3. (Lab #3) Function Generator and Oscilloscope

In this lab you learn how to use the oscilloscope and function generator.

1. Equipment & Materials:

a. Breadboard

b. Wire cutters

c. Wires

d. Oscilloscope

e. Function Generator

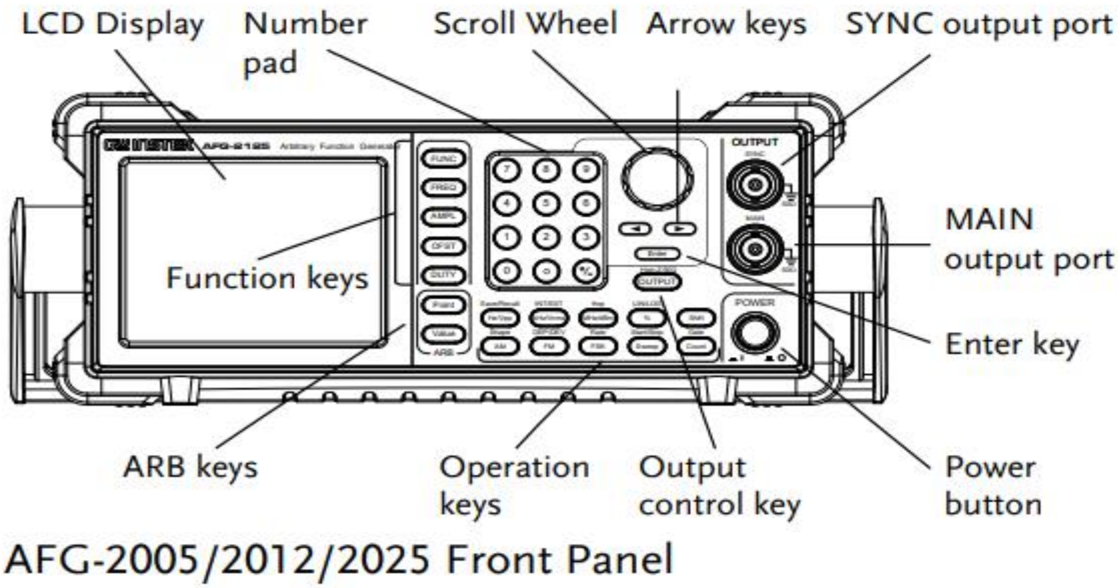
f. 1k resistor x 2

h. Various connectors (banana plugs-to-alligator clips) for connecting breadboard to power supply and for multimeter connections.

2. Basic Knowledge & Skills

a. The Function Generator

The front panel of your function generator is shown in Figure (3-1). This instrument outputs a time-varying periodic voltage signal (the **OUTPUT** connector, do not use the sync connector, refer to figure (3-2)). By pushing the appropriate buttons on the front panel, the user can specify various characteristics of the signal.



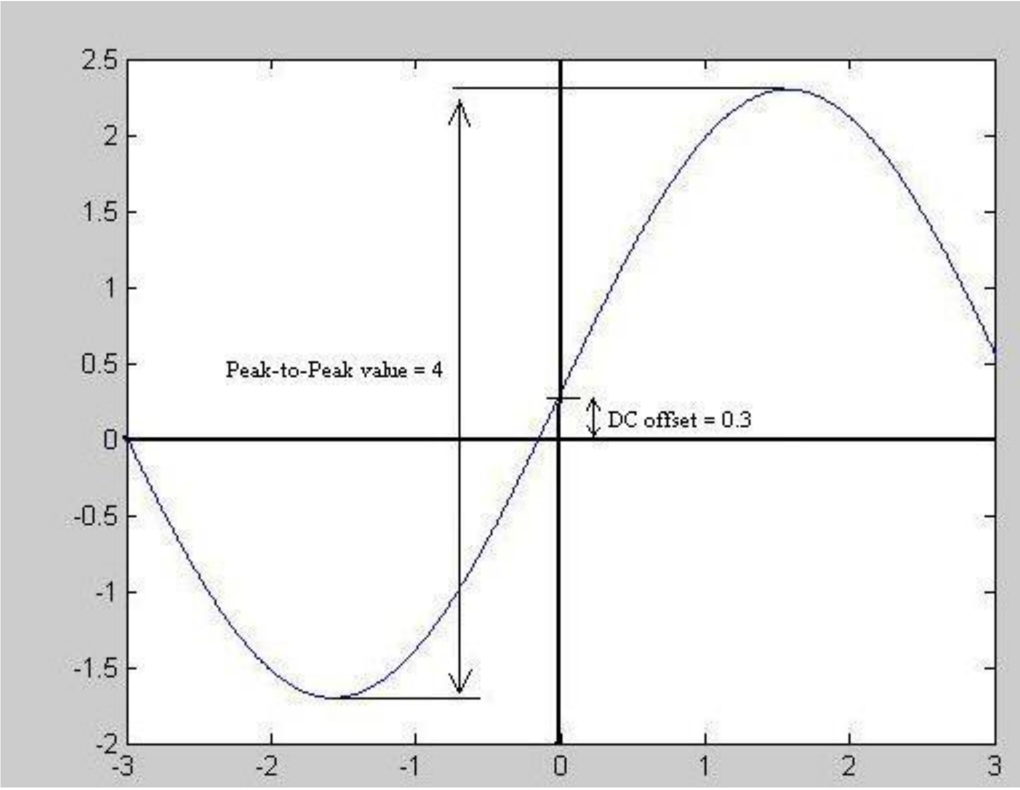
[Figure 3-1] Front panel of your function generator

