

Introduction to Physics 15b Laboratories

Goals:

1. Provide reinforcement of material presented in lecture and the text. Many of the problems are derived from questions in Purcell or demonstrations that have traditionally been used to illustrate the lectures. Each lab is primarily associated with one or two chapters in Purcell.
2. Provide additional examples of physical phenomena and technological applications that rely on principles presented in the lectures and the text.
3. Provide an opportunity to explore how physical quantities are determined using measuring apparatus, including considering how the measurement alters the quantity being measured. This process is more subtle than it appears. For example, most voltmeters do not actually measure voltage, they measure current and then convert the current to voltage.
4. Provide an opportunity to find creative solutions to problems with no correct answer. MIT is famous for challenge problems such as using popsicle sticks and rubber bands to protect an egg dropped from the largest possible height h .
5. Provide practice in presenting oral presentations describing scientific work.

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Scheduling: There will be four labs during the semester, plus a brief introductory session to familiarize you with the laboratory portion of the course. The labs will be sectioned during the first week of class. The introductory session is scheduled for the week of February 11. The labs will cover material after it is presented in lecture. The labs cover chapter 3, chapter 4, chapter 6 and 7, and chapter 8. They are scheduled for the weeks of Feb 25, March 3, March 31, and April 7. Each laboratory session will last three hours, the introductory session will be approximately an hour.

Pre-Lab Assignments: The write-ups will be available a week in advance of the lab. Each lab has pre-lab questions that are to be answered before the labs. Solutions to the bonus questions are **NOT** required, but they offer a chance to think more deeply about the physics underlying the experiments in the lab. In addition, you should prepare a template to be filled in with the results of your experiments. You may prepare this template using Word, PowerPoint, or any other editor available on the computers in the 15b lab. The supplemental information provided with the labs is **NOT** required reading. It simply offers additional information that may be interesting or useful.

The Labs: The labs will be done in the Science Center in room 104. Three hours is allocated to complete each of the labs. The first 1.5 to 2 hours will be devoted to the mandatory experiments. Written answers to the pre-lab questions are to be turned in when you arrive in lab. Written solutions to the pre-lab questions will be given to you at the same time. The write-ups that you prepared in advance will be used to record your responses to the questions in this section. The completed documents will be graded as you work through the labs. Any parts of the lab that are not acceptable can then be corrected, so you should leave the science center with a correct and complete laboratory write-up. The bonus questions are not required, but will be graded if they are done. You will be given a written overview of the solutions when you leave the lab. It outlines the main points of the lab. It is not a detailed solution to all of the lab problems. The last part of the lab will be devoted to trying the challenge problems for which no documentation is required.

At the end of the challenge session, short (~ 3 minute) talks will present the results of the challenge problems. This is similar to the group meetings that are held by most researchers. In the group meetings, people present results of their work and also discuss problems that they have had, even problems that they have not yet solved. Detailed model lab write-ups including solutions to all of the bonus questions will be posted on the website the week after the labs. There is no required post-lab work. Some of the data will be taken using oscilloscopes, Labview, and LoggerPro. The introductory session will provide an opportunity for people to practice using oscilloscopes, Labview and LoggerPro if they wish. LoggerPro is available from FAS.

Grading: The labs are pass/fail. Each lab is graded separately, and each must be passed.

Electrical Safety: Electricity is most harmful when current enters the body at one point and leaves at another. There are three major types of injuries: 1. cardiac arrest; 2. burns; 3. internal damage including neurological damage. These can be prevented by not placing your body in contact with different electrical potentials. The danger is often stated in terms of a voltage, which is correct if the threat is a voltage source that can provide infinite current. Static electricity experiments often involve large voltages, but very little charge and thus very little current; therefore, they can use high voltages and still not be dangerous. Taking off a fleece jacket can generate more than 1000V of potential with respect to ground. The GFI (ground fault interrupt) switches in houses limit the current that flows through the circuit but does not return to the voltage source. This missing current must be flowing to ground through a path other than the circuit. The GFI is typically tripped at approximately 5 mA, a current level that is considered safe. Experiments in this course are designed so that people doing the labs do not make contact with any device that could put 5 mA across a person. Some devices in the labs, such as the computers, do draw higher currents, but the current path is not accessible.

Apparatus Exercise: The signal generators are set to provide a 100 Hz sine wave with a 3 volt amplitude. Display this voltage signal on an oscilloscope ("scope"), so the amplitude is 3 boxes and 3 periods of the sine wave are shown. Make the connection from the signal generator to the scope using each of the following: a BNC cable; a micrograbber to BNC cable; and an oscilloscope probe. Please display the micrograbber and scope probe signals simultaneously on 2 different channels. Inside the scope probe is a voltage divider; however, the scope senses when the probe is connected to its input and compensates so that the signal displayed on the scope corresponds to the true input voltage on the probe. Verify this. Demonstrate that the scope probe output really is 1/10 the input. What happens when the trigger voltage exceeds the amplitude of the input voltage? Display the signal generator output on the computer using the vernier voltage probe, LabPro, and LoggerPro. Keep the result in one window, while adding a second window below that shows a plot of the signal on a semi-log scale where the time axis is linear and the voltage axis is logarithmic.

