# CNS Institute for Physics Teachers

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| **Title:** | Introduction to Oscilloscopes |
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| **Appropriate Level:** | Regents, AP, University |
| **Abstract:** | The oscilloscope is a versatile and heavily used measuring instrument in science, engineering, and industry.  It earns this status because it neatly provides an instant graph of how the voltage of a signal varies as a function of time or as a function of a second signal. It also allows easy comparison of separate signals.  This lab will provide an introduction to the basic operation of a 'scope.'  An examination of AC and DC voltages, of various waveforms, and of other phenomena will provide a useful means to that end. |
| **Time Required:** | Two to three single lab periods |
| **NY Standards Met:** | STANDARD 1—Analysis, Inquiry, and Design<br>*Key Idea 1:* Abstraction and symbolic representation are used to communicate mathematically.<br>M1.1  • represent physical quantities in graphical form<br>      • construct graphs of real-world data<br>*Key Idea 3,* S3.1 Use various means of representing and organizing observations and insightfully interpret the organized data.<br>*Key Idea 4,* 4.1 Observe and describe transmission of various forms of energy.  viii. measure current and voltage in a circuit<br>4.3 i. compare the characteristics of two transverse waves such as amplitude, frequency, wavelength, speed, period, and phase<br>   ii. draw wave forms with various characteristics<br>   iv. differentiate between transverse and longitudinal waves<br>   vi. predict the superposition of two waves interfering constructively and destructively<br>• identify possible sources of error in data collection and explain their effects on experimental results |
| **Special Notes:** | **Introduction to Oscilloscopes** is a kit available from the CIPT Equipment Lending Library, www.cns.cornell.edu/cipt/. |
| **Credits:** | http://www.physics.udel.edu/~watson/phys345/lab/scope.html<br>George Watson, Univ. of Delaware, 1999. |

Many physics teachers have not learned to use oscilloscopes. This teacher section is largely about how a scope works, and it will help the teacher answer many of the questions their students will surely ask. Teachers are cautioned to carefully work through _all_ of the steps of the student section paying particular attention to areas where their students might have difficulty.

**Objectives**:
Upon completion of this lab/tutorial activity, the student should be able to
- Explain the principal features and benefits of an oscilloscope.
- Measure voltages, periods, and frequencies using an oscilloscope.
- Correctly use the dual trace functionality of an oscilloscope.

**Time required:**
- approximately two – three regular class periods

This lab/tutorial on the use of oscilloscopes is a very reasonable activity for any physics student, but it is long. We recommend that you have your students do the pre-lab in advance, inform them that there ARE a lot of steps, and assure them that the many steps are all quick and easy to do.

**Materials needed/3 person team:**
- 1 Tektronix TDS-1002B dual trace digital oscilloscope (Any analog or digital dual trace oscilloscope _could_ be used, however this lab is written for use with digital scopes and uses features not typically found on analog scopes.)
- 2 BNC oscilloscope probes
- 1 digital multimeter (DMM) with both DC and AC measuring capability
- 1 set of test leads for the DMM (1 banana plug & 1 alligator clip per lead)
- 1- 9 V **AC** plug-in wall power supply
- 1 function generator - Kelvin function generator kit (PCB #440598)
- 1 mini amplified speaker (RadioShack Mini Audio Amplifier #277-1008)
- 1 'patch cord' (3.5 mm male audio plug on one end of the wires, and alligator clips on the other end.)

**Alternative equipment:**
- 30 volts or less variable voltage AC power supply
- Research quality digital function generator
- Computer based (excellent, but need a computer with a sound card)
    - Audacity (a free download)
    - Vernier LabPro function generator application (free add on)
    - Many other programs can be found with a quick search online.

## Oscilloscope Tutorial:
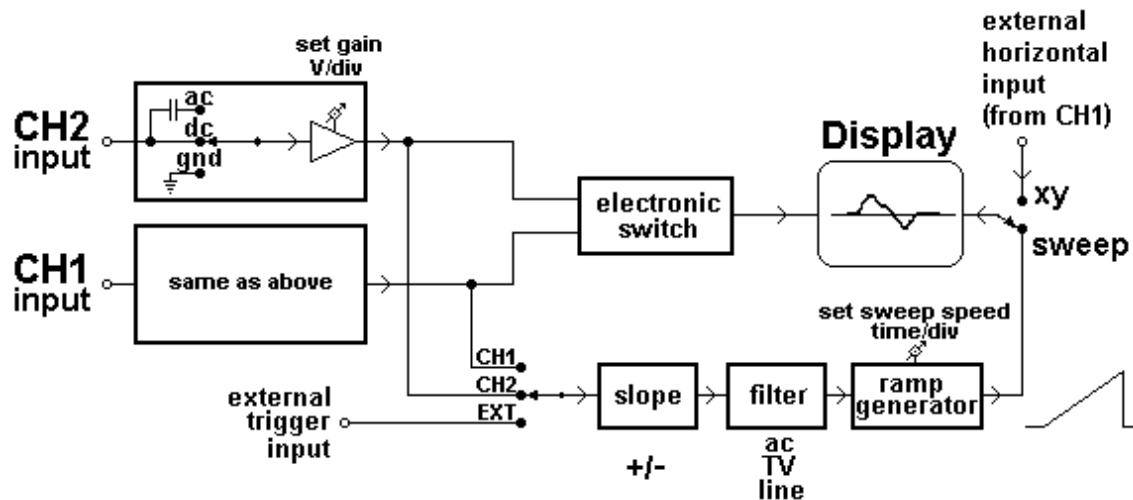


(Diagram reprinted by permission from Dr. George Watson, University of Delaware)

Figure 1: General Block Diagram of a 2 Channel Analog Oscilloscope

Analog and digital oscilloscopes are both commonly used in science and industry. A digital scope has many more features, is easier, and is more versatile, but it is much more expensive. An analog scope is generally much more basic, but it does give a sharper display and costs much less. The basic controls on both instruments, with a few important exceptions, are the same.

