Electronics and Electromagnetism

Lab 3: Introduction to basic Electronic devices and Electronic Components Part 2
(Function Generator and Oscilloscope)

Purpose

The Purpose of this lab to get experience in how to use the function generator and an Oscilloscope which are major instruments used to generate and observe time varying electronic signals.

The Function Generator

A **function generator** is a device that can produce various patterns or waveforms of voltage at a variety of frequencies and amplitudes. A common use is to test the response of circuits to a known input signal. Most function generators allow you to generate **sine, square** or **triangular alternating current (AC) signals** or signal that change with time.

Figure 1: Front Panel of your Signal/ Function generator

You could observe the signals produced from a signal generator by directly connecting it to an oscilloscope using a coaxial cable with BNC (Bayonet Neill–Concelman) connectors at both ends (BNC-COAX-BNC). You can also use a coaxial cable that has a BNC connector at one end and alligator type clips on the other end (BNC-COAX-ALLIGATOR) in case you want to connect to a circuit in a breadboard. In this case, **the red wire will be used to connect the positive polarity in your circuit and the black to negative.**

Figure 2 : Metal connections inside the breadboard

Waveform Characteristics

The term "**wave**" can be defined as a pattern of varying quantitative values that repeats over some interval of time. Waves are common in nature: sound waves, brain waves, ocean waves, light waves, voltage waves, and many more. All are periodically repeating phenomena. Signal generators are usually concerned with producing electrical (typically voltage) waves that repeat in a controllable manner. Each full repetition of a wave is known as a "**cycle**". **A waveform is a graphical representation of its variation over time**. A voltage waveform is a classic Cartesian graph with time on the horizontal axis and voltage on the vertical axis. Note that some instruments can capture or produce current waveforms, power waveforms, or other alternatives. In this lab we will concentrate on the conventional voltage vs. time waveform.

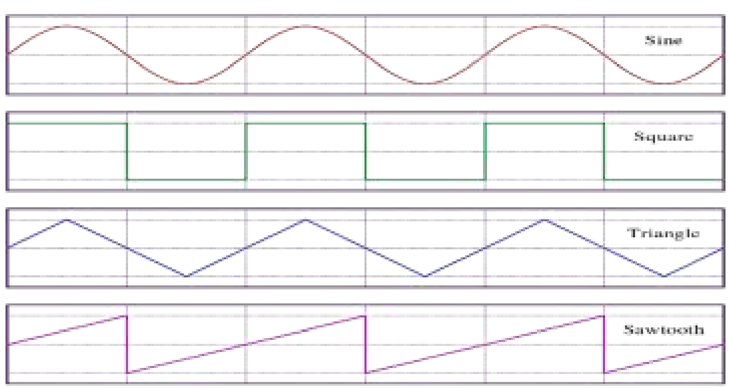


Figure 3: Different Waveforms

Amplitude, Frequency, Phase and DC Offset

The main properties of a wave form are amplitude, frequency, phase and DC offset.

Amplitude: A measure of the voltage "strength" of the waveform. Amplitude is constantly changing in an AC signal. Signal generators allow you to set a voltage range, for example, -3 to +3 volts. This will produce a signal that fluctuates between the two voltage values, with the rate of change dependent upon both the wave shape and the frequency. The peak to peak voltage (Vpp) in the case of -3 to +3 is 6V.

*Do you know what is **Vrms**, **Vav** of a AC voltage? It's time to find out!!!!*

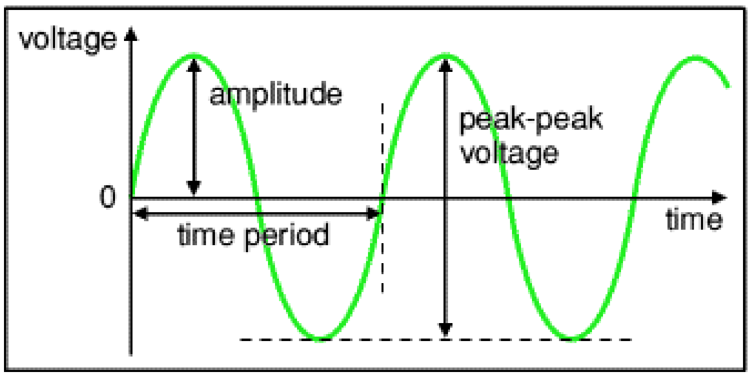


Figure 4: Amplitude and the Vpp (Peak to peak) of a AC Voltage signal

Frequency: The rate at which full waveform cycles occur. Frequency is measured in **Hertz (Hz),** formerly known as **cycles per second**. Frequency is inversely related to the period (or wavelength) of the waveform, which is a measure of the distance between two similar peaks on adjacent waves. Higher frequencies have shorter periods.