Bonus: Disconnect the alligator clip inputs from the signal generator and measure the voltage as a function of time again. Explain the origin of the time dependent voltage that is shown on the computer. Try to minimize the signal. Try to maximize the signal. Compare with the micrograbber signal and scope probe signals in the absence of input.

Supplemental Information

Apparatus Exercises

Materials: 1 four channel oscilloscope; 1 signal generator; 1 vernier voltage probe to connect with the LabPro input; 1 computer running LoggerPro; 2 sets of micrograbbers with BNC jacks; 1 BNC to banana connector with wires clamped in the banana posts; 2 BNC cables; 1 oscilloscope probe

Recall that absolute voltage or potential has no meaning, only voltage or potential difference has physical significance. The signal generators are set so that their voltage output as function of time is given by

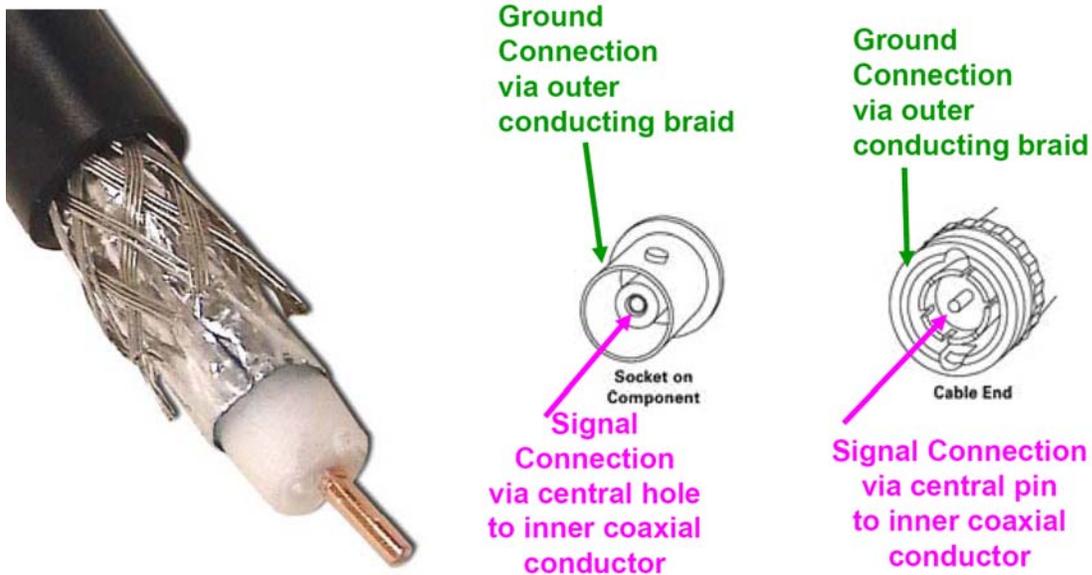
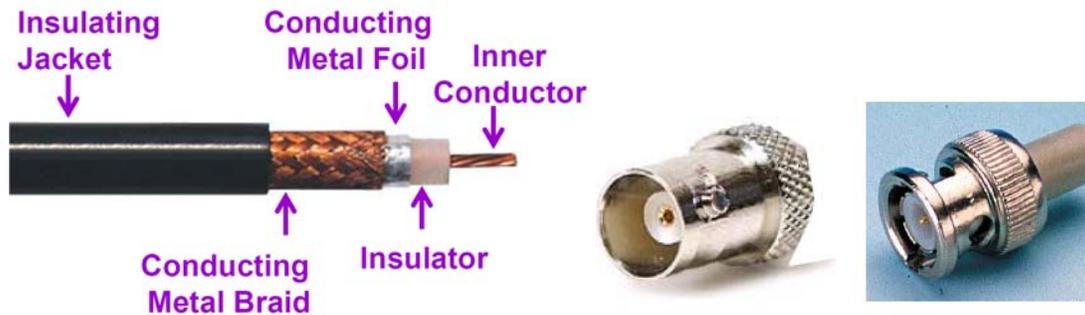
$$V_{\text{signal}} = 3 \text{ Sin } [2 \pi 100 t]$$

where this voltage refers to the potential difference between the signal voltage and the ground reference that is usually designated as $V=0$. Thus, in this system the potential difference between any signal voltage and ground is the same as the signal voltage itself, so the explicit reference to ground is often omitted. Every apparatus used to measure voltage must really measure the difference between two potentials or voltages. The rest of this section is an overview of different apparatus that are frequently used to monitor voltage differences.



