Fourier Methods

February 12, 2018

1 Introduction

1.1 Background Reading

1. "Fourier Methods Instructor's Manual", TeachSpin, Inc.
2. "Spectrum and Spectral Density Estimation by the Discrete Fourier transform (DFT), Including a Comprehensive List of Window Functions and Some New Flat-Top Windows", G. Heinzel, A. Rüdiger, and R. Schilling (2002).
3. "Measurements and their Uncertainties", Ifan G. Hughes and Thomas P. A. Hase.

1.2 Motivation

The purpose of this lab is for you to become familiar with thinking in the frequency (Fourier) domain. While working with signals in the time domain may seem more intuitive, a wide range of technologies, including wireless communications (radio, television, WiFi, cellular phones, etc), radar, fiber optics, precision clocks, etc. are often more easily understood and measured in the frequency domain.

This lab includes several "model" systems for you to explore. The frequency-omain techniques you learn with these experiments will be used for the remainder of the semester with more complex physics systems.

2 Objectives

These objectives are intended to guide your experiments. They are not a step-by-step procedure.

1. Introduction to spectrum analyzers. View on oscilloscope and spectrum analyzer. Record both. Use a FFT to transform the oscilloscope data to the spectral data using numpy or matlab (as well as you can). Explain the effect of the frequency resolution (measurement time), windows, and linear versus log scale. Give a mathematical description of the origin of the frequency domain signatures you observe for each signal.
   (a) Sine, square, and triangle waves.
   (b) Sum of two sine waves (using "Summer" module). Test the conditions under which you can and cannot resolve the two peaks in the frequency domain.
   (c) Amplitude modulated wave (using "Multiplier" module).
   (d) Sine wave buried in noise (using "Buried Treasure" module).
   (e) OPTIONAL: Frequency modulated wave (using "Voltage Controlled Osc." module).

(f) OPTIONAL: Mixed signals (using "Audio Mixer" module).

2. LCR filter: Measure the response of the LCR circuit at a few frequencies using a single-frequency drive and oscilloscope. Measure the transfer function in steady-state using a noise drive, and the phase-sensitive transfer function response using a chirp. Measure the transient response using a square wave. Relate all the results mathematically and check if they agree.

3. Acoustical cavity: Measure the response of the acoustical cavity at a few frequencies using a single-frequency drive and oscilloscope. Measure the transfer function in steady-state using a noise drive, and the phase-sensitive transfer function response using a chirp. Measure the transient response using a square wave. Relate all the results mathematically and check if they agree.

4. Coupled torsional reed oscillators: Use the techniques you have learned to characterize the coupled reed oscillators, including avoided crossings as you tune the resonance frequencies. Explain what is happening mathematically.

5. OPTIONAL: Explore demodulation of an amplitude-modulated signal.

6. OPTIONAL: Explore demodulation of a frequency-modulated signal.

7. OPTIONAL: Explore the fluxgate magnetometer.

3 Questions

These questions should be specifically answered in your lab notebook, and can also serve as a guide for discussion in your lab report analysis.

1. How does the SRS spectrum analyzer normalize the signals it displays?

2. In which measurements did you find frequency domain analysis to be most useful? Could you do or interpret these experiments in the time domain alone?