The diagram above is a block diagram of the major components of an <u>analog</u> oscilloscope, which is the type of scope to which most teachers are likely to have immediate access. In analog scopes, the graph line (trace) is created when the scope sweeps an electron beam across the display and the electrons hitting the phosphor coating cause it to glow where they hit. Digital scopes use an entirely different process to actually make the trace, but the rest of the process is analogous, so we will use the details of analog scopes here. Here is a very quick and very dirty explanation <u>for teachers</u> of how an **analog** scope accomplishes the display of a signal:

- **The Display**: 'Free' electrons are provided by thermionic emission from a heated filament/cathode located at the back of the cathode ray tube (CRT) which runs the length of the oscilloscope case. They are accelerated towards a positively charged electrode, called the plate, and pass through a small hole resulting in a narrow electron beam. The front of the CRT is coated with a phosphor material which glows when struck by the electron beam. So far there is a glowing dot in the center of the display. In order to create a graph of an applied signal on the screen, one simply 'draws' it on the phosphor surface with the electron beam. Since the glow doesn't last very long, one draws over and over the same path to maintain a stable display. The next sections provide some detail on how the scope 'draws' with an electron beam, and how it times the repetition of the electron beam path.

- **The y-axis**: Parallel electrically charged plates above and below the beam-path determine the vertical position of the beam when it hits the phosphorescent surface of the screen and creates the small dot of light. The input signal voltage is amplified exactly enough to give

the desired graph scaling factor for the display and then that voltage is applied to these plates. The more the voltage applied to these vertical deflection plates, the farther above or below the centerline of the display the dot will appear. (Part of this is shown for channel 2 in the top left block of the diagram above. The triangle is the amplifier. Gnd is the ground which is used to provide a zero reference and set the location of the center line.)

- **The x-axis** is generally the time axis, and is obtained as follows: The ramp generator in the lower right of the block diagram in Figure 1 above creates a saw tooth wave signal like that shown below in Figure 2 and also in the bottom right of Figure
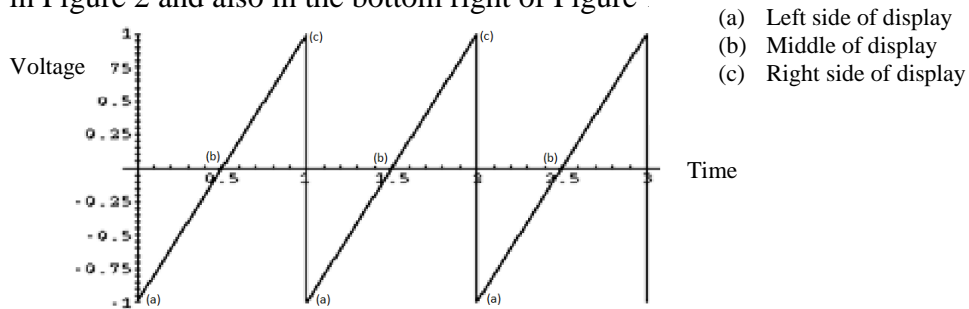


(a) Left side of display
(b) Middle of display
(c) Right side of display

**Figure 2: Graph of Voltage vs. Time for a Sawtooth Wave**
(http://www.upscale.utoronto.ca/GeneralInterest/Harrison/Vibrations/transp11.7.gif)

A *triggering* (initiating) signal causes the saw tooth signal to begin at a particular moment in time. The voltage of the saw tooth is applied to parallel conducting plates to the right and left of the CRT beam-path and charges them (+) and (-). As the voltage climbs in a sloped portion of the saw tooth graph, the amount of charge on the plates varies. The amount of charge on the plates is what determines the horizontal position of the beam when it hits the phosphorescent surface of the screen, and the smoothly changing amount of charge causes the electron beam of the scope to sweep smoothly across the display. The constant slope of the saw tooth causes the electron beam to scan across the x-axis at a constant speed; and the steeper the slope, the faster the sweep. When the saw tooth reaches the maximum voltage, and the electron beam is hitting the far right hand side of the display, the voltage drops quickly back to the maximum negative voltage, bringing the electron beam back to the far left hand side of the display where the next sweep begins. Each saw tooth pulse results in one sweep of the electron beam across the display.

Since the voltage varies in a regular pattern with time, the position of the beam varies in exactly the same way. The steeper the slope of the diagonal portions of this waveform, the more quickly the charging of the plates changes, and the more quickly the electron beam is moved across the screen. This sets the sweep speed, which determines the x-axis time scale on the scope. Each tooth in the diagram represents one sweep of the beam across the screen, with the verticals providing the jump back to the left side of the screen for the next sweep. By sweeping the beam across the screen slower than the phosphorescence fades and more quickly than our eyes can adjust, the graph which results looks continuous even though it is created by a single moving point.

This is similar to the sweep used in CRT television displays and scanning electron microscope displays, except that scopes only sweep the x-axis, while the other examples sweep both x and y to fill the screen with an image … not just a line graph. The digital scopes used in this

lab/tutorial use digital processing and liquid crystal displays like those found in flat panel televisions or computer displays.  Some scopes even work by bringing the signal into a computer and processing and displaying the information right on the computer monitor.  Regardless of how they do it, oscilloscopes are simply drawing graphs really, really fast.

Analog CRT scopes have a FOCUS knob and an INTENSITY knob to adjust the sharpness and brightness of the trace.  Digital scopes have neither, and their displays are generally not as sharp.  They do, however, have many advantages.  They can freeze displays, save displays to USB flash drives, perform mathematical manipulation of displays, and much more.

Very Important:  When using an analog CRT scope, set the trace to be sharp and bright enough to be easily viewed, but no more intense than necessary.  *An overly bright display on an analog scope will 'burn' the phosphor of the display making it quickly and irreparably deteriorate.* If you loan your analog scope to another teacher, be sure to remind him/her about this.

**Using the oscilloscope probes:**
It is important that you tell your students how to properly use the oscilloscope probes to prevent them from being damaged.
- The probe has a male 'BNC' connector. Connect the probe to the CH 1 input by lining the pegs up with the slots and pushing the male BNC connector on the wire straight onto the female BNC connector on the scope and then turning **its sleeve** (the ring around the connector) about a quarter turn clockwise to lock it in place.  When you want to remove it later, turn the sleeve ccw until it stops, and then pull the connector straight off.
- The probe has a thin wire coming from its side which is the 'ground lead' or 'ground wire'.
- The tip of the probe can be either a pointed metal rod or a spring-loaded clip. The pointed tip is simply touched to the location of the signal one wishes to view as a graph.  The spring-loaded clip can be used the same way, but is really for attaching the probe to a wire when one wants it to stay in place.  To use the clip pull back on the plastic sleeve on the end of the probe and a very small hook will be exposed.  Hook onto a wire, release the sleeve and a spring will hold the probe in place on the wire.

