Physics 338 Advanced Physics Laboratory

Fourier Project

First draft due **Monday, April 15, 2024, 5 p.m.**
Peer Review due **Thursday, April 18, 2024, 1:15 p.m.**
Final report due **Thursday, April 25, 2024, 1:15 p.m.**

Safety

There are no unusual safety hazards in this experiment. Some projects do use permanent magnets with moderately strong magnetic fields.

1 Introduction

In the previous experiment, you learned how to use the Stanford Research Systems SR770 Fourier Analyzer, as well as some of the TeachSpin Fourier Modules accessories, to create and analyze a variety of waveforms. In this project, you will use those tools to study a particular system in greater depth.

This experiment is different from previous experiments in this course in that the choice of experiment and most of the experimental design decisions are up to you. Several possible suggested projects are listed below. In addition, the TeachSpin manual contains a large number of possible projects in chapters 10 through 18. Feel free to browse through the manual and propose a different project, if one catches your eye. These additional projects differ greatly in depth and complexity, so please consult with me before embarking on a new experiment.

The next three weeks are entirely devoted to this project. Following the usual expectations for a 4-credit course, that amounts to 12 hours per week, or 36 hours total. Budget your time wisely. Writing often takes longer than we imagine. Allow yourself plenty of time to take data, analyze it, realize you need more or different data, and then go back and get more data. Some of the projects could lead to much deeper exploration, but you will not likely have time to do such explorations.

You are not expected to do this all on your own. I expect that nearly everyone will need help at multiple various times throughout with both the theory and experiment. That is good and appropriate. I will be happy to help you out, but you must *allow enough time.*

1.1 Report Requirements

This report will also be the second major writing assignment for this course, so you will submit a first draft, revise that draft after peer review, and then submit your final paper.

The final goal is produce an article describing your project in a style suitable for the *American Journal of Physics.* There are specific submission milestones laid out below, but you should feel free to consult with me (and with your classmates) at any time throughout the process.

Each student should do an individual project and write an individual report. If two students want to cooperate on related topics, please consult with me to make appropriate arrangements.

Assume an audience of peers—junior or senior level physics majors. You should assume the reader is familiar with Fourier Transforms in general, but is probably unfamiliar with the application of Fourier analysis to the particular problem you are investigating.

Length

A typical American Journal of Physics article is approximately 4,000 to 5,000 words, plus equations, tables, and figures. Your paper will likely be a little shorter. Specifically, in the double-spaced preprint format with `\documentclass[prb,preprint]{revtex4-1}`, your paper will typically be about 8 pages. In the tight two-column format with `\documentclass[prb,twocolumn]{revtex4-1}`, your paper should be approximately 3 to 4 pages.

Report Structure and Content

Your report should be structured along the same general lines as the previous formal report. See the `https://workbench.lafayette.edu/~doughera/courses/phys338-2024/reports/notebook-report.pdf` document distributed the first day of class, and also available on our Moodle page, for more details. However, since the different projects involve different mixes of theory, experiment, and exploration, you should adjust your report accordingly. The article guidelines are just that, *guidelines*. It is *your* responsibility to arrange your article so it is most useful for the reader.

In general, you should reference at least a few relevant journal articles or textbooks. You almost certainly will want to reference the TeachSpin manual as well, since it contains a wealth of theoretical background for most topics. You do not need to do an extensive or exhaustive literature search, but you should provide enough references to give the reader context and background information.

The precise mix of theory and experiment description varies significantly among the different projects, so there are no simple universal guidelines.

First Draft

By 5:00 p.m. on Monday, April 15, 2024, you should submit an electronic copy of your first draft with your name removed (for anonymous peer review). The first draft should be submitted in preprint (double-spaced) format. This format makes it *much* easier for the reviewer to make helpful comments. The final submission should be in journal format, which simply involves removing the `preprint` option.