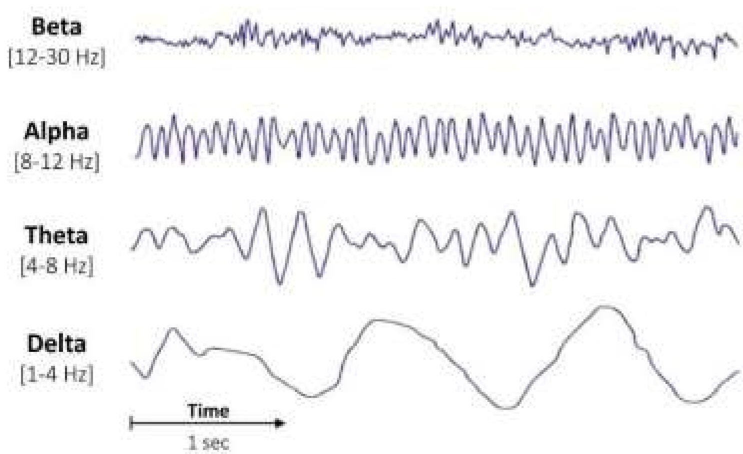


Figure 5: Different frequencies of signals

Phase: In theory, the placement of a waveform cycle relative to a 0-degree point. In practice, **phase is the time placement of a cycle relative to a reference waveform or point in time**. Phase is best explained by looking at a sine wave. The voltage level of sine waves is mathematically related to circular motion. Like a full circle, one cycle of a sine wave travels through 360 degrees. **The phase angle of a sine wave describes how much of its period has elapsed**. Two waveforms may have identical frequency and amplitude and still differ in phase. **Phase shift, also known as delay**, describes the difference in timing between two otherwise similar signals, as shown in Figure 6. Phase shifts are common in electronics. The amplitude, frequency, and phase characteristics of a waveform are the building blocks a signal generator uses to optimize waveforms for almost any application. In addition, there are other parameters that further define signals, and these too are implemented as controlled variables in many signal generators.

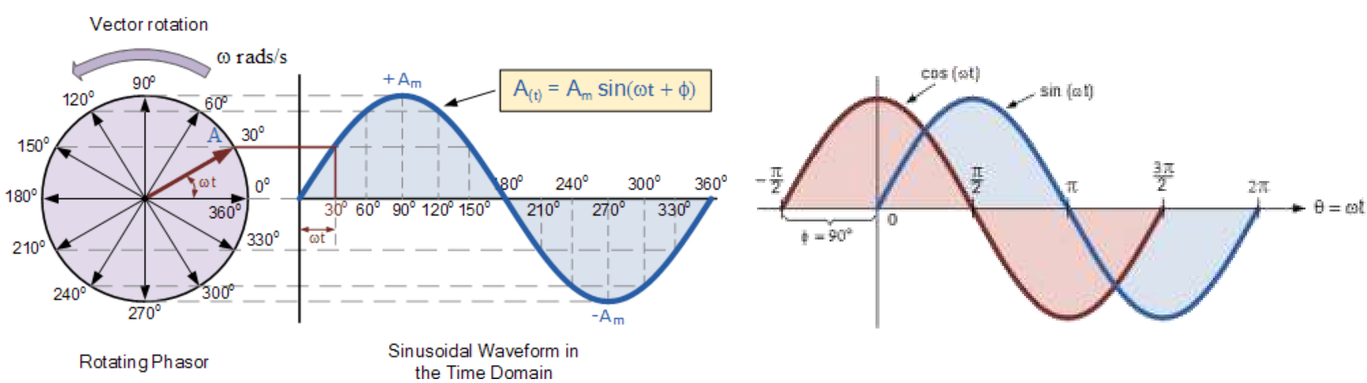


Figure 6: different phases and the phase shift between cosine and sine function

DC Offset: Not all signals have their amplitude variations centered on a ground (0V) reference. The "offset" voltage is the voltage between circuit ground and the center of the signal's amplitude. In effect, the offset voltage expresses the DC component of a signal containing both AC and DC values.

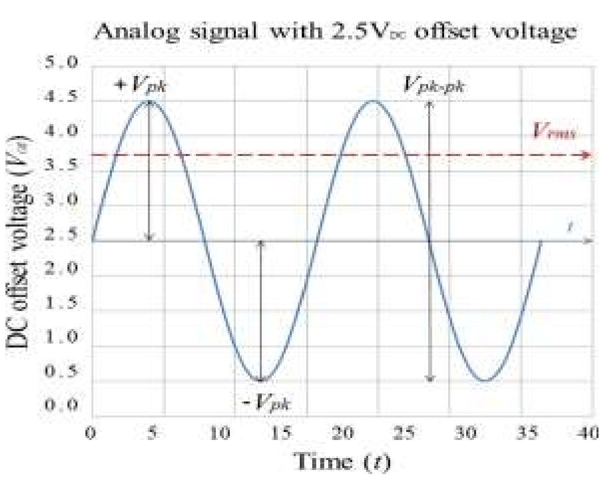


Figure 7: Example for DC offset of a signal

Waveform Shapes

Waveforms come in many shapes and forms. Most electronic measurements use one or more of the following wave shapes, often with noise or distortion added:

- Sine waves
- Square and rectangular waves
- Sawtooth and triangle waves
- Step and pulse shapes
- Complex waves

Complex waveforms: In operational electronic systems, waveforms rather complex than in your textbooks. Certain clock and carrier signals are pure, but most other waveforms will exhibit some unintended distortion (a by-product of circuit realities like distributed capacitance, crosstalk, and more) or deliberate modulation. Some waveforms may even include elements of sines, squares, steps, and pulses. This is achieved through a process called modulation. In the below Figure you can see an example of amplitude, frequency and phase modulated signals.

