Recovery of signal in noise via synchronous detection

PRE-LAB:

Most of you will be using a Tektronix 2022B oscilloscope and type 502 pulse generator. Read first the pulse generator manual, which can be found on the /Electronics page. The 502 is a bit hard to use, so you will need to fully understand it before coming to lab. Consider visiting the lab sometime before class. Also look at the 2022B scope manual, especially pages 41-42. Finally, be sure to read the file "Boxcar averaging."

LAB:

Most experiments in physics involve signals that are buried in noise or obscured by systematic error or interference. As you might guess, some clue as to the form of the signal – perhaps merely its arrival time – can be used to extract it from the noise if it is repetitive. If you can arrange for the signal to be repetitive at exactly some rate, then you can examine the noise+signal for something that has exactly that repetition rate. There are often situations where you can design the experiment in this way: inject some trigger or stimulus into a system and look for its low-level effects on the output. Examples abound in condensed matter physics, high energy physics, bio-physics, and radar. Perhaps the signal is buried in the noise, or the goal is high statistical precision in the presence of noise or systematic error, or both.

What follows is a rough guide to some experiments you can do with this technique, sometimes called "*boxcar averaging*" in condensed matter physics or "*gated integrator*" in high energy or nuclear physics and radar. Record your findings in your lab book.

1. Your noise source for most of these experiments will be the noise generated in the preamplifier within the scope. Check this noise level on your 2022B scope. With the time base set to about 25 microsec per division, increase the gain to the most sensitive setting. You should see noise. Measure this rms noise using the MEASURE function, described in the manual. This measures the entire waveform displayed on the screen. You may want to measure both the RMS voltage and the peak-to-peak voltage (Pk-Pk). Your signal source for these experiments will be a low level repetitive pulse. In order to correctly measure pulses, you need to match impedances: use 50 ohm coaxial cable [RG 58] terminated in 50 ohm resistive load at the scope (you will study transmission lines and pulse propagation later in this course in some detail). So make sure your scope input has a 50 ohm resistive termination [2022B scopes do not have an internal 50 ohm input impedance option].

2. Begin by measuring a pulse from the 502 pulse generator. First adjust the controls on the 502 to give a positive pulse, zero volt baseline, of duration about 20 microseconds and low pulse repetition rate (1 KHz or even lower). Connect the front panel 50 ohm output of the 502 to the scope and then trigger on the pulse. Start by using the scope in the auto mode, then switch to normal and adjust the sensitivity and trigger level to trigger on rising part of the leading edge of the pulse. Adjust the 502 pulse output to one volt or less. In order to reduce the output further, pull out the switch in the lower center "BACK TERM".

3. Reduce the pulse amplitude to millivolt level by inserting the 1000:1 resistive divider in series: 50 ohm pulse generator output fed into the 10,000 ohm resistor shunted by a 10 ohm resistor. Your pulse on the scope now is likely barely visible.

4. Here is where you use the repetition averaging "boxcar" technique. Trigger the scope externally from the trigger output of your pulse generator. You should see the pulse near the middle of the screen. Using the most sensitive setting on your scope input, adjust the output of the pulse generator so you can barely see the pulse on the scope as a slight positive offset of the noise.

5. Now average together *n* scans by selecting the ACQUIRE function. First re-measure the rms noise in the simple sample mode:

ACQUIRE. SAMPLE Measure the signal-to-noise ratio S/N:

Use the MEASURE function to measure the entire displayed waveform. To measure the noise, make sure you either unplug the 502 output or move the pulse off the screen with the horizontal control. Measure the signal using the *Mean* function in MEASURE, making sure to have the entire pulse width filling the screen (by changing the time resolution), then do this for the zero signal case (by unplugging the 503 output or moving the entire pulse off screen), and subtract the two means. [Experiment with this at higher pulse amplitudes to make sure it is working correctly.]

Then average $n = 4$, etc times.

AVERAGES [4-128] AVERAGE Measure S/N for each value of *n*.
i.e. after selecting the number of averages via AVERAGES, start averaging:
AVERAGE. Then repeat the measurements of RMS noise (with no pulse) and the differences of the *means*.

6. Note that for low *n* the S/N improves as *n* increases. What is your finding: how does the S/N ratio improve with *n*?

7. However, note that for *n* above some value the S/N appears not appear to improve. This is due to another kind of "noise" that is not stochastic and thus does not average down with *n*: digitization noise. Read the scope manual; the input

preamp is followed by an analog-to-digital converter of limited precision. Below some average rms noise, one or two bits covers the full range of the averaged noise.

8. Repeat this at a lower level where you cannot visually detect the pulse in single scan mode. The inner knob on the 502 is a bit touchy at the bottom of its range; remember, you can reduce the pulse height by a factor of ~2 by pulling out the "BACK TERM" control on the front panel of the 502. If an external wideband pre-amplifier is available [we will give you an update in class], use it to avoid this problem. Hook the preamp ahead of the scope input; it will amplify the signal from the 502 and at the same time will be the dominant source of noise. *Explain why.* Thus your scope will have many bits per noise + signal, and the "dynamic range" will be larger – so you can explore the S/N improvement by boxcar averaging over a wider range of *n*.

9. Think about what you might do to further increase the S/N beyond boxcar averaging. Perhaps you care only about the amplitude of the pulse rather than its detailed shape. Or maybe you *know* its expected shape. Perhaps you only know its spectrum. What might the advantage or disadvantage be in each case? How would you implement? Record some ideas. [You will lean much more about this later in the course.]