Additional information you may want to give you students for Activity 5:
You probably already know that sound waves are longitudinal waves, consisting of successive compressions and rarefactions of the medium carrying the sound wave.  A speaker produces sound waves when its incoming electric signal varies, and that electric signal can be visualized with a scope.  The signal on the scope will vary in a transverse wave that corresponds to the sound's variation in a longitudinal wave.  Remember that the sound wave is still longitudinal. The voltage going to the speaker is being graphed and *that* is transverse.  This process can be reversed, as well.  A microphone can pick up the compressions and expansions of sound waves, and convert them to an electrical signal that can be visualized with a scope.

**References:**
The Tektronix website has a good and comprehensive introduction to oscilloscopes at:
 http://www.tek.com/Measurement/App_Notes/XYZs/

**Tips for teachers:**
- Troubleshooting: If inappropriate readings are showing up, check that the scope probe is switched to the 10x position, and push **Probe→Voltage→Attenuation→10x** on the scope.
- Troubleshooting: If an RMS voltage value is not displayed in the Autoset mode when it is requested in the lab, check to be sure that menu option button [14a] has been pressed to get a multi-pulse display and the RMS voltage should appear onscreen. If menu option button [14b] is active providing a single cycle display, then a *mean* voltage will be displayed instead of the RMS voltage requested in the lab.

This can also be resolved by using the following alternate means of getting RMS voltage (and other measurements as well): Press the MEASURE button which is just to the right of the SAVE/RECALL button [2]. The display will initially show all the option buttons as 'CH1 None'
a. Press the top option button [14a] to display the measure 1 menu
b. Make sure the SOURCE option is set to CH 1
c. Press the TYPE option [14b] repeatedly until the 'Cyc RMS' option appears and the RMS voltage will be displayed.
d. To exit measure mode, press DEFAULT SETUP

**Answers to questions:** send email to cipt_contact@cornell.edu to request answers

# AN INTRODUCTION TO DIGITAL OSCILLOSCOPES
## Pre-Lab

### Answer all questions on Student Answer Sheets following Student Section

The oscilloscope or 'scope' is one of the most versatile and heavily used electronic measuring instruments in science, engineering, and industry. The oscilloscope earns its status as an important instrument because it neatly **graphs how <u>voltage</u> varies as a function of <u>time.</u>** Time varying voltage signals are really important in electronic devices. Oscilloscopes are useful for much more than just electronics, however, since many other types of signals that are converted into electrical signals for analysis.  A transducer is a device that converts one type of energy to another. A microphone is a transducer that converts sound waves into an electric signal that varies with time and can be amplified or recorded. You can "see" music or someone's voice if you connect a microphone to an oscilloscope. If you have used PASCO or Vernier probes in your labs, then you already have experience with a number of other transducers and an oscilloscope-like device that allows you to observe how those signals change as a function of time.  An oscilloscope also allows easy comparison of separate signals.

This lab/tutorial will introduce the basic operation of a oscilloscope.  The combination of reading and doing will allow you to master the basics of this fairly complex instrument.  Don't skip anything, but don't be intimidated by the number of controls on the front of the scope, either. You will quickly discover a lot of duplication and a bit of exploration will allow you to really master all of the basic controls. You will use a function generator in this lab/tutorial as one signal source. The function generator produces uniform sine, square, and/or triangle shaped periodic waves (signals) over a wide range of selectable frequencies and amplitudes.

Answer all questions on the separate answer sheet.

1.  An oscilloscope is an electronic instrument that quickly, easily, and automatically performs what important task?

2.  What is the purpose of a 'function generator?'
**An oscilloscope doesn't display the input signal itself, but rather displays a processed and scaled graph of it.**  When you do a physics lab you make measurements. Then you might do

some calculations to modify the data, choose a scale that will allow you to draw a well-proportioned graph, and draw the graph.  That's a little like what the scope does, but the scope draws the graph continuously in real time as it receives the information.

**Scopes are usually used to display the graph of signal voltage (y axis) as a function of time (x axis).**  Scopes can also display the graph of signal voltage (y axis) as a function of a second signal voltage (x axis).  In either case, **the graph drawn on a scope is called a '*trace.*'  A 'dual trace' scope is simply one that can display two graphs at once.**

**The input signal is not changed when one adjusts the scaling of the x or y axes on a scope.  Think of scale adjustments as zooming in or out on the view of the graph of the signal.**

<u>The x-axis</u>: Generally a **time axis**
A trace is created when a point on the scope plots a large set of points by 'sweeping' across the x-axis of the display at a constant speed. For a slow sweep, the length of time plotted out on the x-axis will be longer than for a fast sweep, which will capture a shorter interval of time. A ***triggering*** (initiating) signal causes the plotting to begin (triggering will be important for the lab). When the sweep gets to the right side of the display screen, it jumps back to the start, and begins the next sweep across the screen.  If the signal is unchanging, each successive graph lands right on top of the previous sweep, and you see it as a static graph. If the input data is changing, then you will see the graph change with each successive sweep since this repeated cycling continuously refreshes the display.  Both the method of initiating the sweep (triggering), and the rate of the sweep are adjustable with controls on the front panel of the scope.  The key points about the x-axis are:

- **The x-axis is generally a time axis.  In that mode, the point on the screen sweeps across at a constant user selectable speed, covering equal distances across the screen in equal times.**
- **If there is no input signal, you will see a horizontal line at y = 0, usually in the center of the display.**
- **Changing the scan rate changes the scale of the x-axis of the graph the scope displays.**
- **Time is scaled in units of <u>seconds/division</u> (SEC/DIV). To rescale the time axis, change the SEC/DIV.**

<u>The y-axis</u>: Displays **voltage**
When an external signal voltage is connected to one of the two oscilloscope inputs, the signal is amplified to the extent set with the vertical gain control on the front panel of the scope.  This sets the y-axis scale. For a given vertical gain, the more positive the input signal becomes, the higher up the display screen the point is plotted. Similarly, the more negative the input signal becomes, the lower (below the x-axis) the location where the point is plotted.  The key points about the y-axis are:

- <u>**The y-axis is the voltage axis.**</u>  **The higher the voltage, the farther from the x-axis the graph point moves for a given vertical gain setting.**

- **Voltage can be positive or negative relative to 'ground' (the zero reference). Positive moves the graph point above the x-axis; negative moves it below the x-axis.**
- **Changing the vertical gain control changes the graph's y-axis scale (expressed in <u>Volts/Division</u> or VOLTS/DIV). It <u>doesn't</u> change the value of the input voltage.**

**<u>The graph</u>: Since the x-axis and y-axis motions described above occur at the same time, they result in the automatic plotting of a graph of the input voltage vs. time.**

3. What characteristic of the sweep allows the x-axis to be a time axis?

4. If one wants the voltage vs. time graph to be more spread out horizontally, the sweep across the screen should be (*faster, slower, at the same rate*) in order to get the SEC/DIV to be a (*smaller, larger*) time interval. (Warning: This can seem tricky, so look at Graph A and B on the next page for a hint.)

