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	Keysight E36311A Triple Output DC Power Supply
(1) Function Generator	Agilent 33522A Function/Arbitrary Waveform Generator
(1) Digital Multimeter (DMM)	Agilent 34460A (DMM)
(1) Digital Oscilloscope	Keysight DSOX1204G Digital Oscilloscope
(1) Breadboard	Prototype Breadboard
(1) BNC T-Connector	One input to two output BNC connector
(1) Test Leads	Banana to Alligator Lead Set
(2) Test Leads	BNC to Alligator Lead Set
(2) BNC Cables	BNC to BNC Cable

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	0.1μF	C_1	Basic/Capacitor	Polyester Film, 104K
LED	Red	LED1	Diodes/LED/LED_red	Red LED

Table 2 – Component List

OBJECTIVES

- Review fundamental theory behind AC signals
- Use the Agilent function generator to generate AC voltage waveforms
- Use the Agilent digital 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 Agilent digital oscilloscope to measure the voltage drop across components in an AC circuit
- Use the Agilent digital 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.

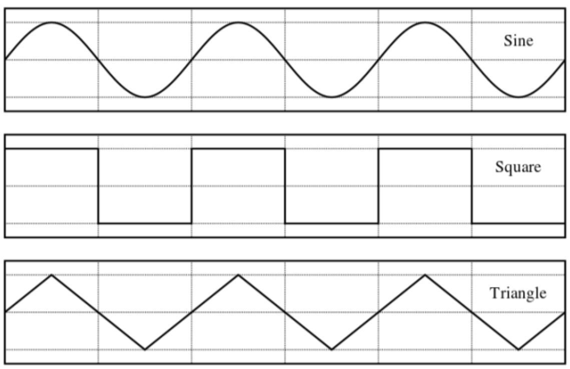


Figure 1 – Common AC Waveforms

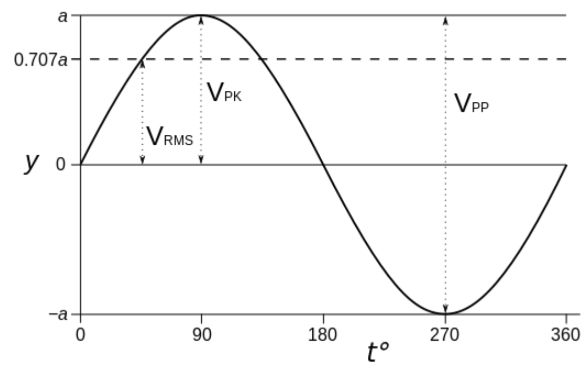


Figure 2 – Sine Wave Showing V_{pp}, V_{pk}, V_{rms}

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**): $V_{pk} = \frac{Vpp}{2}$
  - **Root-Mean-Squared Voltage**:
    - Sine Wave: $V_{rms} = \frac{Vpk}{\sqrt{2}}$
    - Square Wave: $V_{rms} = V_{pk}$
    - Triangle Wave: $V_{rms} = \frac{Vpk}{\sqrt{3}}$
- 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 ($\omega\omega = 2\pi\pi ff$).
- The **period** (**T**) of a signal is the duration of one cycle of a repeating event (unit is seconds).

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

- The **phase shift** (ϕ) 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).

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

Introduction to the Function Generator

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.

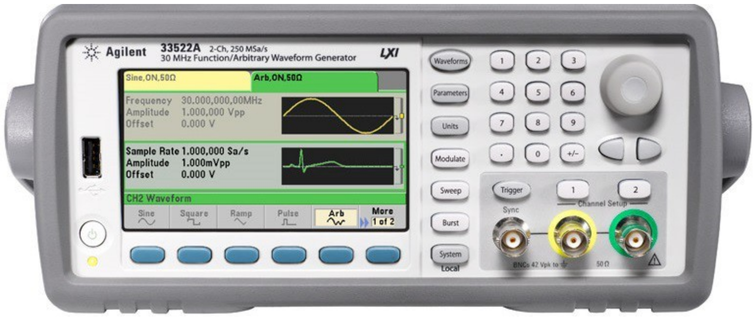


Figure 3 – Agilent 33522A Function Generator

The Basics:

- A function generator produces time-varying voltage signals that can be used in AC circuits.
- The function generators 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 unintrusively monitors input signals and then graphically displays these signals in a simple voltage versus time format [1].

