EE 201 Lab

Agilent DSO-X-2024A digital oscilloscope

In its basic mode of operation, an oscilloscope takes a rapid sequence of voltage measurements and displays these in the form of a plot showing the voltage as a function of time. Imagine if you and your lab partner were to take a series of voltage measurements at specified interval, say every 3 seconds, and then enter your measurements into Excel. You could generate a plot of the voltage as function of time, giving you an "image" of the time-varying waveform. This is what the oscilloscope does, but significantly faster than you and your lab partner. The voltage measurements of the oscilloscope may be only 1 ns apart (1 billion measurements every second). Thus, it provides a detailed view of a waveform from some part of circuit. The oscilloscope works particularly well with periodic signals, because it can be "triggered" from the periodic signal and offer a continuous display of the signal. However, when set up properly, the oscilloscope can also capture aperiodic (or "one-shot") waveforms.

In some sense, the oscilloscope can be viewed as a "waveform microscope". Using a biology lab microscope, we peer through the lenses and then adjust the magnification to get clear images. If we are trying to look at an amoeba, we would like to set the magnification so the image amoeba will just fill up the entire field of view of the microscope. If the magnification is too low, the image of the amoeba is too small to see details. If the magnification is too high, the amoeba more than fills the field of view and we may miss something interesting. In the same way, we can adjust the time- and voltage-axis settings of the oscilloscope to get a clear graph of the waveform. Sometimes we may want to reduce the scale in order to zoom in on some portion of a waveform. Other times, we may need to increase the scale so that we can see several periods of the waveform.

The oscilloscope has an *Autoscale* function, which captures a waveform and then sets up the display to give a reasonable graph. As you start out with the oscilloscope, you may use this feature frequently, but as you become more proficient with the "scope", you should use Autoscale less and less. Typically, we will use the Autoscale to get the preliminary measurement and then make adjustments to the settings in order to look more carefully at things of interest.

> **EE 201 rule of thumb:**
> On any particular measurement on circuit, you should use the Autoscale no more than once, right at the outset in order to get "close". After that, all adjustments should be made with the time and voltage settings knob. Excessive use of Autoscale is a clear indication that the user is a rookie.

The oscilloscopes in Rm 2014 are *quad-channel*, meaning that they can measure and display four separate voltage waveforms simultaneously. This is very useful for seeing how a circuit modifies a signal. For example, we can apply a voltage signal from the function generator to the input of an amplifier or filter circuit and observe the source voltage with one channel. We can use another channel to observe the output voltage waveform. If both waveform *traces* are displayed on the oscilloscope screen, we can immediately see the amplification or the signal filtering action.
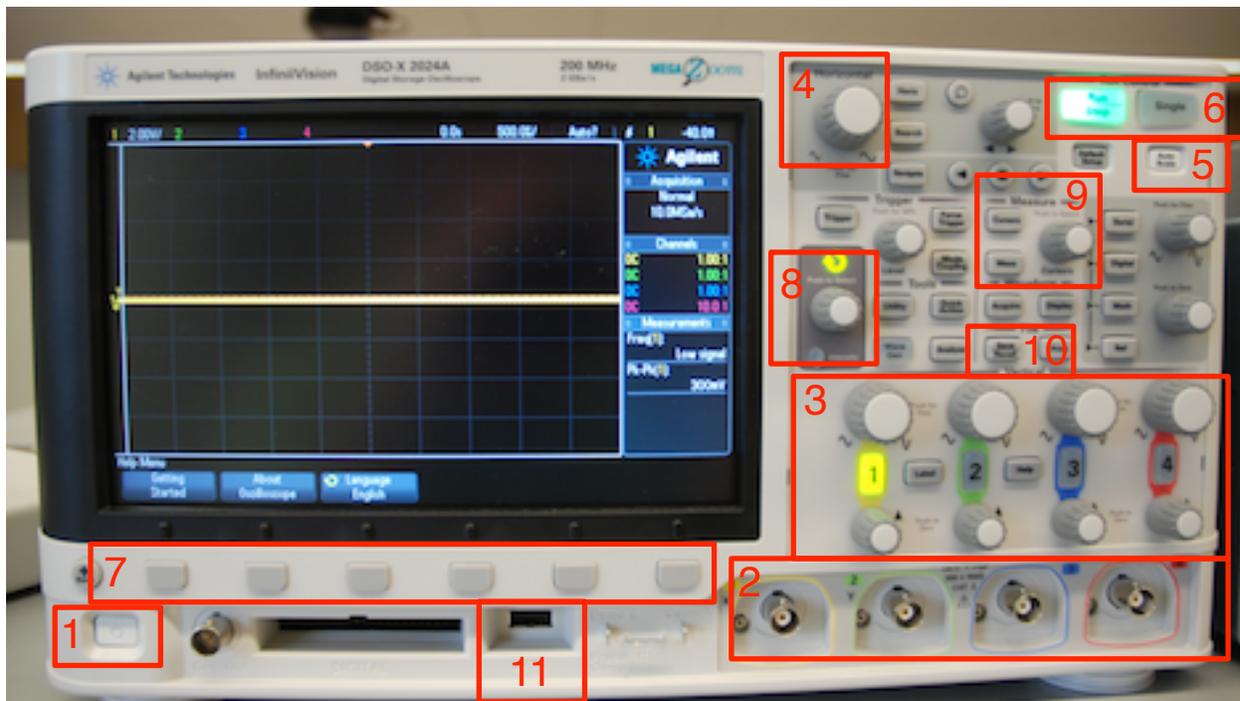
Figure 1. Some important items on the front panel of the Agilent DSO-X-2024A oscilloscopes in the EE 201/230 laboratory.

