

**EE283 Electrical Measurement Laboratory**  
**Laboratory Equipment Tutorial**  
August 18, 2017

**Purpose:**

This document is intended to provide basic information needed to operate the laboratory instruments used for course EE283 at Wilkes University. This course is taught in Stark Learning Center (SLC) room 125. Each laboratory station has, in addition to a Windows computer, four essential pieces of equipment that will be used during the course:

1. Agilent 34401A Digital Multimeter (DMM)
2. Tektronix PS280 DC Power Supply
3. Tektronix AFG320 Signal Generator
4. Tektronix TDS210 Two Channel Oscilloscope

The DMM and power supply are used from the beginning of the course for DC and digital circuits, Laboratory exercises 1-4. In addition, the Signal Generator is used to provide AC waveforms, which can be observed by the oscilloscope, during the remainder of the course, where AC signals and measurements are the focus. This document discusses each of these instruments in turn.

**Agilent 34401A Digital Multimeter**

The Digital Multimeter (DMM) is designed to measure resistance (in Ohms) for circuit components that are not powered, and Voltage (in Volts) and Current (in Amperes) for either DC or AC. Figure 1 shows the appearance of the meter with the function of resistance selected.

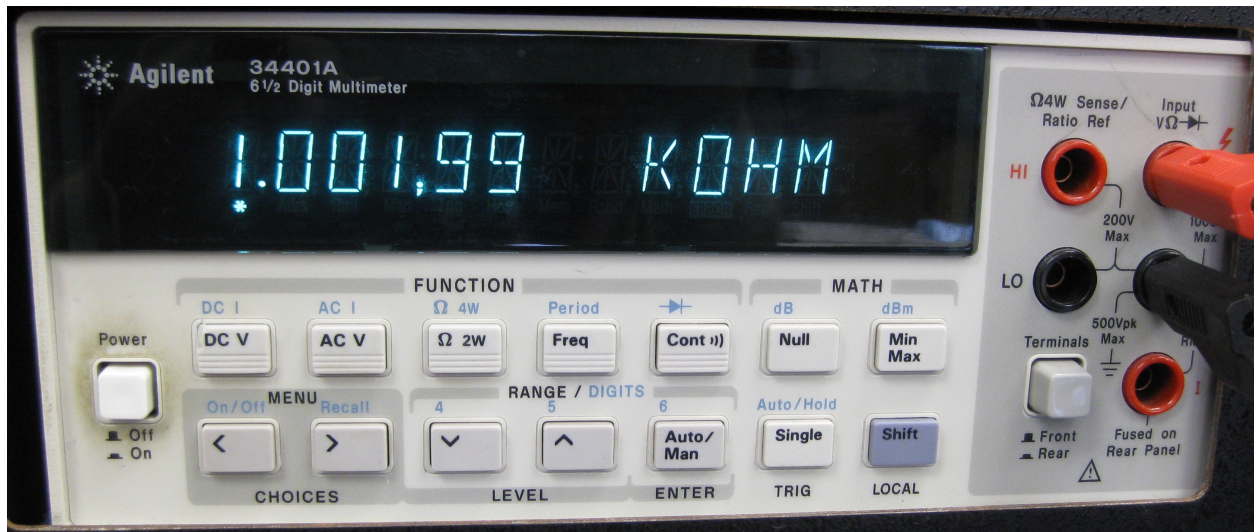


Figure 1 Agilent 34401A Digital Multimeter

Notice the placement of the black (neutral) and “hot” (red) test leads. Unless you are measuring current, this is where the leads should be connected. For measuring resistance, the polarity matters when measuring the resistance of nonlinear elements such as diodes. For resistors, it shouldn’t matter. The meter on power-up comes up prepared to measure DC Voltage. To select resistance, the button marked “ $\Omega$  2W” is pressed. (The “2W” means that the component is tested with the “2 wire” option, the only way we will make resistance

measurements.) Normally we will let the meter “auto-range”, that is, select the placement of the decimal point. You can do that manually using the “Auto/Man” and up and down buttons in the middle of the bottom row of buttons.

In this case, the meter was measuring the resistance of a 1.0K Ohm 5% resistor connected to the meter leads, lying on the lab table. When the resistor was picked up and held, the reading changes to that shown in Figure 2 below.



Figure 2 Another measurement of the same resistor

The reading is different! So, what is the actual resistance of the resistor? You could safely say 1000 Ohms, or (better) 1.00 K Ohms. Only three digits are significant. The remaining digits are not really significant because the resistance actually varies depending on conditions, from room temperature to about 97° when held between two fingers! Even though the meter shows 5 or 6 digits, they are not usually all “significant” digits.

One final remark about resistance measurements: You should NEVER make a resistance measurement of a component with any power applied. The way the meter works is, it applies a Voltage to the component and measures the current. If the component is powered, the Voltage applied to the component is not what the meter is applying, and further, is likely to be large enough to damage the meter. (I have blown out expensive meters by failing to change from Ohms back to Volts before measuring a powered circuit.)

