THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2110: CIRCUIT THEORY LABORATORY

Experiment #2:
Introduction to Lab Equipment: Function Generator, Oscilloscope, and Multisim

EQUIPMENT

Lab Equipment	*Equipment Description*
(1) DC Power Supply	Supplied by the Digilent Analog Discovery 2 (AD2)
(1) Function Generator	Supplied by the Digilent AD2
(1) Digital Multimeter (DMM)	Harbor Freight Model 63759 Handheld Digital Multimeter
(1) Digital Oscilloscope	Supplied by the Digilent AD2
(1) Breadboard	Prototype Breadboard
(1) Test Leads	Banana to Alligator Lead Set
(2) Jumper Wires	

Table 1 – Equipment List

COMPONENTS

Type	*Value*	*Symbol Name*	*Multisim Part*	*Description*
Resistor	2kΩ	R_1	Basic/Resistor	---
Resistor	3kΩ	R_2	Basic/Resistor	---
Resistor	--- Ω	R_{LIMIT}	Basic/Resistor	---
Capacitor	0.082µF	C_1	Basic/Capacitor	Ceramic Disk
LED	Red	LED1	Diodes/LED/LED_red	Red LED

Table 2 – Component List

OBJECTIVES

- Review fundamental theory behind AC signals
- Use the Analog Discovery 2's function generator to generate AC voltage waveforms
- Use the Analog Discovery 2's oscilloscope to measure AC voltage waveforms
- Compare and explain the results obtained from the DMM and the digital oscilloscope for measurements of different periodic waveforms
- Use the AD2's oscilloscope to measure the voltage drop across components in an AC circuit
- Use the AD2's oscilloscope to measure the phase shift between the AC voltage waveforms

INTRODUCTION

In addition to Direct Current (DC) signals, Alternating Current (AC) signals are an important part of circuit theory and design. The circuits encountered in the first lab dealt with DC signals only. The DC power supply is used to produce the DC signals, and the DMM is used to measure the signals. DC voltages are constant over time.

In this lab, circuits will have AC signals. AC voltages vary with time and are generally periodic, meaning they repeat at a specific time interval. **Figure 1** shows four common AC signals: the sine, square, and triangle waveforms. We will use two new pieces of equipment to produce and measure these signals in our circuits. The first piece of equipment, the **function generator,** will be used to produce AC signals. The second piece of equipment, the **oscilloscope,** will be used to measure and visualize the AC signals in the circuit.

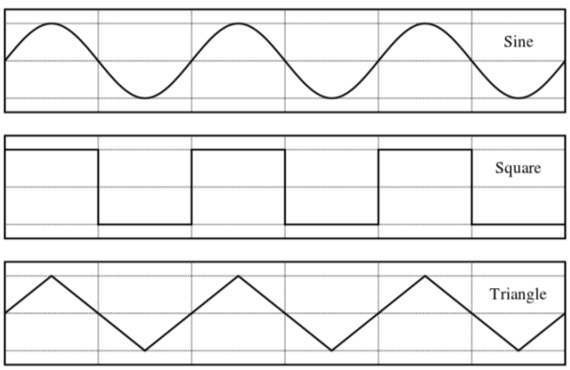


Figure 1 – Common AC Waveforms

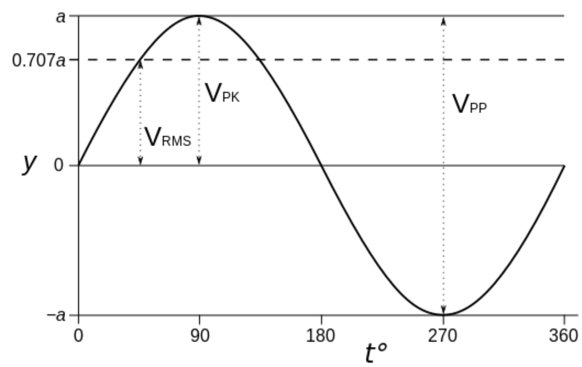


Figure 2 – Sine Wave Showing V_{pp}, V_{pk}, V_{rms}

AC Signal Characteristics

- The **voltage** of an AC, time-varying signal can be described in various ways:
    - **Peak-to-Peak Voltage**: $V_{pp} = V_{max} - V_{min}$
    - **Peak Voltage** (**Amplitude**): $V_{pk} = \frac{V_p}{2}$
    - **Root-Mean-Squared Voltage**:
        - Sine Wave $\boldsymbol{V_{rms}} = \frac{\boldsymbol{V_{pk}}}{\sqrt{2}}$
        - Square Wave $\boldsymbol{V_{rms} = V_{pk}}$
        - Triangle Wave: $V_{rms} = \frac{V_{pk}}{\sqrt{3}}$
- The **frequency** (**f**) of a waveform is equal to the number of repetitions per unit time (unit is Hz).
    - **NOTE**: When frequency is given in radians/second, ω is used $(\omega = 2\pi f)$.
- The **period** (**T**) of a signal is the duration of one cycle of a repeating event (unit is seconds).

$$T = \frac{1}{f} \quad and \quad f = \frac{1}{T}$$

- The **phase shift** (ɸ) of one signal with respect to another is the ratio of the offset between them to their period (assuming both signals have the same period) (unit is degrees or radians)

$$Phase\ Shift(\phi) = \frac{offset}{T} 360° = \frac{offset}{T} 2\pi\ [radians]$$

Introduction to the Function Generator in *WaveForms*

A function generator is an electronic instrument that produces a voltage that varies with time. This function or waveform that is output from the function generator can be used as the input signal to different circuits in a variety of applications.