One more detail before we do the lab … **<u>Graph Scaling</u>**
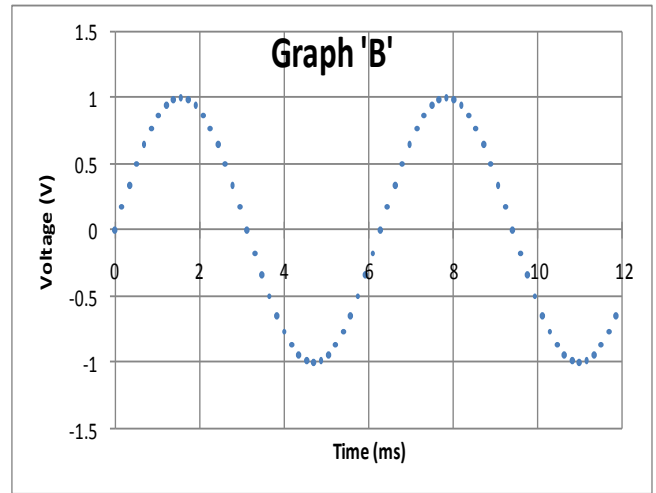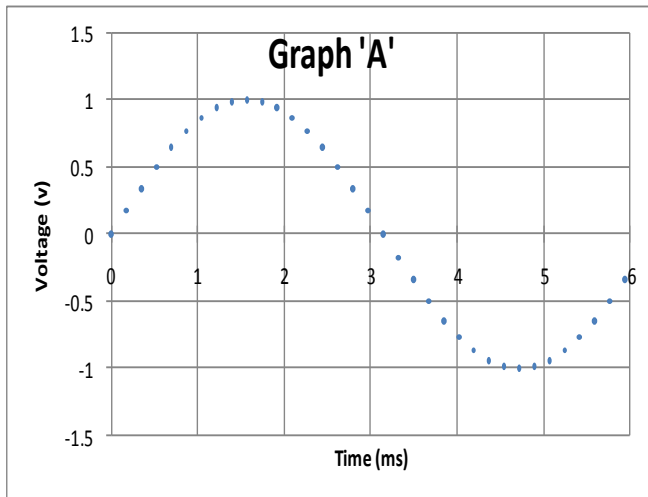


5. In what ways is the data in Graph 'A' different from that in Graph 'B'?

6. In what ways is the data in Graph 'A' the same as that in Graph 'B'?

7. When you change the scale used on a graph how does the magnitude (size) of the original data which is plotted change?

8. Why does one choose to use a particular scale in drawing a graph?

**These same concepts about graph scaling also apply to oscilloscopes.**

# AN INTRODUCTION TO DIGITAL OSCILLOSCOPES
## Lab Activity

**Answer all questions on Student Answer Sheets following Lab Activity Section**

**Materials**
- Tektronix TDS 1002B Dual Channel Digital Storage Scope
- oscilloscope probe

## Activity 1: Identifying the Controls

The diagrams in Appendix A show the controls of the function generator and the oscilloscope the CIPT provides for this lab. Feel free to 'try out' any or all of the controls on both devices, as much of your learning here will come from exploring the instruments. The diagrams are numbered and labeled to help you find the various functions. Let's start discovering how scopes work and what they can do for us by 'looking at' electric signals.

**Setting Up the Scope**

- Plug in the oscilloscope and turn it on. The scope will go through a warm up cycle and ask for your language preference.
- Adjust the feet for comfortable viewing.
- Push the DEFAULT SETUP button [7] for generically useful settings.
  **If you ever feel 'lost' in the process, this button is a good place to get a fresh start.**

You should observe a rectangular graph grid with a heavy black horizontal line in the middle of the display.  The screen says 'DEFAULT' at the top and 'Undo Default Setup' at the bottom. The DEFAULT setting dictates that **the x-axis (time) is at 0 volts in the middle of the screen and the y axis depends on a scope setting**, yet to be discussed.

Important Notes:

- ✓ The 1 on the left hand side of the graph means you are observing channel 1 (CH 1), and the tiny arrow shows 'ground potential' or where zero is.
- ✓ The 0.00 V you see in the lower right corner of the display has to do with an important scope function called 'triggering', and is <u>NOT</u> the applied voltage. Triggering will be discussed later.

9. Reading information from the graph, how much voltage is being applied to the CH 1 scope input?

    a. How did you get this from the graph?
    b. How do you know this from the present experimental set-up of the scope?

- Push the button labeled CH 1 MENU [4]. *This is an on/off button for the display of the graph of the channel #1 signal. If you press it again, the display of the channel #1 input will be turned off.*

  When channel 1 is selected, the right-hand side of the display shows a column of labels beneath the header CH 1.

  - The first label is 'Coupling', and it will be in the default 'DC' mode. DC coupling feeds the input signal directly into the scope for graphing exactly as it is without any special processing. This will be clearer in a moment.

- Push the function button [14a] to the right of 'DC' on the screen and the coupling will change to 'AC', which is a setting used later in the lab.

  - As soon as any non-zero voltage is displayed with 'AC Coupling', it will be centered vertically on the position of the CH 1 x-axis. (The centering in AC coupling is accomplished by stripping out any underlying DC potential).

- Push the function button [14a] once more and the coupling will change to 'Ground'. This removes the input signal, providing an accurate zero reference for calibration purposes.

- Push the function button [14a] again and the scope will be back in 'DC' coupling.

- Turn the narrow CH 1 VERTICAL POSITION knob and you will see the position of the x-axis change. A caption will appear at the bottom of the screen for a short period of time to let you know where you have moved the x-axis. Use this adjustment to look at two graphs simultaneously (CH 1 and CH 2) without them overlapping.