The voltage output of the signal generator is delivered to a BNC jack, such as the one labeled **b** in the image on the left above. The connector was named after its bayonet mount locking mechanism and its two inventors, Paul Neill of Bell Labs (inventor of the N connector) and Amphenol engineer Carl Concelman (inventor of the C connector). Thus BNC stand for Bayonet Neill Concelman. The small hole in the center of the BNC jack carries the signal, and the metal rim around the outside carries the ground reference. The output voltage is the potential difference between the signal and the ground reference. The signal is carried from the signal generator to the oscilloscope using BNC cables, with connectors at both ends that are similar to the one labeled **a** in the diagram on the left above. BNC cables are coaxial cables. http://en.wikipedia.org/wiki/Coaxial_cable They consist of a central conductor that is surrounded by an insulator, which is in turn surrounded by a second outer conducting layer that shares the same axis as the central

conductor as shown below. In the image at left, the successive layers have been stripped away. In 15b and most research labs, the cables that are used are designated as RG58U.



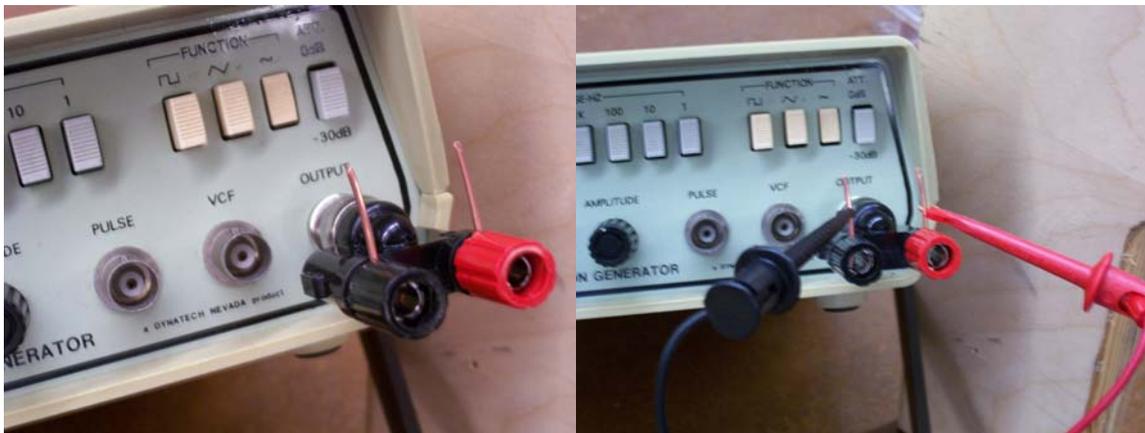
<http://tara-labs-info.com/cable-technology-glossary.html>

In the image on the left above the foil has been bent back and the braid metal braid has been separated to show that it consists of many very small flexible wires that are collected into strands and then braided. The connections between the cables and the connectors are illustrated on the right. The connector is attached to the jack by pressing them together, rotating the connector clockwise until the connector slips over the jack, then rotating clockwise by another quarter turn to lock the connector in place. To undo a BNC connection, gently press in and rotate $\frac{1}{4}$ turn counterclockwise, then pull back to separate the connectors. Attach a BNC cable so it connects the output of the signal generator and the input of the oscilloscope.

Turn on the scope, and adjust the settings so that the 3 full periods of the sine wave show on the screen, and the signal has an amplitude of 3 boxes. The default setting of the scope is to trigger on channel 1. This means that the time at which the voltage display begins is controlled by the input to channel 1. The time is actually set by picking a voltage at which the display begins. If the chosen voltage is never reached, the scope triggers at a random time and the signal appears to jump to different positions on the screen. When you adjust the trigger knob, the trigger level should show as a thin

horizontal line. This is the voltage at which the display begins. Shift the phase of the signal using the trigger. A detailed discussion of oscilloscope use is presented at the end of this section. The word oscilloscope is commonly shortened to just “scope.”

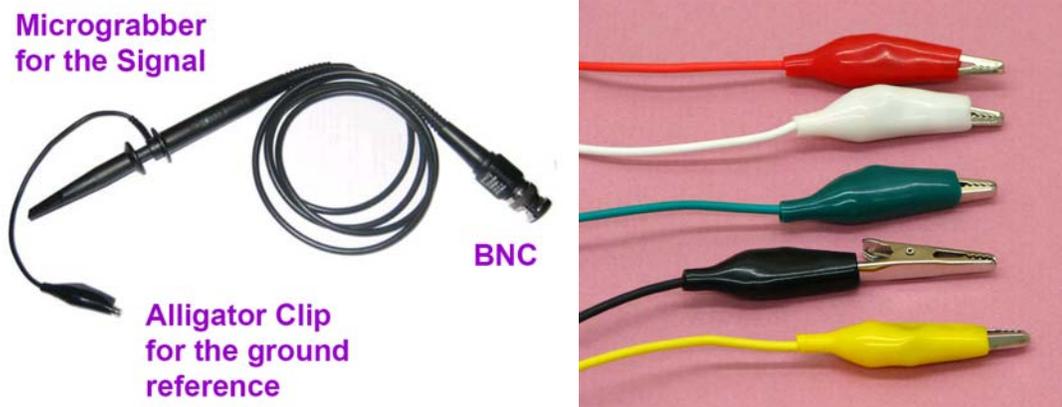
Since the signal generator has a BNC output and the scope has a BNC input, it makes sense to make a connection using a BNC cable; however, scopes are often also used to probe voltages inside electrical circuits. In this case, micrograbbers are often used. A micrograbber pair is shown in the image on the right above. A micrograbber is connected to a wire by pushing on the plunger at the back of the connectors. The plunger moves the hook on the micrograbber forward. The hook is then attached to the wire, and the plunger is released. The spring inside the micrograbber holds the hook around the wire, making an electrical connection. In general, micrograbbers are used to apply a voltage to or measure the voltage on a bare wire. The BNC jack at the end of the micrograbbers can then be connected to a BNC, which in turn can be connected to the cable that BNC input on a scope. Similarly, the output of the signal generator can be applied to wires in circuits using a BNC to banana jack. An example of such a connector is labeled **c** on the image on the left above. The banana jacks can be used in two ways. Cylindrical banana plug connectors at the end of insulated wires can be inserted directly into the back of the banana jack, as suggested by the two banana plugs that are shown to just to the right of the BNC to banana jack above. Alternatively, the red and black cylinders on the banana jack can be unscrewed to reveal holes. Bare wires can be inserted into these holes, and the cylinders can then be screwed back in to hold the wires securely in the jack. This was done for you in advance, to provide wire stub connections at potentials that correspond to the signal and ground reference voltages of the signal generator when the BNC connector is attached to the signal generator.



