EXPERIMENT 2: THE OSCILLOSCOPE AND AC MEASUREMENTS

The main purpose of this laboratory is to gain some experience in the use of the laboratory digital oscilloscopes. The scope is an extremely versatile and powerful instrument that we will use throughout the semester for observing time-varying electronic signals. The oscilloscope is your "window" into what is happening in your circuit. You should get into the habit of always having it turned on when you’re working at the bench, and of using it even when you think you’re measuring a quantity that doesn’t vary in time (just to be sure it really doesn’t!).

An analog oscilloscope consists of a cathode ray tube and various circuits to deflect the cathode ray beam in the vertical and horizontal directions. The CRT has a glass envelope which is evacuated to high vacuum and a cathode which is heated to boil off electrons. The electrons emitted by the cathode are accelerated by a potential difference between the anode and the cathode (typically 20 kV) and focussed into a beam. The beam produces a fine, bright spot when it hits the fluorescent screen on the face of the CRT. The electron beam can be deflected to an arbitrary point \((x, y)\) on the screen by voltages that are applied to horizontal and vertical deflection plates.

In contrast, the input to a digital scope goes to a very high speed analog to digital converter which samples the input waveform up to as many as several times \(10^9\) samples per second. There is thus a pair of \((x, y)\) coordinates for every sampling point. Each \((x, y)\) pair corresponds to a particular pixel on the LCD screen and the waveform is displayed on the LCD screen, usually with points so close together that it appears as a continuous line. "Digital phosphor" oscilloscopes can display multiple traces on the screen at one time, attempting to mimic some of the useful characteristics of the old electron beam on phosphor screen oscilloscopes by making the LCD display brighter where traces overlap. This allows the user to see how often variations from the average occur.

The scope has two distinct modes of operation. In \(XY\) mode the user supplies both the horizontal \((x)\) and the vertical \((y)\) deflection signals through input connectors located on the front of the scope, so that what appears on the screen is a plot of \(y\) versus \(x\). In time-base mode the samples are drawn across the screen from left to right at a constant speed (which the user can select) while the vertical deflection is generated from an input signal supplied by the user. This shows the input signal directly as a function of time, which is usually the most useful setting.

Most signals are repetitive and successive time segments can be overlaid on the screen to show gradual or occasional changes. To keep this from being a mess, however, it is necessary to line the segments up so that the plots largely lie on top of each other rather than being placed randomly in time. The is accomplished by the "trigger" circuit, which identifies a common point on each time segment and always puts it at the same point along the \(x\)-axis on the screen. The user picks a certain voltage, or vertical level, that the input hopefully crosses only twice in each period. If the signal is repetitive, it has to cross any level at least twice if it crosses it at all. So you also get to choose whether you want the crossing going up or coming down. The point you pick will be lined up at the same point on the screen on each crossing, giving the appearance of a stable waveform.

The trigger source can either be one of the input channels (this is called internal triggering), or a separate signal attached to the aux in input. The scope can also be set to trigger on the 60 Hz AC line voltage (line triggering).

The Tektronix MSO 2014B scope can display up to four different voltages simultaneously. Each plot ("trace") can have its own vertical scale, but all will be plotted against a common time base along the
horizontal axis, allowing you to compare the relationships of the voltage at different points in the circuit at the same time.

Almost all oscilloscopes, including the MSO 2014, have earth ground as the common reference for all the input signals. So the shield (D) sides of all the BNC input connectors are not only connected together, but are connected through the AC power cord ground to the grounds of other instruments. This easily forgotten ground connection can lead to confusion and incorrect measurements if you are not careful (and sometime spectacular results if you try to connect the low side of the input to the output of a grounded power supply). If you want to measure the potential difference between two ungrounded points, you must connect the to two separate input channels. Each of these will show the potential of that point to ground, but you can use the \texttt{math} feature of the oscilloscope to display the difference of any two inputs.

Your instructor will give a demonstration of the basics of using the oscilloscope, including how to send copies of everything that shows on the screen to the color printer, so you can make copies to put in your lab notebooks. But you should get accustomed to looking up additional information in the User’s Manual for the 2014B. This (and manuals for other instruments) are available on the course home page, and can be downloaded. A little time spent skimming through this will reveal many things not mentioned here that the scope can do for you, as well as showing you how to make measurements more efficiently.

1. As you go through the following steps keep notes in your lab notebook describing your observations.

   (a) The first step is to display a sine wave. Set the trigger source to channel 1. Set the function generator to produce sine waves with a frequency of around 200 Hz and connect it to the channel 1 input.

   (b) Set the time base control to 2 ms/division, and then adjust the trigger level and the channel 1 amplitude control (volts per division) to get a reasonable display. Play with the level and slope trigger controls until you understand what they do. Observe the effects of changing the frequency and amplitude of the generator signal, and the effects of changing the time base and channel 1 amplitude controls.

