ADC, FFT, and Noise

Introduction
In this lab we will analyze the Fourier components of a number of repetitive waveforms and compare them to expectations; we will build a noise generator, examine its frequency dependence and measure its amplitude spectrum.

Analog to digital conversion and the FFT
Set your pulser to generate a 10kHz sine wave with 1V amplitude and display it on Ch1. of your Digital Phosphor Oscilloscope (DPO) choosing the horizontal scale so that at least 10 full waves are visible on the screen. From the “Acquire” menu select “Average” from the choices for “Acquisition Mode”. From the “Math” menu select “FFT” with input “Ch1”, vertical scale “Linear RMS” and window “Blackman-Harris”. Make a note of the “Sample Rate” indicated on the lower right of the screen. At this point it might be useful to consult the reference booklet “TDS3FFT FFT Application Module”.

Use the horizontal zoom to expand your Fourier spectrum so that the parts of the frequency spectrum of interest are clearly displayed. Using the vertical “Cursors”:
1. Measure the frequency of the most prominent line in the spectrum. What is it? Are there any other frequencies visible, in particular, multiples of the fundamental? For more sensitivity you may wish to switch the vertical scale to dBV RMS. Print a copy of the screen and paste it into your lab notebook.
2. With the vertical scale on “dBV RMS” measure the width of the primary frequency component (±3dB).
3. Change your display of Ch.1 so that 10 times more waves are displayed on the DPO. Re-measure the width of the primary frequency peak. Compare its value to your previous measurement. Is there a difference? Speculate on the reason for any difference in widths.

Leaving the frequency at 10 kHz, change the waveform from sine to sawtooth. Make an informed choice for the sampling frequency. Using the cursors measure the frequencies and amplitudes of the first six peaks in the frequency spectrum. Make a comparison of the relative sizes of the peaks with the Fourier spectrum for a sawtooth waveform given in Chapter 4 of your text.

Repeat the exercise above for a square wave.

Because there is no anti-aliasing filter in front of the ADC, some components of the triangle and square are bound to be above the Nyquist frequency (component frequencies greater than half the sample rate) and lead to aliasing. But if the fundamental frequency is low, the components should be small. On the basis of this, justify your choice of the sampling frequency.

Noise
A good way to build a noise generator is to use a zener diode, reverse biased, and a high-gain amplifier. Figure 1 below shows how.
The strength and quality of the noise depends upon the diode and upon the current limiting resistor $R_1$. As a rule, high-voltage zeners work best. Because the power supply is 15 volts, a zener with breakdown voltage between 10 and 13 volts is recommended.

Different zeners behave differently as noise sources. Even if they come from the same production lot they behave differently. The noise output from each zener is maximized by a different value of $R_1$. Some zeners don’t make much noise for any value of $R_1$. Some zeners make a lot of noise but only for a rather specific value of $R_1$. Other zeners make a lot of noise for a wide range of values of $R_1$. In the end, if you want to make a noise source, buy ten high-voltage zeners and select the best one.

For this lab you will use a 12-volt zener, type 1N4740. The optimum value of $R_1$ is in the range 30 to 50 kΩ. Try a couple of resistors in this range selecting the one that gives the most noise. The output of this circuit is limited by the frequency response of the opamp. For instance the TL084 has a moderate slew rate of 12V/µs which effectively limits its bandwidth to 1 or 2 MHz. Keep this in mind when you make your measurements.

Build the circuit and display the resulting noise spectrum on your DPO. Place a copy in your notebook.

**The Color of Noise**

White noise has equal power per unit frequency. That is, the spectral density measured in watts per Hertz is the same for all frequencies. The zener diode noise source makes noise that is white over a very broad frequency range.

1. Show that noise cannot be absolutely white by showing that if the spectral density is constant over an infinite frequency range then the total power is infinite.
2. Examine your noise FFT spectrum using the FFT features of your oscilloscope. What is the highest frequency that does not violate the Nyquist criterion?
3. Is your noise spectrum consistent with white noise? If not, at what frequency does it start to deviate from it?
(4) Observe your noise spectrum at the highest frequencies carefully and try to characterize its dependence on the frequency.

(5) Examples of white noise in electronic system include Johnson noise, the thermal noise generated by random movements of electrons in a resistor and shot noise which is noise generated by moving charges in conductors. In addition to white noise, electronic systems also exhibit pink noise which has a 1/f frequency dependence. Does your measured spectrum show the presence white noise or pink noise? Justify your conclusions. Print out a display of your Fourier noise spectrum using the dBV scale and paste it in your notebook.

**Noise Density Function**

Looking at your DPO noise distribution, it is clear that the noise spectrum is quite chaotic with positive and negative pulses of variable size. We would like to measure the distribution of this noise and compare it to predictions for Johnson noise and extract an effective noise temperature realizing full well that this is not Johnson noise and the temperature that we extract will depend on the details of the Zener diode and will have nothing to do with the kelvin temperature. The rms distribution of Johnson noise is given by the following expression:

\[
V_{\text{noise}}(\text{rms}) = \left[4kTRB\right]^{1/2}
\]

where \(T\) is the temperature in kelvins, \(R\) is the resistance in ohms, \(B\) is the bandwidth of the measurement in Hz and \(k = 1.38 \times 10^{-23} \text{ J K}^{-1}\), the Boltzmann constant. The probability distribution of Johnson noise is Gaussian:

\[
\frac{dP}{dV} = \frac{1}{V_n \sqrt{2\pi}} e^{\frac{V^2}{2V_n^2}}
\]

where \(V_n\) is the Johnson noise spectrum in (1).

We wish to measure the noise temperature at the input of our amplifier. What is the gain of our amplifier? Other quantities that we will need include, \(R\) and \(B\). What are the values that we should assign these variables?

**Making the measurement**

Make sure that the signal to your DPO is AC coupled. What is the Nyquist limit for this measurement? Go to your web browser and enter the IP address of your DPO. Select “data” with the source “Ch1” and “Spreadsheet” format. Pushing “Get” will transfer 10,000 data points of your spectrum to your PC. Save this file in your area on “C” disk. Open Excel and enter the data from your file into the spreadsheet. It is “comma” delimited and if all goes well you should have two columns of data with 10k points each. At this point it is easier to Copy the 2nd column and Paste it into Kaleidagraph. Make a histogram of the data and place a copy into your lab notebook. Does it look Gaussian? Using the “Statistics” option compute the Standard Deviation of your distribution and use this value as your noise voltage to extract an effective noise.
voltage. Show your work. Extract an effective temperature (in kelvins) for your device. How much lower would the rms noise be if you were really trying to measure Johnson noise?