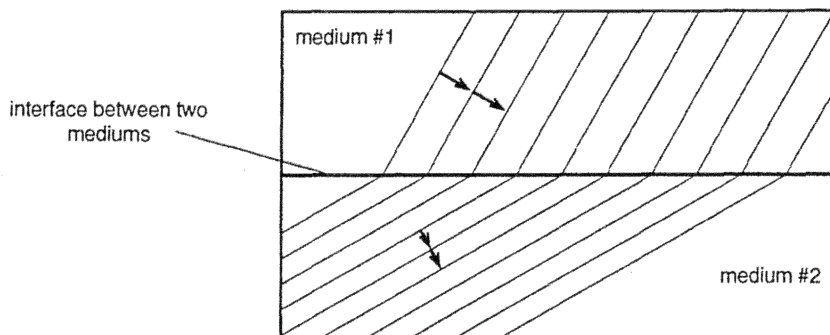


Figure 2.1: A Wave Slowing Down

Setup

Type of Actuator: Plane Wave Actuator Bar
Water Depth: 10mm
Actuator Depth: deep as possible
Frequency: setting A or B (2-5Hz)
Amplitude: maximum

- ① Fill the tank with water to a depth of about 10 mm.
- ② Level the tank.
- ③ Put the plane wave actuator bar on the ripple generator. Adjust the height of the ends of the bar so the bar is level with the surface of the water. Then lower the whole ripple generator until the bottom of the bar is submerged as far down as possible, leaving room for the bar to oscillate. If

the bar hits the bottom of the tank when it oscillates, raise it until it just barely clears the bottom of the tank while oscillating.

- ④ Loosen the phase lock knob, set the phase setting to zero, retighten the phase lock knob.
- ⑤ Set the amplitude to the maximum setting.
- ⑥ Set the frequency to setting "A" or "B".
- ⑦ Plug in the ripple generator and the light source.

Part I: Refraction Using a Straight Refractor

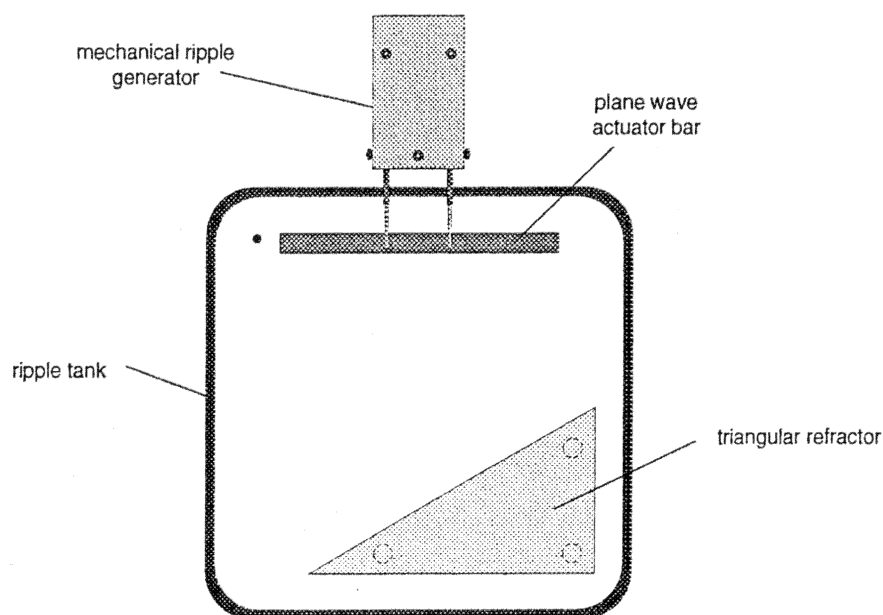


Figure 2.2: Position of Triangular Refractor

Procedure

- ① Place the triangular refractor in the water at an angle to the incoming plane waves. See Figure 2.2. To simulate two different mediums, the depth of the water must change. Raise the triangular refractor by placing an equal number of coins under each corner of the triangle. Adjust the height in this manner so the depth of the water on top of the triangle is only 2 to 3 mm.
- ② On the paper below the tank, place the metric rule parallel to the plane waves that are incoming to the refractor. Make a line to show the incoming wave front.
- ③ Align the rule with the refracted wave over the triangle and make a line to show the refracted wave.
- ④ Trace the position of the edge of the triangular refractor that the wave hits.
- ⑤ Turn off the light source and ripple generator.
- ⑥ Draw a line that is perpendicular to the incoming wave front. Extend it to the edge of the triangular refractor. This represents the incoming ray so draw an arrow on it pointing toward the triangle.