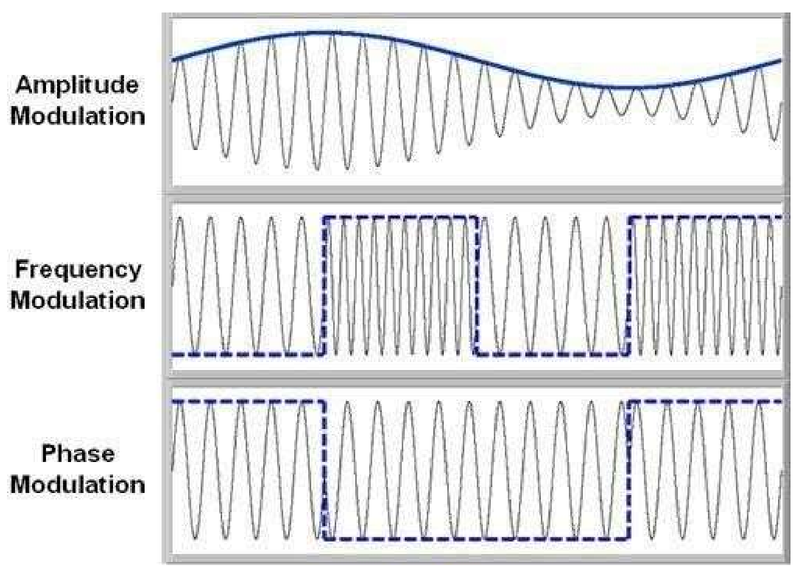
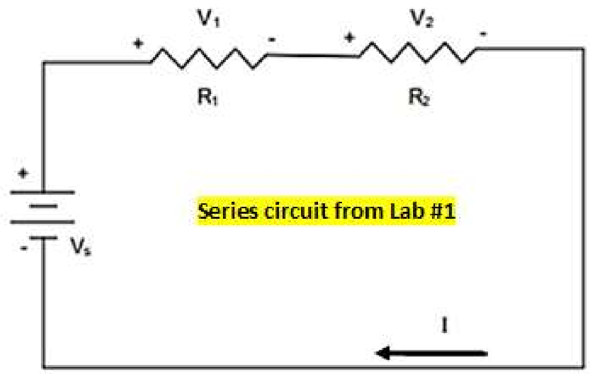


Figure 8: Schematic of an AC to DC power conversion

Find out the uses of sine, square, sawtooth, triangle and step wave form uses.

Output of the function generator

When we discuss the output of the function generator it's important to understand the concept of the **voltage divider** circuit. You all must now be familiar with the idea of connecting two resistors is a series manner. From Lab 1, you have also measured the voltage across the two resistors and proved that the sum of their voltages is equal to the supply voltage. In other words, the supply voltage is divided between the two resistors in some ratio. This is one of the most important applications of a series connection of resistors.



- Ohm's Law states, $Vs = IR$, where Vs= Supply Voltage, I = Current flows through the circuit, R = Resistance
  Hence $I = \frac{V}{R}$ the current I is same through both R1 and R2 (due Series connection of resistors)

Therefore,

$$V_1 = \frac{V_s \times R_1}{R_1 + R_2}$$

$$V_2 = \frac{V_s \times R_2}{R_1 + R_2}$$

Where,

$$\frac{V_1}{R_1} = \frac{V_2}{R_2}, \quad V_s = V_1 + V_2$$

Now, let us turn to the function generator. There is a **50 Ω internal resistor** connected in series with the oscillating voltage source inside the function generator (Figure 9). The purpose of the internal resistance is to have **impedance matching** to 50 Ω, especially important for radiofrequency (RF) circuits to minimize signal losses via reflections. Therefore, if you connect the function generator to an external resistor **RL (LOAD resisto**r), it will form a **voltage divider** with the 50 Ωresistor.

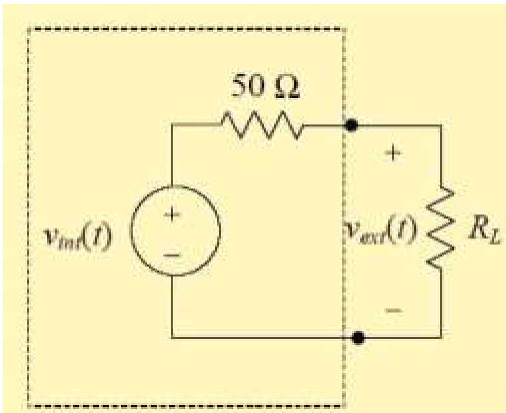


Figure 9: The internal **50-Ω** matching resistor in your function generator and the external load resistance RL, when connected.

