EXTRACTION OF SIGNALS FROM NOISE

Equipment

Zener diode
Operational amplifiers
Lock-in amplifier

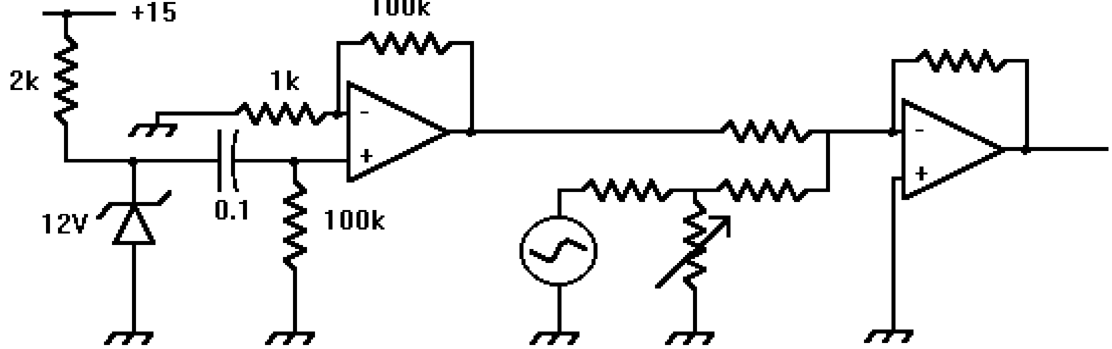
Overview

As you will learn in your reading of the textbook, all electrical circuits contain sources of noise. All real signals also contain unrelated “noise” at some level. The first problem that must be solved in signal processing is to assure that the input system does not increase the natural noise of the signal source. For very small signals this requires low noise preamplifiers, typically differential amplifiers with FET inputs. After minimizing the intrinsic noise of the signal source and detection system, it is still possible to enhance the desired signal relative to undesired “noise” that accompanies it. In this experiment you will build a noise generator to provide a relatively large noise voltage. You will then build an adder to add the noise to a sine wave from a signal generator. You will then test two different methods for enhancing the signal relative to the noise. The first is by computing the spectral density and the second is by using a synchronous detector or “lock-in amplifier”.

Procedure

I. Make a noise generator

FIGURE 1



A Zener diode is constructed so that it breaks down in a nondestructive manner under a sufficiently large reverse bias. Under these conditions the voltage across the diode is nearly independent of the current so that its most common use is as a constant voltage source. However, there is also a relatively large amount of random noise on the voltage, particularly for the high voltage devices. The left hand portion of the circuit of figure 1 uses an op amp to amplify this noise. (What is the purpose of the 0.1 µF capacitor?) Build this portion of the circuit and examine its output on the oscilloscope. We would like it to be white noise (actually “pink noise” or noise with a high frequency limit). What, if any, characteristics do you observe? For example is there a 60 Hz or other obvious periodic component? If so you may wish to change your circuit so as to eliminate it.

II. Measure the amplitude spectrum of the noise

Connect the output of the first amplifier to channel 0 of the A/D interface used in Experiment 1. A TestPoint program called “noise.tst” has been stored for you to use to examine the signals in this lab. It will automatically take the Fourier transform of the signal on channel “0”. The algorithm used is called the Fast Fourier Transform (FFT). It requires many fewer computations than a full Discrete Fourier Transform (DFT) but requires that the total number of data points examined be a power of 2 such as 512, 1024, 2048, etc. Examine the “action list” for the start button to determine the sampling rate, number of samples and other parameters of the data sampling and analysis.

Now run the program and examine the amplitude spectrum (People usually use the power spectrum, which is the absolute square of the Fourier transform and is proportional to the signal power per unit frequency interval. Unfortunately, squaring the amplitude reduces the relative height of secondary peaks and makes them harder to see.) Are there any significant peaks? If so, do they correspond to what you observed on the scope? (The scope presents the signal in the time domain, the FFT represents it in the frequency domain. The time domain graph in TestPoint is displayed with too little time resolution to show what you see on the scope.) Does the spectrum have any gradual frequency dependence or is it "white" (constant) over the range measured? Explain whether this is consistent with the circuit that you have built.