DC Voltage is measured by pushing the “V” function button, and placing the leads on the nodes between which Voltage is to be measured. Two different cases are common. One is the Voltage across a particular component, say, a resistor. Place the red lead on one end, and the black lead on the other. If the red end is more positive, you get a positive number. If the red end is more negative, the meter shows a negative value. Unlike analog meters, a DMM is not harmed by having the leads “backwards” to produce a negative reading. The second case is to measure the Voltage “at a node”. That means, between the node and the reference ground. Connect the black (reference) lead to ground, and then place the red (positive) lead on the node. You will then read the node Voltage, which might possibly be negative, that is, below ground. (Often we will use the meter this way, and use a black banana to banana cable to connect the meter black terminal to the power supply ground.)

DC current is measured by placing the meter in the circuit. Use the red terminal BELOW the black terminal (marked “I”). The meter looks like a short circuit to the circuit. Press the purple button for “Shift” and the “DC V” button (which has “DC I” over it in purple). As with Voltage, you can get either a positive or negative current, depending on which way the current is flowing, positive if from the red lead to the black one. After measuring current, be sure to put the red lead back to its normal position and set the function back to Volts.

AC Voltage and current measurements work the same way as DC Voltage and current, but you won’t get a negative value. The numbers show “Root Mean Squared” (RMS) AC Voltage and current values. That is, the Voltage or current which, if it was DC, would deliver the same amount of power. (This is a “True RMS” meter. Cheap DMM’s simply measure peak

Voltage and divide by the square root of 2, which is wrong for waveforms which are not sinusoids.) The meter will accurately measure AC values up to 3KHz and some waveforms above that frequency.

In making DC Voltage measurements, the meter puts a 10 M $\Omega$  impedance on the measured circuit, and 1M $\Omega$  for AC measurements.

One final remark: The meter has a second set of terminals on the back. The button near the terminals is used to select the back terminals if pushed in. That disconnects the front terminals. Make sure that button is not pushed in!

### **Tektronix PS280 DC Power Supply**

The power supply has three separate supplies in the one unit. There are two variable supplies (0 to 30 Volts at up to 2 A) and one fixed 5 Volt supply at up to 3A. You will use the fixed 5V supply for digital projects, as the power supply for digital logic gates and other digital devices. For other work, you will use one or both of the variable units. Figure 3 shows a photo of the supply front panel.

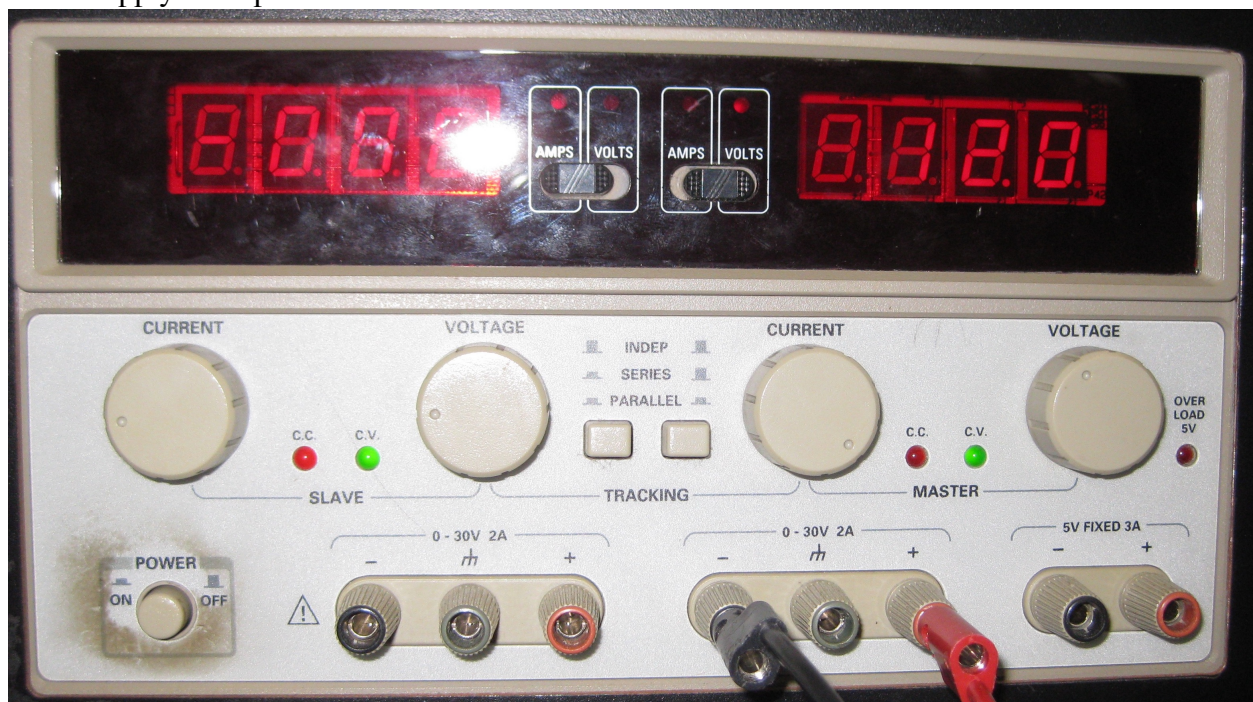


Figure 3 Tektronix PS280 DC Power Supply

Each variable supply has a current knob (used to limit the amount of current, if desired). If no limit is needed, you can turn the left knob all the way up. That lets you draw up to 2A. If that would harm devices in your circuit, set it at a lower limit. (Students sometimes have problems with the supply, and the problem is that the current limit is all the way down to zero!)

