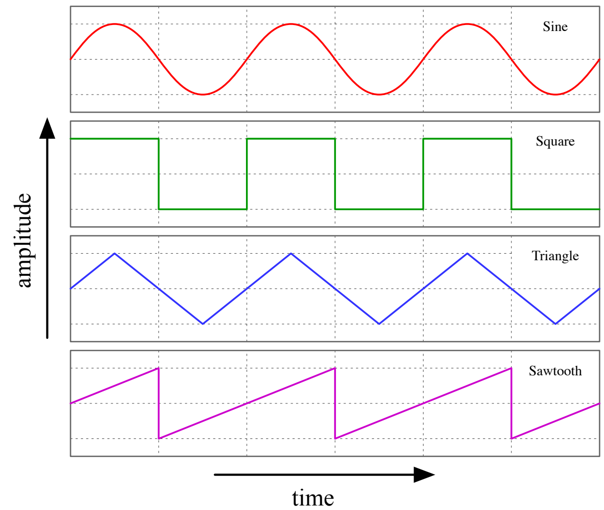
Experiment: Generating AC waveforms with a Function Generator and operating a Digital Oscilloscope

A. Objectives

To learn the basic types and properties of alternating current (AC) signals, how they are generated with a Function Generator and measured with an Oscilloscope.

B. Equipment

- Function Generator
- RIGOL DS1104 oscilloscope (4 Channels, 100 MHz)
- Breadboard, capacitor, various cables, and connectors, especially BNC cables.



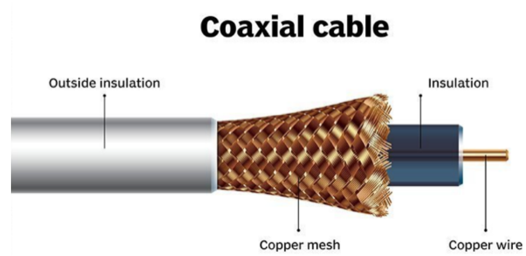
C. Introduction

A function generator is a piece of electronic test equipment or software used to generate different types of electrical *waveforms* over a wide range of frequencies. A waveform is a time-varying voltage or current signal. Some of the most common waveforms the function generator produces are the sine wave, square wave, triangular wave, and sawtooth shapes (shown in the figure). These waveforms can be either repetitive or single shot (which requires an internal or external trigger source). Another feature included on many function generators is the ability to add a DC offset in amplitude.

In this course, we will use only the sine and square waveforms. And the amplitude will be voltage.

D. Generating waveforms with a function generator

We will be using the RIGOL function generator. The output signal is delivered at the BNC[i] connector/cable on the side. A coaxial cable has the ground-voltage conductor as a mesh on the outside and an internal copper wire for the signal (which can be at positive or negative voltage). The ground mesh shields the signal from external sources of noise, such as electromagnetic waves present in the room.



The buttons and switches on the RIGOL signal generator do the following:
POWER switch: turns the device on or off
Sine and Square buttons: changes between generating sine, square waveforms
Output1 button: illuminated when activated. Turns on the output to CH1
Main screen: displays the frequency, amplitude (in volts "peak to peak"), DC offset and phase of the output. Top half is for CH1; Bottom half is for CH2.
Right-side of screen & corresponding blue buttons: Switches between the properties activated to be changed by the user. E.g., Frequency, Period, Amplitude, Offset, Phase.
Rotating knob: used to change the value of the activated property at the "current digit."
Left and Right horizontal arrows below Rotating knob: changes the "digit" to be changed

Once you've familiarized yourself with the function generator, use a BNC cable to connect the output to Channel 1 (CH1) of the signal generator to the oscilloscope. Set the Function Generator to produce a 123 Hz sine-wave with zero DC offset. Set the amplitude to 2.5V and push the Output1 button.

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[i] BNC stands for "Bayonet Neill–Concelman". It is a miniature quick connect/disconnect connector used with coaxial cables, commonly used for carrying radio-frequency signals.