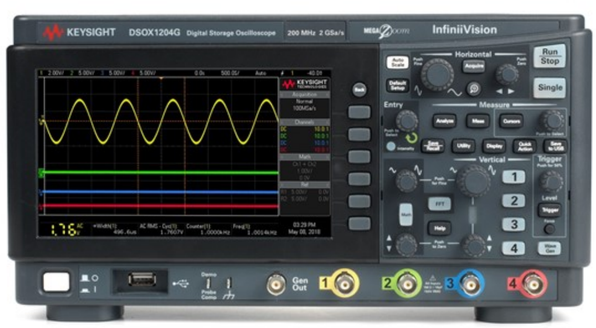


Figure 4 – Keysight DSOX1024G Digital Oscilloscope

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** as shown in **Figure 4**.
- The X-axis of the display represents time.
- The Y-axis represents voltage.
- The control panel has controls for four separate input channels.

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

Let us begin by first getting acquainted with the most important controls/knobs on the oscilloscope. Near the top of the oscilloscope are the "Horizontal" controls shown in **Figure 5**. The larger knob sets the horizontal scaling in seconds/division. This control sets the X-axis scaling of the displayed waveform. One horizontal "division" is the Δ-time between each vertical grid line. If you want to view faster waveforms (higher frequency signals), then you will set the horizontal scaling to a smaller sec/div value. If you want to view slower waveforms (slower frequency signals), then you typically set the horizontal scaling to a higher sec/div setting. The smaller knob in the Horizontal section sets the horizontal position of the waveform. In other words, this control moves the horizontal placement of the waveform left and right.

Figure 5 – Oscilloscope Horizontal (X-axis) Controls

The controls/knobs closer the bottom of the oscilloscope (refer to **Figure 6**) in the Vertical section (just above the input BNCs) set the vertical scaling of the oscilloscope. There are four channel buttons, each labeled 1-4. To change the settings of one the channels, simply press its number and then begin adjusting using the horizontal and vertical controls. There are two main knobs that are used to control all four channels. The larger knob in the Vertical section sets the vertical scaling factor in Volts/division. This is the Y-axis graphical scaling of your waveforms. One vertical "division" is the ΔV between each horizontal grid line. If you want to view relatively large signals (high peak-to-peak voltages), then you would typically set the Volts/div setting to a relatively high value. If viewing small input signal levels, then you would set the Volts/div setting to a relatively low value. The larger knob can be pressed in for finer tuning of the Volts/div scale, allowing for more precise measurement. When pressed, you will see a pop-up appear on screen with a blue box indicating that it has been activated. The smaller control/knob in the Vertical section is the position/offset control. You use this knob to move the waveform up and down on the screen.

Figure 6 – Oscilloscope Vertical (Y-axis) Controls

Key Points:

- The value of the X-axis scale is set using the sec/div knob under the Horizontal section.
- The value of the Y-axis scale is set using the Volts/div knob under the Vertical section.
- The smaller knobs in each section can be used to move the signal around the display.
- Pressing the 1, 2, 3, or 4 button will turn on/off the display of individual channels.

Triggering

Another very important oscilloscope setup variable is the trigger level control/knob shown in **Figure 7**. This control knob is located near the right-hand side of your scope's front panel, just below the section labeled Trigger. Triggering is probably the least understood aspect of an oscilloscope, but it is one the most important capabilities of a scope that you should understand. Think of oscilloscope "triggering" as "synchronized picture taking." When an oscilloscope is capturing and displaying a repetitive input signal, it may be taking thousands of pictures per second of the input signal. In order to view these waveforms (or pictures), the picture taking must be synchronized to "something." That "something" is a unique point in time on the input signal.