Each Variable supply also has a Voltage knob, used to set the Voltage. Normally you do that before connecting anything. Each unit has a meter that can be set to measure Voltage or current. In the photo, the left meter is measuring current and the other Voltage. These meters are not as accurate as the DMM; they are used to set Voltages (or currents) to an approximate value, which you will usually then measure exactly with the DMM. The supplies are “regulated” so that, once set, they give the same Voltage regardless of the amount of current drawn.



If a unit is in its normal “Voltage limit” mode, a green LED will be on, and the Voltage will match the set value, the current being less than the current limit. If the current limit is exceeded, the Voltage will drop below the set value and the red LED will come on to indicate “current limit” mode. That will often indicate that there is a “short circuit” in your project. (The red LED for the 5V supply also come on if the circuit wants to draw more than 3A.)

There are two buttons between the two supplies that allow them to be internally connected in series or parallel. Leave both of these unpressed; we won’t need that feature.

Each variable supply has a negative (black) terminal (binding post / banana socket) and a positive (red) one. In between is a green “earth/safety ground” terminal that goes back to the ground on the power cord and the chassis of the supply. Often (but not always) we will connect that to the circuit ground. The earth/safety ground is also connected to the outer BNC cable conductor of the oscilloscope. It is possible to create innovative and confusing short circuits using these grounds.

### **Tektronix AFG320 Signal Generator**

The signal generator gives us AC waveforms used for a variety of purposes in this course. It is NOT a power supply. The AC signals are relatively weak. The signal generator has, in effect, an internal 75 Ohm Thevenin equivalent resistance. If you want more powerful AC signals or power, you need a transformer (for 60Hz) or a power amplifier (for arbitrary signals).

The signal generator has two separate signal sources. We will normally use just one, “Channel 1.” Channel 1 is normally left connected to the oscilloscope, as seen in Figure 4.

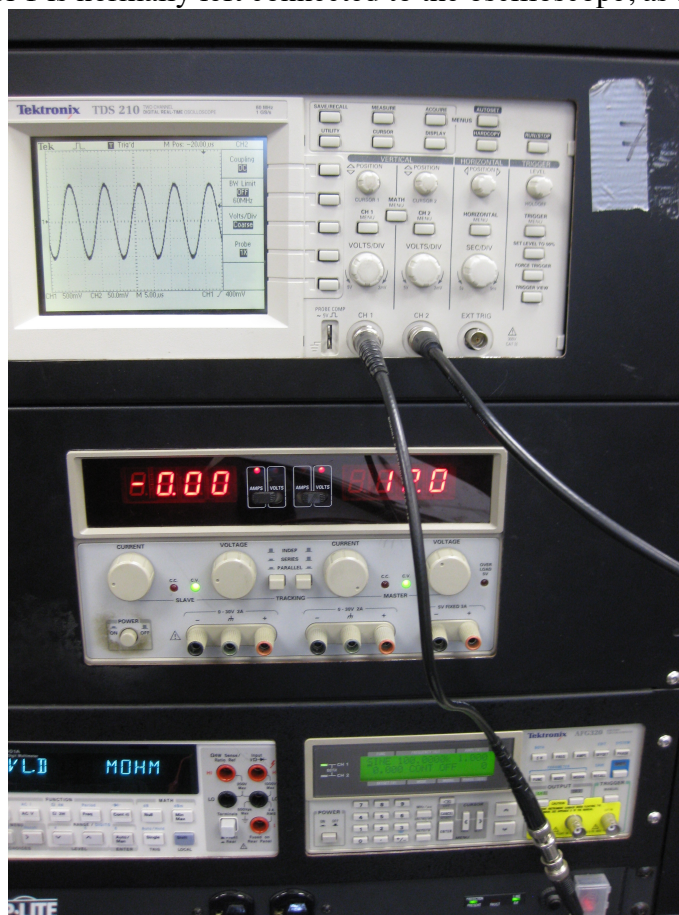


Figure 4 Lab Station Configuration



As seen in the figure, a BNC “T” connector connects the output of Channel 1 of the signal generator to Channel 1 of the oscilloscope. Channel 1 is also connected to the circuit using a BNC to banana cable. A second banana cable is used to connect the oscilloscope Channel 2 to the variable to be observed in the circuit.

Figure 5 shows a closer view of the signal generator. The display shows the default configuration at power-up. Channel 1 is selected (upper left LED), The top left button to the right of the cable selects which channel is being set. Right now, the output is a sinusoid at 100 KHz, of 1 Volt (peak) amplitude, with 0 Volts of DC offset, and no modulation (continuous waveform) and zero degrees of phase. Any of these properties can be changed by pushing a button on the right side of the instrument, say for frequency, then pressing buttons at lower left to first key in a number, then set the scaling of units to either Hz, KHz, or MHz (buttons to right of the numbers). You can also set parameters by selecting the parameter and then using the left/right cursor arrows to position the cursor (right now under “Sine”) and then the up and down arrows to bump the parameter up or down. This is most useful for adjusting frequency while looking for a resonant peak.



