3.4 The fast Fourier transform

The importance of Fourier methods in data analysis derives from the existence of the *fast Fourier transform* (FFT) algorithm, which is, well, a fast way of computing the DFT. (What does fast mean? The DFT requires $\mathcal{O}(N^2)$ calculations to compute the transform of N values; the FFT requires $\mathcal{O}(N \log N)$ — when N is of the order of 10^3, a typical value, the FFT is about 1000 times faster than the DFT. . .) This makes the use of Fourier transformation practical, and explains the wide use of Fourier techniques in experimental physics.

3.5 Power spectrum

The power spectrum gives essentially the intensity of the time-domain data as a function of frequency.
It is defined by

$$P(\omega) = |F(\omega)|^2$$

A single frequency in the data will result in a delta function in the power spectrum. However, the FFT is always applied to a finite domain, and this causes 'power' to leak to adjacent frequencies. Hence the delta function is spread into a peak of finite width. The spread can be shaped by 'windowing' the data. See, e.g. Numerical Recipes for further information.

3.6 Filters

It is common practice in signal processing to filter out certain components or regions of a signal under investigation. There are several techniques in electronics that can achieve this and filters come in very different forms and have very different functions.
In the previous LRC lab session you investigated the behaviour of both series and parallel LC combinations. Such a circuit was in fact a filter. You were selecting a single frequency to transmit or reject. In some cases there may be a need to reject or transmit a whole bandwidth of frequencies from a given signal. This can be achieved both at the software level and/or hardware level. In today's lab session, we will be focusing on the software implementation.
The three simplest filters are the low pass filter, band pass filter and high pass filter. In the case of the low pass filter, all frequency components of a signal up to a specified frequency are transmitted. In the case of the band pass filter, as the name would suggest, a continuous band of frequencies are filtered through. In the case of a high pass filter, all frequency components of the signal starting from a specified frequency are transmitted. You should be able to find a whole range of other filter designs online and in standard electronic books.

4 Experiment

4.1 Introduction and Aims

You will make use of two programs in this lab session today. The first, FT.exe, will be used to provide Fourier analysis on a selection of input signals, from voltage signals supplied from a function generator to the input of sounds processed through a microphone. The second, Equi.exe, will give you the opportunity to understand how a sound graphic equaliser that you may have come across on a sound system or PC actually works. All programs are available for download from Vula.

During this lab session you should gain valuable experience with signal processing and come to understand the practical nature and uses of Fourier analysis. You will gain exposure to band pass filters and learn to work in both the time and frequency domain.

4.2 Setup and Measurements

There are three different setups that you will need to carry out during this lab session. Each setup will be discussed below with the corresponding tasks that you should carry out.

4.2.1 Function Generator Signals

In the first part of the experiment you will investigate the periodic signals(sinusoidal, square, triangular) coming directly from the function generator. Using the wire provided, connect the positive and negative outputs from the signal generator to the AI 0_+ and AI 0_- ports of the myDAQ respectively. Use the supplied screw driver to ensure that all the wires are secured tightly.
Start the FT.exe program. The first plot will display the signal from the function generator. The second plot displays the FFT of the output from the function generator. Here you will be able to see what fundamental frequencies combine to form the output from the function generator. The software also allows you to apply a low pass filter to the signal from the function generator. The filtered signal in the time domain is plotted on the third set of axes with the FFT spectrum of the signal from the output of the filters plotted on the fourth set of axes. Make sure that the Microphone toggle switch is set to the OFF position.

Task Try all three waveforms available from the signal generator (sine, square, triangular). For the square and triangular waves measure the size (height) of the peaks corresponding to the fundamental and its harmonics. Do this for fundamental frequencies of around 80 Hz and 300Hz. The measured values of the Fourier power spectrum should be proportional to the coefficients in the Fourier expansions in Section 3.1. To check this, determine the ratios of the amplitude of the first fundamental of your data to that of the subsequent harmonics amplitudes from the power spectrum for both the square and triangular wave signals and check this against the ratio of the amplitude of the first term with that of the higher terms as given in equations 1 and 2. Do the values agree? Discuss.

4.2.2 Microphone Signals

In this section you will investigate signals coming in from the microphone. Connect the microphone to the Audio Input on the myDAQ. Once again make use of the the FT.exe program. This time make sure that the Microphone toggle switch is set to the ON position. Capture, in a similar manner to the previous section, the signals coming in through the microphone. Investigate different sound sources (instruments, tunning forks, voices).

Task Investigate what effects the filtering has on the signal. Log down all your observations and capture plots to help with your discussion in the report writeup.

4.2.3 Solar Panels

You will now investigate the output signal from a solar panel. The solar panel is a semiconductor based device that generates a voltage with the absorption of light. In your third year of physics you will learn more about semiconductor materials. For now, you are expected to see how the Fourier transform can help with producing a desired signal from the panels and removing any unwanted noise.

Connect the two output wires from the solar panel into the AI 0_+ and AI 0_- ports of the myDAQ. Any orientation will suffice. Make use of the of the the FT.exe program. Make sure that the

Microphone toggle switch is set to the OFF position. You will need to monitor the signal coming in from the panel. The solar panel is capable of generating a DC voltage. The magnitude of the voltage is determined by the amount of light reaching the panel. The size of the panel and the type of material used will determine the maximum voltage possible. The solar panel used here can supply a maximum nominal voltage of 17.5V.
This will vary depending on the load placed across the panel and the strength of the sun on the panel.

From the software you should notice that the signal appears to oscillate.

Task Determine the frequency of the oscillation. You can use the oscilloscope if need be. Simply connect the output of the panel to the scope. Play around with the filter to see if you can remove the oscillation.Explain where you think this oscillation comes from?

4.2.4 Graphic Equiliser

By now you should have a good understanding of Fourier Transforms and filtering. If not stick your hand up and get help!

Open up the Equi.exe program. This program is designed to operate as a graphic equaliser. On sound systems and PC's a graphic equaliser is designed to enhance or suppress certain frequencies that make up the sound signal. This is usual split into two broad categories, tribble (high frequencies) and bass (low frequencies).

Connect your phone or laptop to the Audio Input of the myDAQ using the audio cable provided and your headphones to the Audio Output of the myDAQ.

Play a source of music and investigate what effects the different sliders have on the output of the song you can hear through the headphones as well as the plot of the power spectrum plotted.

Task Describe how you think the equaliser works.

4.3 Report Write-up

For this prac, you are expected to hand in a lab report detailing the investigations that you carried out during the afternoon. There is no generic structure to this report and you should include plots and data for each section that allows you to explain what you learned from each section. Think of this report as an investigatory article describing to the reader how Fourier transforms and filtering works over a range of inputs and applications. The report must be scientific in nature and must include all answers to the tasks posed in this prac manual. If you are unsure of what is required of you, simply ask!