- Push the CH 2 MENU button and then turn the CH 2 position knob counterclockwise (ccw).

10. What happens?

- Turn the CH 2 postion knob clockwise (cw), and watch the caption that appears on-screen. Adjust it back to zero, turn CH 2 off, and press the CH 1 MENU button to return to that screen.

- Return the scope to its original state.

## Activity 2: Connecting the Oscilloscope Probe and Exploring More Controls

The oscilloscope probe is used to connect the scope to electric signal sources.
- Make sure the switch on the side of the probe is in the 10X position.
- Connect the probe to CH 1. The line on the scope begins to 'ripple' a bit because the probe is acting as an antenna and picking up electrical noise from the room.
- Hold the probe away from the scope or any other electronic device, press your finger against the end of the probe, and you will note that the displayed graph gets very large and stable. You have just become part of the 'antenna' and boosted the received signal.
- Adjust the seconds/division (SEC/DIV) knob so you can see more than one cycle. The SEC/DIV value is displayed in the middle of the screen under the graph. **A division, or DIV, means one large grid space.**

11. Use the x-axis scale (SEC/DIV) and information read from the displayed graph to show the calculation that produced this frequency.

- While touching the end of the probe, read the frequency of the displayed noise shown in the lower right corner of the display. This frequency should look familiar. It is the standard frequency of A.C. electricity in the U.S.

12. Noise Frequency =

**Remember, at any time during the lab, if you are not happy with the graph you see on the screen, try changing the scale** of the X-axis using the SEC/DIV control [10] and/or the Y- axis using the VOLTS/DIV control [12] for the channel the probe is plugged-in to.

- Turn the HORIZONTAL POSITION knob [9] a bit while watching the graph and the M Pos number at the top of the screen. The M Pos number is the time at the center graticule (grid-line) on the display.

13. What happens?

- Return the horizontal position of the display to where it was. (The top of the screen shows mpos 0.000 s) You can always use the 'DEFAULT SETUP' button to return to the complete group of original settings.

- Play with the vertical and horizontal controls until you figure out how to determine which channels are displayed, where they are displayed, and the scales in VOLTS/DIV and SEC/DIV. If you can answer the following questions, you probably have the controls we've used so far figured out:
  - ✓ How do you know which channel display goes with which line?
  - ✓ How do you know the x-axis scale for each channel? Where is it displayed?
  - ✓ How do you know the y-axis scale for each channel? Where is it displayed?

**Discuss these with your lab partners to be sure you understand the controls so far.**

## Activity 3: DC Voltage of a Battery

**Materials:** Tektronix TDS 1002B Dual Channel Digital Storage Scope
- oscilloscope probe
- 1 AA battery
- AA battery holder
- Digital  multimeter (DMM)
- Meter probes (wires)

Remember:
**If you are not happy with the graph you see on the screen, try changing the scales**

- Insert the battery into the battery holder.
- Set the digital multimeter (DMM) to measure DC voltage on an appropriate scale, and carefully measure the voltage of a standard 1.5 V AA cell.  It is not going to be exactly 1.5 V.

14. What is the measured voltage?  DMM $V_{battery}$ =

- Turn the DMM off.
-  Now connect the oscilloscope probe to the battery holder and use the scope to measure the voltage.
  - There may initially be a substantial curved graph of 60 Hz noise on the display, if so, then ignore it.  As soon as you connect the battery, it will overpower that signal.
  - Adjust the CH1 VOLTS/DIV knob to display a graph that is not too small and not so big it goes off the display.

15. What does the graph on the scope look like?

16. Why does this graph make sense for the DC electricity from a battery?

17. What is the VOLTS/DIV number shown in the bottom left of the display? Use this scale to make a good estimate of the battery voltage.

18. Scope $V_{battery}$ =

- Turn the CH 1 Volts/Div setting one step ccw.

19. What happens to the line on the graph?

20. What is the VOLTS/DIV number in the bottom left of the display?

21. Has changing the scale of the graph changed the numbers you read from the graph?
22. How do the values from the DMM and the scope compare?

- Autoset is one of the best features of digital scopes. It is like using a 'point-and-shoot' automatic camera where all of the set-up is done for you. Press the AUTOSET [8] button. Wait a moment and the scope display will show the CH 1 mean voltage.

23. CH 1 Mean Voltage of the battery  =

- Now you know one way to get the scope to read the graph for you. Press the Undo Autoset button [14e] next to the display, and the system will return to the CH 1 menu.

How does this DC (**D**irect **C**urrent) signal from a battery compare with the AC (**A**lternating **C**urrent) signal from an AC transformer? Let's use the DMM and scope to find out.

## Activity 4: AC Voltages

**Materials:**
- all previous materials
- 9 volt **AC** plug-in wall transformer

Most plug in power supplies are designed to supply a DC voltage to a device, but some do produce AC. A quick look at the label on the unit will give its specifications.
- Look at the label on the transformer and make a note of its specs.

24. Input:              Output:

- Plug the transformer into a wall outlet.
- Set the DMM to the 20V **DC** scale and measure the actual output voltage of the transformer.

25. DMM $V_{transformer}$=

- Set the DMM to the 200V **AC** scale and repeat the measurement.

26. DMM $V_{transformer}$ =

- Turn off the voltmeter when you are done making your measurements.

**Discussion points**
Why should one need different DC and AC measuring modes for a DMM? Why did you get the results you did? Why are these results so different from the specifications printed on the transformer? If the voltage from an electric wall socket is measured directly using a **DC** meter, the result would be the same as just obtained for the DC voltage from the tranformer. That being the case, why can a person still be electrocuted by an electric shock from an AC wall socket?

27. Discuss this with your lab partners and take notes.

You will now use the scope to try to answer these questions.

- Press the 'Default Setup' button.
- Press the 'CH 1 Menu' button to display the CH 1 options.  Press [14a] to s**et the coupling to AC**.
- Connect the oscilloscope probe to the transformer output and you will see that the graph goes way off-screen in both the x and y directions.  Adjust the VOLTS/DIV and the SEC/DIV to get enough of the graph displaying onscreen to be able to describe its shape.