[Figure 3-2] Make sure you use **BLACK** BNC input cables. Connect them to the OUTPUT terminal as shown above. Do not use the SYNC connector

The main characteristics that you will be concerned with in this class are:

- Shape: sine, square, or triangle waves.
- Frequency: inverse of the period of the signal; units are cycles per second (Hz)
- Vpp: peak to peak Voltage value of the signal
- DC Offset: constant voltage added to the signal to increase or decrease its mean or average level. In a schematic, this would be a DC voltage source in series with the oscillating voltage source.

Figure (3-3) below illustrates a couple of the parameters above.



[Figure 3-3] Sine wave Vpp and DC offset

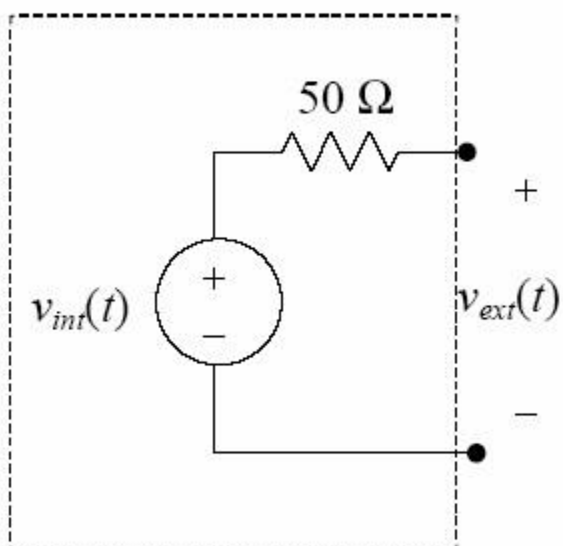
When the function generator is turned on, it outputs a sine wave at 1 kHz with amplitude of 100 mV_{PP} as shown in figure (3-4).

[Figure 3-4] Function generator has been turned on

You must specify the characteristics of the signal you need. For example, to set the frequency of the signal:

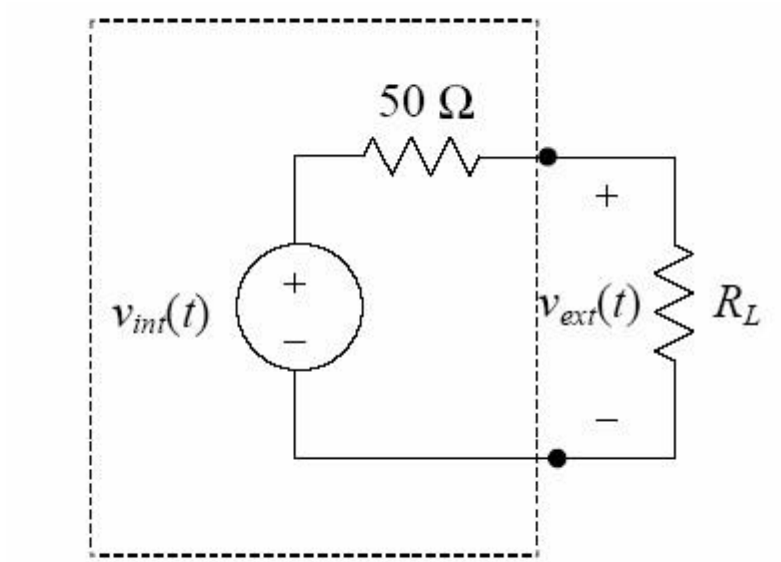
1. Enable the *frequency modify* mode by pressing the `Freq` button.
2. Enter the value of the desired frequency by pressing the `Enter Number` button and entering the appropriate numbers on pads labeled with green numbers, or by using the wheel and the left and right arrows to move the tens place. (To cancel the number mode, press `Shift` and `Cancel`.)
3. Set the units to the desired value by using the arrow keys (up or down) on the right side of the front panel.