- ⑦ Draw a line from the point where the incoming ray strikes the triangle so it crosses the refracted wave front at a right angle. This represents the refracted ray so draw an arrow on it showing which way the wave is traveling.
- ⑧ Draw the normal (perpendicular) line at the point of refraction on the triangle.
- ⑨ When the wave goes from the deep water to the shallow water in the triangle area, does the wave bend toward or away from the normal?

- ⑩ When the wave goes from the deep water to the shallow water in the triangle area, does the wave speed up or slow down?

Part II: Refraction Using Curved Refractors

Procedure

- ① Replace the triangular refractor with the convex refractor, placing it a few centimeters from the plane wave generator.
- ② Turn on the ripple generator and trace the pattern seen.

- ③ Measure the focal length of the lens. This is the distance from the center of the lens to the place where the plane waves are focused.
- ④ Replace the convex refractor with the concave refractor and trace the pattern seen.

Experiment 3: Diffraction

EQUIPMENT REQUIRED

- Ripple Tank (WA-9773)
- triangular refractor
- long straight reflector (2)
- short straight reflector
- clear metric rule
- 50W Halogen Point Light Source (WA-9776)
- Ripple Generator (WA-9777)
- plane wave actuator bar
- paper (40 cm x 40 cm)
- rod stand (90 to 120 cm long)

Purpose

The purpose of this experiment is to determine how the diffraction pattern changes as the slit width and the wavelength are varied.

Setup

Type of Actuator: Plane Wave Actuator Bar

Water Depth: 7mm

Actuator Depth: touching water surface

Frequency: 10Hz (setting "E")

Amplitude: setting 4

- ① Fill the tank with water to a depth of about 7 mm so the water is just above the step in the rubber gasket.
- ② Level the tank.
- ③ Put the plane wave actuator bar on the ripple generator. Adjust the height of the ends of the bar so the bar is level with the surface of the water. Then lower the whole ripple generator until the bottom of the bar just touches the surface of the water.
- ④ Loosen the phase lock knob, set the phase setting to zero, retighten the phase lock knob.
- ⑤ Set the amplitude to setting #4.
- ⑥ Set the frequency to setting "E".
- ⑦ Plug in the ripple generator and the light source.

Procedure

- ① Place the two long straight reflector about 3 cm apart in the water as shown in Figure 3.1.