Figure 7 – Oscilloscope Trigger Level Control

Key Points:

- The oscilloscope's trigger function synchronizes the horizontal sweep to produce a stable waveform on the display.
- Oscilloscopes display a moving wave. When the wave runs out of space on the display screen, it continues, starting at the far left. When that section of the wave is not aligned with the section of the wave already on the display screen, it is untriggered, and either appears to be moving as shown in **Figure 8**.
- Adjusting the trigger knob defines where on the wave to trigger (on the way up or the way down), as illustrated below, until the wave becomes stable (see **Figure 9**).
- It is common to simply push the Trigger knob on the oscilloscope to trigger at 50% of the signal, but understanding how to manually trigger is an important skill to learn.

Correct Trigger Level
(Notice only one continuous wave can be seen)

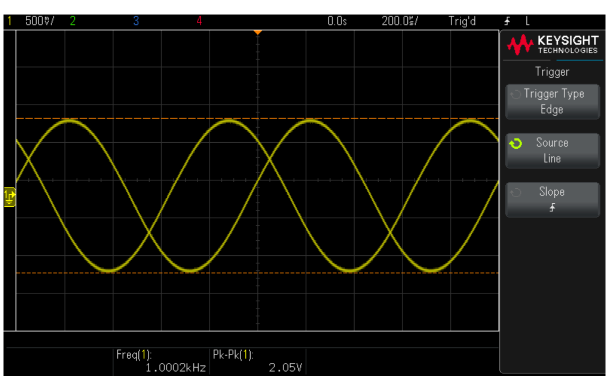


Figure 8 – Untriggered Signal

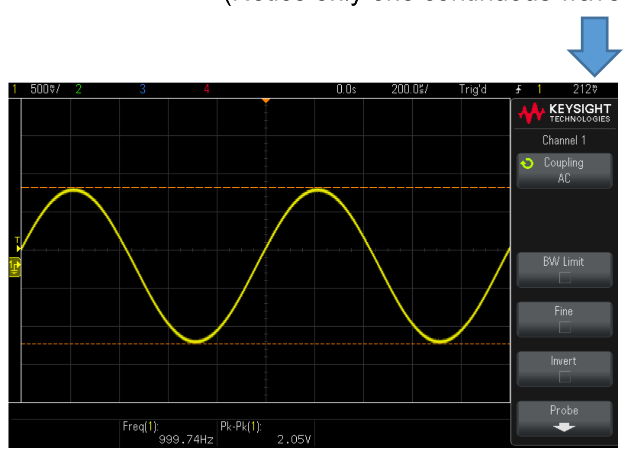


Figure 9 – Properly Triggered Signal

Multiple Channels

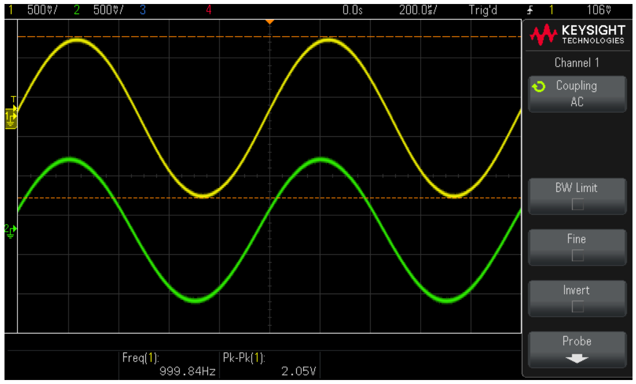


Figure 10 – Display Showing Two Channels

- The oscilloscope in **Figure 4** has four separate input channels, allowing four different signals to be displayed on the screen simultaneously (**Figure 10** shows an example with two signals).
- The vertical position dial allows 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 green signal (channel-2) has been shifted slightly lower than channel-1.

