Introduction to the oscilloscope and digital data acquisition: Part 2

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v2.1

1 Multiple traces

Last week you captured and displayed a single electronic signal using Channel 1 of the oscilloscope. You probably noticed that there was a Channel 2, and you may even have concluded that you could capture and display two different signals at once. This is, in fact, possible, and it is a feature that is widely used in research. You will use it in this lab. The feature is so important that more expensive 'scopes often have more channels, the most common number being four, and the four-channel version of this scope, the TDS3014, is one of the most popular 'scopes used in research labs.

1.1 Multiple independent signals

Exercise 1: Use the RIGOL function generator to create two signals, one at 1.000 kHz and another at 1.001 kHz. (You can toggle between the two channels by using the button labelled $\frac{\text{CH1}}{\text{CH2}}$.) Set both to the same amplitude, say 1.0 Volts peak-to-peak, and feed them into the two separate channels on the TDS3012 oscilloscope. Trigger off the 1.000 kHz signal, observe the resulting traces on the screen, and describe what you see in your lab notebook. Now set the second signal's frequency to 0.999 kHz. Can you explain what happens?

1.2 Reference Traces

On the front panel of the oscilloscope, beneath the yellow and blue Channel 1 and Channel 2 buttons, are a red button labelled Math and a white button labeled Ref. These behave like separate channels, except that they display the results of internal calculations or memory, as opposed to external signals.

The Reference channel saves a copy of a trace as it appears on the screen at a particular time. If you press the white Ref button you will see a series of options come up on the screen. They are largely self-explanatory, so I'll let you explore them on your own terms.

Exercise 2: Save a snapshot of Channel 2 as a reference trace. After the "live" Channel 2 has drifted away from the reference take a screenshot, and tape it into your lab notebook.

1.3 Math

The Math channel allows you to add, subtract, multiply, or divide one channel by another.

Exercise 3: Set the signal going into Channel 1 to a frequency of 1.0 kHz and an amplitude of 1.0 Volt peak-to-peak. Set the Channel 2 signal to 100 kHz, with a similar amplitude to Channel 1. Now press the Math button, and follow the onscreen menus to add Channels 1 and 2 together. Try subtraction, multiplication, and division as well. Can you explain the results in each case? Print out a screenshot for multiplication.

Math also allows you to calculate the Fourier transform of a signal. To do this, select the soft menu labeled FFT, which stands for Fast Fourier Transform, a technique discovered by Cooley and Tukey in the 1960s for efficiently calculating the Fourier components of a signal using a digital computer. This is a fairly deep subject that is mostly beyond the scope of this lab, but I want you to be aware of this option.

Exercise 4: Take the FFT of Channel 2 using the Math channel. You should see a single peak corresponding to the one frequency at which Channel 2 is oscillating. This peak may be very near the left edge of the screen, so you may have to zoom in on that part of the signal to see it clearly. Cycle through the different windowing options to see the effect on the signal. Take a screenshot of the peak, using whatever window you like best, and tape it into your lab notebook. We will talk more about windowing later in the term.

Exercise 5: Go back to the arithmetic options in Math mode, and re-generate your product signal, Channel 1 times Channel 2. Save this as a reference trace, and take its Fourier transform. Zoom in on the relevant peaks, take a screenshot, and add it to your lab notebook. Does the signal agree with your expectations?

2 XY Mode

You can display one voltage as a function of another, rather than two voltages versus time. This is called "XY Mode," and it is available on almost all oscilloscopes, even the old analog ones. In this mode both the vertical and horizontal positions of the oscilloscope spot are controlled by the input voltages, rather than the vertical being controlled by an input voltage and the horizontal being controlled by a timer, as is the case in ordinary operation. XY mode can be immensely useful in comparing one signal to another, as you will see below.

Exercise 6:

1. Clear the Math channel by pressing the red Math button, and then pressing the "Off" button in the Vertical control group.

2. Clear any reference channels the same way.

3. Check that the Channel 1 signal is still at 1.0 V and 1.000 kHz, and reset the Channel 2 signal to 1.0 V and 1.001 kHz.

4. Press the "Display" button, near the top of the control panel, and choose "XY Display" from the soft menus at the bottom of the screen. This will bring up a series of options along the right side of the screen. Choose "Triggered XY," and verify that Channel 1 is assigned to X and Channel 2 to Y.

5. Can you explain what you see on the screen? If so, write up a brief explanation in your lab notebook.

If the result of the previous exercise puzzled you the next one will help, and you might learn something new about the function generator.

Exercise 7:

1. Set both channels of the function generator to 1.000 kHz and 1.0 V amplitude.

2. Turn XY mode off (we'll come back to it soon), and display Channels 1 and 2 versus time, triggering off Channel 1.

3. The buttons just below the function generator's screen do more than just set the amplitude and frequency. One, labelled "Phase," allows you to adjust the relative phase between the two channels. Push this button, and check that the phase is 0.0° for both channels. If it's not, set it to 0.0°. This does *not* synchronize the channels to each other. It just sets a separate baseline for each. We will synchronize the two channels in the next step.