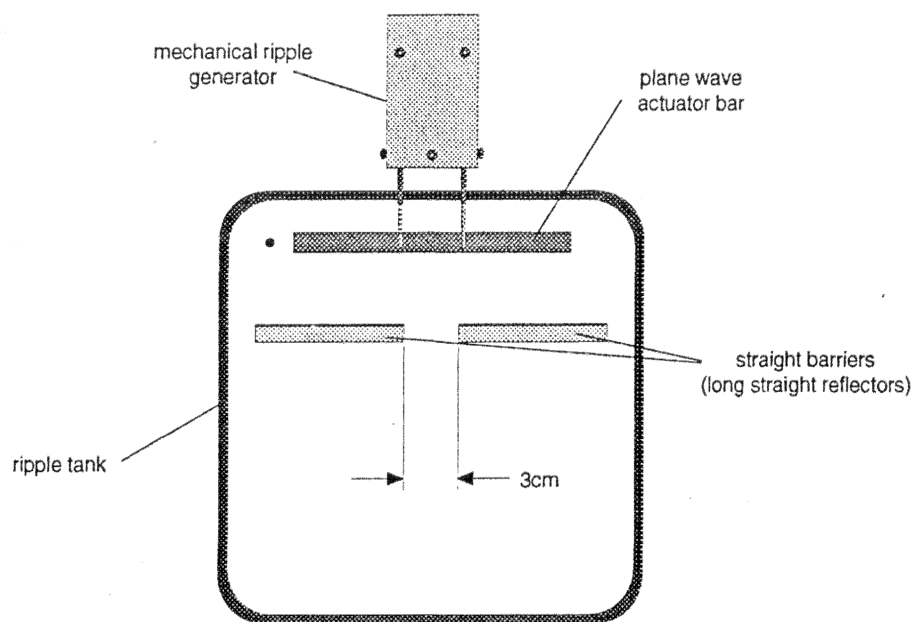


Figure 3.1 Position of Straight Barriers

- ② On the paper below the tank, trace the reflectors and roughly trace the angle that the waves spread out when they pass through the slit. Make a sketch of the wave pattern here.

- ③ Change the slit width to about 1.5 cm by sliding the two reflectors closer together.
- ④ On the paper trace the new angle that the waves spread through. Is this angle more or less than the angle for the wider slit?

- ⑤ Keeping the same slit width of about 1.5 cm, increase the frequency of ripple generator to setting "J".

How does increasing the frequency affect the wavelength?

How does increasing the frequency change the spread angle?

- ⑥ Replace the slit with the mini straight reflector. Remove the two long straight reflectors. See Figure 3.2.

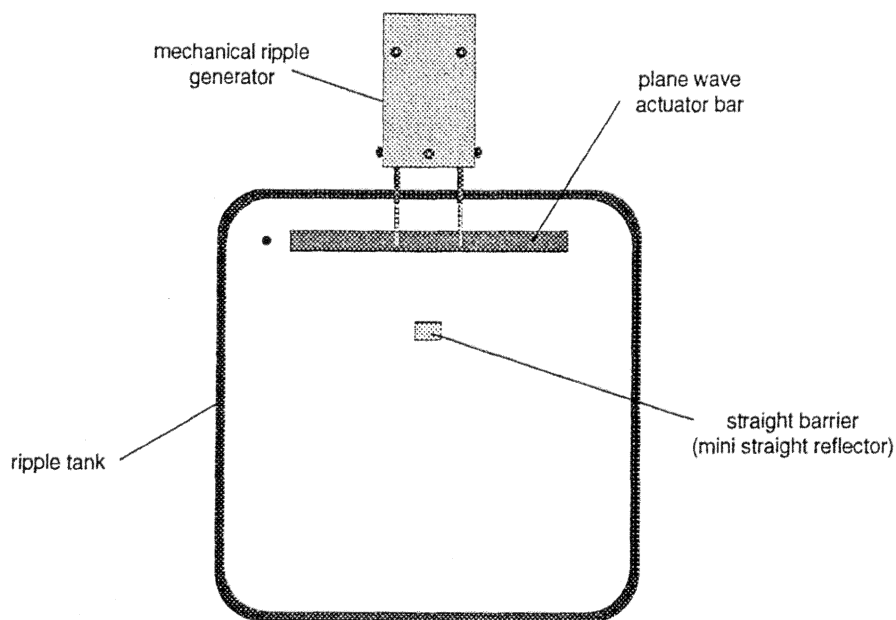


Figure 3.2: Diffraction for a Solid Object

- ⑦ Sketch the resulting wave pattern here.

How does this pattern compare to the same-size slit pattern?

Experiment 4: Interference

EQUIPMENT REQUIRED

- Ripple Tank (WA-9773)
- long straight reflector (2)
- short straight reflector
- clear metric rule
- 50W Halogen Point Light Source (WA-9776)
- Ripple Generator (WA-9777)
- plane wave actuator bar
- paper (40 cm x 40 cm)
- rod stand (90 to 120 cm long)

Purpose

The purpose of this experiment is to determine how the interference pattern changes as the slit separation and the wavelength are varied.

Theory

When a wave passes through two slits, the positions of maximum intensities are given by

$$d \sin \theta = m \lambda \quad (\text{where } m = 0, 1, 2, \dots)$$

where “d” is the slit separation, θ is the angle between maxima, λ is the wavelength, and “m” is the order. See Figure 4.1.