Figure 5 Tektronix AFG320 Signal Generator

One very important point to note: The outputs of the signal generator are not driven until you “turn on” the output. There is a button just above the BNC output connector, and an LED just above the button which says the channel is “on” or not. In Figure 5, Channel 1 is “on” (you can just see the corner of the LED indicator) and Channel 2 is off.

### Tektronix TDS210 Two Channel Oscilloscope

An oscilloscope is an instrument which displays a waveform, usually graphically as a Voltage (vertical) vs time (horizontal). Modern oscilloscopes are simply computers that record data and then display it on a (small) monitor. (The original analog oscilloscopes deflected electron beams aimed at a phosphor coated screen, similar to analog CRT television technology.)

This oscilloscope (see Figure 6) can display either or both of two signals, received on the “Channel 1” and “Channel 2” BNC inputs. Normally we will use Channel 1 to see the signal coming out of the signal generator, which we will usually call the “input” signal. Channel 2 is usually used to measure something else in a circuit, the “output” perhaps.

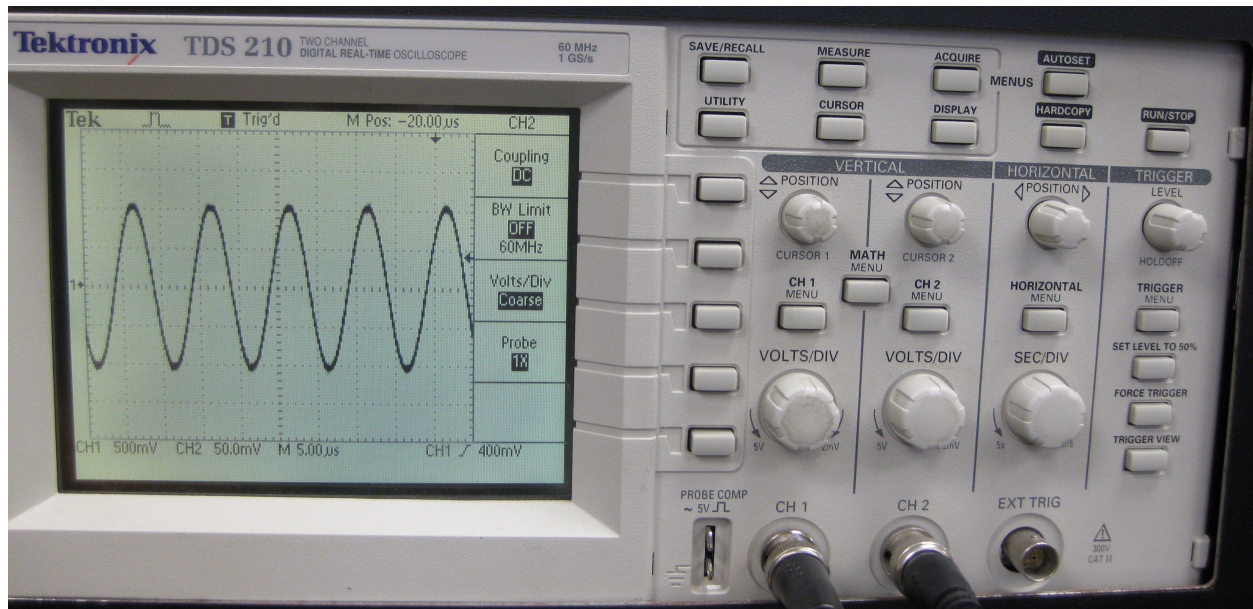


Figure 6 Tektronix TDS210 Two Channel Oscilloscope

The outer conductor of the BNC cables, the “shield”, is at earth/safety ground (connected to the ground wire of the AC plug). The inner conductor carries the signal. For either of the BNC-banana wires used to connect to the oscilloscope and signal generator, it is important to distinguish which banana plug terminal is which. Usually the ground side has a tab marked “GND” or such on it. Usually you want to connect that to the reference node of your circuit and the power supply.

The oscilloscope shown in Figure 6 is connected to the signal generator, showing the default 100KHz 1Vp AC signal. The scaling of the time base (units of time per 1cm division on the screen) is adjusted using the rightmost larger knob. Here it is at 5.00  $\mu$ s (as seen at the bottom of the display). The precise position can be adjusted left or right using the third (from the left) small knob. Usually you want to see one to four or five cycles of a waveform on the screen. You adjust the time base to make that happen.

You will usually also need to adjust the vertical scaling of the waveform. The leftmost larger knob does this for Channel 1. It is now set so that each 1cm division of the screen represents 500mV, so the amplitude of the signal (above its center) is 2.0 divisions  $\times$  500mV = 1.0 Volt (peak). From the top of the waveform to the bottom is 4 divisions, or 2 Volts p-p. The smaller leftmost knob can be used to move the waveform up or down. Right now, it is positioned so that zero Volts is exactly on the middle grid line. The little arrow on the left side of the screen with a “1” shows where “zero” is.