<u>IMPORTANT NOTE</u>: There is an internal resistor 50 ohms in series with the oscillating voltage source inside the function generator, refer to figure (3-5).



[Figure 3-5] The internal load resistor in your function generator

Thus, if you connect the function generator to an external resistor R_L , it will form a voltage divider with the 50 ohms resistor, refer to figure (3-6).



[Figure 3-6] External resistor forming a voltage divider

Hence the voltage seen at the output of the instrument is:

$$v_{ext}(t) = \frac{R_L}{R_L + 50\Omega} \cdot v_{int}(t) \qquad (3\text{-}1)$$

The purpose of the internal resistance is to have impedance matching (especially important for high frequency circuits). In RF electronics, resistances of 50 ohms are very common. Therefore if R_L = 50 ohm, we have:

$$v_{ext}(t) = \frac{1}{2} v_{int}(t) \qquad (3\text{-}2)$$

The front panel meter assumes R_L = 50 ohms. As we saw above, a 50-ohm load leads

to a voltage divider with a gain of ½, so the instrument compensates for this by raising v_{int} to twice what the display shows. In other words, if you set the instrument to produce a 5 V sine wave, it actually produces a 10 V sine wave on v_{int} and relies on the external voltage divider to reduce the signal by a factor of two. We are not going to change the default setting of this instrument, so **just remember that you are getting twice the voltage displayed on the function generator at the output terminal.**

That's all for the function generator. Let's get to the crux of this lab – the oscilloscope.

b. Oscilloscope

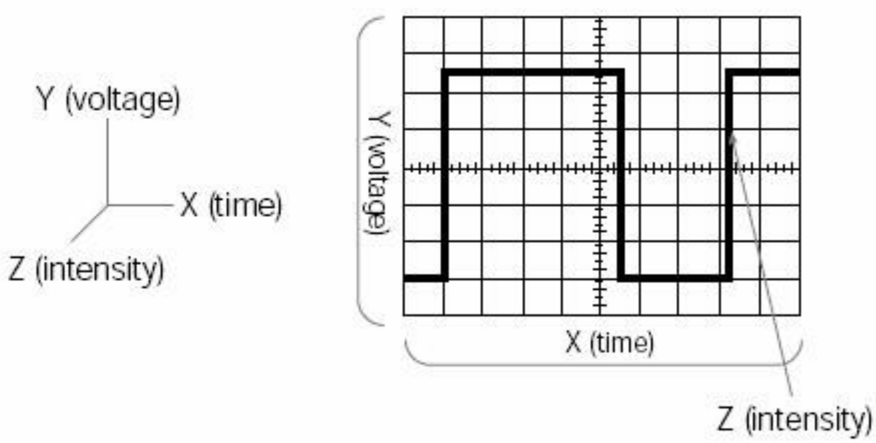
Nature moves in the form of a sine wave, be it an ocean wave, earthquake, sonic boom, explosion, sound through air or the natural frequency of a body in motion. Even light – part particle, part wave – has a fundamental frequency which can be observed as color.

Sensors can convert these forces into electrical signals that you can observe and study with an oscilloscope. You will learn an example of a sensor – the Strain Gauge – in a later lab. For now, we will learn how to use an oscilloscope.

Oscilloscopes enable scientists, engineers, technicians, educators and others to "see" events 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.

i. Basic concepts behind an oscilloscope

What is an oscilloscope? 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 Zaxis (refer to figure (3-7).