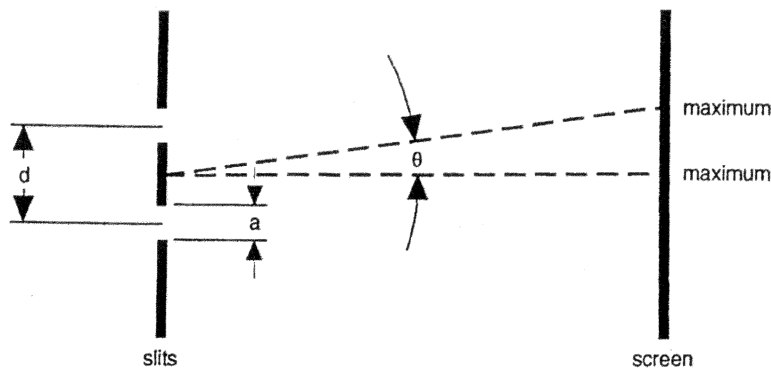


Figure 4.1: Double-slit

Setup

- Type of Actuator:* Plane Wave Actuator Bar
Water Depth: 7mm
Actuator Depth: touching water surface
Frequency: 10Hz (setting “E”)
Amplitude: setting 4

- ① Fill the tank with water to a depth of about 7 mm so the water is just above the step in the rubber gasket.

- ② Level the tank.
- ③ Put the plane wave actuator bar on the ripple generator. Adjust the height of the ends of the bar so the bar is level with the surface of the water. Then lower the whole ripple generator until the bottom of the bar just touches the surface of the water.
- ④ Loosen the phase lock knob, set the phase setting to zero, retighten the phase lock knob.
- ⑤ Set the amplitude to setting #4.
- ⑥ Set the frequency to setting "E".
- ⑦ Plug in the ripple generator and the light source.

Procedure

- ① Place the short straight reflector between the two longest reflectors to form two openings about 2 cm as shown in Figure 4.2.

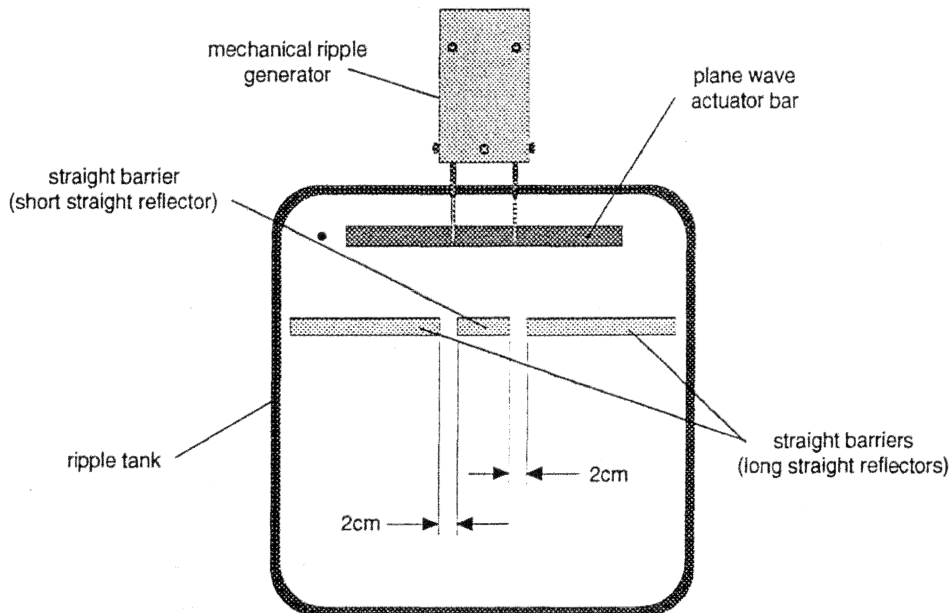


Figure 4.2: Position of Straight Barriers

- ② On the paper below the tank, trace the reflectors and roughly trace the angles that the waves spread out when they pass through the slit. Find the regions where the waves from the two slits tend to cancel each other and find the regions where the waves add together to make waves with higher peaks. Make a sketch of the wave pattern here.