E. Measuring time-varying voltage signals with an oscilloscope

A time-varying signal from the waveform generation can have a frequency as high as ~ MHz. It would be impossible to observe the time variation of the voltage using a digital multimeter. An oscilloscope, a common and fundamental piece of scientific and engineering equipment, is used to observe and measure time-varying voltages. The voltage versus time “plots” shown on the display of an oscilloscope is called the “trace.”

In this course, we will use the Rigol DS1104 oscilloscope that can display four traces (voltage-vs-time plots) simultaneously on the same time axis. The “scope” can sample (i.e., measure) the input voltages up to 10^9 times per sec (1 Giga-Samples/sec). It is capable of analyzing signals with a frequency of up to 100 MHz. A scope measures the voltage at its input. As shown at the BNC connectors, the inputs have an internal resistance of 1 MΩ and can accept up to 300 V (root-mean-squared).

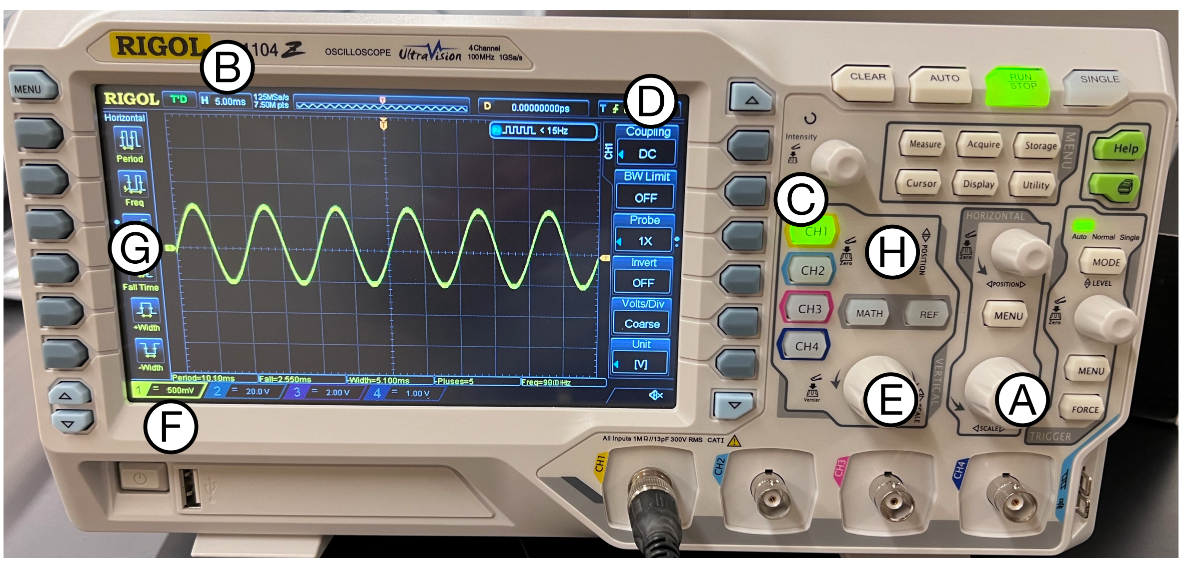
E.1: Adjusting the channel display settings

The (A) knob adjusts the horizontal scale of the display. The time per horizontal division or grid line, the same for the traces of all channels, is shown at location (B). The buttons found at (C) are also lights. If a channel is lit up, the trace for that channel is displayed. Press the button to enable or disable that channel. Pressing the buttons at (C) are used to adjust the settings for that channel. After pressing, the screen at (D) changes to display the following settings:

- Coupling: DC to display the absolute voltage measured on the channel. If this is in AC mode, the offset (calculated from a long-time average) is subtracted from the display so that you won’t see offsets.
- BW Limit: keep as OFF. This is if you want to limit the BandWidth of that channel.
- Probe: Keep as 1x. Different “probes” that can be used with the scope to scale the display voltage. We will make sure we set our probes to 1x as well.
- Invert: keep as OFF. ON means we invert the voltage (positive to negative and negative to positive).
- Volts/Div: keep as coarse for now. Changing this will allow you to make fine adjustments of the vertical scale.
- Unit: Keep as [V] for voltage.