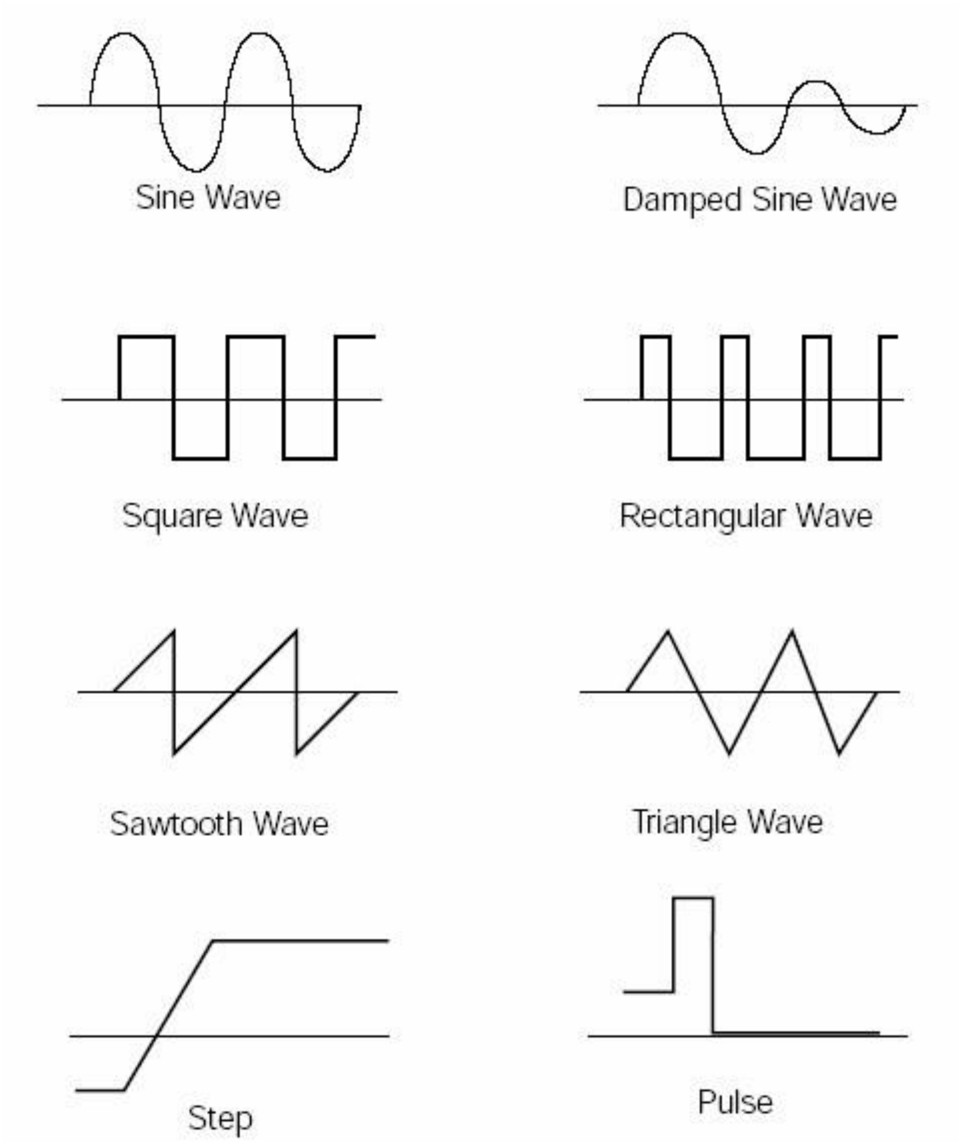


[Figure 3-7] X, Y and Z components of a waveform

This simple graph can tell you many things about a signal such as:

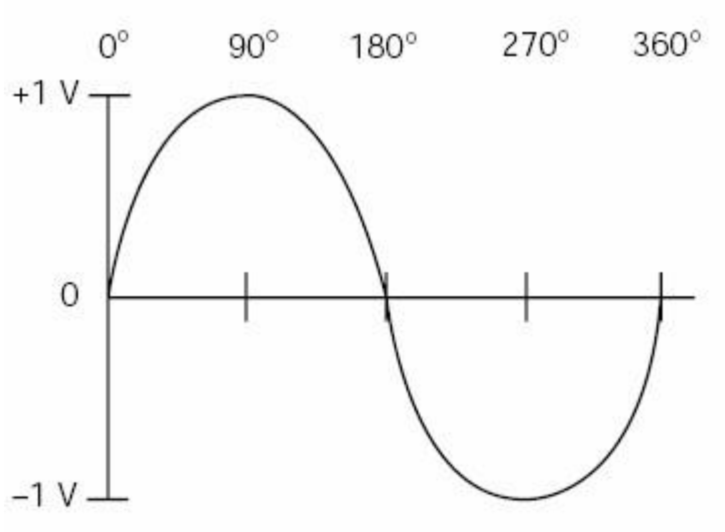
- The time and voltage values of a signal
- The frequency of an oscillating signal
- Whether or not a malfunctioning component is distorting the signal
- How much of a signal is direct current (DC) or alternating current (AC)

What kind of signals can you measure with an oscilloscope? Figure (3-8) shows some common signals (or waveforms).