The draft will be graded and count as 15% of the total score for this project, but that grade is primarily based on having a mostly complete paper. If it is substantially incomplete, I may simply return it ungraded. Only papers that are mostly complete will be included in the peer review process. *The closer to complete your first draft is, the more useful feedback the reviewers can provide.*

Peer Review Report

Published articles ought to be free of scientific error, and written in a manner that makes them clear and accessible to the target audience. To help attain that goal, articles submitted to journals usually undergo anonymous peer review. Accordingly, we will exchange papers within the class for a peer review process. Your participation in this process counts for 5% of your total course grade.

I will give you two articles to review as a referee, along with fresh copies of the reviewer guidelines. Your basic goal will be to judge whether the paper is suitable for publication in the American Journal of Physics as is, without any modifications. Specifically, you will be asked to evaluate both the scientific merit of the work and the quality and clarity of the presentation.

The reviewer guidelines are very detailed, but you do not have to answer every question or correct every mistake in an article. They are intended as much to guide you as an author as they are to guide you in your role as a referee. If a particular section (e.g. the Introduction) is fine, you may simply write something like "The Introduction is fine." If there are many issues or questions in a section, simply list the first few or the most important ones, and add a brief comment that there are others as well. In short, it was the author's responsibility to write the article; it is not your responsibility as the referee to fix it.

Please be kind and professional in your comments. Your review may be either typed or hand-written. You may write directly on the review packet, or you may simply write a fresh document. You may bring your review in-person to class, or you may submit it via the link on our Moodle page. Please include the review packet cover sheet with your review. I will remove the identifying cover sheet before giving the comments back to the authors.

Peer review reports are due in class on Thursday, April 18, 2024. As a courtesy to your fellow authors, please do not be late. Since the peer review process is time-sensitive (authors only have one week to make their revisions in this class) late peer review reports will normally not be accepted.

Final Version

Normally, if the author wishes to resubmit a paper after review, he or she must submit a revised version along with a cover letter explaining the choices made during the revisions. An author may disagree with a referee about specific changes, but must still defend those choices.

After you receive your referee reports, you should revise your paper in light of them. You will then submit your revised report and include a cover letter explaining your choices. Often, if the changes are simple or straightforward, the letter can be quite short.

The resubmittal letter and final report are due at the beginning of class on Thursday, April 25, 2024. The final report will count as 85% of the total grade for this project.

1.2 Resources

The detailed instruction manual for this apparatus is available on the course Moodle site. The manual for the SR770 is available there as well.

For most of these topics, you can find good articles using the Web of Science tool on the library's web site. Many are also discussed in a variety of other online websites, but if you do not use a peer-reviewed source, you are responsible for otherwise establishing the quality and reliability of the information. I will be happy to help you find appropriate references.

1.3 Saving Data

Both the oscilloscope and the SR770 can save data to a file. The SR770 sometimes has problems with USB drives. The blue USB "TeachSpin" drive has been formatted on the SR770 and verified to work with it. Feel free to use it to transfer data to the computer, but leave the blue USB drive with the experiment.

To save data from the SR770, see the "Getting Started" instructions near the beginning of the SR770 manual. If the drive does not appear to work, try reformatting it. There is also a simple LabView program on the computer that can be used to take data from the SR770 and save it on the computer.

There are a couple of options for downloading data and screenshots from the oscilloscope. You can use a USB drive to save data and images. See the instruction manual (next to the oscilloscope) under "Data Logging."

The oscilloscope can also be connected to the computer via a USB cable. Launch the `OpenChoiceDesktop` program. This program can

1. Capture screen images and save as PNG files, suitable for import into LaTeX.
2. Save raw Ch1 and Ch2 data (you need to select Ch 2 on the channels menu) as a "Comma Separated Values" (csv) file, suitable for import (or even pasting) into `Excel` (or *Mathematica*, if you prefer, but it might be easier to clean up the columns in `Excel`).

Again, I will be happy to help you with any data transfer issues.

2 Project: Transfer Function (Chapters 7 and 9)

In this project, you will see how to measure the "Transfer Function" for an electronic circuit. In particular, you will learn how to interpret both the real and imaginary parts of the complex Fourier transform.