4. Find the button labelled "AligPha." This is short for "Align Phase," and it will synchronize the phase between Channels 1 and 2. Push it, and you should see the two sine waves line up on the screen.

5. Now adjust the phase of Channel 2 using the "Phase" button on the RIGOL function generator. You can use the dial to adjust the phase, or you can type in a value on the function generator's numerical keypad. If you've set your triggering right, the blue Channel 2 trace on the oscilloscope screen should shift relative to the stationary, yellow Channel 1 trace.

6. Try switching back and forth between XY and standard (YT) mode for different phase shifts. Can you see how the phase shift determines the shape of the curve in XY mode?

7. Print out screenshots in both XY and standard (YT) mode for relative phase shifts of 0.0°, 45°, 90°, 135°, and 180°, and tape them in your lab notebook. Explain your results.

The above exercise illustrates how XY mode can be used as a sensitive detector of relative phase between two signals of the same frequency, and this is a trick that is widely used in physics research labs. The stability of this figure (ellipse, circle, line, etc.) also tells you how closely-matched the two channels are in frequency, as you saw in the previous exercise where the frequency of the two channels differed by only a small amount.

This same idea can be used to check two signals to see if one is a harmonic of the other, and if so what their relative phase difference is.

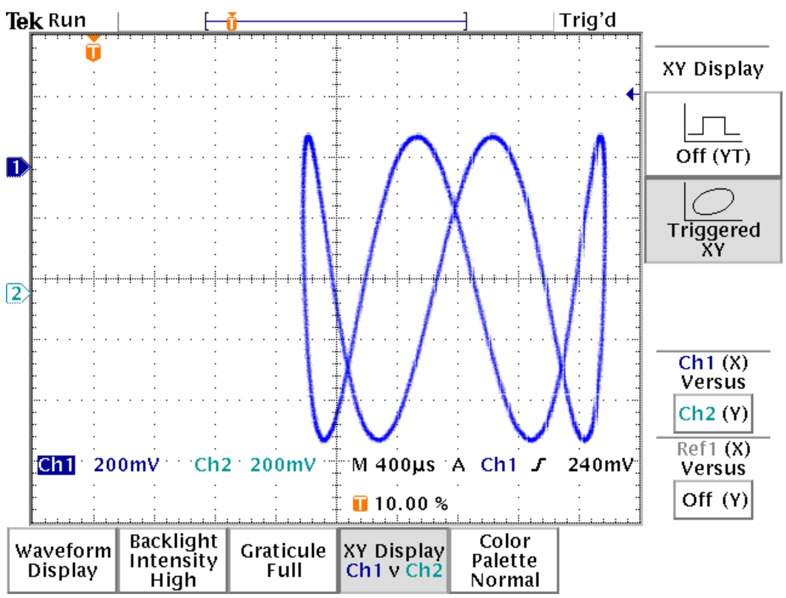

Figure 1: XY mode, with a Lissajous figure.

Exercise 8: Change the frequency of the Channel 2 signal to 4 kHz. In XY mode you should see something similar to Figure 1. This is called a *Lissajous figure*, named after the 19th-century French mathematician who investigated and popularized them. He didn't have oscilloscopes to generate these curves and had to use beams of light and tuning forks. (Does this make him an experimentalist, or an artist?) Change the frequency of Channel 2 by a few hertz above and below 4 kHz, say up to 4.001 kHz and down to 3.998 kHz, for example, and watch what happens as the phase between the two channels drifts. Print out a screenshot, and put it in your lab notebook.

Exercise 9: Set the frequencies of your two channels to 2.000 kHz and 5.000kHz, and align the phase. In XY mode, look at the Lissajous figure for different timebases, ranging from as high as 100 ms down to about 1.0 μs. Can you explain what you see?

3 Acquisition modes

Acquisition mode refers to how the data are collected before being displayed on the screen. The most basic mode is *sample*, which is just what it sounds like, a direct, one-to-one correspondence between the voltage at the input and the trace on the screen. Other modes are *peak-detect, envelope*, and *average.*

Exercise 10:

1. Switch the function generator's output from Sine to Noise on Channel 1.

2. Set the amplitude of this noise to 100 mV, and then set the timebase of the scope to 4 ms per division.

3. Under the set of controls labelled "Acquire" on the oscilloscope (on the far right-hand side of the control panel), press the MENU button. This will pull up a set of soft menus on the screen. Select the "Mode" option at the bottom of the screen. This should pull up four options along the right side of the screen: Sample, Peak Detect, Envelope, and Average.

4. Choose "Sample" if it's not already selected, and you should see a signal that appears to be random noise. Print out a screenshot, and tape it into your lab notebook.