- ③ Decrease the slit separation by replacing the center reflector with the mini straight reflector but keep the slit width at 2 cm.

Does the spread angle of the wave increase or decrease?

- ④ Keeping the same slit width of about 2 cm and the same slit separation, increase the frequency of ripple generator to setting "J". This decreases the wavelength. How does decreasing the wavelength change the spread angle?

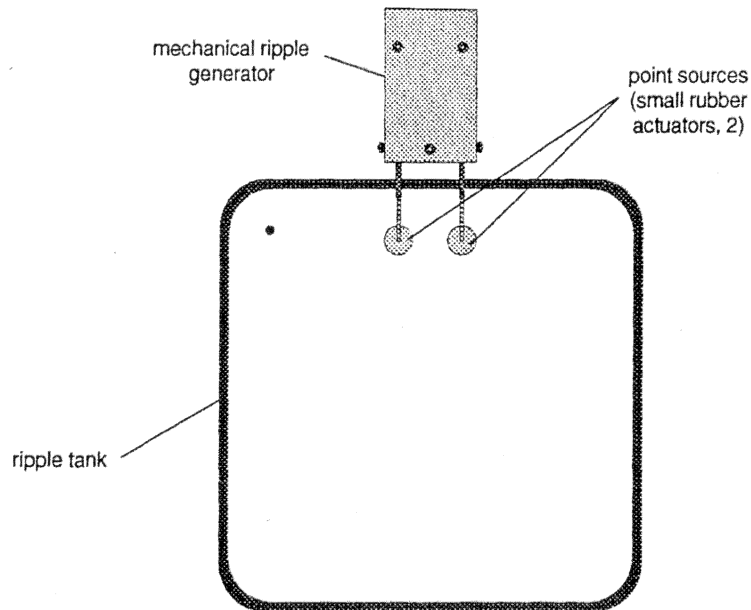


Figure 4.3: Interference Using Two Point Sources

- ⑤ Now remove the straight barriers from the tank and replace the plane wave actuator bar with two point sources (large end of the small rubber actuators) as shown in Figure 4.3. Using the same settings, compare the point source wave pattern with the two-slit pattern.

Lab 3: Resonant Flame Tube

EQUIPMENT WARNING:

- When the gas is turned on, be sure the flame is lit so that we don't have unburned gas escaping into the room--this can cause a serious hazard. As a precaution, open the door of the lab room to vent gas and fumes. Also watch for gas leaks at end of tube.

Find at least 4 resonances for the flame tube. For each resonance, sketch both the pressure and displacement waves in this tube, and find frequency, f , and wavelength, λ , and thus the velocity of sound in the gas using the relation $v = f\lambda$.

Do you expect the velocity v to be the speed of sound in air? Explain.

Are the ends of the tube pressure nodes or anti-nodes?

Other observations and comments.

Lab 4: Vibrating Chladni Plates

EQUIPMENT WARNING:

- The wave driver is simply a speaker with a driving rod attached. Therefore, if you place significant force on this when attaching or removing the plates, it will damage the speaker diaphragm, and break the wave driver. Please be **VERY GENTLE** when attaching and removing the plates.
- There is a "stop ring" on the shaft of the wave driver. If the voltage applied to the driver is too large, this ring will impact against the metal plate giving an audible warning--immediately reduce the voltage to avoid damaging the wave driver.

Find at least 3 resonances for 3 different plates including the violin shaped plate. For this lab, the attached instructions are quite useful.

- Sketch the resonance patterns and the associated frequencies.
- Comment on any patterns or general features that you observe.
- Is there any relation between the resonant frequencies you observe and the harmonic series that we have been studying?
- Other observations and comments.