Waveform Math

- The outer conductor of the coaxial BNC cables used by oscilloscopes is always grounded. Therefore, oscilloscopes ***cannot*** directly measure the voltage across a component unless one end of the component is grounded. Instead, oscilloscope measurements are limited to nodevoltage 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 oscilloscopes in lab can perform the following math functions:
  - **Add**, **Subtract**, **Multiply**, and **FFT** (Fast Fourier Transform)
- Waveform Math is turned on and the Math menu is accessed by pressing the **Math** button located on the left side of the front panel of the oscilloscope.
- **Figure 11** shows the subtraction of two signals. The resulting signal is in the middle.

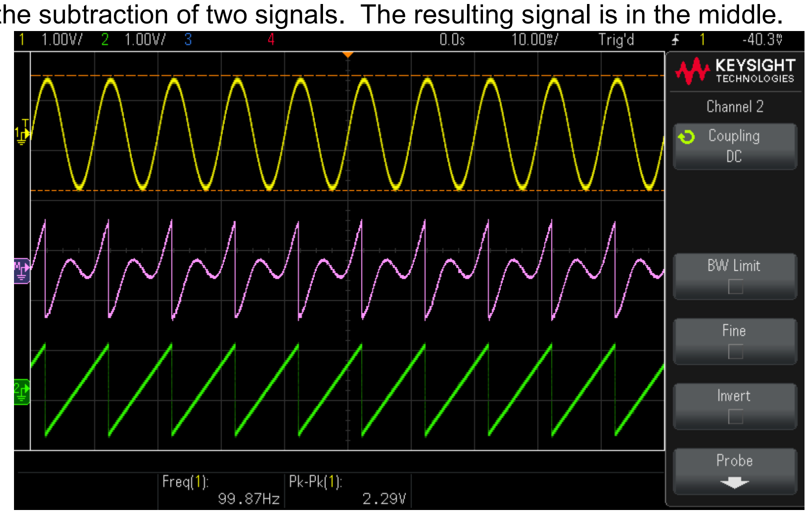


Figure 11 – Subtraction of Two Signals

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.

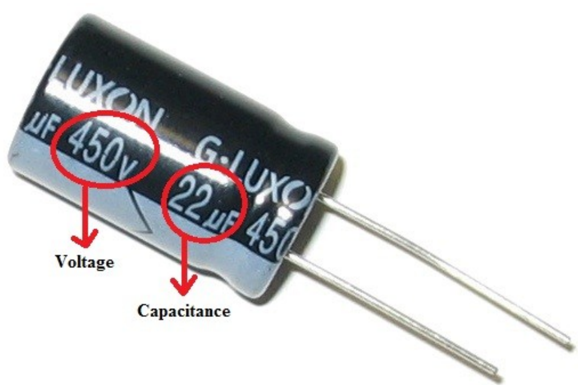


Figure 12 - Electrolytic Capacitor

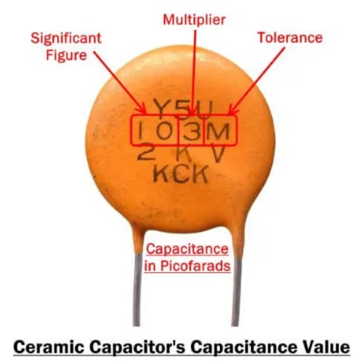
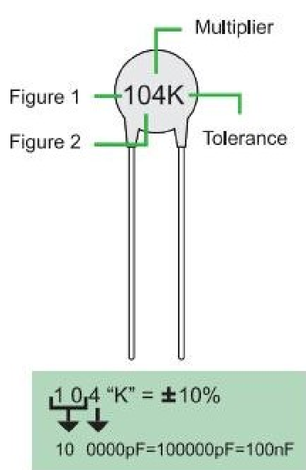


Figure 13 - Ceramic Disc Capacitor



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 Keysight DSOX1024G digital oscilloscope available in the data sheet section of the ECE 2110 website.
3. **Answer** the following questions about the Keysight DSOX1024G from the data sheet:
    - What is the **maximum peak input voltage**?
    - What is the **input impedance**?
    - What is the **maximum frequency** for the oscilloscope?
    - What is the **sample rate**?
4. **Download** and **Review** the "**Using an Oscilloscope**" [2] 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