   (c) Next, make sure you understand the input coupling setting (AC, DC, or GND). For this step, adjust the DC offset of the function generator to produce a sine wave that is offset from zero by some amount. Change the input coupling setting to GND, which grounds the input (this prevents the trigger circuit from firing, but you can still observe the trace by using the \texttt{auto} trigger feature). Adjust the vertical position to center the trace on the screen, and then observe the input signal with the input coupling set to AC and DC. Do you understand what you see in each case?

2. Connect the function generator to channel 1 and a 6 V transformer to channel 2. Display first channel 1 alone, then channel 2 alone, and then both channels together. As you do so, observe the effect of changing the trigger source (CH 1, CH 2, \texttt{vert}, and \texttt{line}). Investigate the function of the “+” and “-” operators found under the \texttt{math} mode button. (You might have to use the "single-shot" mode to get the display stable enough to read.) Briefly describe your observations, and record the waveforms by making a few rough sketches or printing screenshots. Why is this transformer described as a “6 V” transformer?
3. Use the output from the transformer (which will be 60 Hz to very good accuracy) to check the sweep calibration of the scope. Set the sweep time to 20 ms/div and determine the time it takes for the trace to cross the screen by counting the number of waves. How accurately is the scope calibrated? At 20 ms/div, how precisely can you measure the time between two points on a waveform? Let the scope measure the waveform’s frequency by pressing the measurement button and selecting period and frequency measurements.

4. Use a DC voltage supply and a DMM to check the voltage calibration for one of the four channels. Connect both the DMM and scope across the output of the power supply (i.e., connect them in parallel with each other, and then to the power supply).

   (a) Set the power supply to an output voltage close to 1.0 V. How do the DMM and scope readings differ? How does the scope reading change when you adjust the voltage resolution setting of the scope? Does the scope’s mean measurement match what you read by eye?

   (b) Compare the DMM and scope mean readings for voltages near 100 mV, 1.0 V, and 10 V. (Note: you should use the bipolar power supply for voltages below 1 V. If you try to use the Lambda or PMC supplies for the 100 mV measurement, you’ll find that they don’t work properly. If you try either supply, record what happens when you try to set them to a voltage around 100 mV. The PMC supply’s behavior is especially interesting if viewed on the scope.) Tabulate your results and the differences. How accurately is the scope calibrated?

   (c) Do the same for an AC input signal: have the scope make amplitude, RMS, and cycle RMS measurements for a 1 kHz sine wave, and compare with the DMM’s AC “True RMS” reading. Do you get the expected results? (Remember: the RMS voltage of a perfect sine wave is 1/(2 \sqrt{2}) times its peak to peak amplitude.)

5. The input impedances for the scope vertical inputs is 1 MΩ. If you use one of the 10× probes, it becomes 10 MΩ. Try plugging in one of the probes (please treat these well – they are easily broken if left on the floor and stepped on) and watch how the vertical scale changes. Now measure the DC input impedance of the oscilloscope with and without the probe using the “voltage divider” method (described in part 4 of experiment 1) with the aid of a resistance box with megohm resistors. Then, measure the AC input impedance (without the probe only) by the same method, using sine waves from the function generator as your voltage source. Use sine waves with frequencies near 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz, and 1 MHz. (You may have to turn on signal averaging to get stable results at 1 MHz.) How does the impedance depend on frequency? Plot your results. (Which axes of the plot would usefully be logarithmic?)

6. The ratio of the frequencies of two AC voltages can be measured by using the x-y mode of the scope. Set up the first Lissajous figure as follows:

   (a) The 6 V transformers have two yellow connectors (the two sides of the transformer) and a black connector (the transformer center tap). Connect one side of the transformer to both channel 1 and channel 2 scope inputs and the center tap to the ground inputs of both channels. You will now have identical signals on channels 1 and 2. Observe the Lissajous pattern by running the scope in XY mode. Record the waveform and explain what you see.

   (b) Now set up two signals 180° out of phase by connecting one yellow connector to channel 1 and the other yellow connector to channel 2. Leave the center tap as the ground for both channels. Record the waveform and explain what you see.
7. Now set up for additional Lissajous figures using the 60 Hz transformer output for the channel 1 scope input and a sinusoidal output from the function generator for the channel 2 scope input. Observe the Lissajous patterns for function generator frequencies of 20, 30, 60, 120, and 180 Hz. You will notice that unless you get the frequency set exactly right, the pattern will slowly rotate as the relative phase of the signals changes. Record the waveforms and explain what you see. Below are examples of Lissajous figures taken from the lab setups. Identify the phase and frequency ratio for each figure.