You should start with Chapter 7, which uses the LCR system to introduce transfer functions. The first part of this experiment (pg. 7-1 through 7-5) should be familiar, since you probably did this experiment in Phys 218. You don't need to repeat the measurements, but this part does describe how to hook everything up, and also introduces the notation used throughout this project.

Start at the bottom of pg. 7-5. Measure the magnitude $M(f)$ for the LCR module and compare it to the theoretical prediction. Next, replace the LCR circuit with the Filter module, and again measure $M(f)$. What does the Q setting do?

This method gives you the magnitude of each of the Fourier components, but does not tell you anything about the phase. To learn about the phase, you will next use a *transient* waveform.

Follow the discussion in Chapter 9 to take the Fourier transform of a transient waveform. Measure the real and imaginary parts of the Fourier transform for the LCR module, as in Fig. 9.1 in the instruction manual. Compare to the theoretical prediction.

Finally, replace the LCR module with a filter module. Again compute the real and imaginary parts of the Fourier transform. Discuss any significant differences between the LCR and Filter modules.

Your final report should contain the theoretical background for this application of the complex Fourier transform, as well as your experimental results.

3 Project: Acoustic Transfer Function (Chapter 8)

In this project, you will use Fourier analysis to measure the resonance frequencies for a simple cylindrical chamber. The theory and experiment are described in Chapter 8 of the instruction manual.

The theory is an extension of the two-dimensional circular drum sometimes studied in Phys 218, but with two changes. First, the boundary condition for the pressure waves is that the *gradient* be zero at the edges, not the amplitude. The second is that there is an additional standing wave condition in the z-direction.

The main goal of the experiment is to test the prediction for the resonant modes given on pg. 8-6 of the instruction manual, namely

$$f_{0n\ell}^2 = c^2 \left[\left(\frac{x'_{0n}}{\pi} \frac{1}{2R} \right)^2 + \left(\frac{\ell}{2L} \right)^2 \right] . \tag{1}$$

Obtain a careful spectrum of resonant frequencies for one setting of L. Use the techniques described in the instruction manual to label as many of the peaks as possible. Finally, use your data to compute an average speed of sound c and then compare your experimental spectrum with the predicted one.

In your report, you need not derive all the theory behind the experiment. You may assume the reader is familiar with the two-dimensional cylindrical drum and Bessel functions, but you should describe how that theory needs to be adapted to the present system.

For your final data, you do not have to vary L; you may simply use the results from a single L value. However, as discussed in the manual, varying L is often a good diagnostic tool to help you understand the origin of the various peaks.

4 Project: Pulse modulation (Chapter 10)

In this project, you will look at a simple on/off modulation in both the time domain and the frequency domain. Although the process is conceptually quite simple, the resulting Fourier analysis reveals a rich complexity with wide applicability.

Work through the exercises in Chapter 10. The `Tenma 72-5010 2 MHz Sweep Function Generator` oscillator is a good choice for this experiment. Use the `Pulse` output. Set the frequency to about 300 Hz and look at the output on the oscilloscope. You may find it convenient to use the oscilloscope's `Measure` feature to measure the pulse positive width ("on" time), negative width ("off" time) and duty cycle. Change the duty cycle by pulling the `Duty cycle` knob out and adjusting it. You ought to be able to get a pulse that is on for about 2 ms and off for at least 14 ms so that within a single 16 ms acquisition window on the SR770, there will only be a single pulse.

First, produce the spectrum for a single square-wave pulse. Compare it to the predicted value.

Next, consider the case of a double pulse. You ought to obtain a spectrum similar to Fig. 10.1 on pg. 10-6. (This requires a duty cycle of 25%, which is easily obtained with this instrument.) Again, compare it to the predicted value.

Your report should derive the theoretical predictions, skipping simple algebra steps, but giving enough detail so another student could understand and reproduce the work. Your report should also discuss this modulation in a broader context, such as modulating fiber optic signals or synthetic aperture radar.

5 Project: Chaos (Chapter 12)

In this project, you will explore some of the properties of the Lorenz system. Chapter 12 includes a fairly detailed description of the problem; there are numerous other references available in journals and books, as well as on-line.