Notice that the x and y axes of the plots can be adjusted to display only the desired range of values. This is done in “Edit” mode. Double click on the graph of interest, then follow the menus which appear.

Put a low pass RC filter in the circuit with a time constant long enough to yield a measurable drop off in the spectrum. Notice that because of aliasing, a 1 kHz sampling rate will cause the noise spectrum of each 500 Hz interval(0-500,500-1000,1000-1500,etc.) to be superimposed on 0-500 Hz. Thus, a filter with corner frequency above 500 Hz will only cause a relatively uniform drop in the noise spectrum by eliminating the higher 500Hz intervals. It takes a low corner frequency like 100Hz to make an easily observable result. Record another data series and examine its FFT for consistency with the RC filter.

III. Add a sine wave

Now, if you have not already done so, build the right hand portion of the circuit in Figure 1. The noise signal should have been sufficiently large so that no additional gain is needed. Therefore, the adder stage can be made with a gain of 1. After construction, test that the noise signal appears unchanged on the output of the second amplifier.

Add a sine wave from the signal generator as shown in Figure 1, using a frequency between 100 and 160 Hz. View the output of your amplifier on the scope and adjust the generator output so that it is several times the amplitude of the noise. This will assure that you will notice the new peak in the spectrum at the frequency of the sine wave. Notice, however, that the sine wave from the generator is very pure (the FFT is nearly a delta function) so that the peak will consist of only one or a few points. Therefore, if the signal generator frequency is not exactly on one of the frequencies computed by the FFT it will not display its true Fourier amplitude. Test this by changing the signal generator frequency a small amount and examining the FFT a few times. What could be done to improve the resolution of the FFT? Try it and describe the results.

Now adjust the signal generator so that, on the scope trace, the sine wave is just barely visible in the noise (that is a signal/noise ratio of about 1/1). Use this same level for the measurements with FFT and lockin amplifier which follow.

Now measure the amplitude spectrum again and estimate the ratio of the peak amplitude from the signal generator to the noise amplitude at adjacent frequencies. Is it greater than 1/1? Explain and measure the difference if you shorten your record length from 4096 to 1024 points.

IV. Measure the signal with the lock-in amplifier

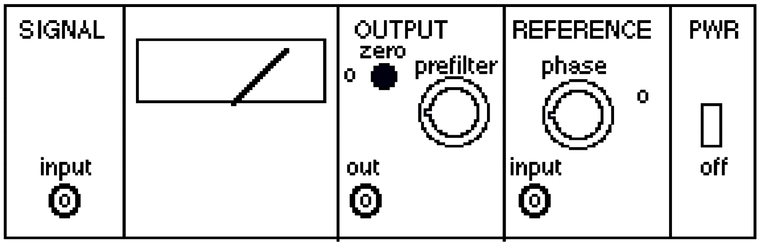


FIGURE 2

The lock-in amplifier provides the best possible enhancement of the signal to noise ratio but is applicable only when the frequency of the desired signal is, or can be, synchronized with the internal switching frequency of the lock-in. The lock-in will be discussed in more detail in a lecture. Since we are deriving our signal directly from a signal generator, we can use the output from the same generator for the switching frequency.

Connect the same noisy signal used in part III to the lock-in amplifier signal input. This lock-in does not have its own internal oscillator so that you must connect a signal from the same generator that you are using for the signal sinusoid. Any wave form will work as long as it is large enough and relatively free of noise. A fixed amplitude, 5 Volt square or sine wave will be ideal. Connect it to the reference input.

Adjust the phase of the lock in so as to yield a maximum signal. This can be accomplished with greatest precision by pushing the button that will shift the phase by exactly 90 degrees and adjusting the continuous phase adjust to null the lock-in output. Then switch back by 90 degrees to obtain the maximum signal.

Estimate the signal to noise ratio of the lock-in output, for the weakest signal measured above, with "pre-filter" time constants of .01, .1, 1 and 10 seconds. With the 10 second time constant, decrease the output from the signal generator to find the smallest signal voltage that can be detected by the lock-in in the presence of the noise. Finish your discussion by making a quantitative comparison between the minimum detectable signal on the scope, in the Fourier spectrum, and using the lock-in.

V. Experiments with Fourier transforms. See the accompanying Test Point note.