3

Basic Measurements / Oscilloscope and Function Generator

Objective: To learn to use two basic lab tools - the Oscilloscope and the Function Generator.

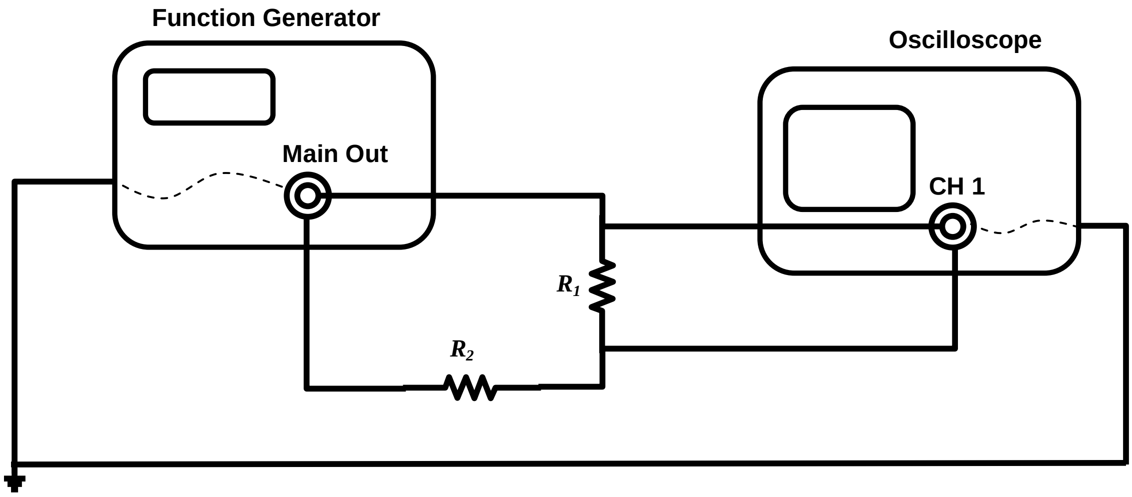
Background Information

Refer to the *Equipment Information* Document at the course web site for background basic information on the oscilloscope and function generator.

These two instruments use BNC type connectors, shown below. With these connectors, rather than mating with separate red and black wires, there is a center contact which mates with the center conductor of a coaxial cable, and an outer conductor which mates with the outer conductor of the same coaxial cable. The outer conductor is always the reference node, and is generally connected to the instruments chassis (metal housing), and to earth ground through the instrument's power cable. The inner conductor is the signal of interest - either the output signal of the function generator, or the signal to be measured by the oscilloscope. Our lab cables have red and black alligator clips added to the coax section – red to the inner and black to the outer conductor.

BNC Connectors

The oscilloscope measures voltage, and since voltage is by definition a difference in potential, this is a two-terminal measurement, the same as with a voltmeter. Note however that when making oscilloscope measurements the reference node is always earth ground. This is in contrast to the DMM where you could connect the black/COM wire to any node you wanted to use as reference. Only one node in a circuit can be at earth ground potential. If you clip two scope reference terminals (black alligator clips) to two different nodes in a circuit, you will short them together through the oscilloscope. This is illustrated below. In the future we will generally let the power supply COM terminal be the same as earth ground (hence the jumper wire on the power supply), so that our oscilloscope measurements are with respect to the common node.



Example of incorrect grounding. R_2 is effectively removed from the circuit since both of its terminals are connected to ground via the power cords of the two instruments.

The above comments strictly apply only if the instruments are in fact connected to earth ground. This will always be true in our lab, but it is possible to make "floating" measurements, either by defeating the grounding of the power cord, or by using a battery-powered oscilloscope.

Terminology (Peak-to-Peak, Average, RMS)

You will be measuring sinusoidal, half-sinusoidal, and square periodic waveforms in this experiment. It is important to understand the terminology used to describe their amplitude characteristics.

Peak-to-peak describes the total amplitude excursion of the signal under measurement, top-to-bottom of the waveform.

Average value is defined as the area under the waveform over some period of time T, divided by T. T should be equal to or an integer multiple of the period. Average value is sometimes referred to as the "DC offset" or "DC component".

$$V_{average} = \frac{1}{T} \int_{t}^{t+T} v(t')dt'$$

RMS refers to "Root Mean Square" and is a measure of the average power associated with the signal. Note that the RMS value of a signal is quite dependent on the waveform type.

$$V_{RMS} = \sqrt{\frac{1}{T}\int_{t}^{t+T}[v(t^{'})]^2\,dt^{'}}$$

Refer to Sections 5-4 and 5-6 in Thomas and Rosa, *The Analysis and Design of Linear Circuits*, 5^{th} ed., Wiley, 2006 for a more in-depth description.