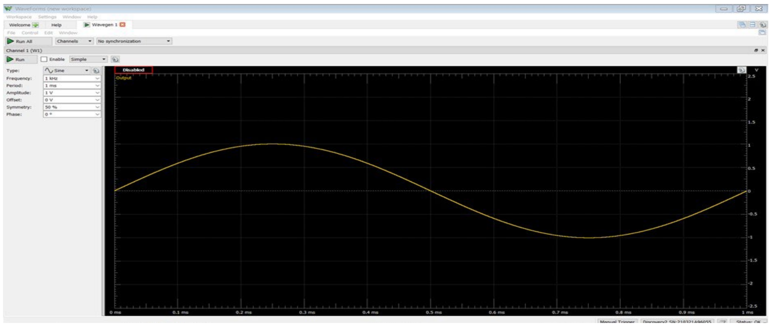


Figure 3 – Opening "Wavegen" screen

The Basics:

- A function generator produces time-varying voltage signals that can be used in AC circuits.
- The function generator used in this lab have two independent output channels.
- The time-varying signal can be configured using the following parameters:
  - **Waveform**: basic types of waveforms are sine, square, and triangle
  - **Frequency**: number of repetitions per unit time (Hz)
  - **Amplitude**: voltage magnitude of the signal (may be defined by V_{pk} or V_{pp})
  - **Offset**: DC offset of the signal (in voltage) with respect to ground
  - **Phase Shift**: offset of the signal (in time) with respect to an unshifted signal

Introduction to the Oscilloscope

An oscilloscope is an electronic measurement instrument that unobtrusively monitors input signals and then graphically displays these signals in a simple voltage versus time format [1].

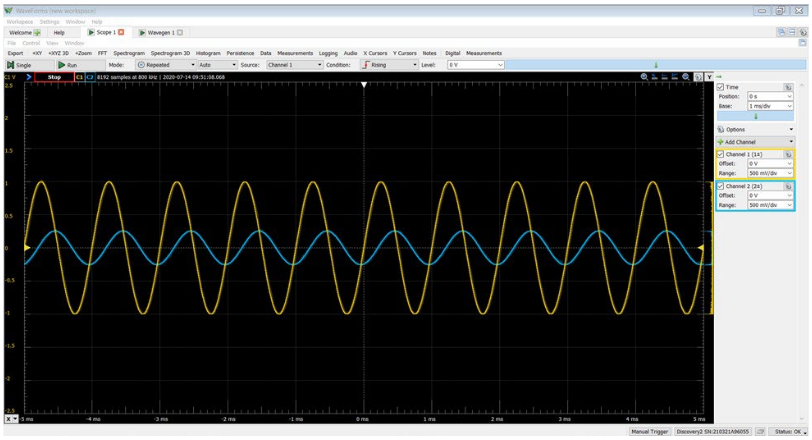


Figure 4 – Oscilloscope in WaveForms

The Basics:

- An oscilloscope measures and displays voltage as it changes with time.
- It consists of a **display** screen with an X & Y-axis and **control panel** seen on the right hand side.
- The X-axis of the display represents time.
- The Y-axis represents voltage.
- Each input channel has its own separate controls.

Setting the Scales for the Oscilloscope's X & Y-Axes

Let us begin by first getting acquainted with the most important controls on the oscilloscope. On the right hand side of the oscilloscope are the two main controls for each input Channel, shown in Figure 5. These drop downs allow you to set the "Offset" and the "Range". The Offset moves the waveforms up and down along the Y Axis. This is useful for when we need to separate the waveforms on screen. The Range adjusts the scaling of the Y Axis, and is labeled V/div, volts per division. You will find that as you increase the V/div value, the "size" of the wave will shrink. The actual value of the wave is not changing, but you are increasing the scale of the Y Axis, so the graph will adjust accordingly. If you lower the V/div value, the wave will appear to grow. Again, the value of the actual wave is not changing, you are now decreasing the scale and the graph adjust accordingly. The Range should be set at a value where you can see both peaks of each wave.

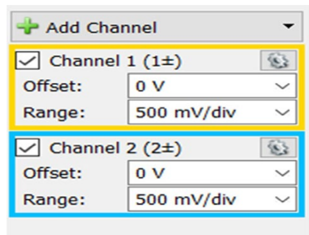


Figure 5 – Channel Controls

Another useful tool within the Oscilloscope is the "Time" feature, which can be found directly above the Channel controls. With this, we can jump to a specific point in time with the "position" feature. This is useful because it not only allows to see the start of our circuit, but we can jump to a specific point where maybe something went wrong within the circuit, allowing us to troubleshoot. This number can be adjusted with the drop-down bar with set time values, by typing in your own value, or by clicking and dragging the white down arrow at the top of the oscilloscope screen. This value can also be changed by clicking on the graph and dragging either left or right. You will see the position value adjust accordingly. The other value is the "Base". Like V/div adjusted the scale of the Y Axis, the base adjusts the scale of the X Axis, but for both channels. The X Axis is measured in seconds per division, or sec/div. This is useful because it can help us home in on one specific cycle or see multiple cycles. This value can also be adjusted by scrolling in or out with the mouse pad or scroll wheel. It is worth noting that the green arrow below the Base value will allow you to change more features along the X Axis. Unless otherwise specified in the lab, you can just leave these values as is.