1. Power switch.

2. Channel input terminals, 1 - 4.

3. Vertical (voltage) scale and offset controls, one set for each channel. Usually, the first signal is applied to channel 1 and channels 2-4 are added as needed for the particular measurement. Channels are activated automatically when an *Autoscale* is performed. When a channel is active, its channel button will be lit and there will be a trace on the display for that channel. In Fig. 1 above, only channel 1 is active – the yellow "1" is lit while all the other channel buttons are dim. Channels can be manually activated or de-activated by pushing the channel buttons.

4. Horizontal (time) scale knob.

5. *Autoscale* button. This causes the oscilloscope to automatically acquire a voltage signal and draw a trace on the display. It will activate each channel where a voltage signal is sensed. Sometimes the Autoscale activates a channel even if there are not leads attached. Other times, a channel that should be activated may not be. You can manually activate / de-activate channels as described in item 3 above.

6. *Run-stop* and *Single* measurement buttons. In *run* mode, the oscilloscope continuously measures and displays the voltage at the inputs. Pushing the button once causes the measures to stop and the display will freeze with the last measured cycle of the input. *Single* is used to capture a voltage transient that happens only once.

7. *Softkeys* for selecting various options during oscilloscope set up. The function of the button changes depending on what you are trying to do.

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8. Multi-function *Entry* knob. Adjusts various settings on the oscilloscope.

9. *Meas* and *Cursors* keys. Use these to obtain new measurements from the channel traces or to use cursors to look at specific points on the traces.

10. *Save/Recall* key. Use this to enter the Save/Recall menu when you would like to capture a screen image of the graph and data to include in a report.

11. USB port.

Basic measurements

A typical oscilloscope measurement involves a small number of steps that are used almost every time.

1. Power up

2. Make connections from your circuit to the oscilloscope.

3. Perform an *Autoscale* so that the oscilloscope will automatically acquire a trace and draw a it on the display.

4. Make manual adjustments to the time scale and voltage scales in order to set up for any measurements you would like to perform on the voltage traces.

5. (Optional) Use cursors and measurements to obtain specific voltage levels, voltage differences and time differences from the voltage traces.

6. Save a screen image of the graph, if needed.

Each item is described below. Most of the real work occurs during step 3. However, since the oscilloscope is doing most of that work, the step requires little explanation. Ironically, the most mundane step, making connections, requires the longest explanation below.

1. **Power up**

When the oscilloscope is powered up, it will go through a boot-up cycle, enters the default state, and waits for you to initiate a measurement. There will be a horizontal yellow line on the display indicating that Channel 1 is turned on, but there is no voltage applied.

2. **Connections**

To measure voltages, you must attach leads from your circuit to the channel inputs. In principle, you can use any channel, but typically, we make the first connection to Channel 1 and sequentially move down the line as we need more measurement points. (It will be a rare occasion when we have an EE 201 circuit that is so complicated that we will need 4 simultaneous measurements.)

There are two methods for making oscilloscope connections in EE 201 lab. The first is to use *scope probes,* which are designed specifically for use with an oscilloscope. (Using the scope probe is the way the professionals connect the oscilloscope to circuits.) A scope probe has a BNC connector on one end that connects to the input jack of the oscilloscope, and pair of leads at the other end for connecting into the circuit. One lead is a small alligator clip that is the negative connection. The other lead is either a sharp probe that can be used to contact a point

in the circuit or small clip that can be hooked onto a wire in the circuit.

The other method for making connections is to use a BNC to banana-plug adapter on the oscilloscope input and then use the superstrip leads that we regularly use for the multimeter and power supply connections.