Briefly, the Lorenz system is a set of coupled nonlinear differential equations that display deterministic chaos. There is a single control parameter, r. As r is increased from 0, the system goes from a stationary state through oscillating states, and eventually to chaotic states. There are periodic "windows" at larger r values as well. The transition to chaos in the Lorenz system has similarities to transitions to chaos in many other mathematical and physical systems. In this project, you will explore that route to chaos.

This chapter is rather long, but is mostly walking you through the set-up and initial control settings. This experiment appears to works best if you take the bulk of your careful data in a single session.

The goal is to perform and report on the explorations described on pg. 12-10 and 12-11. As you are working, remember that the relationship between the dial reading R_{dial} and the control parameter r is

$$r = 36.4\, R_{\text{dial}}\ .$$

In your report, you should introduce the Lorenz model, but you need not try to solve it analytically, and you don't have to give a general introduction to deterministic chaos. You should, however, be explicit about the scaling between the model parameters x, y, and z, and the measured parameters V_x, V_y, and V_z.

6 Project: Acoustics and Music (Chapter 14)

In this project, you will explore the application of Fourier analysis to audio signals. There are many directions you could take; the following is one specific set of suggestions. If you have other suggestions, please discuss them with me before investing too much time and effort.

First, you should work through the general connection exercises, which bridge the world of audio signals and the electronics test and measurement world. Once everything is working, try the following two applications.

In your report, you should make reference to appropriate background literature, and relate the general issues of pitch and timbre to the Fourier analysis you have performed here.

6.1 Musical Timbre

In this portion, you will consider the spectrum of musical instruments.

First, consider a single instrument playing a single note. In first-year physics, we develop a simple model, such as a clamped string, or an open or closed pipe, to describe a resonating system. How does that simple picture compare to reality? Record a Fourier Spectrum for an actual instrument and compare it to a simple first-year physics model.

Next, consider two different instruments (real or synthesized) playing the same note. How do their spectra differ?

So far, you have ignored transients. Would the SR770 be of much help in analyzing transients? Think about the particular time and frequency scales involved. See the discussion in Chapter 9.

6.2 Vocal Formants

Test the claim at the bottom of pg. 14-6 and top of 14-7, namely that the formants that characterize vowel sounds remain at a fixed frequency even as the fundamental frequency (or pitch) of the note is changed.

7 Project: Coupled Oscillators (Chapter 16)

In this project, you will study the behavior of two coupled oscillators, and investigate the phenomenon known as “avoided crossing.” In your introduction, you might wish to cite the relevant literature for the relevance of avoided crossings in other realms, including quantum mechanics.

There is a fair amount of experimental set-up required, but the manual walks carefully through it. Your ultimate goal is to make the plots suggested at the bottom of pg. 16-15.

Your report need not reproduce the detailed derivations of the torques on the coupled oscillators. The main idea is that you have driven coupled oscillators, and that the various constants involved have known (or calculable) values. You should state the results at the level of specificity needed to make your discussion understandable, but you need not give excessive detail. The focus is on the general properties of coupled oscillators, not the specific mechanics of this particular set-up.

Your report need not reproduce all the algebra. You may assume the reader has mastered the matrix description of coupled oscillators at the Phys 218 level, but you should cite particular results that make clear what you are plotting.

8 Project: Detecting Nonlinearity (Chapter 17)

In this project, you will investigate the Fourier features of *nonlinear* systems. In particular, you will see how nonlinearity gives rise to new frequencies in an output signal. Sometimes such nonlinearity is an unwelcome distortion, but other times it is a particularly useful technique. One common use of nonlinearity is frequency doubling. The field of nonlinear optics, for example, provides a wealth of applications.

In this project, you should work through the Intermodulation Distortion tests, and then do the tests suggested in the last paragraph on pg. 17-6 for at least two other modules. (Or, if you wish, you may test some other device entirely.)

Your report should include a reasonably thorough discussion of the theoretical expectations as well as your experimental findings. You do not need to include every step, but it should be readily comprehensible by a fellow junior physics major.