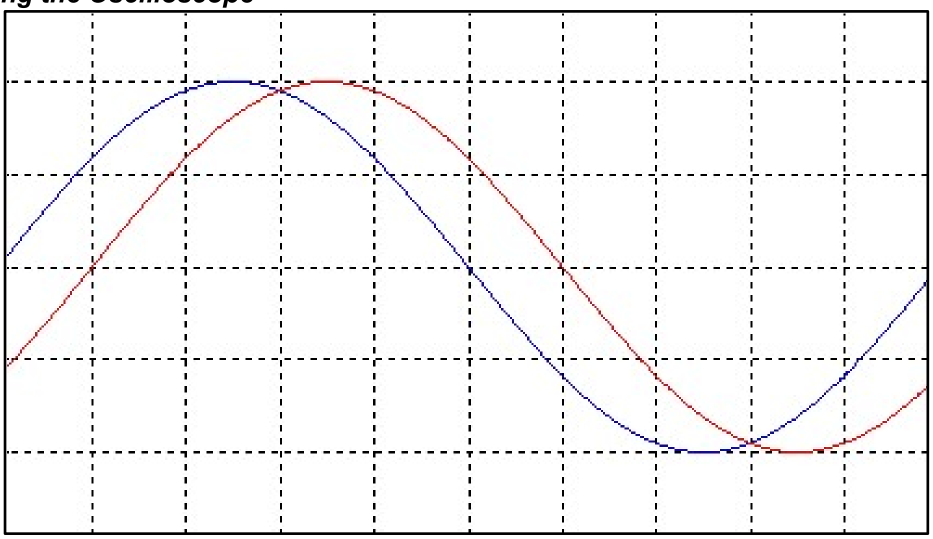


Figure P.1 – Overlapping Sine Waves (Channel-1 – Blue, Channel-2 – Red)

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

- sec/div knob is set to 150µs
- Volts/div knob on channel-1 is set to 50V
- Volts/div knob 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** (12 divisions on the x-axis and 8 divisions on the y-axis) and the sec/div and Volts/div knobs 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. **Configure** the **Keysight DSOX1024G** digital oscilloscope.
   ******The following steps should be done prior to each use of the oscilloscope.******
   a. **Turn on** the oscilloscope.
   b. **Press** the **Default Setup** button on the front panel.
   Note: Default Setup *will put the oscilloscope into a factory-preset configuration. Not only will this set the scope's X and Y scaling factors to preset values, but it will also turn off any special modes of operation that one of your fellow students may have used. When beginning new measurements with the scope, it is always good practice to begin with a default setup.*
   c. **Press** the channel-1 button to bring up its menu and ensure the **Probe ratio** is set to **1.00:1**.
   d. Select **Display -> Grid** and change **Intensity** to **100%** by turning the "Entry" knob.
   e. Click the **Intensity** button and set this value to 100%.
   f. On the same menu, change **Screen** from Normal to **Inverted**. This will invert the colors on the display, providing a white background that is better for printing after images are saved.
   g. **Press** the **Back** button multiple times to return to the main screen.
2. **Connect** the BNC end of the BNC to alligator test leads to channel 1.
3. **Connect** the alligator ends of the test leads to the **Probe Comp** terminals of the oscilloscope shown below in **Figure 1.1**. **Attach** the red lead to the left terminal (test signal output) and the black lead to the right terminal (ground).