Experiment

Part 1 Ground

1. With the oscilloscope and function generator off, check for continuity between the reference terminals of the oscilloscope and function generator. These are the metallic outer barrels of the Ch 1 and Ch 2 BNC terminals of the scope and the Main Out BNC terminal of the function generator. Recall that a continuity check is just a resistance measurement where any low number of ohms constitutes a connection. Now check continuity between any of these terminals and the Ground terminal of the power supply (temporarily disconnect the jumper wire between COM and Ground). Are they all connected? (The correct answer is "yes".) Temporarily unplug the function generator to verify that the connection between the function generator and oscilloscope is through the power cords.

Part 2 Waveform Viewing and Measurement

Connect the Function Generator's Main Output to Channel 1 of the oscilloscope – red to red and black to black. For later convenience, attach the alligator clips to wires on your breadboard, rather than directly to each other.

1. Set the function generator to output a 1kHz, 4V peak-to-peak amplitude, sine wave. Make sure the DC Offset knob is pushed in, and that the Main 0.2Vp-p button is out. Press the Ch1 menu button on the scope and select DC coupling, BW Limit off, Probe 1x, and Invert off. Adjust the scope's time scale, SEC/DIV knob, to get 2-3 cycles of the waveform displayed. What setting accomplishes this?

2. Press the Measure button to bring up the scope's measurement screen. Set the measurement boxes to use Ch1 as the source, and select Freq, Cyc RMS, Pk-Pk, and Mean as the measurement types. Record the values shown.

3. Configure the DMM as a voltmeter and connect it to the function generator output along with the scope – COM to ground and V/Ω to signal out. Record and compare the voltmeter readings for AC and DC volts. Change the function generator to triangle, and then to square wave, comparing the DMM to the scope. Do the two instruments compute the same RMS value? Which is closest to the theoretical value for the amplitude.

4. Does frequency measured by the oscilloscope match the frequency in the function generator display? Measure the period of the sinewave by counting divisions, and compute frequency as 1/T. Do you agree with the scope? Change the measurement type of one of the measurement boxes to Period. Are the scope's period and frequency measurements self consistent?

5. Use the Horizontal position knob to move the waveform left and right, and then leave it centered. Notice the black arrow at the top of the screen, and the M Pos readout that tells you how far off center you are. Likewise use the Vertical position knob to move the trace up and down, and then leave it centered vertically. Do any of the measurement values change when you adjust the horizontal or vertical position?

Part 3 Triggering

1. Press the Trigger button to access the scope's trigger menu. Select Edge, not Video, Slope Rising, Source Ch1, Mode Auto, and Coupling DC. Be sure you still have 2 - 3cycles of the waveform visible on the screen. Notice the black trigger arrow on right of screen. Adjust trigger level using the Trigger Level knob. What relation is there between the level of the trigger arrow and the value of the waveform at time zero v(t=0)?

2. Change Slope to Falling. What changes? Change the trigger level – is the relationship between trigger level and v(t=0) the same as before? What happens if trigger-level raised beyond amplitude of the trace? Notice the "T Trig'd" at the top changes to"R Auto".

3. Press Run/Stop. What happens? Notice the Stop sign. Press Run/Stop again. With the trigger level still greater than the signal amplitude, change the trigger Mode to Normal. Notice the trigger status is now "R Ready". Adjust the trigger level back down to 500mV.

4. Press Autoset.. What all changed?

Lesson: Don't press Autoset unless you're prepared to have your settings changed.

5. Adjust the function generator to make the output peak-to-peak 1.0V. Make sure you have a triggered, stable display, then disconnect the scope ground (black clip) from the function generator ground. Is it still stable.

6. Reconnect the ground. Press the 0.2Vp-p button on the function generator. Verify that you now have a peak-to-peak amplitude of 100mV. 20mV/Div would be a good vertical sensitivity for viewing this waveform. Try to get a triggered, stable display, then disconnect the scope ground again. What happens? Press Run/Stop to get a look at the signal. Spread it out in time with the Sec/Div knob if you like. Why is it difficult to trigger on this signal?