Connect the BNC to banana connector with the wires stubs to the output of the signal generator as shown in the image at left above. By convention, the red micrograbber or banana is associated with the center of the BNC connector, so it carries the signal. The black is connected with the outside of the BNC connector, so it carries the reference ground. Connect the micrograbbers to the wires stubs so that the red micrograbber connection is connected to the wire in the red banana plug terminal and the black

micrograbber is connected to the wire in the black banana plug as shown on the image on the right above. Then, connect the BNC output of the micrograbbers to a BNC cable that is connected to the input of the oscilloscope. This sequence connects the central pin on the BNC output of the signal generator to the center connection on the BNC input of the scope, while at the same time connecting the outer conductor of the BNC output to the outer conductor of the BNC input. This is exactly the same electrical connection that was made by the original BNC cable; therefore, you should see exactly the same electrical signal that you saw when you connected the signal generator output directly to the scope input using the BNC cable.

The scope also comes with its own voltage probe. Such a voltage probe is shown in the image on the left below, where the signal is connected to the micrograbber and the ground is connected to the alligator clip. The picture on the right below shows 5 alligator clips. The rubber insulation is pulled back from the black wire to show the complete alligator clip. An electrical connection to a wire is made using an alligator clip by pressing on the back of the clip to open the jaws, placing the jaws over the conductor to which the connection is to be made, and then releasing the back of the clip to allow the jaws to close. Once the jaws are closed, the tension in the clip will maintain the electrical connection to a wire held in the jaws. Note: to make a connection the alligator clips need to be connected directly to a metallic surface, attaching the alligator clip to the rubber insulation on a wire will not make a connection. Keep the micrograbber signal on channel 1, while connecting the scope probe so that its voltage difference is shown on channel 2. Connect the micrograbber to the voltage probe of the oscilloscope using the wire held in the red banana plug terminal. Connect the black alligator clip on the wire held in the black banana plug. Connect the BNC on the probe to the oscilloscope input. Inside the scope probe is a voltage divider, so the output voltage at the BNC connector is $1/10$ the voltage difference between the micrograbber and the alligator. The scope senses when the probe is plugged in, so the voltage that it displays is $10x$ the input voltage. Thus the scale that you read corresponds to the actual voltage difference at the input. Prove that the output of the scope probe is indeed equal to $1/10$ the input voltage.



The vernier voltage probe is setup so that the voltages that it measures are recorded on the computer in LoggerPro. The electrical connection to the vernier voltage probe is made using alligator clips. Attach the red alligator clip on the vernier voltage probe to

the wire clamped in the red terminal of the banana plug, and the black alligator clip on the vernier voltage probe to the wire clamped in the black terminal. Open LoggerPro. The window should display the voltage difference. Choose an appropriate time scale on LoggerPro. Note that the default time is 18 seconds. Acquire the sine wave so that 3 periods show on the screen and the signal appears smooth. When the data acquisition is complete create a second window below the first and plot the acquired voltage on a semi-log scale, where the voltage axis is logarithmic, but the time axis is linear.

Effects of Electricity on the Body

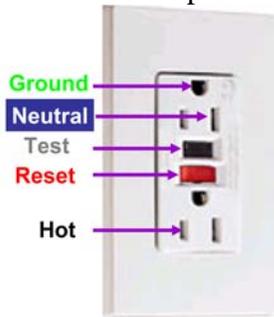
In the United States the voltage at a wall socket as a function of time is approximately given by $V = 170 \sin [2 \pi 60 t]$. Unfortunately, the nerve impulses in the human have a similar frequency, so they are strongly perturbed by the alternating current.