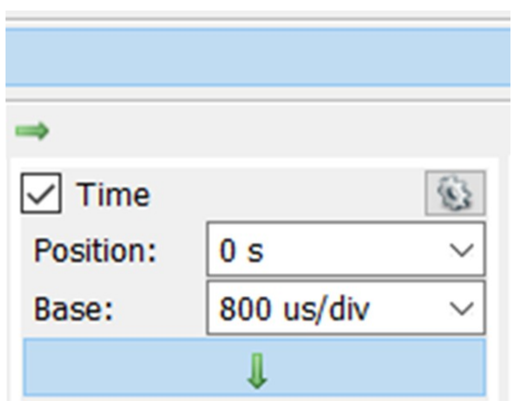


Figure 6 – Time (X Axis) Controls

Key Points:

- The value of the X-axis scale is set using the Time feature, and is measured in sec/div.
- The value of the Y-axis scale is set under each channel, and is measured in Volts/div.
- Both the X and Y Axis can also be adjusted with the mouse.
- Pressing the check button next to each channel will turn on/off the display of that individual channel.

More Important Features

There are many tabs above the Oscilloscope screen, starting with "Export" on the left, all the way to "Measurements" on the right. While you can watch this video to get a full explanation of each of these tabs, the two most important ones are the "Measurements" tab and the "X Cursors" tab. THE MEASUREMENTS TABS DO NOT CREATE THE SAME MENU. To get all the Measurements you will need for this lab and all other labs, it is best to use the Measurements tab that is closer to middle, NOT the one on the far right. The Measurements tab opens a new menu that appears to the left of the Channel controls. By clicking the "Add" button that appears within this menu, we can have the Oscilloscope display very useful data about our waves, on both channels. If we accidentally add a measurement that we do not need, we can simply press the red minus button that is directly right to the Add button. The other important tab is the X cursors tab. This will bring up a menu directly below the Oscilloscope screen. We can add either "Normal" cursors or "Delta" cursors. In this lab, we will use both cursors and see what they do.

A quick note on the AD2's internal wiring: It should be mentioned that the Wavegen and both Channels of the Oscilloscope are internally grounded, meaning that when you go to build the circuits in this class, only the positive ends of these devices are needed when measuring with respect to ground. If you are not measuring with respect to ground, and you want to measure across one specific component, you must use the negative ends of the Oscilloscope Channels (Wires 1- and 2-). These wires will have a white line on them, indicating that they are the negative ends.

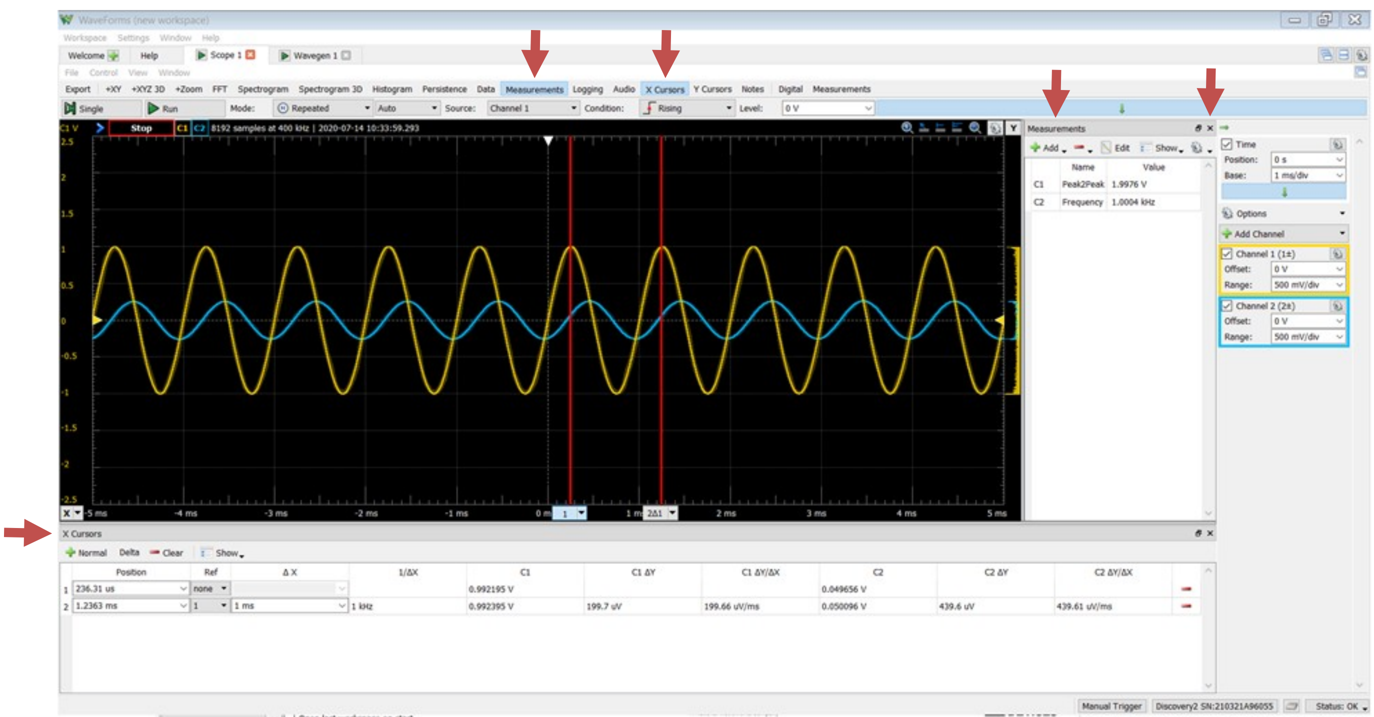


Figure 7 – Example Screen with the Most Common Tabs

Key Points:

- There are many different features available to us with this Oscilloscope, but not all are needed for our purposes.
- It is important to know which "Measurements" tab you are using. The one on the far right will not give you all the measurements you need to display.
- If you ever need to remove a measurement of cursor, there will be a red minus button that will delete them.
- You can also remove both menus from your screen by simply pressing the "x" button at the top right-hand corner of both.