Sometimes the waveform displayed is not stable. The oscilloscope needs to know “where to start”. That is done with the “trigger”. The trigger is shown by a small arrow on the right side of the screen. It’s currently at 400mV, so that’s the Voltage that the signal is as it crosses the position shown by an arrow at top (with 20 $\mu$ s delay). Trigger level can be adjusted up or down with the 4<sup>th</sup> top knob. If the trigger is beyond the range of the waveform, the display will be unstable. There is a “trigger menu” button under the knob that allows various options, including your choice of which channel to trigger on, whether positive or negative going. Choices are made by pushing the buttons just to the right of the screen after pushing the trigger menu buttons. Figure 7 shows a closer view of the oscilloscope screen details.



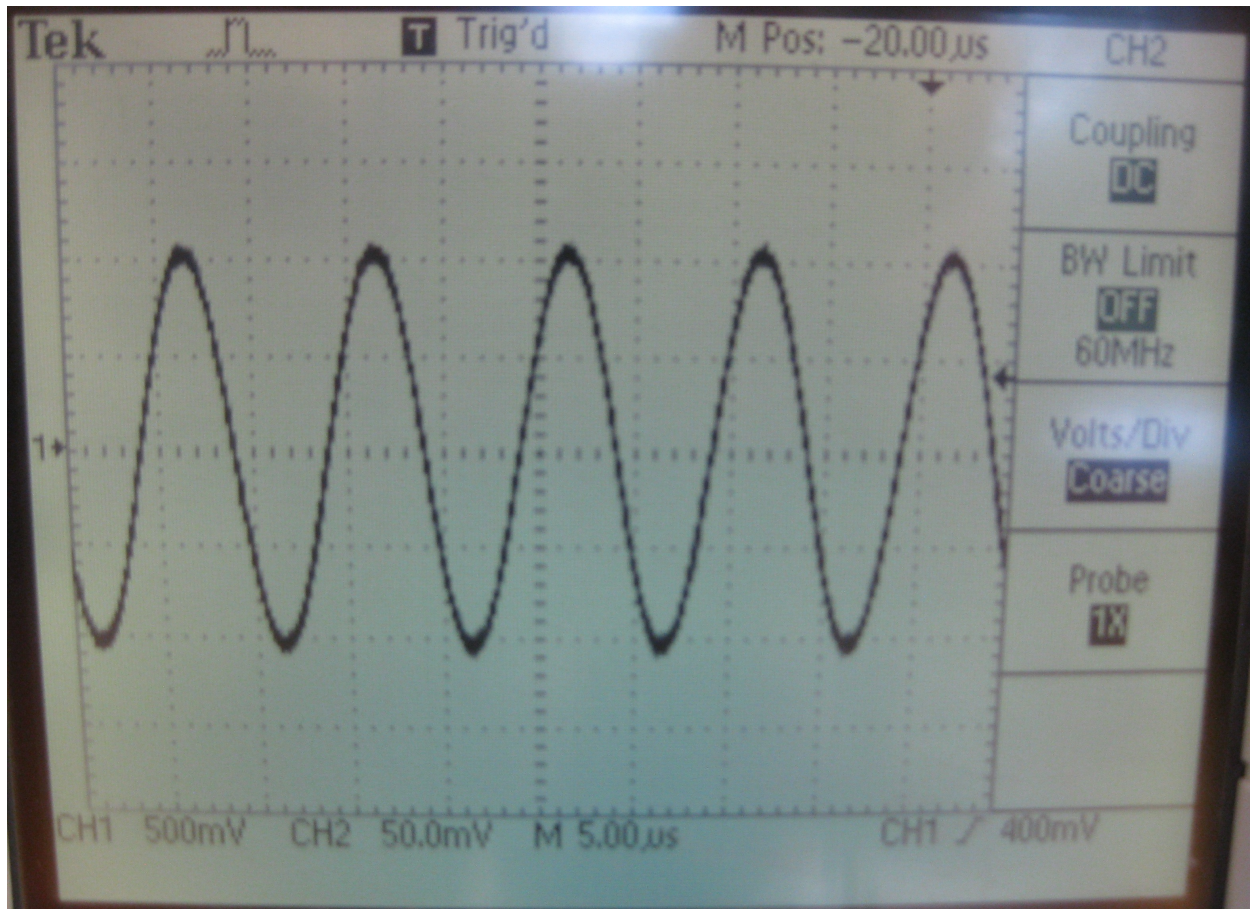


Figure 7 Closer View of Oscilloscope Screen

The figure above shows the settings that have been made for the display across the top and bottom of the screen. At top, we can see that the oscilloscope is being triggered and some parameters associated with the trigger. At bottom, we see that Channel 1 is set to 500mV per division, Channel 2 to 50mV per division (but is not displayed), the time base is 5  $\mu$ S per division, and the trigger is on the rising edge of Channel 1 at 400mV.

By pressing the “Channel 1” button (between the two knobs) you get a menu of options that you can select for that channel. Here we have the Channel 1 menu displayed. We have “DC coupling,” so the oscilloscope shows both the DC and AC components of the signal. (That’s what we will use in this course. In electronics, AC coupling is needed to see small AC signals riding on large DC Voltages.) Bandwidth limiting is off (that’s what we will use), the Volts per division (using the big knob) is “coarse” (we shouldn’t need “fine”), and the “Probe” is “x1”.