28. The graph looks like a periodic

29. Its frequency is

30. The SEC/DIV scale shown in the middle of the screen at the bottom is

31. The VOLTS/DIV scale is

32. The 'Peak-to-Peak' voltage is

   (hint: **Peak-to-peak voltage** is the potential difference taken from the positive peak to the negative peak, or from the maximum voltage to the minimum voltage, measured vertically on the graph.  A**mplitude** is measured **from *the x-axis*** to the positive peak *or* to the negative peak, and is commonly used in the study of acoustics instead of the peak-to-peak amplitude.  The amplitude of a sine wave is just half the peak-to-peak amplitude.)

33. The 'Peak' voltage, or amplitude is

   None of the measurements from the scope match the measurements from the DMM!  There are <u>always</u> errors in measurement. The very act of measuring something changes the thing you are measuring.  But this much? There must be something more to this! Look at the graph on the screen.

34. What information is the Peak-to-peak voltage providing?

35.  What information is the Peak voltage providing?  _

36.  The scope display the positive and negative alternations of the AC source.  'Positive' values correspond to electrons drifting in one direction, and 'negative' values correspond to electrons drifting in the opposite direction.  It is not so obvious on the DMM.  Why would the DMM interpret the voltage as zero when it is in the DC mode?

37.  When the DMM is in the AC mode, an electronic component called a rectifier limits electron drift to only one direction by transforming the negative alternations to positive alternations.  Thus, the DMM in AC mode is actually only looking at positive potentials.  How does this change the value from that read in DC mode?

- Press the AUTOSET button [8].
- If the top menu option on the screen (multi-pulse) is not active, push option button [14a].

   (The single cycle option [14b] displays a single cycle and provides a mean voltage, but does not provide the RMS voltage needed here.)

- If necessary, adjust the scales (V/DIV or S/DIV) and positions.  Record the following:

38. CH 1 Pk-Pk voltage =

39. CH 1 VOLTS/DIV =

40. SEC/DIV =

41. Frequency =

42. CH 1 cycle RMS voltage =

- Press Undo Autoset [14e] to return to the CH 1 menu.
- The DMM actually provides a special kind of average called a Root Mean Square Voltage (RMS voltage) when it is in the AC mode.  It is like asking 'What DC voltage would give me the same amount of useful electrical power as the AC peak voltage that is presently being measured?'  Another way of looking at it is to think about what it would take to get the area under the steady DC graph (a rectangle) to be the same as the area under the constantly varying AC graph (a sine curve) during equal time intervals.

  RMS Voltage can be calculated for sine waves using an equation that requires calculus to derive, but one which is easy to actually use:

$$V_{RMS} = \frac{V_{Peak}}{\sqrt{2}}$$

43. Divide $V_{Peak-to-peak}$ in half to get $V_{Peak}$.               $V_{Peak}$ =

44. Divide $V_{Peak}$ by the square root of 2 to get $V_{RMS}$.        $V_{RMS}$ =

The RMS AC voltages obtained from the scope and the multimeter don't match perfectly since the instruments have different measurement errors. In general, the value from the oscilloscope is more reliable than that from the multimeter.

**Activity 5: Sounds from a Simple Function Generator**

**Materials:**
- function generator
- oscilloscope
- oscilloscope robe
- amplifier/speaker
- patch cord with alligator clip ends

You are about to use an electronic device, a function generator, to provide signals of various waveforms, amplitudes, and frequencies, listen to them coming from a speaker, and examine them with a scope.

- Plug the patch cord into the input of the mini-amplified speaker.
- Connect the black alligator clip to the black wire sticking up from the function generator board (ground), connect the red alligator clip to the red wire sticking up from the function generator board (sine/triangle output)
- Make sure the switch sw2 is in the upper 'sine' position.
- Turn the power to the speaker on and turn the volume up *just a bit*.
- Turn the function generator on and you should hear a steady note coming from the speaker.
- Gently turn the blue variable resistor disk labelled 'Frequency Adjustment' on the function generator a bit counterclockwise (CCW).

45. What do you observe?

- Gently turn the black variable resistor disk labelled 'Amplitude Adjustment' on the function generator a bit counterclockwise (CCW).

46. What do you observe?

- Change the setting on **Switch sw2** to the lower '**triangle**' position.

47. What do you observe?

- Move the red alligator clip from the red wire to the violet wire where it says 'Square/TTL Output'.

48. What do you observe?

- Turn the speaker off, and disconnect the alligator clips from the function generator.

Now you know what sine, triangle, and square waves from a function generator sound like. How might we visualize them and study their details?


### **Visualizing Function Generator Signals - The Wave's Profile**

- Reset the scope with the DEFAULT SETUP button.
- Press the CH1 MENU button and select the AC Coupling option [14a]
- Return the function generator switch [sw2] to the '**Sine**' position.
- Clip the oscilloscope probe onto the red wire sticking up from the function generator board (sine/triangle output), and the alligator clip coming from the side of the probe to the black wire sticking up from the function generator board (ground).
- Push the AUTOSET button [8] in the upper right corner of the scope and adjust the scales to display of a few cycles of a sine wave. A set of values will appear along the bottom and display options will appear along the side of the screen. Record the following:

$$V_{pk-pk} = \qquad \text{cycle } V_{RMS} = \qquad \text{frequency} =$$

You have already worked with most of the numbers shown. Take a moment to **review all the information at the bottom of the screen with your lab partners and make sure all of you understand what each item means** (<u>except</u> for the number just under 'Undo Autoset'). You should also know how to get all of them <u>without the use of autoset</u> because not all scopes have autoset.

49. ***Before you actually do the next step*** to view a triangle wave, use all you have done/observed so far to predict which way to turn the VOLTS/DIV knob to obtain a good display of the wave.                (fewer VOLTS/DIV) or  (more VOLTS/DIV)

50.  Justify your prediction:

Change the setting on **Switch sw2** to the '**triangle**' position, adjust the VOLTS/DIV, and record the following:                $V_{pk-pk} =$          cycle $V_{RMS} =$          frequency =

51. What do you observe about your predictions as compared with the recorded values?  Explain.

52. ***Before you actually do the next step*** to view a square wave, use all you have done/observed so far to predict which way to turn the VOLTS/DIV knob to obtain a good display of the wave.                (fewer VOLTS/DIV) or  (more VOLTS/DIV)

53. Justify your prediction:

• Move the probe tip to the violet wire where it says 'Square/TTL Output, adjust the VOLTS/DIV and record the following:.
                $V_{pk-pk} =$          cycle $V_{RMS} =$              frequency =

54. What do you observe about your predictions as compared with the recorded values?  Explain.

Gently turn the blue variable resistor disk labelled 'Frequency Adjustment' on the function generator a small amount counterclockwise (CCW).

