University of Glasgow | School of Engineering

Communication Systems 3: Laboratory 2
Spectrum Analysis of Waveforms

The objective of this experiment is to gain experience in the use of an oscilloscope and spectrum analyser to investigate a range of waveforms in both the time and frequency domain, including amplitude and frequency modulated waveforms.

You must record your observations, measurements and working as you go along during the timetabled laboratory session individually. You will use these observations to complete a short lab to determine attendance and award of grade for the lab assessment. Your report must be **completed within 1 week** of your lab session.

Equipment

The test and measurement equipment used in this experiment are:

- Keysight DSOX1202G or DSO-X1102G Digital Oscilloscope
- BNC Lead
- you will need a USB memory stick to save oscilloscope traces to your report

Using the oscilloscope as a spectrum analyser

Switch on the oscilloscope and the function generator and connect the output of the function generator to Channel 1 of the oscilloscope. Set the signal generator to output a sinusoidal wave of 1kHz and 200mV peak-to-peak. Press **Autoscale** on the oscilloscope to get a clear time domain display of the signal.

Now use the oscilloscope to examine waveforms in the frequency domain. The oscilloscope has a Fast Fourier Transform (FFT) capability which is the numerical (sampling) equivalent of taking a Fourier Transform to obtain the spectrum. The FFT works by sampling time domain data, storing it in memory and then applying the FFT routine before displaying the resulting frequency domain data on the screen. In the lectures you will be given some background to the FFT process and some differences from the standard Fourier transform which may arise. To use the FFT capability of the oscilloscope:

- Adjust the **Timebase** of the oscilloscope so that there are 10–20 periods of the waveform displayed.
- Press the **Math** key in the **Analog** section of the oscilloscope front panel. A range of softkeys appear at the bottom of the screen.

- Ensure that the **FFT** function is enabled (default). Select **More FFT** to set suitable values to display the relevant portion of the spectrum: for example, **Window**=Hanning, **Span**=10kHz, **Center**=5kHz, **Scale**=5dB, **Offset**=−40dBV.

- Press **1** in the **Analog** section until the time domain trace disappears.

The vertical axis of the FFT on the oscilloscope is displayed using a logarithmic axis, in dBV, where dBV = $20\log_{10} V_{rms}$

The dBV scale has a reference value of $1V_{rms}$=0dBV. Note that as this is a logarithmic scale you can get the ratio between two voltage signals from the difference in dBV values, i.e.

$$\frac{v_2}{v_1} = 10^{\Delta_{dB}/20}$$

What value for Δ_{dB} corresponds to a voltage ratio $\frac{v_2}{v_1} = \frac{1}{\sqrt{2}}$ (i.e. a power ratio of $\frac{1}{2}$)?

Now use the cursor facility on the oscilloscope to make some measurements on the FFT of this signal. First, measure the frequency of the peak. Press the **Cursor** button in the **Measure** section of the front panel. Ensure the **Source** softkey has **Math** highlighted and you are taking an **X** measurement. Use the knob in the **Measure** section of the front panel to place the cursor at the position of the largest peak and read off the frequency. Compare it with the frequency displayed on the signal generator. Occasionally, you may find that these values substantially disagree due to a phenomenon called aliasing which can occur in the FFT algorithm when the time-domain display contains more periods of the waveform than half the number of sampling points. Adjusting the timebase knob should fix this problem if it occurs.

Next measure the peak height. Select the softkey **Y** and use the knob in the **measurement** section of the front panel to place the cursor at the position of the largest peak and read off the amplitude in dBV. Check that this is in agreement with the peak-to-peak voltage set on the signal generator.

Using your code from lab 1, determine what you expect to see on the scope for the FFT of the signal you have generated. Do they agree? Record the result to the from the scope onto USB stick as CSV, to plot in Python/Mathematica or other software, for use in your lab report.

Square wave

Now change the sinusoidal waveform to a square wave by pressing the button with the square wave symbol on the signal generator. Observe the square wave signal in the time domain on Channel 1 of the oscilloscope. What is the measured amplitude of the square wave?

Next use the FFT facility to examine the spectrum of this waveform. Using a USB memory stick, save the data on the oscilloscope display as CSV. What are the frequencies and dBV amplitude values of the first few peaks? Calculate the ratio of the peak amplitude of the fundamental frequency to each of the peak amplitudes of the harmonics.

Changing the duty cycle of the square wave

In the time domain, watch what happens when you change the duty cycle of the square wave by pressing SHIFT %DUTY from the default of 50% to 25%.

In the frequency domain (FFT), what happens when the duty cycle is changed? Using a USB memory stick, save the data on the oscilloscope display as CSV. Write down the frequencies and dBV values of the first few harmonic components. Which harmonic components are removed/suppressed?

Using a USB memory stick, save the oscilloscope display as a CSV for both cases. Write down the frequencies and dBV amplitudes of the various harmonic components. Calculate the ratio of the peak amplitude of the fundamental frequency to the peak amplitudes of the harmonics. Now use Python/Mathematica to calculate the FFT of the square wave. Are these measured values in agreement with your calculation?