The “Probe” is the device used to connect the oscilloscope to the circuit. The BNC – banana connectors deliver to the oscilloscope the same Voltage that’s on the banana pin. More refined oscilloscope probes usually use “x10” probes. The Voltage delivered is only 1/10 of what is actually measured. Good oscilloscope probes are expensive (about \$25 or more each), have much better performance at high frequencies, have a higher impedance input, and tend to break easily. We will use these cheap BNC-banana cables instead. If you get to about 100KHz or beyond, they are not usually good enough for quality work. (We’ll use real oscilloscope probes in EE252 Electronics 2.) Pressing the channel 1 button again will turn off Channel 1. (That’s how we turned off Channel 2 in order to get the display shown above.)



By pressing the Channel 2 button again, we turn on Channel 2. Here we see in Figure 8 the display of Channels 1 and 2. The horizontal axis is common, so you really are seeing what they are doing simultaneously. Channel 1 has been moved up and Channel 2 down so that they can be seen distinctly. However, for comparing phase, it's helpful to put both zeros at the same, mid-screen line. In this case, Channel 2 comes from the circuit shown in Figure 9. Because Channel 2 is measuring the capacitor Voltage, Channel 2 lags Channel 1. (Notice that the time base and signal generator have been adjusted. The frequency is now 1 KHz, with 250  $\mu$ s per horizontal division.

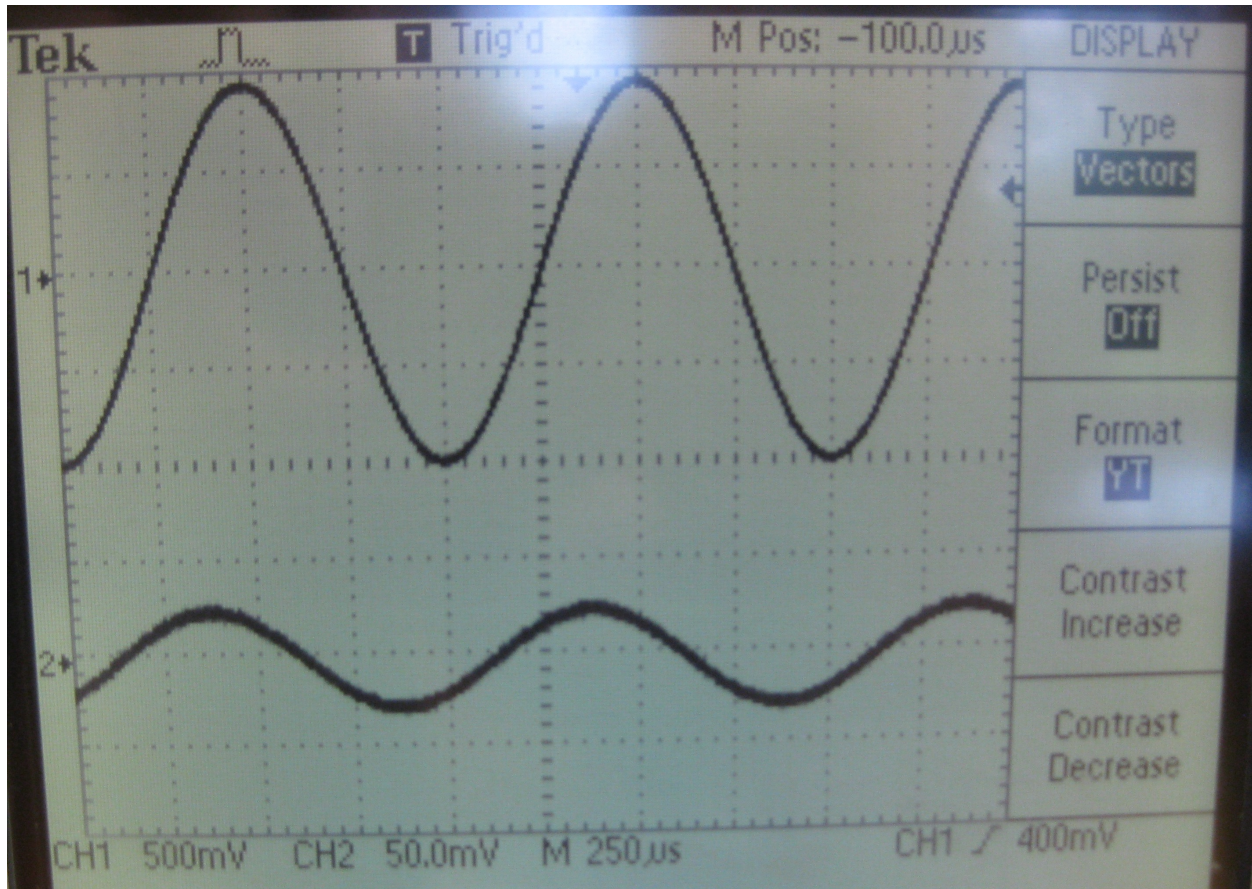


Figure 8 Oscilloscope showing both channels

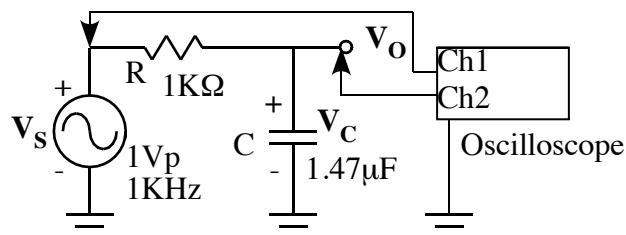


Figure 9 Circuit monitored by the oscilloscope with both channels used

The oscilloscope displays shown so far are in “YT” (or, signal vs time) mode. The display button in the upper right area allows other options. One of those options is to show the signals in “XY” mode, where Channel 1 is on the X axis and Channel 2 is on the Y axis. Using

XY mode we see a vector display of how the two channels vary together, what is called a Lissajous Figure. Figure 10 shows this. This is an RC circuit, so we get an oval. To make the figure larger, the center points for both waveforms have been placed in the middle of the screen. Channel 2 (Y) resolution increased to 10mV. At 10mV per division, Channel 2 is “noisy”.