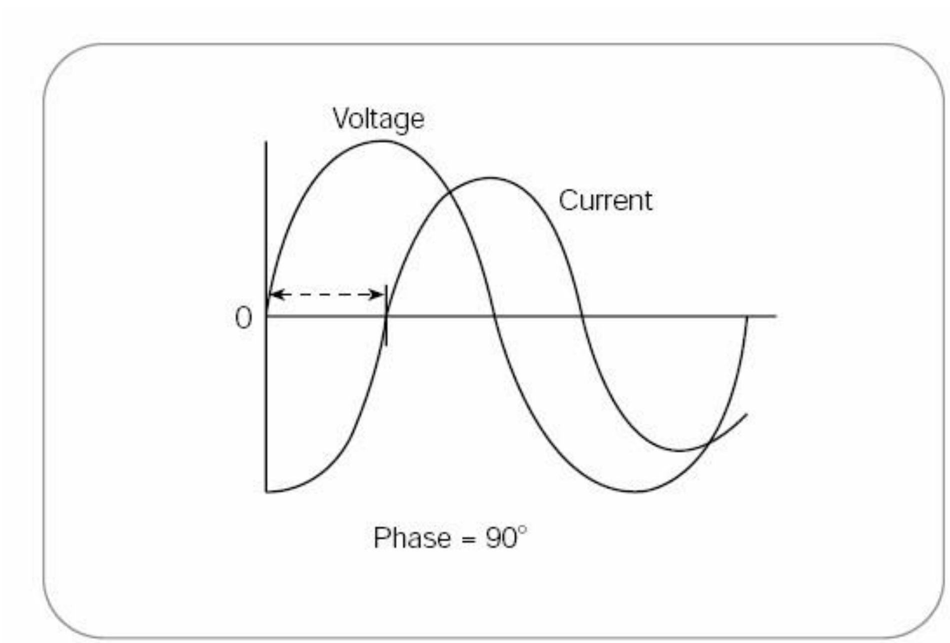


[Figure 3-8] Common waveforms

You can measure different characteristics of a waveform with an oscilloscope – amplitude, frequency, DC offset and phase.



[Figure 3-9] Degrees of a sine wave



[Figure 3-10] Concept of Phase shift

Phase is best explained by looking at sine waves figure (3-9). The voltage level of sine waves is based on circular motion. Given that a circle has 360±, one cycle of a sine wave has 360± (as shown in figure (3-9). Using degrees, you can refer to the phase angle of a sine wave when you want to describe how much of the period has elapsed.

Phase shift describes the difference in timing between two otherwise similar signals. The waveform in figure (3-10) labeled “Current” is said to be 90± out of phase with the waveform labeled “Voltage”. This is because the waves reach similar points in their cycles exactly ¼ of a cycle apart (360±/4 = 90±). Phase shifts are common in electronics.

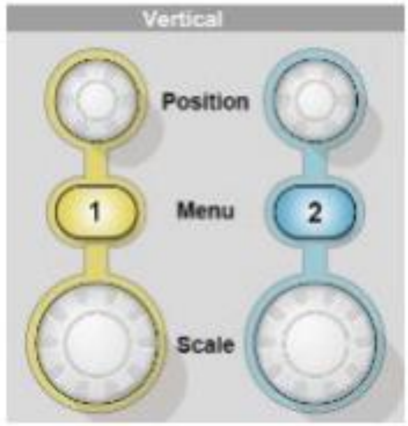
ii. The Systems and Controls of an Oscilloscope

There are different types of oscilloscope on the market – analog, digital, digital storage etc. The oscilloscope that you have costs approximately $5000 and is a digital storage oscilloscope. Figure (3-11) is the front view of your scope.

[Figure 3-11] The oscilloscope

The oscilloscope consists of four main systems – the vertical (ANALOG) system, the horizontal system, the measure system and the trigger system. The different systems are described below. You are not required to use the Logic Analyzer (DIGITAL) system in this course.

a. The vertical (ANALOG) system

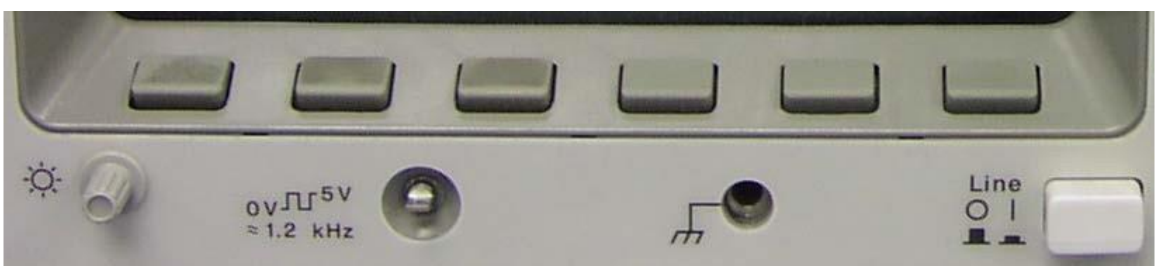


[Figure 3-12] The vertical system controls

Position (1 and 2). Positions a waveform vertically.
1 & 2 Menu. Displays the Vertical menu selections and toggles the display of the channel waveform on and off.
Scale (1 & 2). Selects vertical scale factors.