The voltage seen at the output of the instrument (or across the load, R_L, will then be:

$$V_{ext} = \frac{V_{int} \times R_L}{(R_L + 50)}$$

For example, if we have an external load resistance, $R_L = 50\,\Omega$, then this leads to a voltage

divider resulting in a **GAIN** of 1/2.

Now, keep in mind that V_{ext} is the value of the voltage that you set (it is also the value that displays on your front panel). So, if you set the instrument to produce a 5V sine wave, it produces a 10 V sine wave on $\boldsymbol{V_{int}}$. In other words, **the instrument compensates by raising**

$\boldsymbol{V_{int}}$ **to twice** what the display shows.

Now, what happens when you do not have a 50-Ω load? Or you connect your oscilloscope's input (which is a very high resistance, usually in the MΩ range) directly to the generator? There will be a **disagreement** between the output displayed by the generator and the reading on the oscilloscope. This is because the generator always assumes a 50-ohm load and sets its internal voltage; accordingly, this is twice the voltage that is desired at the load.

Therefore, when 5V is desired at the load, V_{int} **= 10V**. However, since most of this voltage now drops across the load resistor of very high resistance, you will see most of the 10V appear on the oscilloscope screen! That means, you are seeing close to **twice** the value that you set on the generator!

One way to fix this problem is to use a **50 Ω through termination** as shown in the Figure 10. This creates a parallel circuit of a 50 ohm and the high resistance of the oscilloscope. The equivalent (effective) parallel resistance then turns out to be equal to 50 ohms, which is like the scenario when RL was equal to 50 ohms.

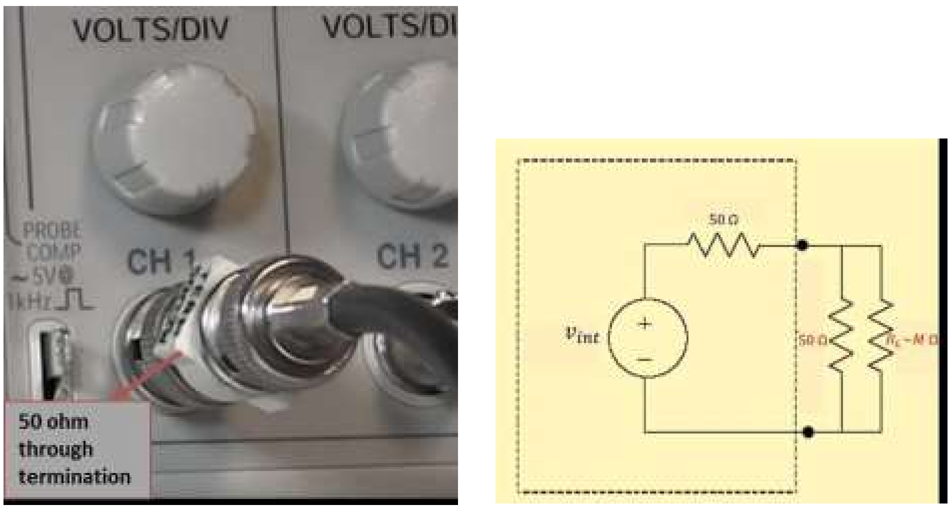


Figure 10: Left: 50 ohms through termination used to match the oscilloscope output to the expected value output by the generator. **Right**: The modified circuit in this case

In some function generators, this whole ordeal can be avoided by switching the impedance mode from 50-ohm to high Z. In the latter mode, the signal generator forces an imaginary 50-ohm termination across the load resistor. Think about how this works and find out if your signal generator has the high Z option!

The Oscilloscope

Oscilloscopes enable scientists, engineers, technicians, educators and others to "see" signals that change over time. They are indispensable tools for anyone designing, manufacturing or repairing electronic equipment. Oscilloscopes are used by everyone from physicists to television repair technicians. An automotive engineer uses an oscilloscope to measure engine vibrations. A medical researcher uses an oscilloscope to measure brain waves. The possibilities are endless.

An oscilloscope is basically a graph-displaying device. It draws the graph of an electrical signal. In most applications, the graph shows how signals change over time: **the vertical (Y) axis represents voltage, and the horizontal (X) axis represents time. The intensity or brightness of the signal is sometimes called the Z-axis.**