Multiple Channels

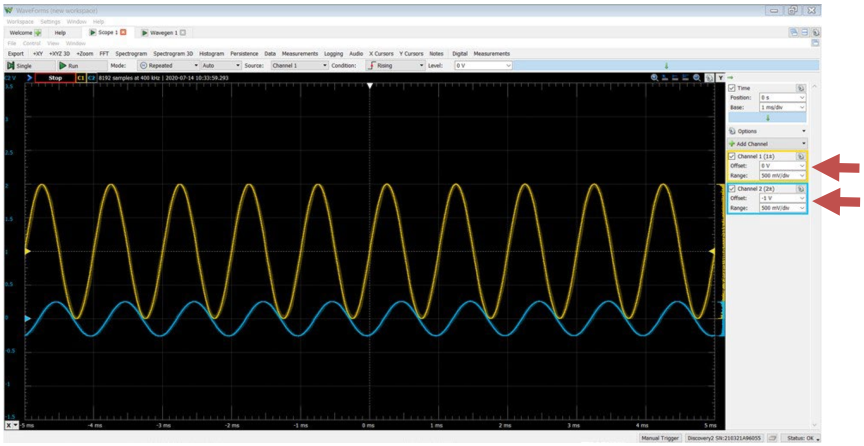


Figure 10 – Display Showing Two Channels

- The oscilloscope only has two separate input channels, allowing two different signals to be displayed on the screen simultaneously (**Figure 10** shows an example with two signals).
- The Offset values allow each signal to be shifted up and down independently of one another. This can be done to separate overlapping signals and to position the signals to make it easier to estimate their amplitudes. In **Figure 10**, the blue (channel-2) has been shifted slightly lower than channel-1.

Waveform Math

- Oscilloscopes ***cannot*** directly measure the voltage across a component unless one end of the component is grounded. Instead, oscilloscope measurements are limited to node-voltage measurements (node voltages are measured with respect to ground by definition).
- For an oscilloscope to measure the voltage across a component, the node voltage waveforms on each side of the component must be acquired and then subtracted.
- The oscilloscope can perform the following math functions:
    - **Add**, **Subtract**, **Multiply**, **Divide, RMS, ATan, AC, and offset.**
- Waveform Math is turned on and the Math menu is accessed by pressing the **Add Channel** button above channel 1 and 2, and then by pressing "Simple" on the drop-down menu.
- **Figure 11** shows the subtraction of two signals. The resulting signal is in the middle.

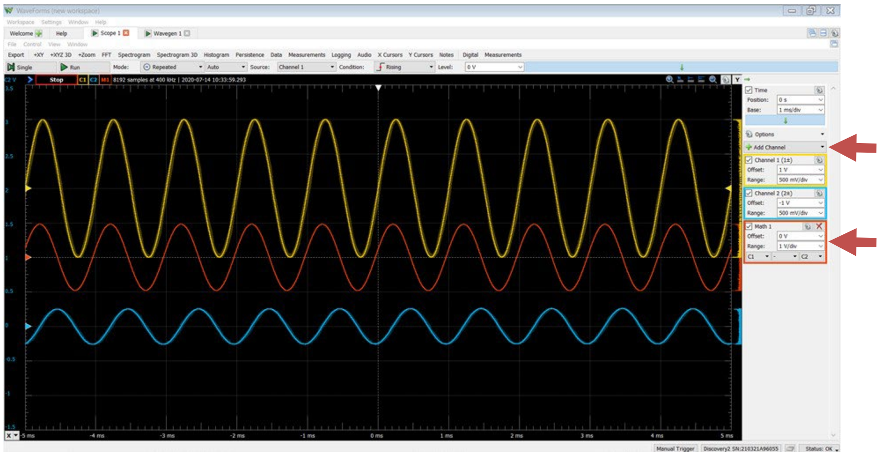


Figure 11 – Subtraction of Two Signals

Reading Capacitors

In Part 4 of this lab, you will be required to use a capacitor. A capacitor is a device that stores electrical charge, but it takes time for this device to charge and discharge, it does not happen instantaneously. The amount of charge the capacitor can hold is measured in Farads. In the last lab, we learned about how to read resistor values. In Part 4 of this lab, we will use a capacitor, so it is important to learn how to read the labels for these components as well. There are many types of capacitors, but the main types you will need in this course are called electrolytic capacitors and ceramic disc capacitors. Electrolytic capacitors (shown in Figure 12) are polarized, meaning that they have a positive end and a negative end. They are easy to read, as their nominal values are written right on the components themselves. Ceramic disc capacitors (shown in Figure 13) on the other hand, are not polarized, meaning that their orientation does not matter in the breadboard. Reading them can be a little trickier though, as their values are given using a series of three numbers, and a letter. The first two numbers are the first two digits of the capacitor, the third number is the multiplier, and the letter is the tolerance. IT IS IMPORTANT TO NOTE THAT THE BASE VALUE FOR CAPACITORS IS PICOFARADS, OR 10^{-12}, SO THE MULTIPLIERS ARE IN TERMS OF PICOFARADS AND YOU MAY HAVE TO CONVERT TO NANO OR MICROFARADS. Some ceramic disc capacitors do not have a letter on them, and all that means is simply a tolerance is not given. A chart is shown below in Figure 14 to illustrate how to read these components.