Spectrum of an Amplitude Modulated Signal

In this part of the experiment, a sinusoidal signal is obtained from the function generator and is amplitude modulated (AM) by another sinusoidal signal at a different (usually lower) frequency. The oscilloscope is used to examine the resulting signals in both the time and frequency domains.

Revert to a sinusoidal waveform as the output of the function generator with 1kHz frequency and 200mV peak-to-peak. Generate an amplitude modulated (AM) signal by pressing **shift AM**. Set the modulation frequency to 200Hz by pressing **shift Freq** and then entering the frequency. Check that the modulation depth of the AM signal is 100% by pressing **shift Level**. Check the trace on the oscilloscope.

Now select the FFT function of the oscilloscope to display the spectrum of the AM signal. You should see three peaks (the centre peak is the carrier frequency and is bounded by the upper and lower sidebands). Using a USB memory stick, save the data on the oscilloscope display as CSV. Measure and note the frequency and amplitude of the carrier and the sidebands.

Change the carrier frequency to 1.2kHz by pressing **Freq** and changing the setting. What happens to the spectral components of the FFT of the AM signal? Reset the carrier frequency to 1kHz. Change the modulation frequency to 100Hz, 300Hz and 500Hz by pressing **shift Freq** and changing the setting. What happens to the spectral components in each case? What can you conclude about the influence of the modulation and carrier frequencies on the AM spectrum?

Finally change the modulation depth by pressing **shift Level** and set the modulation depth to 10, 25, 50, 75, and 100%. For each of these modulation depths, note the ratio of of amplitude of the sidebands to the amplitude of the carrier frequency. Remember that you can get the ratio between two voltage signals from the difference in dBV values. Inspect your measured values, and write down what you conclude for the dependence of the relative amplitude of the sidebands to the carrier on the modulation depth?

Spectrum of a Frequency Modulated Signal

In this part of the experiment, a sinusoidal signal is obtained from the function generator and is then frequency modulated (FM) by another sinusoidal signal at a different (usually lower) frequency. The oscilloscope is used to examine the resulting signals in both the time and frequency domains.

Revert the signal generator to output a sinusiodal wave at 1kHz frequency, 200mV peak-topeak. Generate a frequency modulated (FM) signal by pressing **shift FM**. Set the modulation frequency to 200Hz by pressing **shift Freq** and entering the setting. Set the peak frequency deviation to 200Hz by pressing **shift Level** and entering the setting. Check the trace on the oscilloscope.

Now select the FFT function of the oscilloscope to display the spectrum of the FM signal. You should see a series of peaks (the centre peak is the carrier frequency and is bounded by upper and lower sideband peaks). Using a USB memory stick, save the data on the oscilloscope display as CSV. Measure and note the frequency and amplitude of the carrier and the significant sidebands.

Change the carrier frequency to 1.2kHz by pressing **Freq** and changing the setting. What happens to the spectral components of the FFT of the FM signal?

Reset the carrier frequency to 1kHz. Change <u>both</u> the modulation frequency (by pressing **shift Freq**) and the peak frequency deviation (**shift Level**) to 100Hz. Now change <u>both</u> the modulation frequency and the peak frequency deviation to 300Hz. What happens to the spectral components in each case?

Reset the carrier frequency to 1kHz and the modulation frequency to 200Hz. Now keeping the modulation frequency constant, change the peak frequency deviation of the signal to 100Hz, 200Hz, 300Hz and 500Hz. In each case, observe and describe the spectrum and determine the bandwidth of the signal by considering the harmonic components which are >1% of the overall 200mV peak-to-peak (hint: What is 1% in dB?). To identify this level you should consider your initial measurement of a sinusoidal wave and the expression (above) for the ratio between two voltage signals.

Now adjust the peak frequency deviation until the carrier peak (centre peak) disappears and note the value of this peak frequency deviation.

Now set the modulation frequency to 10Hz and set the peak frequency deviation of the signal in turn to 100Hz, 200Hz, 300Hz and 500Hz. In each case, determine the bandwidth of the signal by considering the harmonic components which are >1% (consider what this is in dB) of the overall 200mV peak-to-peak.

Appendix: Checking the settings of the function generator and oscilloscope

oscilloscope impedance The oscilloscope setting should be for a high input impedance (1MΩ). Check that it is not been left at 50Ω.

function generator impedance should also be set for a high output impedance. This can be checked/set by modifying an element of the SYSTEM menu on the signal generator:

- Switch on the menu screen by pressing **Shift** and **Menu** buttons on the signal generator. The display should read A:MOD MENU. Press the right arrow > key until the display reads D:SYS MENU
- Press the down arrow key until the display shows 50 OHM or HIGH Z
- If required, press the right arrow key to toggle the display to show HIGH Z, then press the **ENTER** key

high resolution It is recommended to set the oscilloscope to high resolution. Press the **Acquire** button on the oscilloscope and the left soft-key can be changed from normal to high resolution.

fft The fft is calculated from the displayed trace on the oscilloscope rather than the input waveform. Therefore if the displayed trace is truncated, there are error artifacts in the fft trace. Check and adjust the oscilloscope gain so that the time-domain trace is entirely displayed on the screen. Additionally ensure that there are not too many periods of the waveform displayed such that aliasing can occur and frequency measurements are incorrect. Adjusting the timebase will fix this, if necessary.