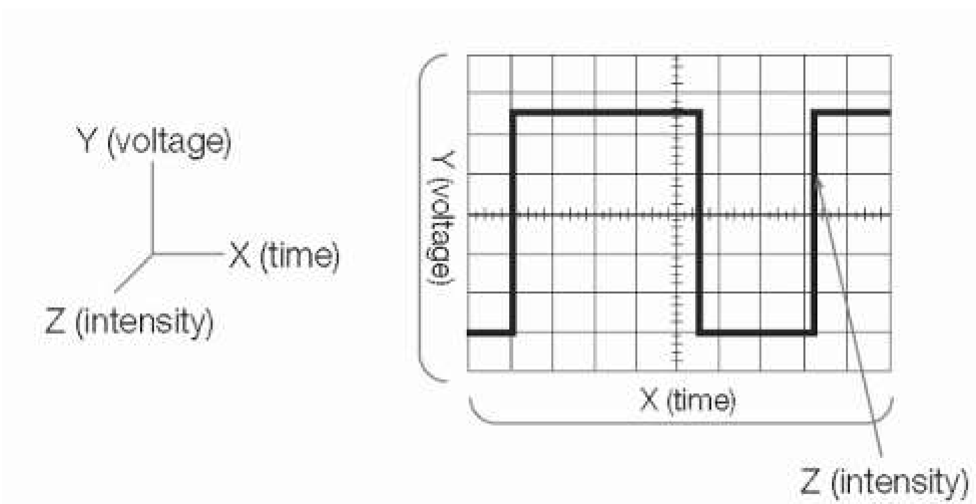


Figure 11: Ohm's Law experimental setup and Results

The Control Systems of an Oscilloscope

There are different types of oscilloscope on the market – analog, digital, digital storage etc. The oscilloscope that you have costs approximately $5000 (~ THB 150, 000) and is a digital storage oscilloscope (DS0). Your oscilloscope consists of four main systems

- the vertical system, the horizontal system, the measure system and the trigger system.

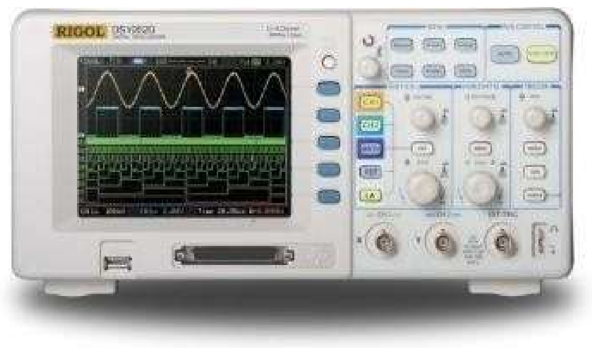


Figure 12: Frontpanelofoscilloscope

Figure 13: Different systems in oscilloscope

Vertical System:

You can select the channel you want by pressing **CH1 or CH2**. The position knobs move the waveform up or down on the scope screen. For reference, you can make use the **volts/div** indicator on the screen and the **scale knobs** to adjust the vertical scale. The **MATH** button allows you to perform mathematical functions **(CH1+CH2, CH1-CH2 etc.) CH1 = Channel 1**

Horizontal System:

The oscilloscope's horizontal system is most closely associated with the acquisition of an input signal. Horizontal controls are used to position and scale the waveform horizontally. The position knob moves the waveforms left or right, the **scale** knob controls the zoom scale on the time axis.

Trigger System:

The oscilloscope trigger function enables repetitive waveforms captured and displayed on the screen like a screen shot of the screen. The trigger enables the time base to start its scan at the same point on each repetition of the waveform. In this way the oscilloscope trigger enables the waveforms to be viewed in a meaningful manner, otherwise the time base would start at a random point on the waveform each time the waveform is repeated and the image of the waveform would not be meaningful, as illustrated in **Figure 14**. When the voltage of the waveform reaches a required level, then a comparator switches and send a start signal to the time base. This enables the time base to exactly synchronize with the displayed waveform so that it remains stable on the screen.

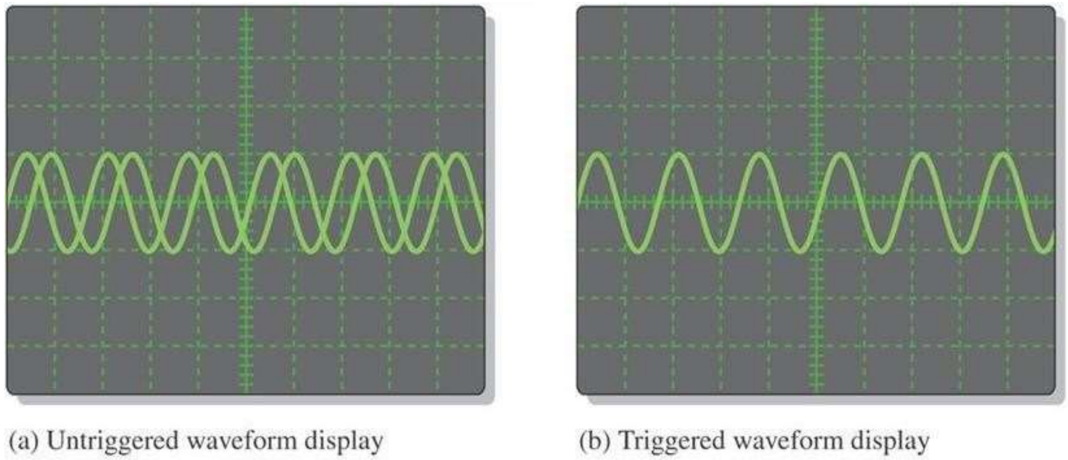


Figure 14: Untriggered and a Triggered wave form in an Oscilloscope display

The Analog level and slope controls (press the menu button to select the edge option to access slope functionality) provide the basic trigger point definition and determine how a waveform is displayed, as illustrated in Figure 15.