Instruction Manual

for

EG-54 Chladni Plates

Introduction

One of the most interesting uses for the EG-50 Audio Driver and EG-52 Electromechanical Driver is to use them to excite vibrations in simple, thin metal plates. The plates are attached at the center to the drive post of the transducer. The idea originated with E.F. Chladni (1756-1827) who devised a method for making visible the vibrations of a metal plate. Fine sand sprinkled on the plate comes to rest along the nodal lines where there is no motion. He excited the motion by using a violin bow on the edge of the plate. Bowing requires much greater skill than using the precise, stable frequency of the EG-50 Audio Driver.

The four plates which make up the EG-54 Chladni Plate set consist of a square, a circle, a triangle, and a violin back shape. The simple geometric shapes have easily found resonances and simple nodal patterns at lower frequencies. The vibrations of the square and circular plates can be studied analytically as well. The mathematical derivation of the motion is a little daunting, but it does provide another level of understanding of the experiment. An excellent theoretical treatment can be found in Fletcher N.H. & Rossing T.D, *The Physics of Musical Instruments*, Springer-Verlang, New York (1991) and in a more abbreviated form in the paperback, French A.P. *Vibrations and Waves*, Norton, New York (1971). These analyses largely deal with clamped edge plates because the boundary conditions are simpler to deal with. In this experiment, the plates all have a free edge. Nevertheless, the theory adds a good deal of insight to the understanding of the vibrations.

The violin back is without theoretical model. The plate vibrates in complex nodal patterns, with many resonances. This is part of the reason that the sound of a violin is so rich in overtones and that, when well played, is so satisfying to listen to. In actual instruments, the violin back has a clamped edge, while in this experiment the plate vibrates with a free edge.

Procedure

The circular plate driven at its center produces the simplest resonances. They are similar to drumhead resonances and are axially symmetrical.

1. Attach the circular plate to the top of the Driver shaft with a #4-40 machine screw and a pair of lock washers. When tightening the screw, hold the end of the shaft with pliers to keep it from rotating while tightening the screw.
2. Place the transducer with the plate uppermost on a level table. This is important, because the sand sprinkled on the vibrating plate will slide off one side if the plate is not horizontal. Turn on the Audio Driver and set the frequency to 100Hz and the amplitude about 1/3 from zero.
3. Increase the frequency slowly and listen for an increase in audible sound. The plate radiates much more sound at resonance than in between resonances.
4. When a resonance is found, reduce the amplitude and sprinkle a little clean dry sand onto the plate. The individual

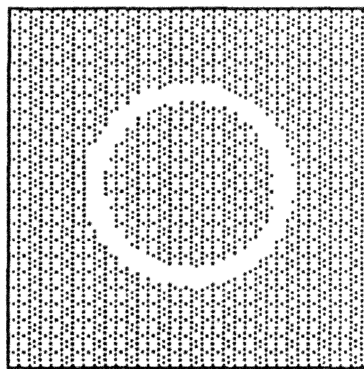
grains will dance on some parts of the plate and lie still at others. Turn up the amplitude a little until a good pattern is found. Sketch or photograph the pattern.

5. Increase the frequency slowly to find the next resonance. As the frequency is increased, the amplitude should be increased a little as well.

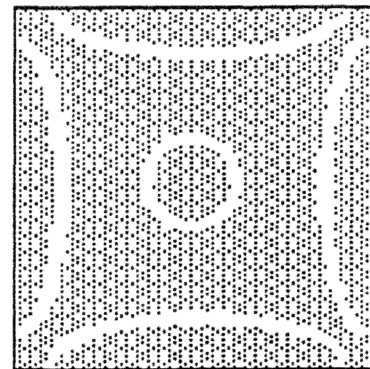
The number of resonances found depends upon your patience. The circular plate vibrates with circular nodal patterns until the higher modes are reached. The theoretical modal frequencies are given in Table 3.2 of Fletcher & Rossing.