scope screen. The 

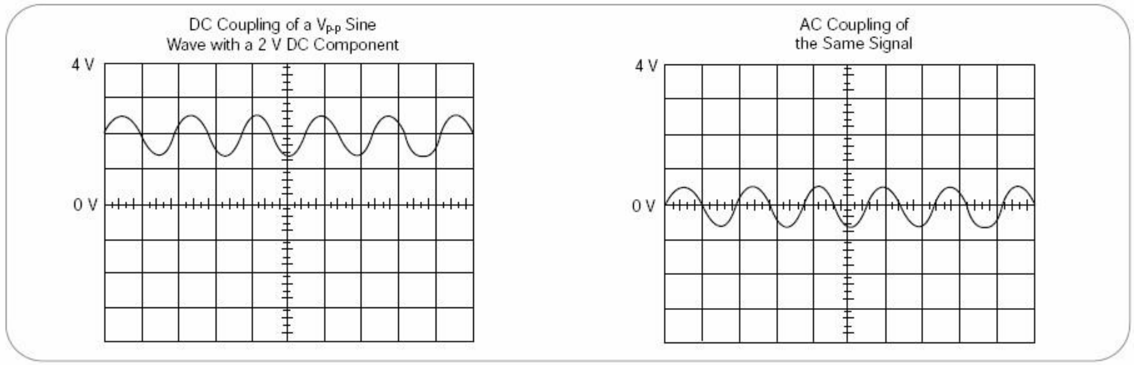
buttons control mathematical functions (like A1+A2, A1-A2 etc). Once you press this button you can select which function you want by using the soft-keys below the oscilloscope screen (refer to figure (3-14)).



[Figure 3-13] Soft-keys for accessing various functions

Also, once you choose the channel you will have various functions to choose from above the soft-keys. One of the most important of these is the 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, AC or ground. DC coupling shows all of an input signal. AC coupling blocks the DC component of a signal so that you see the waveform centered around zero volts. Figure (3-14) illustrates the difference.



[Figure 3-14] AC and DC input coupling

The AC coupling is useful when the entire signal (AC + DC) is too large for the volts/div setting. The ground setting disconnects the input signal from the vertical system, which lets you see where zero volts is located on the screen. Switching from DC coupling to ground and back again is a handy way of measuring signal voltage levels with respect to ground.

b. The horizontal system

An oscilloscope's horizontal system (figure (3-15)) is most closely associated with its acquisition of an input signal. Horizontal controls are used to position and scale the waveform horizontally.

[Figure 3-15] The horizontal system controls

Position. 

Adjusts the horizontal position of all channel and math waveforms. The resolution of this control varies with the time base setting.

NOTE. To make a large adjustment to the horizontal position, turn the Horizontal Scale knob to a larger value, change the horizontal position, and then turn the Horizontal Scale knob back to the previous value.

NOTE. To set the horizontal position to zero, push the horizontal position knob.

Acquire. 

Displays the acquisition modes — Sample, Peak Detect, and Average.

Scale. 

Selects the horizontal time/division (scale factor).

c. The measure system

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. Hence, we first talk about the probes you use with your oscilloscope. Figure (3-16) shows a picture of your scope probe.

[Figure 3-16] Your scope probes. They cost around $50 each, use them with caution

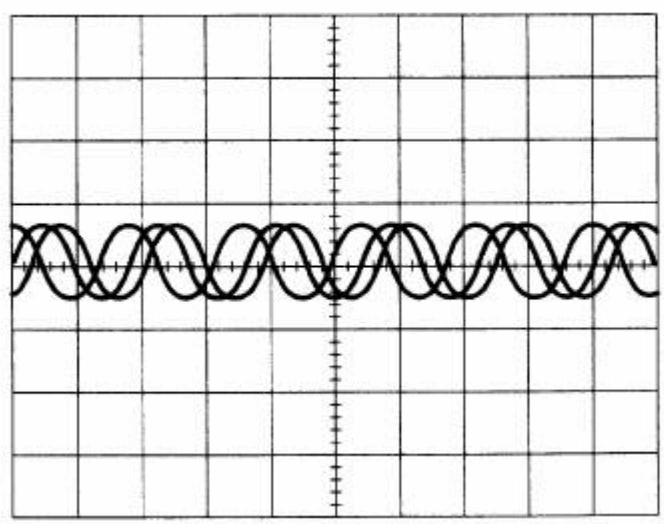
<u>Please note</u>: do not interchangeably use your function generator BNC connectors and your scope probes!