Below is a table of the current that would flow through a resistive object as a function of the voltage across the object. The table is taken from a nice discussion of electrical shock hazards that is presented at <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/shock.html#c3>. The resistances shown correspond roughly to the resistance across a person with dry skin (100,000 Ohms) or wet skin (1,000 Ohms).

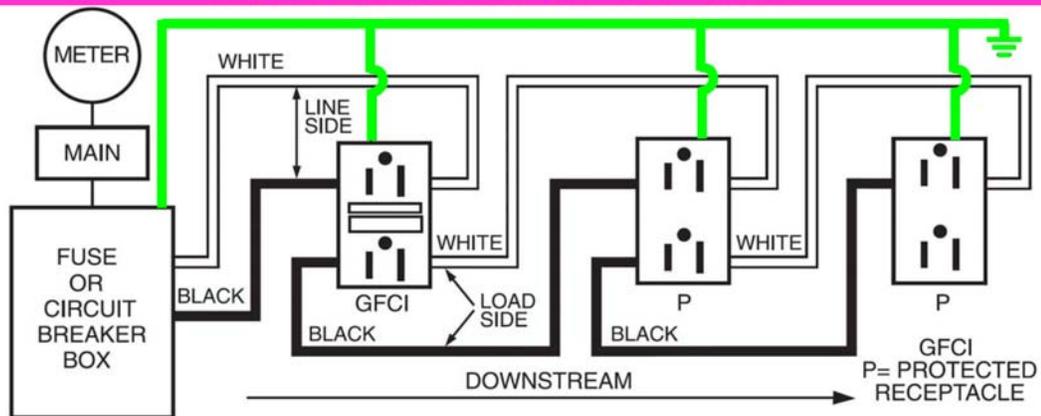
Shock Physiological Effects			
Electric Current (1 second contact)	Physiological Effect	Voltage required to produce the current with assumed body resistance:	
		100,000 ohms1,000 ohms
1 mA	Threshold of feeling, tingling sensation.	100 V	1 V
5 mA	Accepted as maximum harmless current	500 V	5 V
10-20 mA	Beginning of sustained muscular contraction ("Can't let go" current.)	1000 V	10 V
100-300 mA	Ventricular fibrillation, fatal if continued. Respiratory function continues.	10000 V	100 V
6 A	Sustained ventricular contraction followed by normal heart rhythm. (defibrillation). Temporary respiratory paralysis and possibly burns.	600000 V	6000 V

Notice that the AC voltage coming from a wall outlet in the US is not too dangerous if one makes a connection across it with dry skin, though this is certainly **NOT** a good idea. A connection through wet skin is a serious hazard. The effect of the voltage also depends its duration, with shorter exposure producing a smaller effect. This is why GFI plugs that quickly cut-off the current make a significant contribution to electrical safety. Typically, GFI outlets are required in wet areas such as kitchens, bathrooms, and outdoors. An

image of a typically GFI outlet is shown below, along with a wiring diagram. Notice that the two vertical slots in the outlet have different lengths, as required for a polarized plug. The longer slot corresponds to the neutral, and the shorter slot to the hot. In both the image and the diagram black indicates hot, white indicates neutral, and green indicates ground. These correspond to the colors of the insulation in household wiring, though the ground is sometimes uninsulated. If too much current goes to ground without going through the circuit, the GFI cuts off the voltage to all of the outlets connected to it. The red reset button must be hit to restore voltage. Some outlets are GFI protected at the breaker box without a visible test/reset switch at the outlet. The physics that underlie the differential current sensing in the GFI outlet are not presented until Chapter 7 of Purcell. The lab on chapter 7 will include GFI operation.



Black is Hot White is Neutral Green is Ground
 The ground wire is sometimes uninsulated



Wiring Diagram GFCI Receptacle, Feed-Thru Installation

To protect the entire branch circuit the GFCI must be the first receptacle from the fuse or circuit breaker box. Receptacles on the circuit between the GFCI and the box will not be protected, but receptacles downstream from the GFCI will have protection.