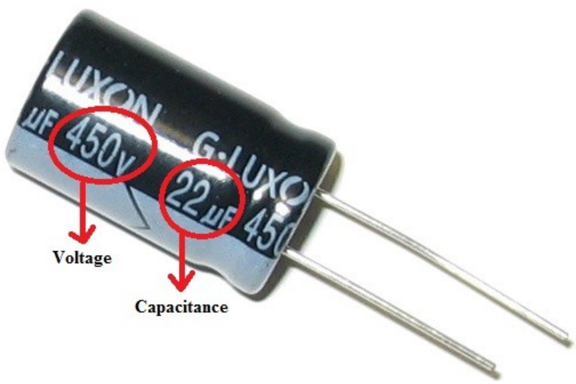


Figure 12 - Electrolytic Capacitor

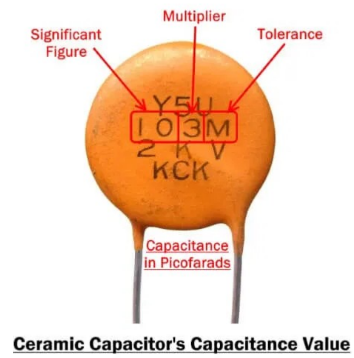
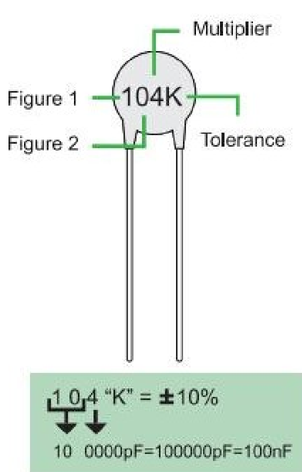


Figure 13 - Ceramic Disc Capacitor



Ceramic Capacitor

VALUE (F1 & 2)	MULTIPLIER	LETTER	TOLERANCE
0	1	B	± 0.1pF
1	10	C	± 0.25pF
2	10^2	D	± 0.5pF
3	10^3	F	± 1%
4	10^4	G	± 2%
5	10^5	H	± 3%
6	N/A	J	± 5%
7	N/A	K	± 10%
8	0.01	M	± 20%
9	0.1	Z	± 80%/-20%

Figure 14 - Ceramic Disc Capacitor Chart

PRELAB

Part I – Using an Oscilloscope

1. **Review** the preceding **Introduction** material on AC signals, the function generator, and the oscilloscope prior to lab.
2. **Review** the specifications for the **Analog Discovery 2's** digital oscilloscope available in the data sheet section of the ECE 2110 website.
3. **Answer** the following questions about the AD2 from the datasheet:
    - What is the **maximum peak input voltage**?
    - What is the **maximum frequency** for the oscilloscope?
    - How many **Channels** can it utilize?
4. **Download** and **Review** the "**Using an Oscilloscope**" PowerPoint presentation from the tutorials section of the ECE 2110 website. This will briefly explain how to use the oscilloscope.

Part II – Reading the Oscilloscope

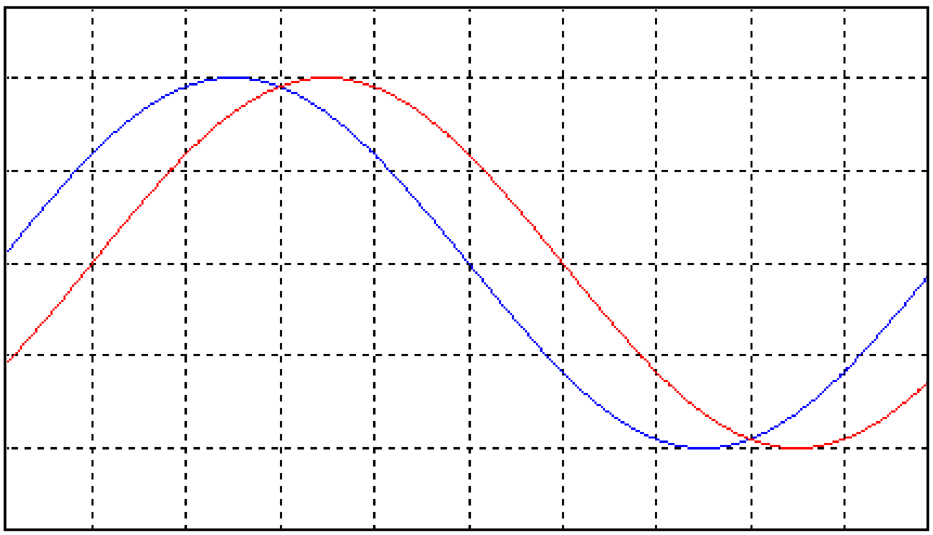


Figure P.1 – Overlapping Sine Waves (Channel-1 – Blue, Channel-2 – Red)

The above graph shows two overlapping sine waves. The oscilloscope is set as follows:

- sec/div is set to 150μs
- Volts/div on channel-1 is set to 50V
- Volts/div on channel-2 is set to 20mV

1. **Complete** the following table based on **Figure P.1**:

Value	***Blue Waveform (CH1)***	***Red Waveform (CH2)***
V_{pp}		
V_{pk}		
V_{rms}		
Period **(s)**		
Frequency **(Hz)**		
Phase Difference **(º)**		

Table P.1 – Prelab Data

Part III – General Oscilloscope Questions

Answer the following questions given the display in **Figure 10** (11 divisions on the x-axis and 10 divisions on the y-axis) and the sec/div and Volts/div controls in **Figure 5** and **Figure 6**.