The scope probes are the preferred approach for making connections. They are robust and provide good contact with minimal loss and stray capacitance – important when making measurements on high-frequency signals. They also provide some protection to the oscilloscope input circuitry, which can be damaged if large voltages are applied. They can be broken if mishandled and are expensive to replace. On the other hand, the breadboard leads are easy to use, cheap to replace. For our relatively simple EE 201 measurements, the simple leads may be adequate, but in general, you should avoid using them, because they tend to act like antennas and pick up all sorts of extraneous signals.

Whenever you connect a probe, you must check and set the *probe scaling factor.* Most of the scope probes have a 10x *attenuator* meaning that the incoming voltage is reduced by a factor of 10 on its path to the input circuitry of the oscilloscope. This is how the scope probes provide protection. (Some probes in lab have 100x attenuation.) You must "tell" the oscilloscope that the signal is being attenuated so that it can compensate and provide accurate readings. If you do not set this properly, all of your voltage readings for a given channel will be off by some factor, usually 10.

To check and set the probe scale factor for a particular channel, start by pushing the channel button (section 4 in Fig. 1.) Press the *Probe* softkey that appears – pressing it once causes a pop-up menu to appear. Continue to press the *Probe* softkey until the *Ratio* menu item is selected. Use the *Entry knob* to adjust the ratio until it matches the channel's probe. For the scope probes, the attenuation ratio is printed on the probe case – most in our lab are 10:1. Of course, the breadboard leads have no attenuation, so the ratio is 1:1.

The connections for the four channels are not completely independent. The negative terminals of all four are in common. There are really only five available connections: positive for Ch1, positive for Ch2, positive for Ch3, positive for Ch4, and the one negative that serves all four channels. The common negative connection has two consequences. First, you only need one negative connection from the oscilloscope to your circuit. (This is good since it cuts down on wires.) Secondly, you can only have one negative connection in your circuit – all four channels must reference the same negative connections. (This is bad because it somewhat limits what you can measure.) If you try to connect the two negative leads from two channels to different points in the circuit, you will mess up your measurement. Connecting negative leads to different points in the circuit effectively shorts out the part of the circuit between the two the leads! Be careful.

3. **Autoscale**
   Once the connections are made, you can press the *Autoscale* button to initiate measurements. The oscilloscope will measure the waveforms at each channel. If a repetitive waveform with a measurable amplitude is present, the channel is turned on, and the waveform trace will be drawn on the display. The display time scale is automatically adjusted to show a two (or a

few) period of the waveform. The voltage scaling for each channel is automatically adjusted to that the amplitude of the trace is an appreciable fraction of the total display.

You can use *Autoscale* at the beginning of any measurement. It is also helpful once you have manually messed up all of the settings and can no longer see any traces. Just hit *Autoscale* again, the oscilloscope will take you back to where you began.

4. **Making manual adjustments**
Autoscaling is nice, but usually it does not provide the trace in exactly the form that you would like. You can manually fine-tune the traces on the oscilloscope to get exactly the view that you want.

You can adjust the time scale by turning the *Horizontal* control knob (item 4 in Fig. 1.) Turning this knob adjusts the time / division of the graph on the display, expanding or contracting the trace in the horizontal direction. The current time / division setting is listed at the top left corner of the graph.

The vertical scaling and position for each channel trace are adjusted using the vertical controls (section 3 in Fig. 1). Each channel has its own vertical scaling, and is adjusted using the vertical scale knob (larger knob above the channel buttons). The scaling (V/division) for each channel is given along the top edge of the graph. In addition, the traces can be moved up and down on the graph using the vertical position knobs (smaller knobs below the channel buttons). The zero point for each trace is indicated along the left side of the graph by a small "ground" symbol. You can move two or more traces so that they have the same zero point in order to make direct comparisons. Or you can move traces away from each for clearer viewing.

5. **Measurements & Cursors**
There are various kinds of measurements that can be made on the waveforms. The values for each type of measurement can be displayed for each channel waveform in the area just to the right of the graph. The default measurements are peak-to-peak amplitude and frequency for each active channel. To add more measurements, press the *Meas* key to display the measurements menu in the softkey area. Use the *Source* softkey to choose which channel trace you would like to do the measurement on. Use the *Type* softkey and the *Entry* knob to choose the type of measurement. Then use the *Add Measurement* softkey to add the measurement to the displayed list.

Cursors are extremely useful for comparing different points on one trace or points on different traces. You can use cursors to find time delays and voltage changes in waveforms. There are two x-cursors (time cursors), each of which can be moved to any point along the time axis. There are two y-cursors (voltage cursors), each of which can be moved to any point along the voltage axis. The value of the trace at the cursor point is listed, along with the difference between the two cursors.