In addition to the above, other settings can be adjusted for a specific channel. The vertical scale of a trace is adjusted by knob (E). The voltage per vertical division for the channels is shown at location (F). The horizontal arrow at location (G) shows the vertical position corresponding to V= 0 V. The 0V-position can be shifted by using knob (H).

Set the time scale so that you can see a whole period T of the signal over two to three horizontal divisions. Set the voltage scale to 1 Volt per division. Set the 0V to be somewhere near the center of the screen.



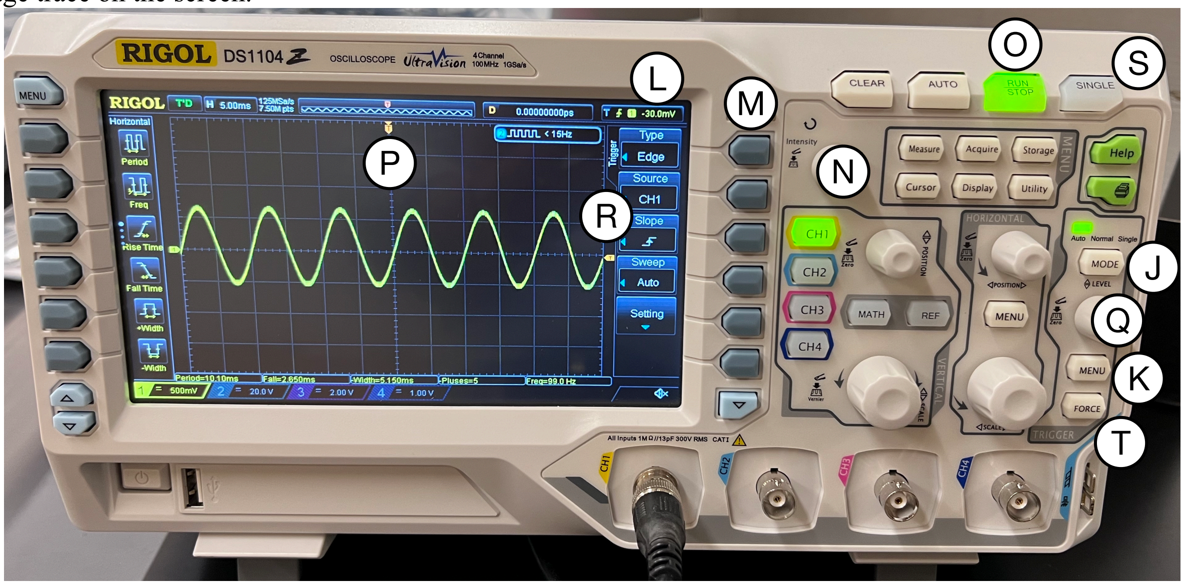
E.2: Adjusting the "trigger" settings

(For your lab report, take photos of the 'scope display with your phone and describe what is happening.) Write down in your labbook the time the photo was taken for a specific part of the lab so it is easier to find the photo later.

Understanding how an oscilloscope triggers is important to know what time interval, or where t = 0, is shown on the display. Your scope may have been previously set up to display a stable voltage trace on the screen. Make sure you have the following settings:

- Set the trigger mode (J) to Auto.
- Press the trigger menu button (K).
- Make settings at (L) the following: Type = Edge, Source = CH1, Slope = upward slope, Sweep = Auto

If you need to change a setting, press the buttons (M) corresponding to that setting, and then turn knob (N) to change the setting, and then press knob (N) to accept. Make sure the Run/Stop button (O) is lit up in green. You should see a stable sine-voltage trace on the screen.



A digital oscilloscope is like a television that continues to display snapshots of the voltages at its input for some time interval (given by the time per division multiplied by the 12 divisions on its display). The location of t=0 is shown where the small orange vertical arrow (P) is. When the display is stable, you are actually watching a (boring) video where the same snapshot is being shown repeatedly. To better illustrate this, turn the trigger level knob (Q) such that the trigger level arrow (R) moves above the highest voltage of the trace. Now, you should see a video where something is changing. Report on this behavior.

To help improve your understanding of what is happening, we are going to trigger the scope manually. To do this, press the Single button (S) and then press the force trigger button (T). This will cause a single snapshot to be shown and then the video is paused. The t=0 of the snapshot shown is at the moment you pressed the force trigger button. You should note that the scope is able to display the signal on both the positive and negative sides of t=0. Press the Single button (S) and then the force trigger button (T) a few times rapidly.