1. What does the x-axis of the oscilloscope display represent? What does the y-axis represent?
2. What Math functions can the digital oscilloscope perform?
3. If the frequency of an AC signal were too high to be seen on the oscilloscope, would you increase or decrease the sec/div?
4. If the frequency were too low, would you increase or decrease the sec/div?
5. If the largest sec/div you can set is 10s, what is the lowest frequency AC signal you can measure with the digital oscilloscope (to see at least one full period)?
6. If the smallest sec/div you can set is 10μs, what is the highest frequency AC signal you can measure with the digital oscilloscope (to see at least one full period)?
7. If the largest Volts/div you can set is 50V, what is the highest voltage you can measure in terms of V_{pp}, V_{pk}, and V_{rms} with the oscilloscope?

LAB

Part I – Basic Oscilloscope Measurements

1. On the adapter, **attach** a wire to W1. This is channel 1 of the waveform generator
   a. **Attach** another wire to the "1+" pin as well. This will be the probe for the oscilloscope. This setup is shown in Figure 1.1a.
   b. Make sure that the "1-" pin is connected to the adjacent ground pin on J3 with a jumper
2. **Assemble** the circuit shown in Figure 1.1b.
3. Set up **Waveforms.**
   a. Open the Waveforms software on your computer.
   b. Click on the **Wavegen** tab.
   c. Click on the **Scope** tab.

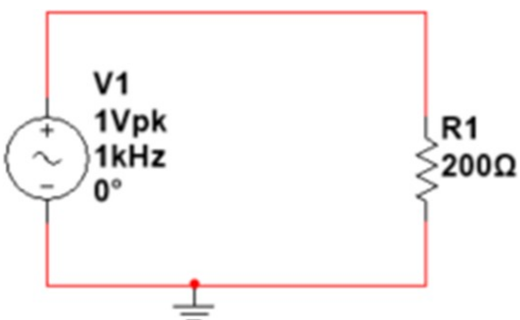


Figure 1.1b - Oscilloscope Testing Circuit

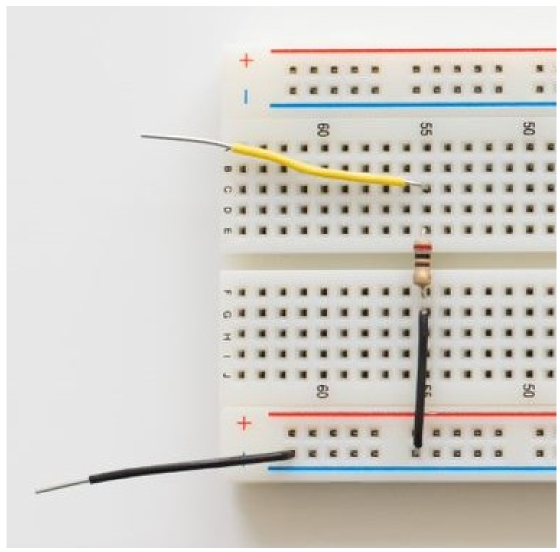


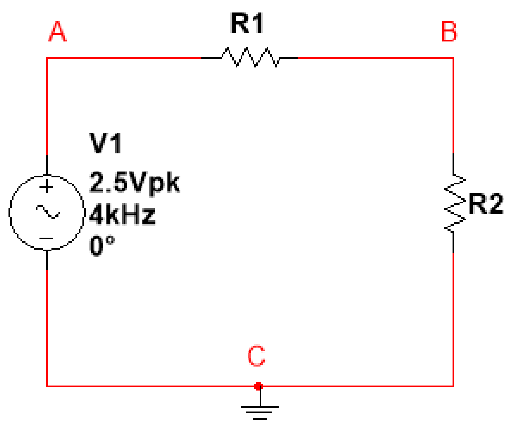
Figure 1.1a - AD2 with WaveGen Ch 1 (Yellow)

4. **Set up** the desired **measurements** to be displayed.
   a. In the oscilloscope you will see a "Measurements" section on the right-hand side.
      i. Press the "Add" button.
      ii. Click "Defined Measurement".
      iii. Click "Channel 1".
      iv. Click "Vertical".
      v. Add the "Maximum", "Minimum", and "DC RMS" measurements.
      vi. Click Horizontal.
      vii. Add the "Frequency" measurement.
      viii. Click "Close".
5. **Click** the play button on both the "Wavegen 1" tab and the "Scope 1" tab.
6. **Click** the stop button on the Scope 1 tab and then the Wavegen 1 tab. **IT IS VERY IMPORTANT TO PRESS STOP IN THIS EXACT ORDER OR YOU WILL NOT SEE THE EXPECTED IMAGE.**
7. **Save** a screenshot of the signal and measurements on the oscilloscope display.
   *******This is how you must capture images of the display to include in lab reports.******

Part II – Generating Sine, Square, and Triangle Waveforms

1. Go to the "Wavegen 1" tab.
2. **Select** the desired **Waveform**.
    a. **Ensure** that the **Sine** waveform is selected.
3. **Configure** the necessary **Parameters**:
    a. **Frequency: 5kHz**
    b. **Amplitude: 5.0V_{pp}**
    c. **Ensure** the **DC Offset** is **0V**.
    d. **Ensure** the **Phase** is **0º**.
4. **Ensure** you have the same setup from Part **I**.
5. **Turn on** the function generator.
6. **Configure** the **digital oscilloscope**.
    a. **Adjust** the vertical **Volts/div** until the entire signal is visible.
    b. **Adjust** the horizontal **sec/div** until the desired waveform is seen on the display. You can use either the drop down or the scroll wheel on a mouse.
    c. **Ensure** you have the same measurements collected in **Part I. I**t is okay if you do not see all 5V, as there may be some clipping.
7. **Save** a screenshot of the signal and measurements on the oscilloscope display.
8. **Change** the signal to a **Square** waveform and repeat steps 5-7.
9. **Change** the signal to a **Triangle** waveform and repeat steps 5-7.