6. Remove the circular plate and replace it with the square one.

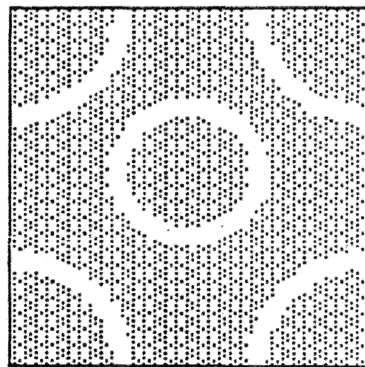
Chladni Patterns



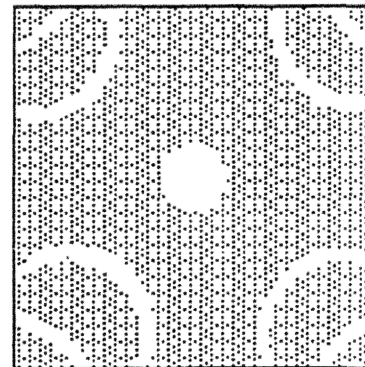
209 Hz



1054 Hz



567 Hz



1641 Hz

Figure One

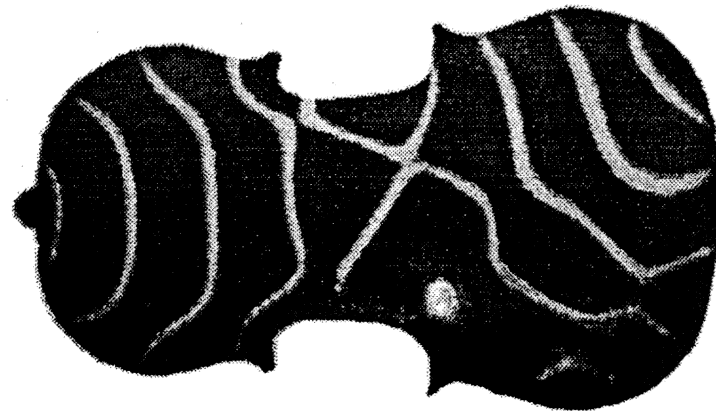
7. Repeat Steps 4 and 5 to find the resonances for the square plate. Typical resonances are shown in Figure One. You should be able to find these same patterns, but not necessarily at quite the same frequencies. The frequencies depends upon the thickness, exact size and strength of the metal. Small differences are to be expected.
8. Tabulate the frequencies and sketch the patterns as before.

9. Repeat with the triangular plate.

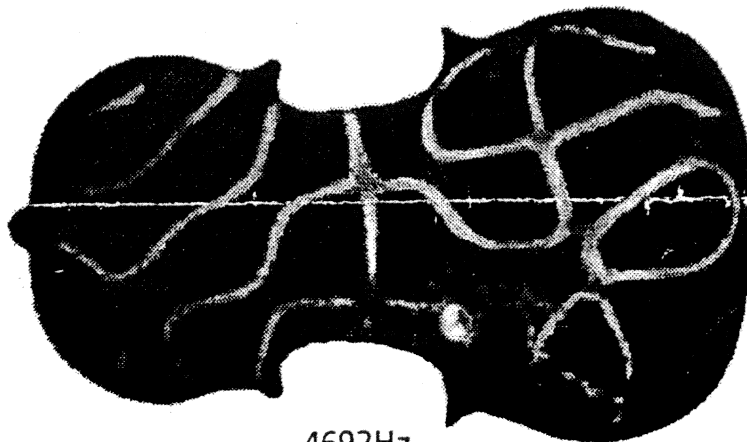
Resonances for a vibrating string are simple multiples of the fundamental frequency. The resonances in plates bear no such simple relationship. These complex harmonic relationships produce the brilliant sound of a cymbal crash where many resonances are sounding together.

The plate shaped like a violin back is designed to attach to the Driver off-center. This mounting position simulated the position of the sound post in an actual violin. This is a small wooden post connecting the top to the back and transmits some of the strings vibration to the back.

The violin plate in this set is a 56% copy of a violin built in London in 1911 by Emanuel Whitmarsh. The frequency of the resonances depend upon the size and the strength of the material, in this case, aluminum versus wood, so that the actual frequencies would occur at much lower frequencies than observed in the experiment. The shape of the nodal patterns should be similar to an actual instrument.



3741Hz



4692Hz

Figure Two

The two pictures shown in Figure Two are taken from photographs of the nodal patterns. The frequency is quite high in these two cases. At lower frequencies, the patterns are much simpler but still more complex than obtained with the simple geometric shapes.