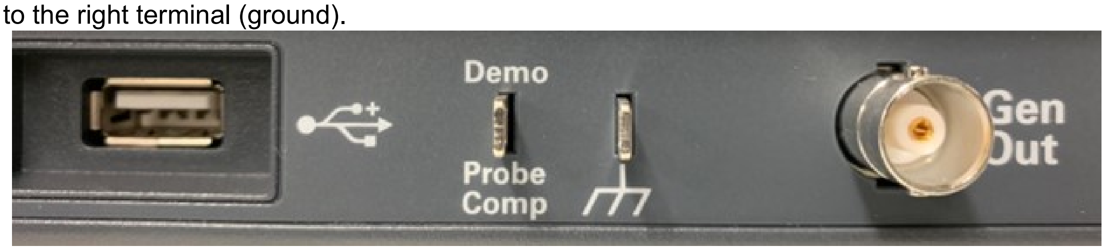


Figure 1.1 – Oscilloscope Probe Comp Terminal

4. **Push** the **Trigger** knob to set the triggering to 50%.
5. **Adjust** the vertical **Volts/div** knob until the entire signal is visible.
6. **Adjust** the horizontal **sec/div** knob until a square wave is seen on the display (see **Figure 1**).
7. **Set up** the desired **measurements** to be displayed.
   a. **Press** the **Measure** button to bring up the measurement menu.
   b. **Ensure** that **CH1** is selected as the input channel to measure.
   c. Select **Voltage**, scroll to $\mathbf{V_{max}}$, and push the select knob to add that measurement.
   d. Select **Voltage**, scroll to $\mathbf{V_{min}}$, and push the select knob to add that measurement.
   e. Select **Time**, scroll to **freq**, and select it to display the **frequency** of the signal.
8. **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.****** a. **Insert** your **USB** drive.
   b. **Press** the **Save/Recall** button to show the menu for saving a screenshot of the display.
   c. Select **Waveform** and scroll down to select **PNG** to save as an image file
   d. Select **External** to save to the USB drive.
   e. Select **New File** and type a name or use the default name, and **Save** the file to your USB.

Part II – Generating Sine, Square, and Triangle Waveforms

1. **Configure** the **Agilent 33522A** function generator for use with the oscilloscope.
   ******The following steps should be done prior to each use of the function generator.******
   a. **Turn on** the function generator.
   b. Select **channel-1** by pressing the "**1**" above **Channel Setup** on the right-hand side.
   c. Select **Output Load** and change it from 50Ω to **High-Z**.
      i. **Press** the **"Set To High Z"** key below the display.

   Note: *The oscilloscope that we use has a high internal impedance/resistance (1MΩ), and it is seen as a load to the function generator. Therefore, we must "tell" the function generator its load impedance/resistance correctly in order to get the correct output signal from the function generator. Keep in mind that this step is* ***always necessary*** *when connecting between the function generator and the digital oscilloscope.*
2. **Select** the desired **Waveform**.
   a. **Press** the **Waveform** key.
   b. **Ensure** that the **Sine** waveform is selected.
3. **Configure** the necessary **Parameters**:
   a. **Press** the **Parameters** key.
   b. **Frequency: 4kHz**
      i. **Select Frequency** using the buttons below the display.
      ii. **Type** in a "**4**" using the keypad on the right side.
      iii. **Select kHz** from the unit options on the display.
   c. **Amplitude: $5.0V_{pp}$**
      i. **Select Amplitude** using the buttons below the display.
      ii. **Type** in a "**5**" using the keypad on the right side.
      iii. **Select Vpp** from the unit options on the display.
   d. **Ensure** the **DC Offset** is **0V**.
   e. **Ensure** the **Phase** is **0º**.
4. **Connect** the **BNC T-connector** to the channel-1 output of the function generator.
5. **Connect** a BNC cable from the T-connector to the CH1 input of the digital oscilloscope.
6. **Set up** the **DMM**.
   a. **Configure** the DMM to measure **RMS AC Voltage**.
   b. **Set** the DMM for **Auto Scale**.
   c. **Connect** a **BNC to alligator** test lead to the open end of the **BNC T-connector**.
   d. **Connect** a **banana to alligator** test lead to the DMM.
   e. **Connect** the mini-grabber and alligator leads together so that the DMM will **measure** the **AC Voltage** of the function generator once you turn it on.
7. **Turn on** channel-1 on the function generator.
   a. **Select** channel-1 using the Channel Setup button on the right-hand side.
   b. **Press Output On** in the lower left to enable the signal.
8. **Configure** the **digital oscilloscope**.
   a. **Select CH1** by pressing the "**1**" button on the oscilloscope. It will light up when pressed.
   b. **Adjust** the vertical **Volts/div** knob until the entire signal is visible.
   c. **Adjust** the horizontal **sec/div** knob until the desired waveform is seen on the display.
   d. Add **Measurements** to the display as you did in ***Part I*** for **V_{pp}**, **V_{rms}**, and **frequency**.
9. **Save** a screenshot of the signal and measurements on the oscilloscope display.
10. **Record** the **AC Voltage** value from the DMM. *Remember this is* V_{rms} *not* V_{pk} *or* V_{pp}.
11. **Change** the signal to a **Square** waveform and repeat steps 8-10.
12. **Change** the signal to a **Triangle** waveform and repeat steps 8-10.