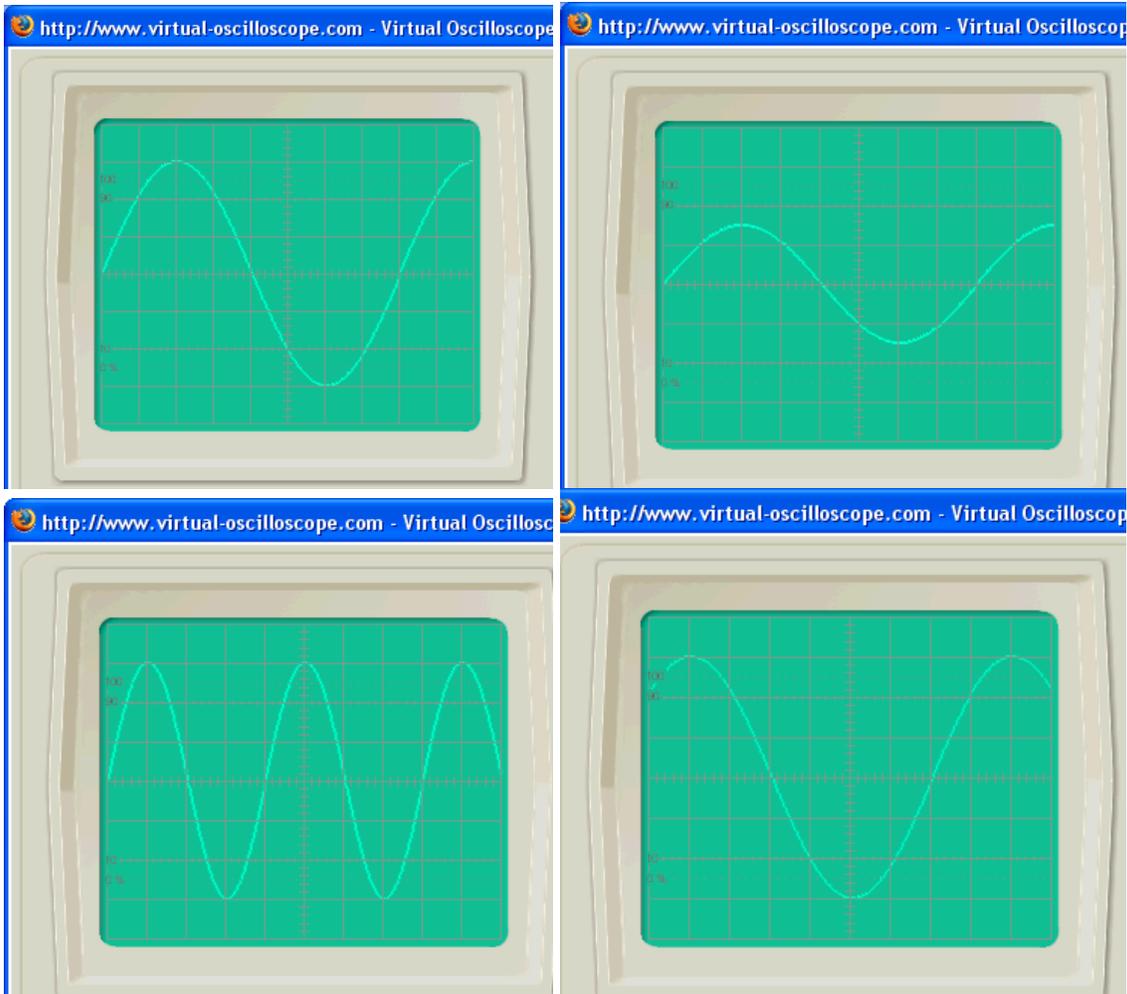
<http://www.passandseymour.com/pdf/U013-U020.pdf>

People who routinely work with high voltage often wear insulating shoes and keep one hand in a pocket, so that even if they contact high voltage there will be no path to ground

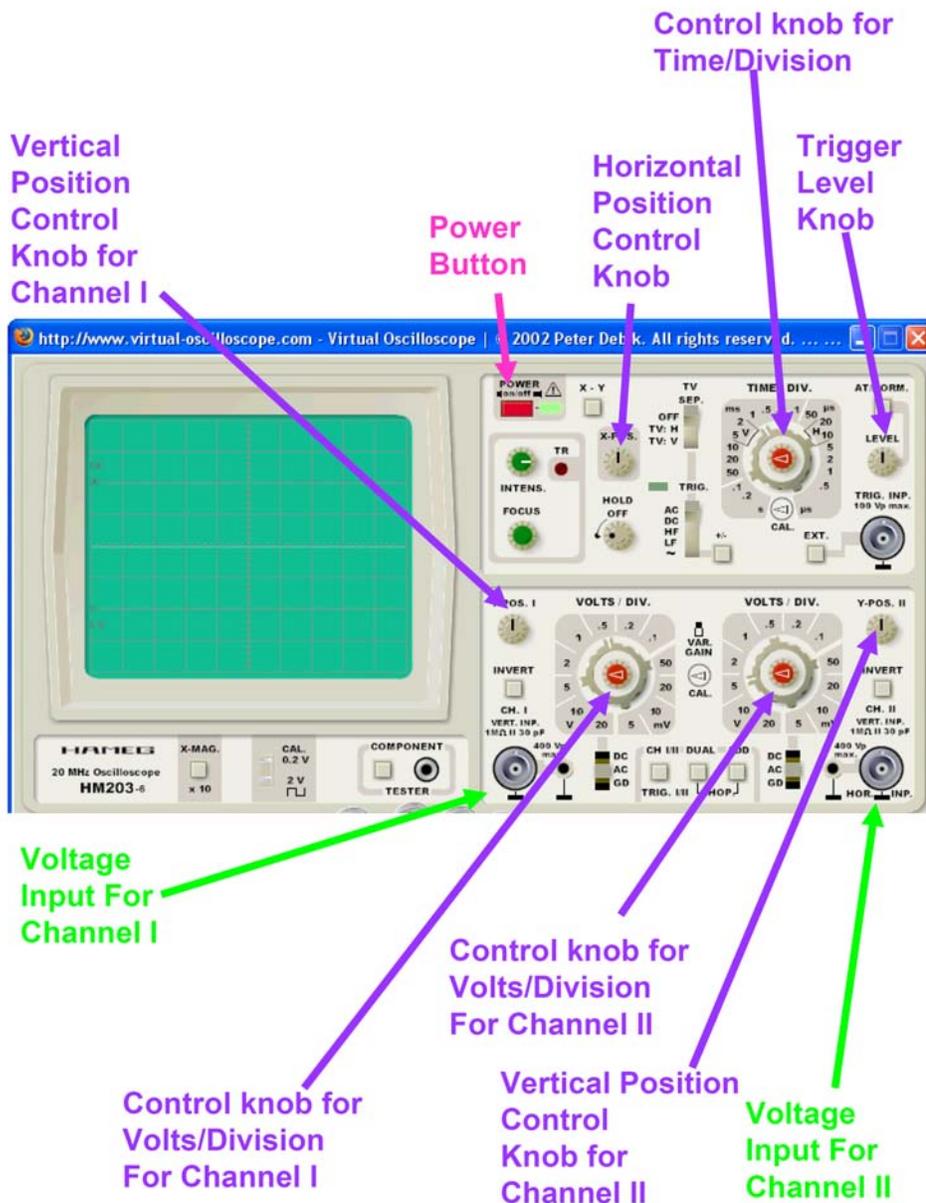
through their chest. Connecting a finger across a few thousand volts will result in a burn, but usually not a more serious injury though it is quite scary, as I can attest.