What you're seeing is the difference in ground references inside the function generator and inside the oscilloscope. Even though we verified with the ohmmeter that these nodes are connected to each other, and to earth ground, it isn't a really solid connection. In terms you will learn later, we could say there is significant impedance at high frequency between the reference terminals. By connecting them together – black alligator clip to black alligator clip – we force them together. Measurements of small signals in really high-speed circuits, like radio receivers, need even better ground connections. A general term for this type of effect is "ground noise".

7. Reconnect the ground and change the trigger coupling to HF Reject. Is it easier to trigger with HF Reject selected? Try the other coupling options.

8. Press autoset. Did anything change? If not, change some settings and press it again.

Lesson: Don't press Autoset unless you're prepared to have your settings changed.

Part 4 DC Offsets, DC/AC Coupling

1. Reset the function generator to the original signal – 1 kHz, sine wave, 4V pk-to-pk. Get a stable display showing 2-3 cycles of the waveform, triggering at the zero level, rising, using Auto mode. Press the Measure button to get the measurement screen. Select AC volts on the DMM. Compare the scope's Cyc RMS measurement to the DMM's AC voltage. Pull out the DC Offset knob on function generator. Adjust until Ch1's Mean =1.0V. Did the DMM AC volts change? How about the Cyc RMS value?

2. Press the CH 1 menu button. Change coupling to AC. Press measure. Now what is Cyc RMS? Mean? What can you conclude about how the scope and DMM measure RMS of a sinewave with a DC offset?

3. Put the DMM in DC volts mode and dial in various DC offsets. Does the scope's display change when the offset changes? Switch Ch1 back to DC coupling. Push in the DC offset knob on the function generator. What happens to the offset?

Part 5 Cursors

1. Set the function generator to produce a 1kHz, 0 to 5V square wave. This means the low-voltage level is 0, or ground level, and the high voltage level is +5V. Trigger on the rising edge of the square wave. Expand the display using the Sec/Div knob to get a good view of the rising edge.

2. Press the Cursor button on the scope to bring up the cursor menu. Select Time as the cursor type and measure the rise time of the square wave. This is the time required for the voltage to change from 10% of the final value to 90% of the final value.   Note that the vertical position knobs are used to adjust the cursor levels.

3. Change the cursor Type to Voltage and measure the overshoot.   That is the amount the signal rises about the final value (5V) before settling.

4. Press the Measure button and change one of the measurement boxes to Rise Time. Does the scope get the same answer you did?

5. Change the measurement to Fall Time? Is there a reading? Change the Trigger slope to trigger on the falling edge. Now is there a Fall Time?

Part 6 Multiple Traces

We will use a new device in this step – the diode. Diodes are nonlinear devices that pass current in only one direction. You are not expected to understand their operation in any great detail at this point.

1. Set the function generator to produce a 5V amplitude, 1 kHz sine wave, with zero DC offset, and connect it to a series diode/resistor circuit as shown in figure 1. Connect channels 1 and 2 of the oscilloscope, and the voltmeter, as shown. Using the Ch 2 menu button, verify that Channel 2 is set for DC coupling.

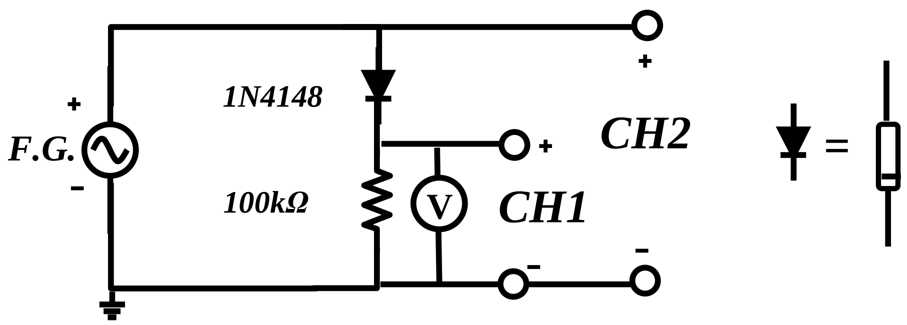


Figure 1.

2. Press Autoset to get an initial acquisition of the two waveforms. If both Ch1 and Ch 2 are not displayed, press the menu button of the one which isn't. You can

alternately press the Ch 1 and Ch 2 menu buttons to see how to remove or recall one or the other trace from the display.