Your scope probes are passive: they don't contain any amplifier circuitry. The main point to know about probes is that 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.

d. The trigger system

An oscilloscope's trigger function synchronizes the horizontal sweep at the correct point of the signal, essential for clear signal characterization. Trigger controls allow you to stabilize repetitive waveforms and capture single-shot waveforms. The trigger makes repetitive waveforms appear static on the oscilloscope display by repeatedly displaying the same portion of the input signal. Imagine the jumble on the screen that would result if each sweep started at a different place on the signal, as illustrated in figure (3-17). Figure (3-18) shows the trigger system on your scope.



[Figure 3-17] Untriggered display

[Figure 3-18] The Oscilliscope trigger system

Trigger Menu. When it is pressed once, it displays the Trigger Menu. When it is kept pressed for more than 1.5 seconds, it will show the trigger view, meaning it will display the trigger waveform in place of the channel waveform. Use the trigger view to see how the trigger settings, such as coupling, affect the trigger signal. Releasing the button will stop the trigger view.

Level. When you use an Edge or Pulse trigger, the Level knob sets the amplitude level that the signal must cross to acquire a waveform. Push this knob to set the trigger level to the vertical midpoint between the peaks of the trigger signal (set to 50%).

Force Trig. Use this to complete the waveform acquisition whether or not the oscilloscope detects a trigger. This is useful for single sequence acquisitions and Normal trigger mode. (In Auto trigger mode, the oscilloscope automatically forces triggers periodically if it does not detect a trigger.)

The trigger mode determines whether or not the oscilloscope draws a waveform based on a signal condition. 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. Normal mode can be disorienting since you may not see the signal at first if the level control is not adjusted correctly.

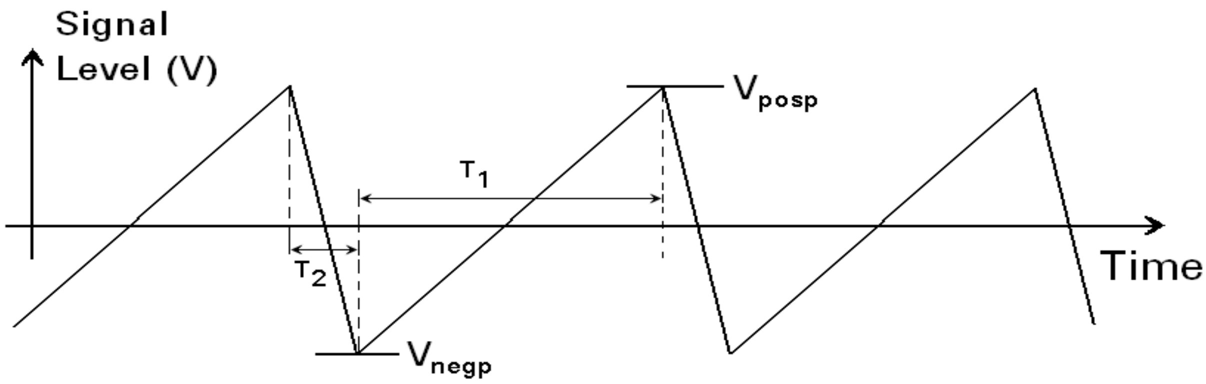
Auto mode causes the oscilloscope to sweep, even without a trigger. If no signal is present, a timer in the oscilloscope triggers the sweep. This ensures that the display will not disappear if the signal does not cause a trigger. However, when the trigger mode is Auto and the trigger level magnitude is greater than the peak-to-peak signal voltage, then your oscilloscope will continue to sweep. Hence your scope screen will become jumbled.

Thus, your scope includes a third trigger mode called Auto Level. Here your scope senses when the magnitude of your trigger level goes beyond your peak-to-peak signal voltage and then automatically resets your trigger level to zero. It is best to leave the trigger mode to Auto Level during the first couple of weeks.

Tasks for the (Lab #3): Function Generator and Oscilloscope

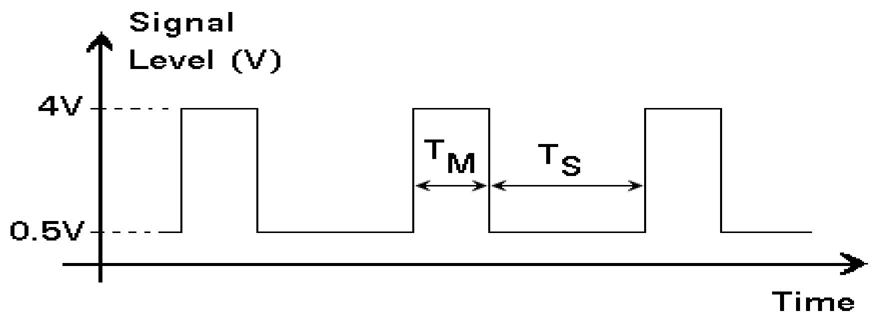
1) Learn how to use function generator and Oscilloscope

1. Use the function generator to generate a triangular waveform. Set the signal amplitude to 2V and the signal frequency to 10 kHz. Display this waveform on the oscilloscope. Measure the voltages at the positive and negative peaks (Vposp and Vnegp) of this signal. Also measure T1 and T2 as shown in Figure (3-19). How do you compare the oscilloscope readings with the signal amplitude and frequency indicated by the function generator? Explain your answer.
2.