   Note: *The Triangle waveform is under the* ***More*** *section of the function generator's* ***Waveform*** *options menu.*

Part III – Waveform Math

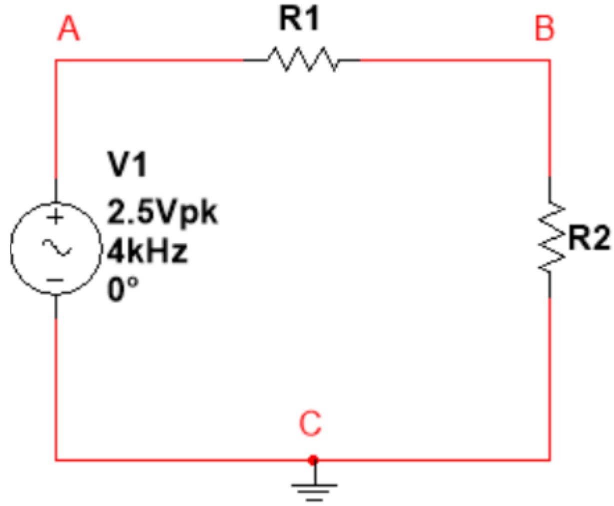


Figure 3.1 – AC Circuit #1

1. **Assemble** the circuit illustrated in **Figure 3.1**. **R_1 = 2kΩ, R_2 = 3kΩ**
2. **Complete** the digital oscilloscope setup as described above for **CH2**.
3. **Connect** one set of the BNC to mini-grabber test leads to measure the voltage of **Node A** with respect to **Node C** (GND) on **CH1** of the oscilloscope.
4. **Connect** another BNC to mini-grabber test lead 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. **Use** the Volts/div knobs and the vertical position knobs to position **CH1 above CH2**, so that the channels do not overlap.
6. **Save** a screenshot showing **CH1 above CH2**. Label **CH1**, **V1** and **CH2**, **V_{R2}** in your lab report.
7. **Press** the **Math** button and subtract **CH2 from CH1** (**A – B**).
8. **Press** the buttons for CH1 and CH2 twice to turn them off, leaving only the **Math waveform** visible on the oscilloscope display.
9. **Save** a screenshot of just the **Math** waveform, **A – B**. Label this signal as **V_{R1}** in your lab report.