6. **Saving traces**
Lastly, you will probably want to save a copy of your measured traces to include in a report. Plug a flash drive into the USB port and press the *Save/Recall* key to enter the Save/Recall

menu in the softkey area. You can then save a screen capture image to a flash drive.

The above sections give only a brief overview of some of the capabilities of the oscilloscope. As with most things in lab, the best way to become proficient in using an oscilloscope is to use it frequently. Don't be afraid to try different things and poke around in some of the menus. If you press and hold a key, a help screen will pop up with some information about the function associated with the key. Also, an extensive manual is available on the web site. http://tuttle.merc.iastate.edu/ee201/lab/agilent2024A.pdf. Reading a thick oscilloscope manual is certainly not a leisure-time activity. However, there is a nice "Getting Started" section at the beginning of the manual. If you want to get all the details on some particular function or feature, you can then dig deeper into the manual.

A simple exercise

Set up a voltage divider like the one shown in Fig. 2 below. For the source, set up the function generator set to provide a sinusoid with a 5-V_{RMS} amplitude and a frequency of 1 kHz. (See the function generator tutorial for details of setting up the function generator.) Measure the voltages on the resistors using the multimeter set to *AC volts* to ensure that the circuit is working properly.
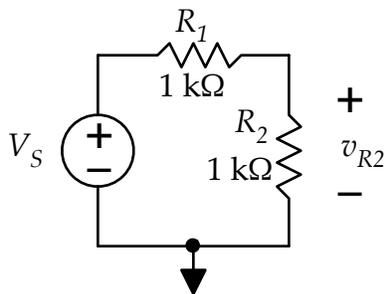
Figure 2. Simple voltage divider circuit for oscilloscope exercise.

1. Power up the oscilloscope.

2. Make connections using scope probes (or use breadboard leads, if no probes are available). Use Channel 1 to measure the source voltage – oscilloscope channel negative to the negative side of the source and oscilloscope channel 1 positive to the positive side of the source. Use Channel 2 to measure the voltage across R_2 – channel 2 positive lead connected to the node between R_1 and R_2. Remember: You do not need to connect the negative side of Channel 2.

3. Press the *Autoscale* key. After a few seconds, the two traces should appear on the oscilloscope display.

4. Adjust the time base (horizontal) so that there are about two full periods displayed on the graph. Note the time scale listed in the upper left-hand corner of the display.

5. Adjust the vertical position of the two traces so that they are both located at the center line of the display's graph. Adjust vertical scaling for Channel 1 so that trace fills as much of the graph as possible without extending outside the graph. Adjust the vertical scaling of Channel 2 to match that of Channel 1. Now you can directly compare the source voltage

and the resistor voltage.

6. Turn on the cursors by pressing the *Cursors* key. Push the cursor's knob (push like it was a button) and then turn the knob to select X1 in pop-up menu. Push the cursor knob again to select X1. Turn the cursor knob to move cursor X1 across the graph. The time and voltage values of the point where the cursor intersects the trace are displayed in the "cursor box". Move the cursor to one of the peaks in the Channel 1 trace. Use the same process to select and move cursor X2 to an adjacent peak in the Channel 1 trace. Note the time difference between the two cursors – it should be one period of the sinusoid. Use the same process to choose and move cursor Y1 to the minimum (trough) of the Channel 1 sinusoid, and then move cursor Y2 to the minimum of the Channel 2 sinusoid. Again, the difference is just the difference in voltage between the input and the output of the voltage divider.

7. Save a screen image of the graph with the two traces and the cursors. Insert a flash drive into the USB port of the oscilloscope. Press the *Save/Recall* key. The Save/Recall Menu will appear in the softkey area. Press the *Save* softkey. The menu changes – press the *Format* softkey, and the *Entry* knob to choose the format – 24-bit .bmp (bitmap) or 24-bit .png (portable network graphics) are are probably good choices. Then use the softkey in the second position to navigate to the desired location on the flash drive for storing your file. Under the *Settings* softkey, you can choose the option *Invert Grat* to change the background color of the graticule from black to white – this might save you a bit of ink when printing out screen images. Finally, press the *Press to Save* softkey to save the image. You should receive a message confirming that the file was stored.

8. Now, play around a bit. Change the type of waveform, the frequency, and the amplitude on the function generator and observe the changes in the oscilloscope traces. Change the time- and voltage-scale settings on the oscilloscope. Poke around a bit and try out some of the different functions of the oscilloscope.