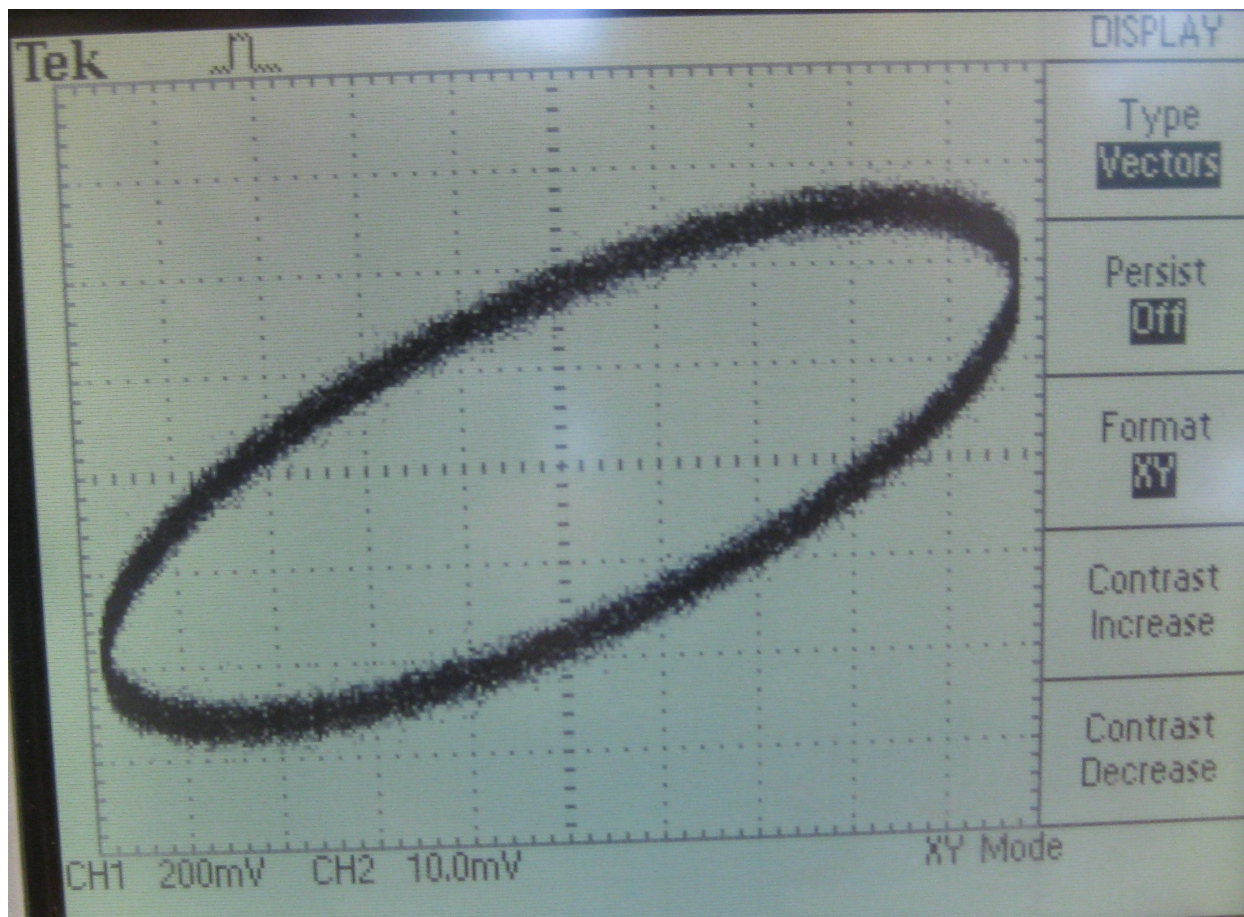


Figure 10 A Lissajous Figure produced using XY mode

Notice that in Figure 10 the “fuzz” that indicates noise or imprecise measurement is just in the vertical direction. Some of this can also be seen in Figure 8 for Channel 2; the trace is a bit wider, or less precise, than Channel 1. Here we can see that at the left and right extremes, the trace is narrowed where it goes vertical. Going back to YT mode, we see that Channel 2 is indeed very noisy, and somewhat unstable. (We don’t want to be triggering on Channel 2!) We can get a better look by using yet another feature of the oscilloscope. We can freeze time. We can do that using the “Halt” button. The image is stable because we are seeing a snapshot in time. Figure 11 shows this. (Halt is often very handy in other situations too. There are “one time trigger” modes that do this under certain conditions.)