Part IV – Phase Shift

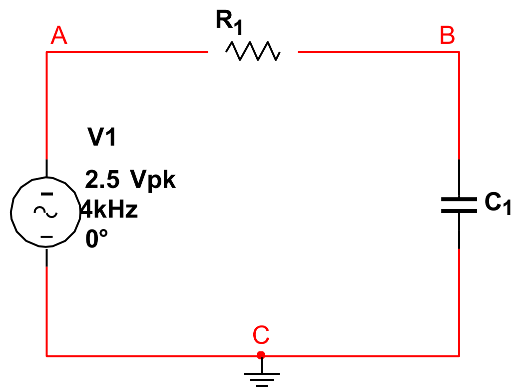


Figure 4.1 – AC Circuit #2

1. **Assemble** the circuit illustrated in **Figure 4.1**. **R_1 = 2kΩ, C_1 = 0.1µF**
2. **Connect** one set of the BNC to mini-grabber test leads to measure the voltage of **Node A** with respect to **Node C** (GND) on **CH1** of the oscilloscope.
3. **Connect** another BNC to mini-grabber test lead to measure the voltage of **Node B** with respect to **Node C** (GND) on **CH2** of the oscilloscope.
4. **Use** the Volts/div knobs and the vertical position knobs to position **CH1 above CH2**, so that the channels do not overlap.
5. **Save** a screenshot showing **CH1 above CH2**. Label **CH1**, **V_{R1}** and **CH2**, **V_{C1}** in your lab report.
6. **Press** the vertical position knobs for **CH1** and **CH2** to center both signals on the y-axis. This should position them so that they **do overlap**.
7. **Save** a screenshot showing **CH1 and CH2 overlapping**. Label this figure appropriately in your lab report.
8. **Measure** the phase shift between V_{C1} and V_{R1}.
   a. **Press** the **Measure** button, then **Time**.
   b. **Scroll** down the list and select **Phas A→B**.
   c. **Save** a screenshot showing the **phase shift**.
9. **Use** the **Cursors** feature to more accurately measure the phase shift between V_{C1} and V_{R1}.
   a. **Press** the **Cursors** button to turn on cursors.
   b. **Use** the selection knob to move the first cursor to the **peak** of your first signal.
   c. **Press** the **Cursors** option on the screen, then select X2.
   d. **Move** Cursor X2 to the **peak** of the second signal.
   e. **Save** a screenshot showing the two signals, cursors, and time shift **ΔX**.

   Note: *At this point, the display will show* ***ΔX****, which is the time difference between the peaks. We can use this information together with the frequency of the signal to calculate the phase shift. The frequency tells us the period of the signal, and* ***ΔX*** *is the percentage of the period that the two signals differ. The same percentage of 360° is the phase shift we are looking for.*

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 simulation in Multisim. In particular, look at pages: 20-23.
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

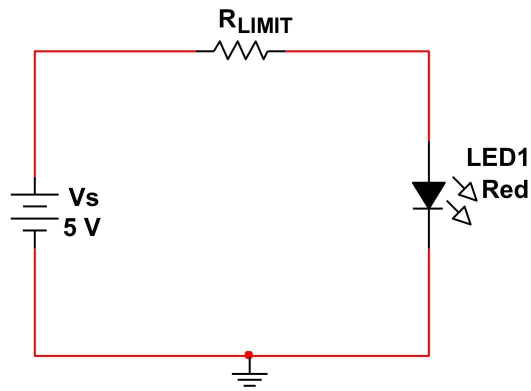


Figure 6.1 – LED DC Circuit

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 **AND130CR** 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 $\mathbf{R_{LIMIT}}$ 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 $\mathbf{R_{LIMIT}}$. 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**: $\mathbf{5.0V_{PP}}$
   d. **Offset**: **2.5V**

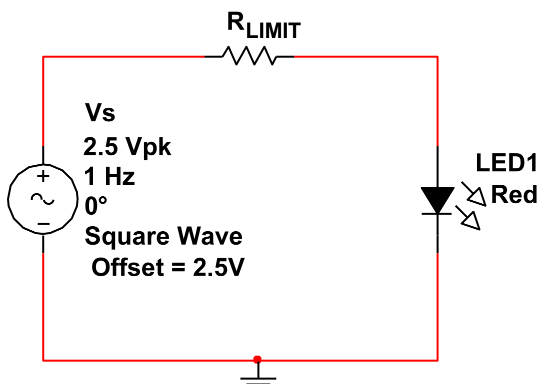


Figure 6.2 – Blinking LED Circuit

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://cp.literature.agilent.com/litweb/pdf/54136-97000.pdf.