Physics 338 Advanced Physics Laboratory

Final Fourier Project

Informal Report due **Friday, December 13, 2024, 11:00 a.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.

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

You will submit an informal report for this project. The exact mix of theory and experiment is different for each project; generally you should follow the guidelines in the particular chapter.

1.2 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 would next use a *transient* waveform. Transients are described in Chapter 9, but we will not pursue them further in this project.

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: 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.