Report: What is the behavior of the snapshots you see? Why do you think this is? Think about the *phase* (or how far along) of the 123 Hz cycle you might be when you press the force trigger button. Do you have control over this?

Repeatedly displaying snapshots of the trace at the same phase at one of the channels is very useful. When the displayed trace is stable, you can make measurements of its amplitude and offset, as well as its period (and thus determine the frequency), and you can also measure the phase difference of the signal in the different. To do this, you'll want the 'scope to trigger the display for you. But you must learn how to tell the machine exactly what to do.

To make the snapshots at a constant phase, lower the trigger level (Q) so that the trigger level arrow (R) is near 0V. Slide the trigger level up and down to the most negative and most positive voltages of the signal. Report on: What do you observe to change? Why do you think this is? Remember that the arrow at (P) is at t=0.

Now you're ready to understand the trigger menu settings (K) and (L) mean. Source = CH1 is to trigger using CH1. The trigger condition is set by Type = Edge and Slope = upward. This tells the device to trigger, which is to set t=0 and display a snapshot, *next time the incoming signal is at the user-set trigger level voltage AND the signal at this time is an upward-sloping edge.*

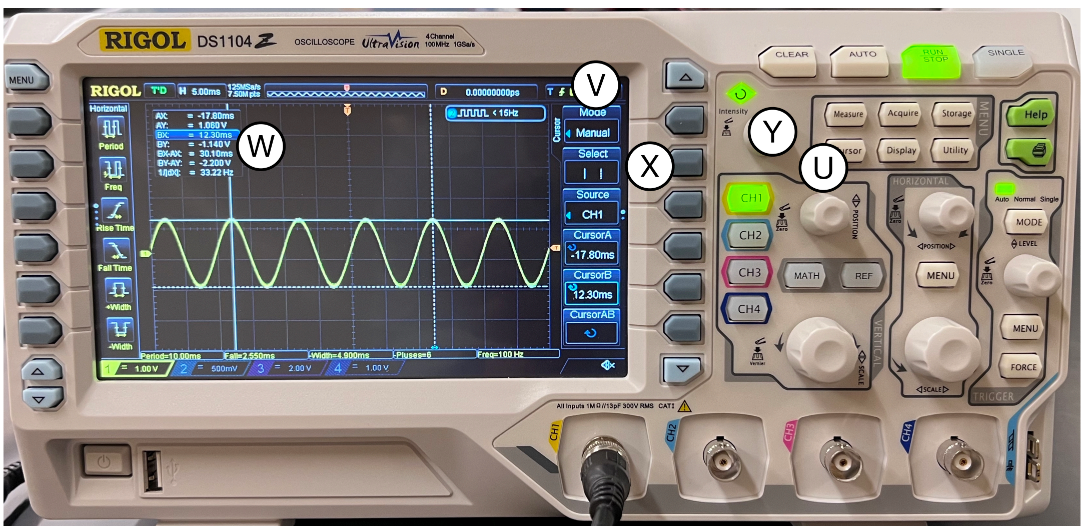
Try changing the Trigger condition's Slope to a downward edge. How does the trace look different at t=0?
E.3: Using the cursor lines for measurements

While the oscilloscope has some built-in settings for performing math and automated measurements of the angles. However, for learning—and to improve understanding of interpreting AC waveforms—performing these measurements with the cursors manually is preferred.

The cursors are the pair of vertical and horizontal lines on the screen that the user can adjust. The cursors menu can be activated by pressing button (U). The settings for the cursors are found at (V). Make sure Mode = Manual.

The positions of the cursor lines are adjusted using knob (Y). Alternate between moving the horizontal and vertical lines by pressing the button corresponding to the Select setting (X). You can toggle between moving each of the two lines or moving both together by pressing on the knob (Y).

The voltage and time values of the lines (as well as their differences) are shown in the box (W). Since voltage scale and offset can be different for each channel, the corresponding channel for the voltage values shown in box (W) are set with the Source = CH1 setting.