Part III – Waveform Math



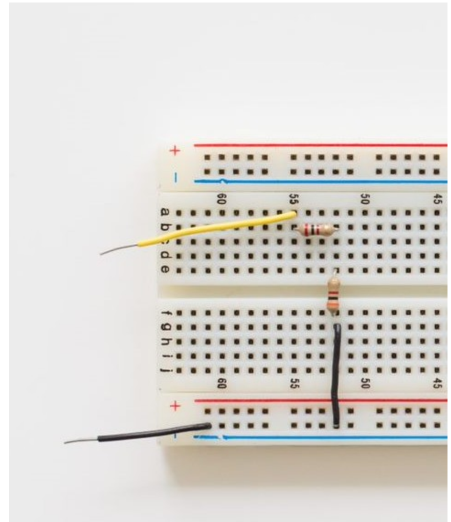


Figure 3.1 – AC Circuit #1

1. **Assemble** the circuit illustrated in **Figure 3.1**. **R_1 = 2kΩ, R_2 = 3kΩ**
2. **Ensure** that **CH2** is checked on within "Scope 1".
3. **Connect** the "1+" wire to measure the voltage of **Node A** with respect to **Node C** (GND).
4. **Connect** a wire to "2+" to measure the voltage of **Node B** with respect to **Node C** (GND) on **CH2** of the oscilloscope.

1. ***Note:*** *The voltage across R_1* ***cannot*** *be measured directly because the outer conductor of the oscilloscope input channel is always shorted to ground. Therefore, we must use node voltages to determine the voltage across R_1.*

5. **Start** the Waveform generator and the oscilloscope.
6. **Stop** the Oscilloscope and then the Waveform generator.
7. **In the Oscilloscope, Use** the "Offset" drop-down to position **CH1 above CH2**, so that the channels do not overlap.
8. **Save** a screenshot showing **CH1 above CH2**. Label **CH1**, **V1** and **CH2**, **V_{R2}** in your lab report.
9. **Add** a Math Channel to the oscilloscope.
   a. On the far right in the "Scope 1" tab, click "Add Channel".
   b. In the drop-down that appears, under "Math:", you will see an option that says "Simple". Click on it, and a red wave should appear on the oscilloscope.
   c. Within the "Math 1" box, which should be under Channel 1 and 2 on the far right, you will see "C1 + C2". Change the plus (+) sign to a minus (-) sign. The Math waveform should adjust accordingly.
10. **Uncheck** CH1 and CH2 to turn them off, leaving only the **Math waveform** visible on the oscilloscope display.
11. **Save** a screenshot of just the **Math** waveform, **A – B**. Label this signal as **V_{R1}** in your lab report.