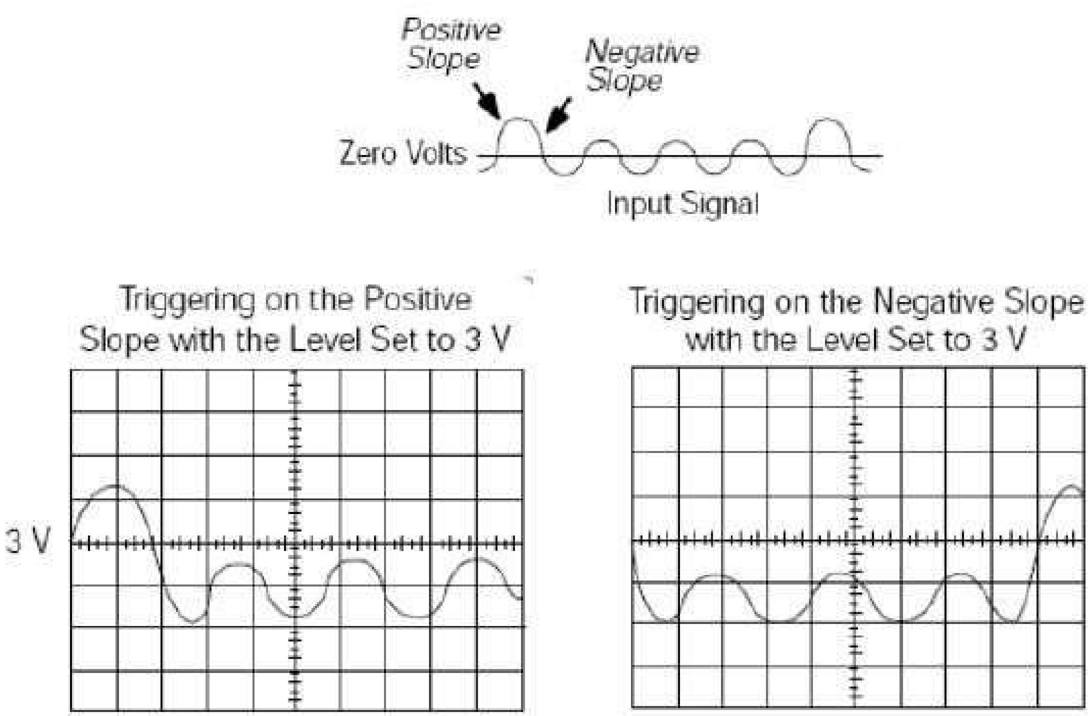


Figure 15: Trigger level and slope functionality

The waveform on which the oscilloscope can trigger can be sourced in a variety of ways. Sometimes having an external source for triggering can make the waveform more stable and enable the waveform to be seen in a more stable form.

- **Signal channel:** The most common source of the waveform used for providing the trigger is the signal channel. On multiple channel scopes the trigger defaults to the **A** channel, but normally it is also possible to trigger on other channels as well. Triggering may be marked **A / B** channel, or equivalent.
- **External source:** On most scopes there is the possibility of selecting an external trigger source. This can be very useful when a system is synchronized to an external signal. It is normally possible to have the same control of trigger voltage and slope for these external signals.

Common **trigger modes** include **normal** and **auto**. In normal mode the oscilloscope only sweeps if the input signal reaches the set trigger point; otherwise (on an analog oscilloscope) the screen is blank or (on a digital oscilloscope) frozen on the last acquired waveform. This trigger facility is fine when a signal is present, and the scope is triggering. However, when no signal is present, it is useful to be able to see where the trace is, for example, to set the trace to a place on the screen before applying the signal and making a measurement. To overcome the lack on trace under no or small signal conditions an auto-trigger capability is added.

For most general use of the oscilloscope, it can be left in **auto-trigger** mode, and only set to "normal" for more exacting measurements and waveforms.

Coupling Function:

Coupling refers to the method used to connect an electrical signal from one circuit to another. In this case, the input coupling is the connection from your test circuit to the oscilloscope. The coupling can be set to DC or AC. DC coupling shows all an input signal. AC coupling blocks the DC component of a signal so that you see the waveform centered on zero volts. **Figure 16** illustrates this difference. AC coupling is useful when the entire signal (AC + DC) is too large for the volts/div setting.