[Figure 3-19] Triangular Waveform

3. Using the function generator, obtain a non-uniform rectangular waveform, with 4 V peak-to-peak amplitude and a minimum voltage at about +0.5 V. Set the frequency to 400 kHz. Try to set TS = 2TM. A typical signal is shown in Figure (3-20).



[Figure 3-20] Rectangular Waveform

4. **Using the oscilloscope,**

a. Measure accurately the frequency of the signal.

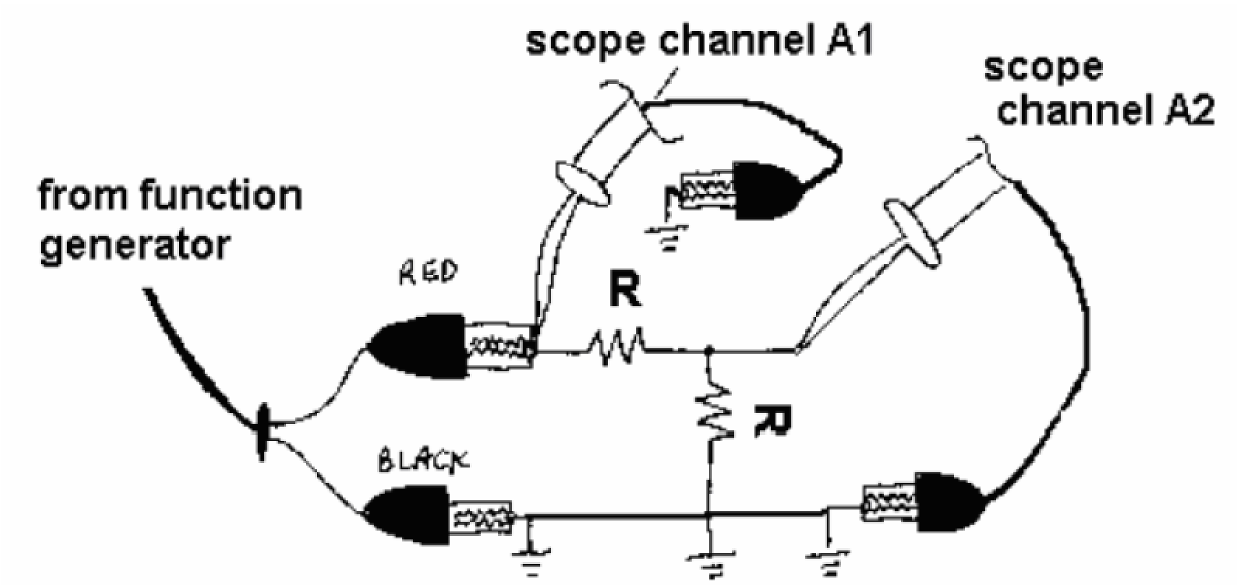
b. Measure accurately the two intervals T_M and T_S as shown in Figure (3-20). How do you correlate these two measurements with the results obtained in (a) above? Find the "Duty Cycle" of this signal. The duty cycle is defined as the time a rectangular wave is at high value with respect to the period of the rectangular wave. It is usually indicated in %, e.g., if the period of the rectangular wave is 10 millisecond and the rectangular is in high position for 2 milliseconds, then the duty cycle is (2/10) x 100 % = 20%.

c. Measure the high and low voltages of this signal.

d. Measure the rise and fall times of the edges of the waveform: t_{rise} and t_{fall}.

e. Compare the measured data with the setting of the function generator. Comment on the differences.

5. **Build the circuit below**



[Figure 3-21] voltage divider circuit

6. Wire the circuit in figure (3-21) on the breadboard (WIRE NEATLY!) The circuit is

repeated below for convenience, along with your function generator and scope connections.

7. R = 1k in the circuit above. Set your function generator to: 1.00 Vpp, 1.00 KHz sine wave. Tune your oscilloscope (DO NOT MODIFY THE FUNCTION GENERATOR

SETTINGS!) until your oscilloscope screen looks like

Now, what happens when you reverse 2 the terminals of your function generator? That is, do the waveforms on the oscilloscope screen change? Before you actually perform the experiment, think what would happen. Write your guess, the experimental observation and a brief explanation below