3. Using the Volts/Div knobs set both channels to the same scale. Using the vertical position knobs center both traces; that is, put the zero reference level exactly at the center. Notice the two black arrows on the left of the screen, indicating where these are. Sketch the resulting waveform. Can you explain the waveforms based on the simple statement above describing the operation of the diode?

4. What RMS values do the scope and DMM make for the waveform of channel 1? This is called a half-wave rectified signal.

5. Pull out the DC offset knob and adjust the DC offset of the function generator. Can you get an entire sine wave to appear on the resistor (channel 1)? What DC offset is required? Zero the DC offset (push in the knob).

6. You may notice that the full input signal does not appear on the resistor – there is some voltage drop on the diode. To see this in greater detail, lower the amplitude of the function generator output to 1V. Change the vertical sensitivity of both channels to 500mV/div, making sure the zero reference for each is still the same. Sketch what you see.

7. Now press Autoset. What happens?

Lesson: Don't press Autoset unless you're prepared to have your settings changed.

8. Return the amplitude to 5V and connect the circuit of figure 2. The LED is also a diode, especially designed to emit light at certain wavelengths. Set channel 1 and 2 once again to have the same V/div and the same zero reference position. Both LEDs should be on, although probably not with equal brightness.

9. Adjust the DC offset until the LEDs appear equally bright. What offset is required? From this, which LED would you say is more efficient?

10. Reduce the function generator frequency to 1 Hz. Explain what you see.

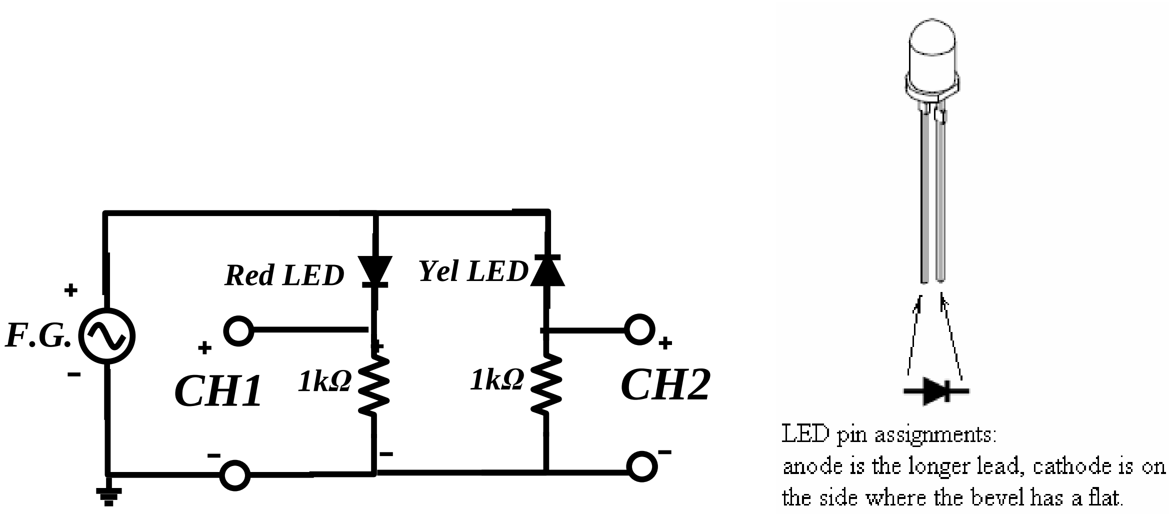


Figure 2

Discussion questions (to be answered in the lab report):

Much of this experiment was tutorial in nature, guiding you through the various steps required to use the oscilloscope and function generator effectively. You do not need to report on all of these observations. The report can focus on the following:

1. Part 4. Calculate the average and RMS values of the 4V peak-to-peak sinewave with and without the 1V DC offset. Compare with the measurements taken with the scope and DMM.

2. Part 5. Report the rise and fall times measured on the square wave. Calculate an average and RMS value for the square wave used in this section.

3. Part 6. You measured what was referred to as a “half wave rectified” sinewave. Explain the waveform observed based on the simple statement above describing the operation of the diode. Sketch or print out the waveform. Report the peak value that you measured, and calculate the average and RMS values of this signal.

4. Explain why a complete sinewave could be observed on Ch. 1 when the DC offset was applied.

5. Explain your observations on the LED experiment (Figure 2).