5. Select "Average," and use the main dial to change the number of averages to 2, then 4, 8, etc. Note what happens to your signal for each number of averages.

6. Run the number of averages up to its maximum, let the signal settle, then take a screenshot, and put it in your lab notebook. Compare this with the unaveraged trace you took earlier.

7. Change the vertical scale on the oscilloscope to 50.0 mV and the timebase to 200ns. Let the trace settle, and you should see some residual structure that *does not average away.* This will probably be the case if you trigger off either Channel 1 or Channel 2. If the noise were truly random, averaging would remove it and leave a flat trace, or at least one that is nearly flat and only fluctuating a little. The persistent trace left over after averaging here shows that the function generator is not actually putting out random noise. It is only putting out a signal that

looks random, but whose structure can be revealed with the appropriate test, in this case averaging. A signal that appears random but that actually has underlying order is called *pseudorandom*, and we will revisit this concept later in the term.

4 Saving data

The TDS3012B oscilloscopes we use in this lab have built-in floppy drives that you can use for storing data. Newer scopes usually have a USB port in place of this disk drive, but otherwise they have the same features and performance as our scopes. We won't be using floppy or USB drives in this lab, since networking is both easier and faster. I'm just pointing this out so you will be aware of it. The ability to save files to some sort of drive (USB or floppy) is common to most modern scopes.

As mentioned above, the TDS3012B oscilloscopes in this lab are networked so that they can share a printer. In fact, each one also runs a web server that will allow you to access it remotely and download the data from the screen in text format. You have already printed screenshots of your oscilloscope traces. Now you will learn how to communicate with your oscilloscope to change its settings and retrieve the data shown on the screen.

Exercise 11: Find the IP address of your 'scope by pressing the UTILITY button on the front panel, then pulling up the leftmost soft menu on the screen labelled "System I/O". From there choose "I/O," then "Ethernet Network Settings," and finally "Change Instrument Settings." This will pull up a screen showing all of the instrument settings, and you can read the instrument's IP address from the appropriate line. Don't change anything here. Just read the IP address, copy it into your lab notebook, and exit out of the screen using the "Menu Off" button. *Note:* If you still have any of your screenshots that you printed out earlier, they probably have the IP address at the top of the page.

Exercise 12: Enter your oscilloscope's IP address as the URL in a web browser from either your own computer or one of the lab computers. This should pull up a page that shows a copy of what the oscilloscope is currently showing on its screen. You now have full control of the oscilloscope, as well as the ability to download the waveform displayed on the screen as a graphics file or numerical data. At the top of the screen are a number of tabs. Select the one labeled "data", and the page will change into a dialog that will allow you to download the data from any channel (including references and the Math channel), control the 'scope remotely, save or upload settings, or even transfer data to the 'scope to be displayed on its screen. We are going to focus on downloading data. Select the channel you want to download and the format you want to download it in.

The default for these scopes is a proprietary Tektronix format, referred to as INTERNAL. Change this SPREADSHEET FORMAT, and then click on the "Get" button.

Exercise 13: Set the function generator to output a sine wave of amplitude 1 V, and adjust your 'scope settings to display at least ten periods on the screen. Download and save this data. You will need it for next week's homework.

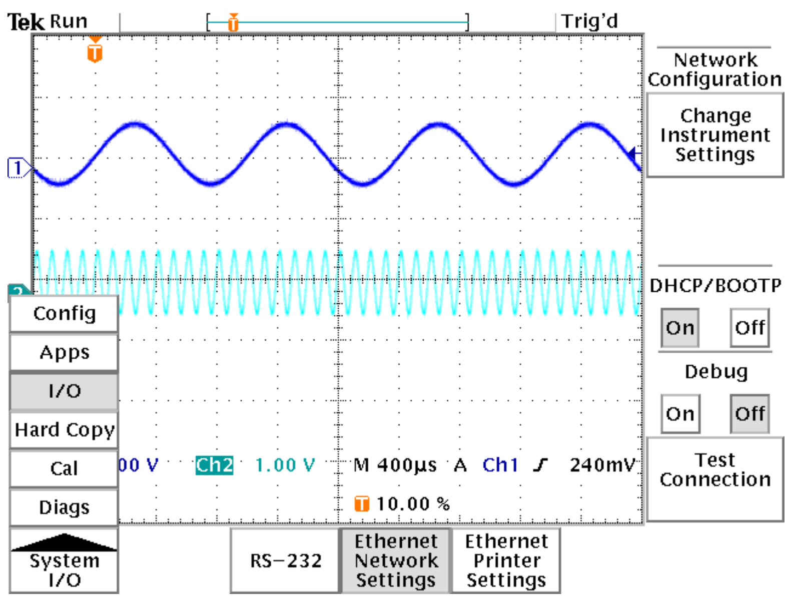

Figure 2: How to find the IP address of your oscilloscope.