55. What do you observe?

• The 'Amplitude Adjustment' on *this* function generator does not affect the square wave output.

## Activity 6: Oscilloscope Triggering

Your pre-lab defined the term '**triggering**' as **initiating the sweep of the trace across the display.**  Here is an introduction to that function:

• Use the function generator to return the scope to a view of a roughly 384 Hz sine wave such that the graph fills roughly a quarter to a third of the vertical space on the display.
• While you watch the small arrow on the right hand vertical edge of the graph grid <u>and</u> watch the sine curve on the display, slowly turn the trigger level knob clockwise until the arrow goes above the positive peak voltage of the graph.  Turn the knob slowly counter clockwise until the arrow goes below the negative peak voltage.

56. What do you observe?

57. Why do you believe the display did this?

When you see a wildly moving display in which you can't read anything useful, the problem is that the scope isn't triggering properly on the signal. If the signal you are trying to view never hits the triggering voltage to which the scope is set, then the scope doesn't start the scan across the screen at a regular, repeating interval that places each 'next sweep' exactly on top of where each 'last sweep' was.

Triggering allows you to view a continuously changing but repeating signal as if it were standing still. You MIGHT be able to adjust the display so that you see the entire waveform on occasion using the adjustments you have learned about already, however it is unlikely that you will be able to get it to be stable. In order to clearly view a signal and obtain numerical information about it, one needs to adjust the oscilloscope triggering.

- Press the trigger menu button (just under the TRIGGER LEVEL knob) and note the captions by the side of the buttons [14a-e]. Here is a summary of the more commonly used settings:
  - The most common 'Type' is 'Edge', meaning the edge of the rising or falling signal when it crosses the trigger level threshold you have set (where the arrow is). 'Pulse' is used for finding normally invisible very short pulses in an otherwise stable waveform.
  - 'Source' specifies which signal the scope should use to trigger. 'Ext' means 'use the signal connected to the 'EXT TRIG' BNC socket on the front of the scope. 'AC Line' uses the signal coming from the electric socket the scope is plugged into as the trigger. It is useful for studying anything that might be reacting to the electricity being supplied.
  - 'Slope' – Try it and see! (Hint: The slope of the triggering signal is positive or negative)
- Turn off the function generator and the oscilloscope.

Triggering Summary:
  - ✓ Triggering sets the moment when the sweep across the screen begins.
  - ✓ In use, one generally chooses an appropriate source and type of triggering, and then adjusts the trigger level to be in the range of the signal to give a stable display.
  - ✓ If you don't have a stable display, it's probably because the trigger level is outside the signal range.

You have been introduced to oscilloscopes, and hopefully can agree that they are useful and versitile instruments. They can do certain kinds of measurements that can't be accomplished by other means. There are many other things a scope can do, like measuring extremely short time intervals (see the CIPT 'Speed of Light' lab), finding phase relationships between separate signals, performing mathematical operations on separate input wave functions and much more that is 'beyond the scope' of this introduction. If you continue to study science or engineering, you will probably revisit the contents of this lab/tutorial often, and we hope it helps immensely.

# AN INTRODUCTION TO DIGITAL OSCILLOSCOPES
**Student Answer Sheets**

## Pre-lab

1. An Oscilloscope is an electronic instrument which quickly, easily, and automatically performs what important task? _____

2. What is the purpose of a 'function generator'? _____
_____

3. What characteristic of the sweep allows the x-axis to be a time axis? _____
_____

4. If one wants the voltage vs. time graph to be more spread out horizontally, the sweep across the screen should be (faster, slower, at the same rate) in order to get the SEC/DIV to be a (smaller, larger) time interval. (Warning: This can seem tricky, so look at Graph A and B for a hint.)

5. In what ways is the data in Graph 'A' different from that in Graph 'B'? _____
_____

6. In what ways is the data in Graph 'A' the same as that in Graph 'B'?_____
_____

7. When you change the scale used on a graph how does the magnitude (size) of the original data which is plotted change? _____
_____

8. Why does one choose to use a particular scale in drawing a graph? _____
_____

## Activity 1: Identifying the Controls

9. Reading information from the graph, how much voltage is being applied to the CH 1 scope input?   V = _____
   a. How did you get this from the graph?   _____

   b. How do you know this from the present experimental set-up of the scope? _____
_____

10. What happens when the CH 2 MENU button is pushed?_____

_____

**Activity 2: Connecting the Oscilloscope Probe and Exploring More Controls**

11. Use the x-axis scale (SEC/DIV) and information read from the displayed graph to show the calculation that produced this frequency here: _____

_____

12. Noise Frequency = _____

13. What happens when the HORIZONTAL POSITION knob is turned a bit? _____

**Activity 3: DC Voltage of a Battery**

14. What is the measured voltage?  DMM $V_{battery}$ = _____ Volts

15. What does the graph on the scope look like? _____

16. Why does this graph make sense for the DC electricity from a battery? _____

_____

_____

17. What is the VOLTS/DIV number shown in the bottom left of the display? _____

18. Use this scale to make a good estimate of the battery voltage:

Scope $V_{battery}$ = _____V

19. What happens to the line on the graph when you turn the CH 1 Volts/Div setting one step ccw? _____

20. What is the VOLTS/DIV number in the bottom left of the display? _____

21. Has changing the scale of the graph changed the numbers you read from the graph? _____

22. How do the values from the DMM and the scope compare? _____

23. CH 1 Mean Voltage of the battery = _____ V

**Activity 4: AC Voltages**

24. Input: _____   Output: _____

25. DMM $V_{\text{wall transformer}} = $ _____V DC

26. DMM $V_{\text{wall transformer}} = $ _____ V AC

27. Notes from discussion of these results:_____
_____
_____
_____
_____
_____

28. The graph looks like a periodic <u>Sine</u> wave. _____

29. Its frequency is _____

30. The SEC/DIV scale shown in the middle of the screen at the bottom is _____ ms/div.

31. The VOLTS/DIV scale is _____ V/div.

32. The 'Peak-to-Peak' voltage is _____ V.

33. The 'Peak' voltage or amplitude is _____Vs.

34. What information is the Peak-to-peak voltage providing?   _____
_____

35.  What information is the Peak voltage providing? _____
_____

36. Why would the DMM interpret the voltage as zero when it is in the DC mode?  _____
_____
_____
_____

37. The DMM in AC mode is actually only looking at positive potentials.  How does this change the value from that read in DC mode?  _____