F. Exercises using the Function Generator and Oscilloscope

For each of the following exercises, take photos of the scope screen with the correct settings and the cursor lines set up to measure the quantities correctly. Show your working in your lab book if a quantity is needed to be derived. Remember to report measurement uncertainties justifying where they come from.

(a) Set the Function Generator to produce a sine-wave with frequency of 80 Hz, amplitude setting in the middle, and no DC offset. Measure the frequency, peak-to-peak voltage V_{pp}.

(b) For the same frequency and zero DC offset as above, change the voltage amplitude setting and measure the frequency and V_{pp}.

(c) Keeping with zero DC offset and keeping the same amplitude setting, increase the FG frequency to 800 Hz. Measure the frequency and V_{pp},

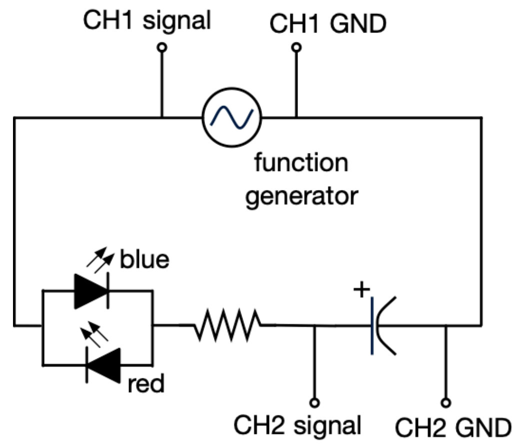
(d) For the same frequency and amplitude above, now add a DC offset of your choice. Measure frequency, V_{pp}, and the DC offset.

(e) Switch to a square wave. DC offset = 0, frequency = 80 Hz. Measure the frequency and V_{pp}

(f) Square-wave. DC offset = 0, frequency = 8 kHz. Measure the frequency and peak-to-peak voltage.

(g) Sine-wave, DC offset = 0, freq. = 200 Hz. Observe two waveforms on the scope simultaneously. Using a BNC Tee splitter on the output of Function Generator, connect two BNC cables into CH1 and CH2. Observe both waveforms but have them vertically offset from each other. Measure frequency and V_{pp} of CH1 and CH2 of both.

G. Charging and discharging a capacitor using a square-wave AC source



In previous experiments, you used push buttons to charge and discharge the capacitor. With the function generator, we can automate this process so that it occurs repeatedly. To do this, build the circuit on the right.

Connect the CH1 of the scope using a BNC Tee-splitter and a coaxial BNC cable.

To build the part of the circuit with the LEDs, resistors and capacitor, you will use the breadboard. To deliver the AC voltage from the BNC cable to the board, you can use the BNC connector on the bottom-right of the breadboard.

For connecting CH2 of the scope, you will use an oscilloscope probe. Probes are connected to the scope via an BNC coaxial cable. On the other end, scope probes commonly have a special "grabber" (for the signal) and an alligator clip (for the ground).

On the probe, there might be a little toggle switch. Make sure it is set to 1x, and make sure the scope input is set to 1x also.

Use the following values:
R = 1 kΩ, C = 10 μF
Trigger on CH1 – normal trigger, raising edge.
Frequency: 4 Hz. Waveform: Square. Amplitude: around 5 V
You might have to increase the Peak-to-Peak voltage for the LEDs to light up.

Recall that during charging and discharging, the voltage across the capacitor is given by:

$$V_C(t) = V_{\max}(1 - \mathrm{e}^{-t/\tau}) \quad \text{(charging)}$$
$$V_C(t) = V_{\max}\mathrm{e}^{-t/\tau} \quad \text{(discharging)}$$

, where V_{max} is the maximum charging voltage.

Measure the time constants for the charging and discharging using the cursors on the scope. It represents the time it takes the capacitor to charge to $V_{\max}\left(1 - e^{-1}\right)$ (when charging), or to discharge to $V_{\max}\left(e^{-1}\right)$ from its maximum voltage (when discharging).

Make sure you take clear pictures of the scope screen and set up during these measurements. Verify that the charging and discharging time constants match the expectation, τ = RC (for same for charging and discharging) with R and C measured with a multimeter.