Lab 5: Wave Interference

EQUIPMENT WARNING:

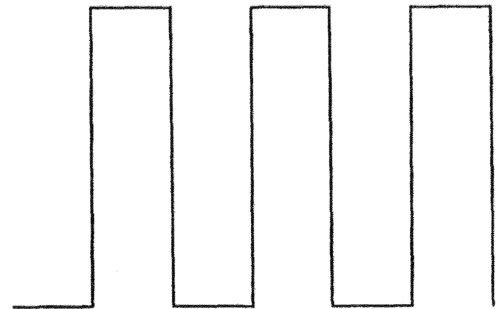
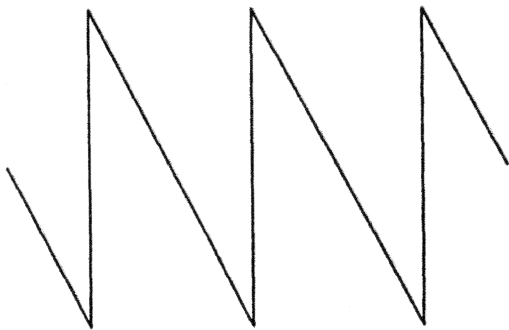
- This lab makes use of a Fourier Transform board, and Oscilloscope, and a home-made laser Lissajous device, all of which are expensive and delicate. If you have questions, please ask, and remember: anyone who is electrocuted or explodes will receive a failing grade for that lab segment.
- The 3rd part of this lab is optional and uses a laser. Please use this with caution: do not look at the laser beam, and do not point the laser beam at any person--this can result in permanent eye damage.

This lab is divide in to 3 parts:

- 1) Fourier Transforms (Frequency Domain Plots),
- 2) Lissajous Figures (superposition of 2 different frequencies)
- 3) Optional: Laser Lissajous figures

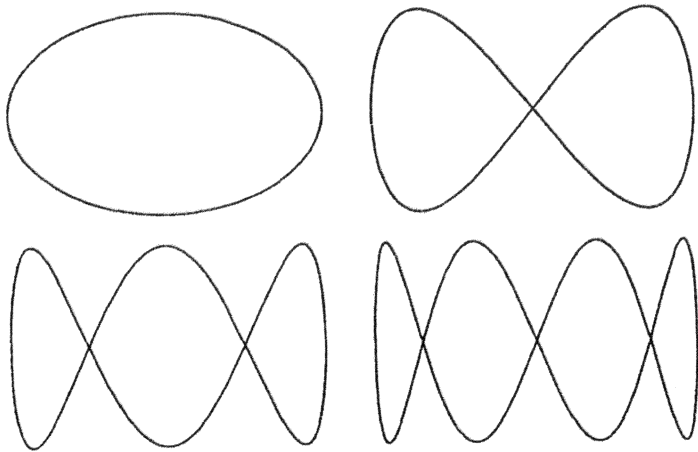
PART 1: Fourier Transforms (Frequency Domain Plots)

Using the Fourier Transform box and an oscilloscope, generate a I) saw-tooth wave, II) a step wave, and III) another wave of your choice. Vary the phase of the different partials. Does the phase affect the waveform? Does the phase affect what you hear?



PART 2: Lissajous Figures (superposition of 2 different frequencies)

Using oscilloscope in an "xy" mode, we will input one frequency on the x-axis, and vary the frequency on the y-axis to produce Lissajous figures. The figure below shows Lissajous figures for frequency ratios of 1:1, 1:2, 1:3, 1:4. Identify each figure with the corresponding ratio. Now you try it with some different frequency ratios. Also, try adjusting the phase. Sketch your results for 3 cases.



PART 3: Optional: Laser Lissajous figures

This part is optional as the equipment is home-made, and may not work. We will repeat the above exercise, but use two mirrors instead of an oscilloscope to generate the Lissajous figures. I suggest that you set up the laser so that it shines on the ceiling (away from anyone's eye), and I recommend you start with frequencies around 100Hz.