Part IV – Phase Shift

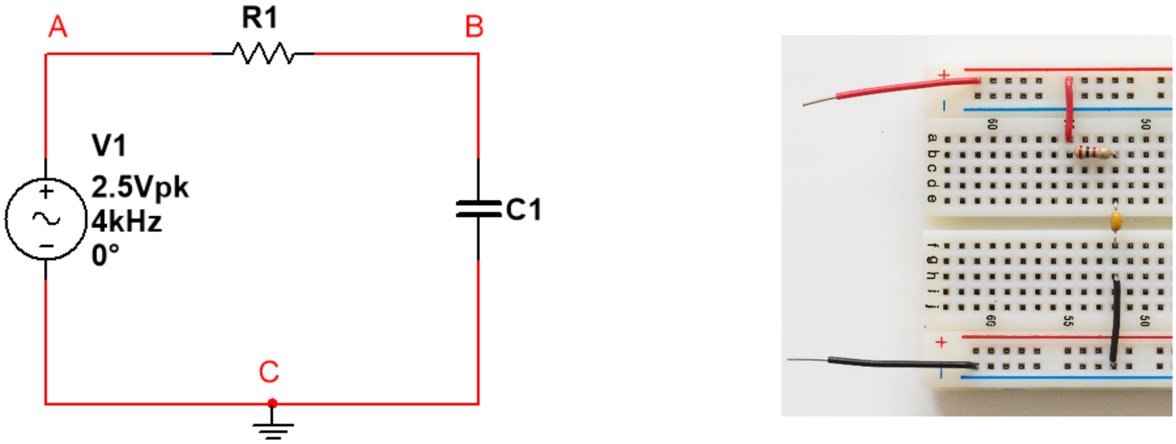


Figure 4.1 – AC Circuit #2

1. **Assemble** the circuit illustrated in **Figure 4.1**. **R_1 = 2kΩ, C_1 = 0.082μF**
2. **Connect** the "1+" wire to measure the voltage of Node A with respect to Node C (GND).
3. **Connect** a wire to "2+" to measure the voltage of Node B with respect to Node C (GND) on CH2 of the oscilloscope.
4. **Start** the Waveform generator and the oscilloscope.
5. **Stop** the Oscilloscope and then the Waveform generator.
6. **Use** the Volts/div drop-downs to position **CH1 above CH2**, so that the channels do not overlap.
7. **Save** a screenshot showing **CH1 above CH2**. Label **CH1**, **V_{R1}** and **CH2**, **V_{C1}** in your lab report.
8. Now set the offsets of both channels back to 0 V.
9. **Save** a screenshot showing **CH1 and CH2 overlapping**. Label this figure appropriately in your lab report.
10. **Measure** the phase shift between V_{C1} and V_{R1}.
    a. Under the "Measurements" box, Press "Add".
    b. Click "Custom Global".
    c. Click "Add". No need to mess with any other options.
11. **Use** the **Cursors** feature to measure the phase shift more accurately between V_{C1} and V_{R1}.
    a. **Press** the **X Cursors** button to turn on cursors.
    b. **Press** the "Normal" button once.
    c. **Press** the "Delta" button once.
    d. Move the "1" cursor the the peak of Channel 1, and the "Delta" cursor to the peak of Channel 2.
    e. Under the "Delta X" column, there should be a time value. **Then use the equation 360 * deltaX * frequency to calculate the phase angle.** Make sure to include this calculation in the lab report.
    f. **Save** a screenshot showing the two signals, cursors, and time shift **ΔX**.

Part V – AC Circuit Analysis Using Multisim

1. The GTA will describe how to simulate an AC circuit in Multisim and obtain time-varying voltage differences across circuit elements.
2. There is also a Tutorial on the ECE 2110 website that explains how to perform an AC Analysis simulation in Multisim. This can be found in Chapter 10, pages 10-35 – 10-37.
3. Perform simulations for the AC Circuits #1 and #2 from **Figure 3.1** and **Figure 4.1** in the lab, and include your results in the lab report.

Part VI – Blinking LED Circuit

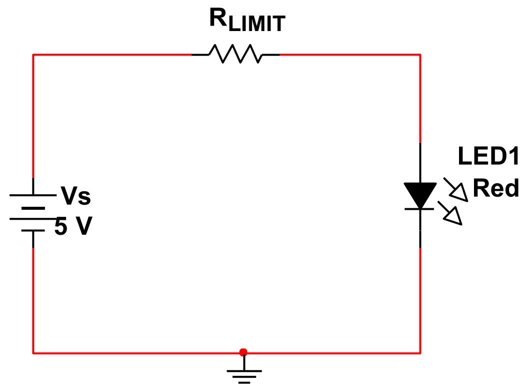


Figure 6.1 – LED DC Circuit

1. **Design** a circuit based on **Figure 6.1** to illuminate the LED.
   a. Use the **DC power supply** set to **5V** as **Vs**.
   b. **Refer** to the data sheet for the **LTL-4221N** Red LED to determine its typical forward voltage. This will be equal to the voltage drop across the LED.
   c. **Calculate** the necessary value for **R_{LIMIT}** to ensure that the current through the circuit is no more than **30mA**.
   Note: *R_{LIMIT} is being used to limit the current allowed to flow through the LED. Limiting resistors are **always necessary** when working with LEDs to ensure that we do not burn them out. Too much voltage or current can easily ruin an LED.*
   d. **Round up** to the closest available resistor for **R_{LIMIT}**. Using a resistance **higher** than the calculated R_{LIMIT} ensures that the current is **less than or equal to 30mA**.
2. **Build** the circuit from **Figure 6.1** on the breadboard using your calculated R_{LIMIT} and observe the behavior of the LED.
3. **Replace** Vs with a square wave produced by the function generator as shown in **Figure 6.2**.
   a. Waveform: **Square**
   b. Frequency: **1Hz**
   c. Amplitude: **5.0V_{PP}**
   d. Offset: **2.5V**

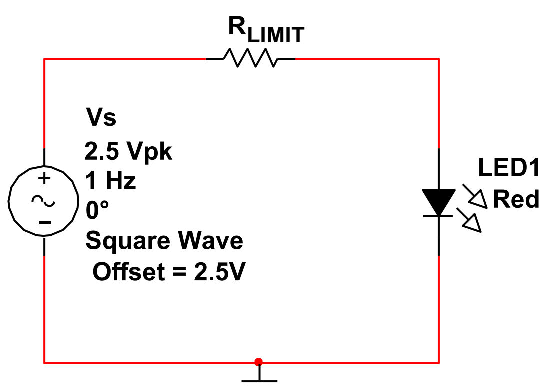


Figure 6.2 – Blinking LED Circuit

4. **Turn on** the function generator after the circuit is assembled. The LED should blink on and off once per second (**1Hz**).
5. **Increase** the **frequency** to find the frequency at which the LED **appears** to stop blinking. The human eye will eventually be unable to perceive the flickering.

POST-LAB ANALYSIS

1. Is it possible to directly measure the AC voltage across a resistor using the digital oscilloscope? **Explain** why or why not.
2. What steps are necessary to determine the AC voltage across a resistor using an oscilloscope?
3. What is the standard AC voltage (V_{rms}) and frequency (Hz) used in most wall outlets in the USA? Why is the frequency important for regular incandescent light bulbs?

REFERENCES

[1] Agilent Technologies. "DSO1000 Educator's Training Resources: Lab Guide and Tutorial for Undergraduate Electrical Engineering and Physics Students: http://literature.cdn.keysight.com/litweb/pdf/54136-97000.pdf