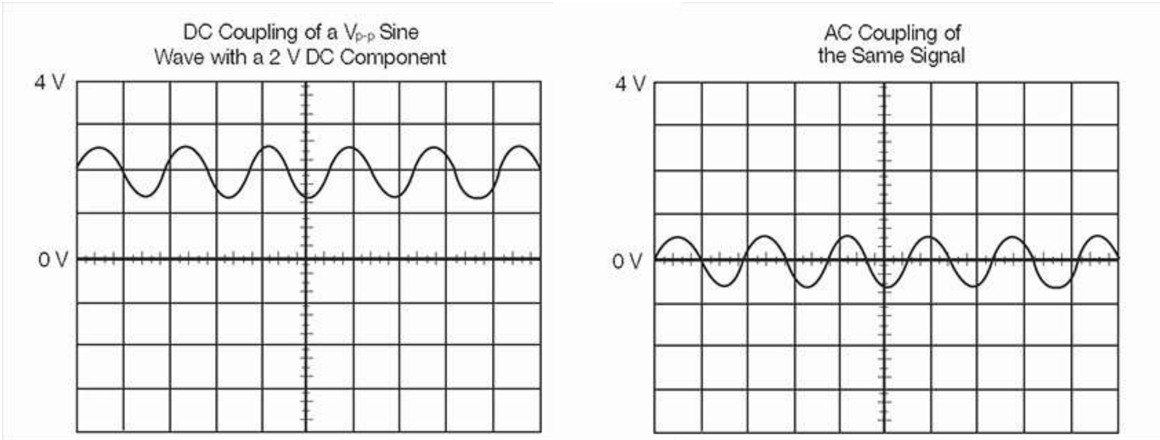


Figure 16: DC and AC input Coupling

Oscilloscope Scope Probes:

Even the most advanced instrument can only be as precise as the data that goes into it. A probe functions in conjunction with an oscilloscope as part of the measurement system. They cost around $50 each, so use them with care!

Figure 17: Oscilloscope Probe

These probes introduce resistive, capacitive and inductive loading that inevitably alters the measurement. This is quantitatively measured by the attenuation factor of a probe – 10X, 100X and so on. Your scope probes are 10X (or so called 10:1 probe). The 10X (read as "ten times") reduces the signal's amplitude at the oscilloscope input by a factor of 10. However, your scope contains auto-detection circuitry that automatically detects the type of probe connected to your input and thus the scope compensates for the 10X attenuation. Once you connect the probe to your scope and hook it up to the circuit, you can use the measurement system (MENU panel) to perform measurements. ** you can use this simulator for practice!!!

Caution: Do not interchangeably use your function generator cables and your scope probes!

Task 1

Set your function generator to output a Sinusoidal waveform with a peak-peak voltage (**Vpp**) of 1V and a frequency of 1 kHz. Make sure that the attenuation setting in your oscilloscope is set to 10X to match the attenuation value of the scope probes. (**Note: your oscilloscope MAY be able to auto detect the attenuation**). Identify the unit of Measurement as well.

1. Connect the output of the signal generator directly to Channel 1 of the oscilloscope using a BNC-COAX-BNC cable. Your circuit should look like below.
2. Verify if all the input parameters match those of the displayed output waveform. If they are different, you need to be able to explain why.
3. Now demonstrate how to vary amplitude, frequency and waveform type. Track these changes on the oscilloscope screen.

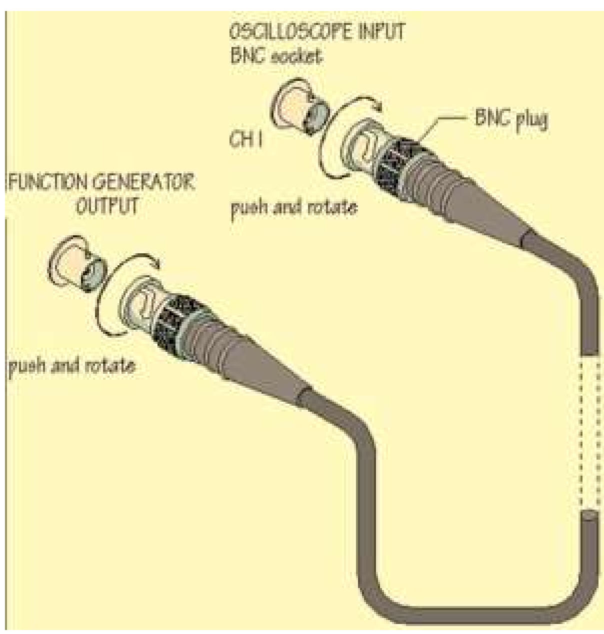


Figure 18: Connecting the signal generator directly to the oscilloscope.

Task 2

1. Making use of your knowledge on using breadboards from Lab 1, Construct the circuit shown below. You will need the below listed items for this exercise.

   Using following equipment

   Breadboard
   Wires
   Oscilloscope
   Function Generator
   1 k-ohm resistor (x 2)
   BNC- COAX-ALLIGATOR cable
   Oscilloscope probes

2. Turn ON your function generator and set all the parameters to output Sinusoidal waveform as per Task 1. Observe the signals in channel 1 and channel 2. What is the relation of the voltage value in channel 2 with respect to channel 1 (Make sure you have two resistors with the same value) ? *** ONLY one channel of oscilloscope should be grounded.