Oscilloscopes

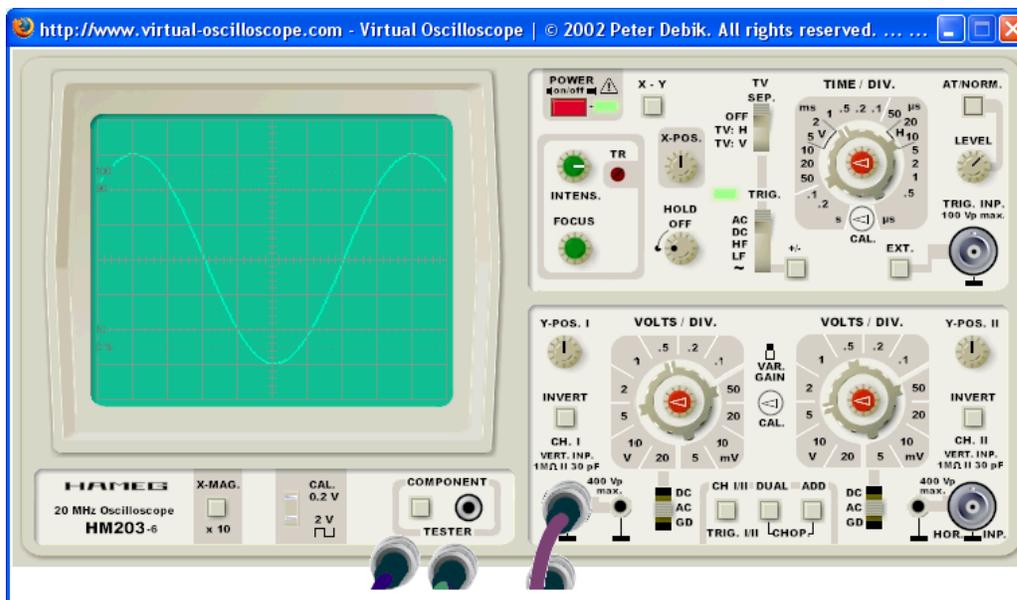
Oscilloscopes are one of the most universally used pieces of test equipment in all of physics. They present graphs of a voltage difference as a function of time. The vertical axis that represents the voltage is typically divided into 8 units each of which is called a division. The divisions are shown below as the grey lines that run across the screen in the horizontal direction. The voltage sensitivity of the scope is expressed by the number of volts represented by each unit, or the volts/division. The time axis is typically divided into 10 divisions corresponding to a time given by the time/division. These divisions are indicated by the gray vertical lines. A time dependent sinusoidal voltage with an amplitude of 1.5 volts and a period of 8 ms is given by $1.5 \sin(2\pi t / 0.008)$ where t is the time in seconds is shown on the virtual scope below in the upper left hand corner of the figure where the volts/div = 0.5 V and the time/div = 1 ms. The same signal is shown in the upper right hand corner when the volts/div = 1 V and time/div = 1 ms. The signal in the lower left hand corner shows the same when volts/div = 0.5 V and time/div = 2 ms.