The problem with a noisy waveform is to measure the amplitude of the signal. What you need to do is imagine a sinusoid that traces through the centroid of the fuzz, going left to right. What is the height from the middle of the fuzz at the bottom to the middle of the fuzz at the top? In this case, I would say the top is at about +1.5 divisions and the bottom at -1.4 divisions, making the sinusoid under the fuzz about 2.9 Volts p-p.



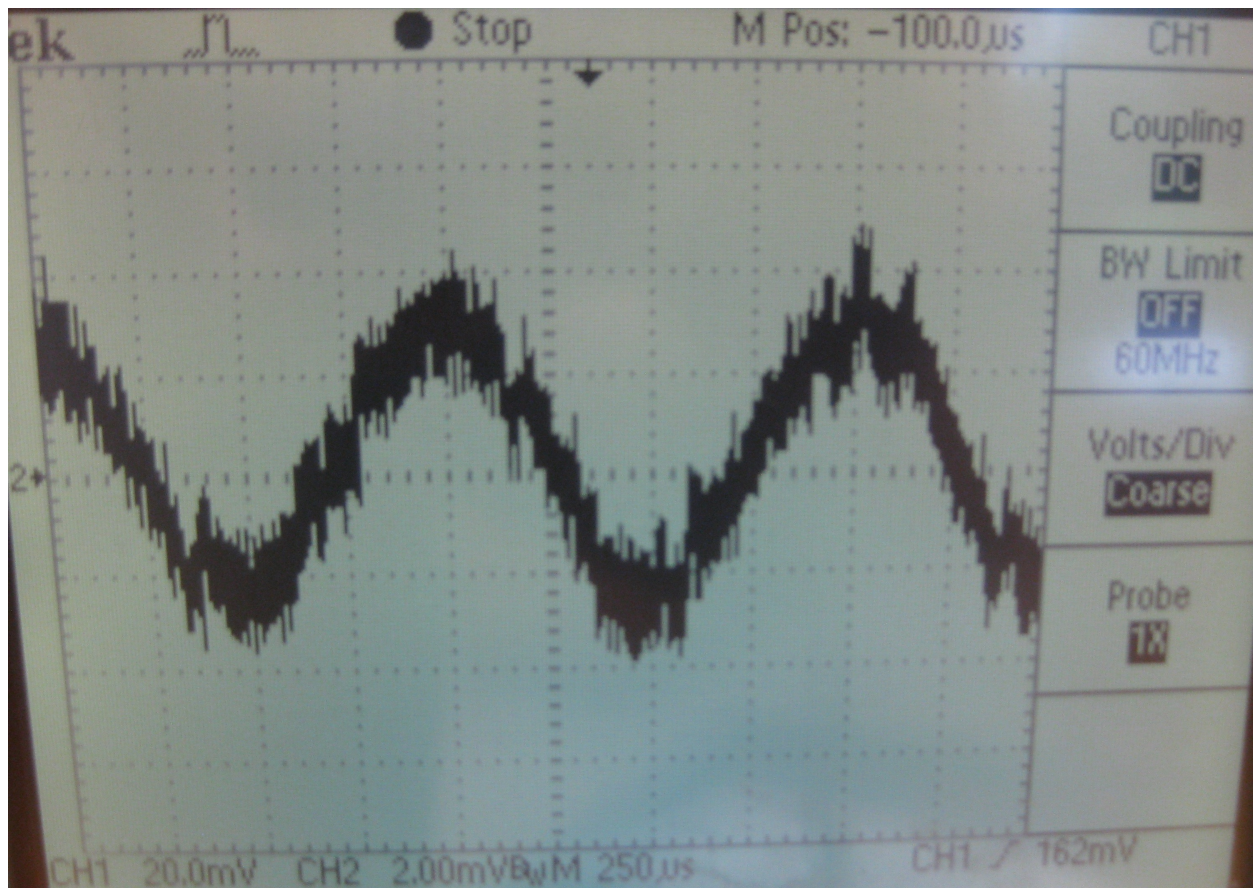


Figure 11 Weak Oscilloscope signal with noise.

There are a few additional important features of the oscilloscope. One is “Math Functions”. The MATH button between channels 1 and 2 brings up a menu of choices. The one we will need is “Channel 1 – Channel 2”. That is, we get a third trace that is the difference between the two input signals. (We can turn one of the channels off for display purposes but it still feeds the math function.) Unfortunately, MATH does not work in XY mode. We will need the channel difference math function.

There is a “measure” button that allows measurements like AC Voltages or waveform period to be displayed. These are not reliable for complex or noisy waveforms. I would not use them other than for very clean signals. They are most precise when the waveform is large, filling most of the screen.

One final button will be mentioned: Autoset. Pushing this button essentially tells the oscilloscope, “I don’t know what I’m doing. You decide for me what to display and how to display it.” You should not use Autoset unless you have become hopelessly tangled up in some weird display or trigger mode, and you don’t know how to climb out. Reserve it for emergencies. Do not routinely use Autoset. It can get you into serious trouble. It is not as smart as you are, and will bite you worst when you have the most difficult or unusual things going on.

### Conclusion:

We do have manuals from the manufacturers for these instruments that can be referred to if necessary. But, it is hoped that this tutorial will meet just about all the needs for EE283.