_____

_____

_____

38. CH 1 Pk-Pk voltage = _____ V

39. CH 1 VOLTS/DIV = _____V/DIV

40. SEC/DIV = _____ ms

41. Frequency = _____Hz

42. CH 1 RMS voltage = _____V

43. Divide $V_{Peak-to-peak}$ in half to get $V_{Peak}$. $V_{Peak}$ = _____V

44. Divide $V_{Peak}$ by the square root of 2 to get $V_{RMS}$. $V_{RMS}$ = _____V

**<u>Activity 5: Sounds from a Simple Function Generator</u>**

45. What do you observe when the 'Frequency Adjustment' is turned a bit CCW? _____

46. What do you observe when the 'Amplitude Adjustment' is turned a bit CCW? _____

47. What do you observe when the mode is switched to 'Triangle'?_____

_____

48. What do you observe when the mode is switched to 'Square/TTL Output'? _____

_____

49. ***<u>Before you actually do the next step</u>*** to view a triangle wave, use all you have done/observed so far to predict which way to turn the VOLTS/DIV knob to obtain a good display of the wave.

       (fewer VOLTS/DIV) or  (more VOLTS/DIV)

50.  Justify your prediction: _____

_____

- Change the setting on **Switch sw2** to the '**triangle**' position, adjust the VOLTS/DIV, and record the following:

  $V_{pk-pk}$ =_____     cycle $V_{RMS}$ =_____     frequency = _____

51. What do you observe about your predictions as compared with the recorded values?  Explain.

_____

_____

52. ***Before you actually do the next step*** to view a square wave, use all you have done/observed so far to predict which way to turn the VOLTS/DIV knob to obtain a good display of the wave.

  (fewer VOLTS/DIV) or  (more VOLTS/DIV)

53. Justify your prediction: _____

_____

- Move the probe tip to the violet wire where it says 'Square/TTL Output, adjust the VOLTS/DIV and record the following:

  $V_{pk-pk}$ =_____     cycle $V_{RMS}$ = _____     frequency = _____

54. What do you observe about your predictions as compared with the recorded values?  Explain.

_____

_____

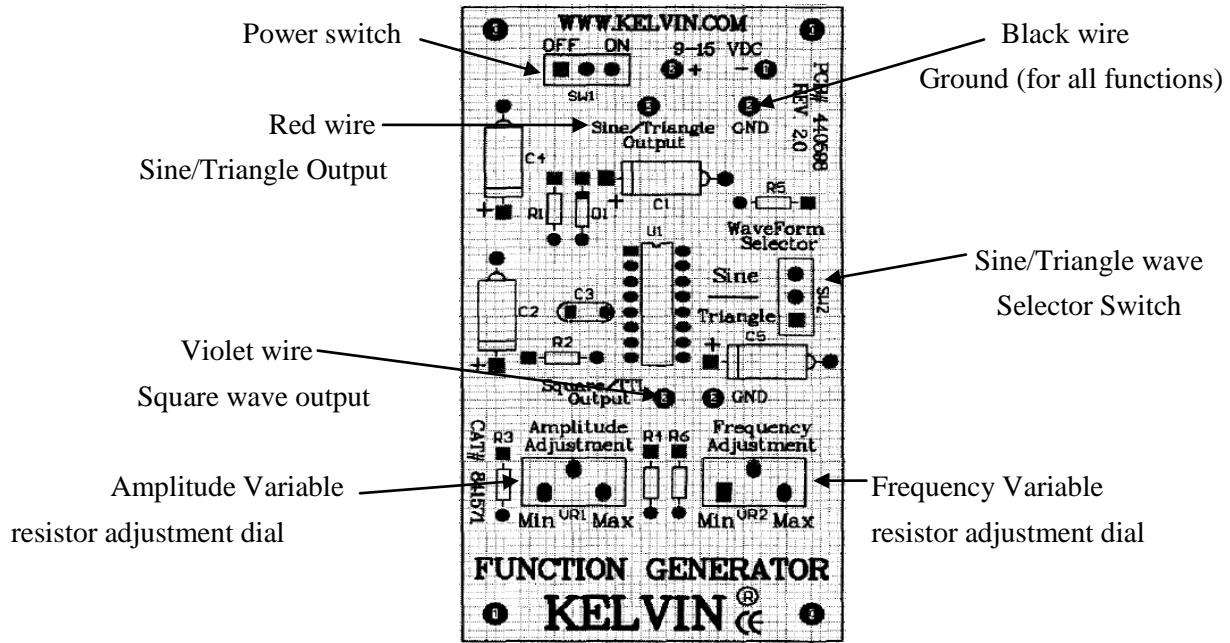55. What do you observe when you turn the function generator 'Frequency Adjustment' CCW?

_____

_____

**Activity 6: Oscilloscope Triggering**

56. What do you observe as you turn the trigger level knob? _____

_____

_____

57. Why do you believe the display did this? _____

_____

_____

## Appendix A

### Kelvin function generator circuit board controls and connections

Power switch

Black wire
Ground (for all functions)

Red wire
Sine/Triangle Output

Sine/Triangle wave
Selector Switch

Violet wire
Square wave output

Amplitude Variable
resistor adjustment dial

Frequency Variable
resistor adjustment dial

WWW.KELVIN.COM
OFF   ON     9-15 VDC

FUNCTION GENERATOR
KELVIN

### Tektronix TDS 1002 oscilloscope front panel

SAVE/RECALL [2]

POSITION (CH 1) [3]
CH 1 MENU [4]

CURSOR [5]

DEFAULT SETUP [7]

POSITION (CH 2) [6]

AUTOSET [8]

Tektronix TDS 1002

HORIZ. POSITION [9]

TRIGGER LEVEL

Screen [1]

VOLTS/DIV      VOLTS/DIV      SEC/DIV

CH 1          CH 2          EXT TRIG

Function buttons [14a -14e]

VOLTS/DIV adjust [12]

SEC/DIV adjust [10]

CH 1 INPUT [13]

CH 2 INPUT [11]