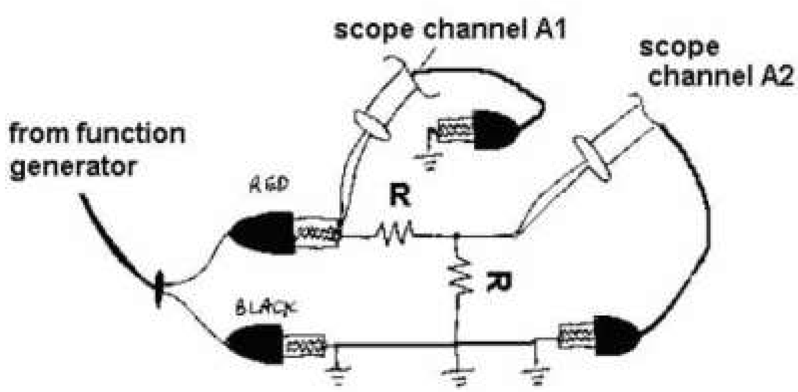


Figure 19: Oscilloscope and signal generator test circuit

Task 3.

Make the following Flashing circuit using **Tinkercad**. Think about why the flash in this manner, using your basic knowledge gained through capacitor, resistor, LED and NE555 datasheet referring *

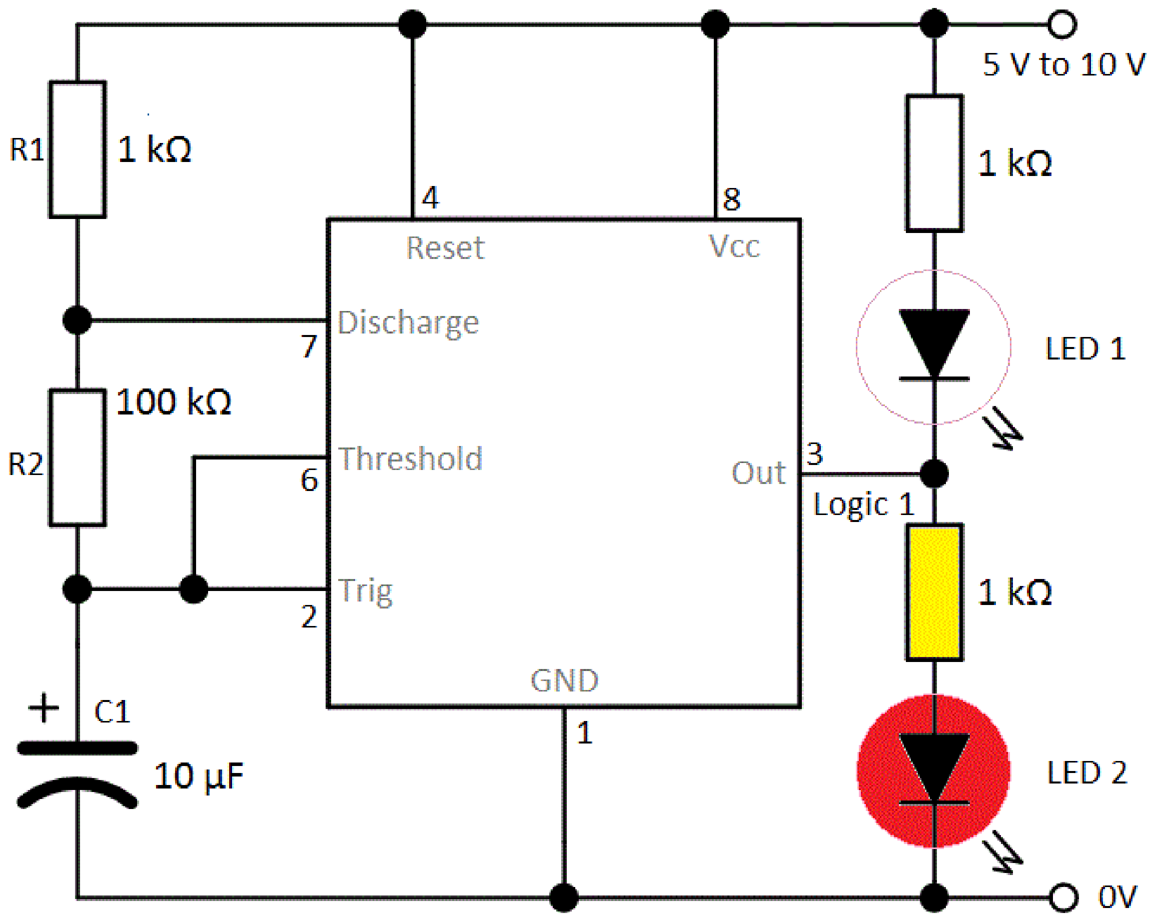


Figure 19: Flashing LEDs using a NE 555 Timer IC