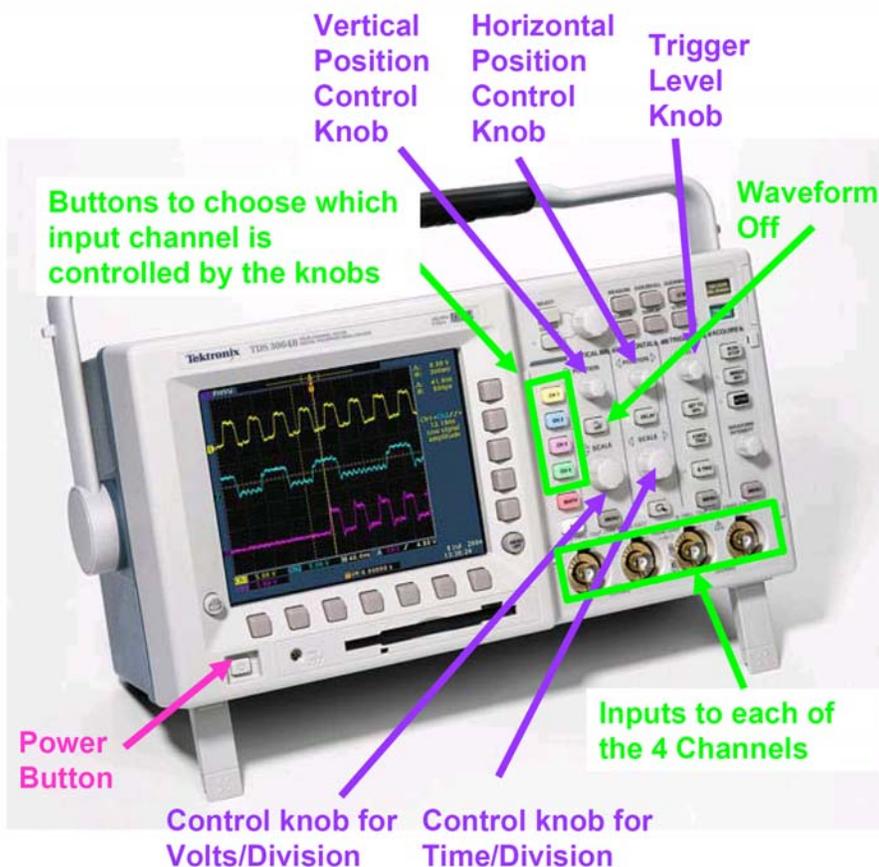
The signal out is not uniquely determined by the voltage and time scales. The time at which the signal starts also matters. The trigger level picks the signal voltage at which the scope begins to display the voltage vs. time. The picture on the lower right has the same settings as the upper left, except that the trigger level is changed to a higher voltage, which corresponds to a later time. The images above are all made using <http://www.virtual-oscilloscope.com/simulation.html#>. This is an excellent website that offers an oscilloscope simulation where the controls are operated using the mouse. It offers a great opportunity to play with an oscilloscope without owning one.



The image below shows an image of the virtual scope with two input channels, labeled I and II. The knobs that control the voltage/div, time/div, and trigger are indicated along with the horizontal position control and vertical position control that allow the image to be moved around on the screen, but do not change the sensitivity or the trigger. The trigger level control only works if the button above the trigger is set to normal. If the button is set to automatic then the scope makes its own decision about when the trigger and the trigger level knob has no effect. Below is the scope showing the sine wave used in the examples above. The voltage inputs are the colored cables at the bottom left. The connectors are called BNC connectors and in real life the cable is connected to the input by pushing the cable end over the scope connector and turning the cable clockwise. On the virtual scope, you just use the mouse to drag the cable to the input. If you turn the power button on and connect the purple cable to the input of channel I, this is the image that you will see. If you go to <http://www.virtual-oscilloscope.com/simulation.html#>, you can try out all of the controls shown above. You will notice that there actually many more controls. We will not consider them here now, but you are more than welcome to try them out. If you double click on a control, a pop-up window will provide an explanation of what the control does. A tutorial that discusses oscilloscope controls in general is available at <https://www.cs.tcd.ie/courses/baict/bac/jf/labs/scope/controls.html> This is a part of a larger and more general discussion of oscilloscopes <http://oscilloscope-tutorials.com/>



The scopes that you will be using in lab are actually nicer than the one shown on the virtual oscilloscope. It actually has four input channels rather than two. The scope above uses one set of three buttons to control the vertical scale, vertical position, and horizontal position of channel I and a second set of three to control channel II. In order to avoid having too many knobs, the scope you will use is designed so that there is only one set of three knobs to control all four channels. To display the voltage that is input to a particular channel, press the channel button corresponding to that signal (ch1,ch2,ch3,ch4). The color of the button corresponds to the color of the signal on the display. To stop the scope from displaying a channel, press the channel selection button corresponding to that channel, and then hit the waveform off button. The knobs control Volts/div, horizontal position, and vertical position. You choose the channel that is being controlled by pressing one of the four buttons at left that are labeled ch1,ch2,ch3,and ch4. The color of the voltage trace for each channel on the scope corresponds to the color of the button. Once you have set the correct values for one channel you can choose a different channel and set its values. Many functions are selected through menus. For example the choice to trigger automatically or manually is made on the edge trigger menu. The menus are controlled by the plain gray buttons at the bottom and right edge of the screen.



The image below provides descriptions of the general functions of all of the controls on the scope, many of which are not covered in the short discussion above. A full description of all of the controls is available in the manuals posted on the course website.

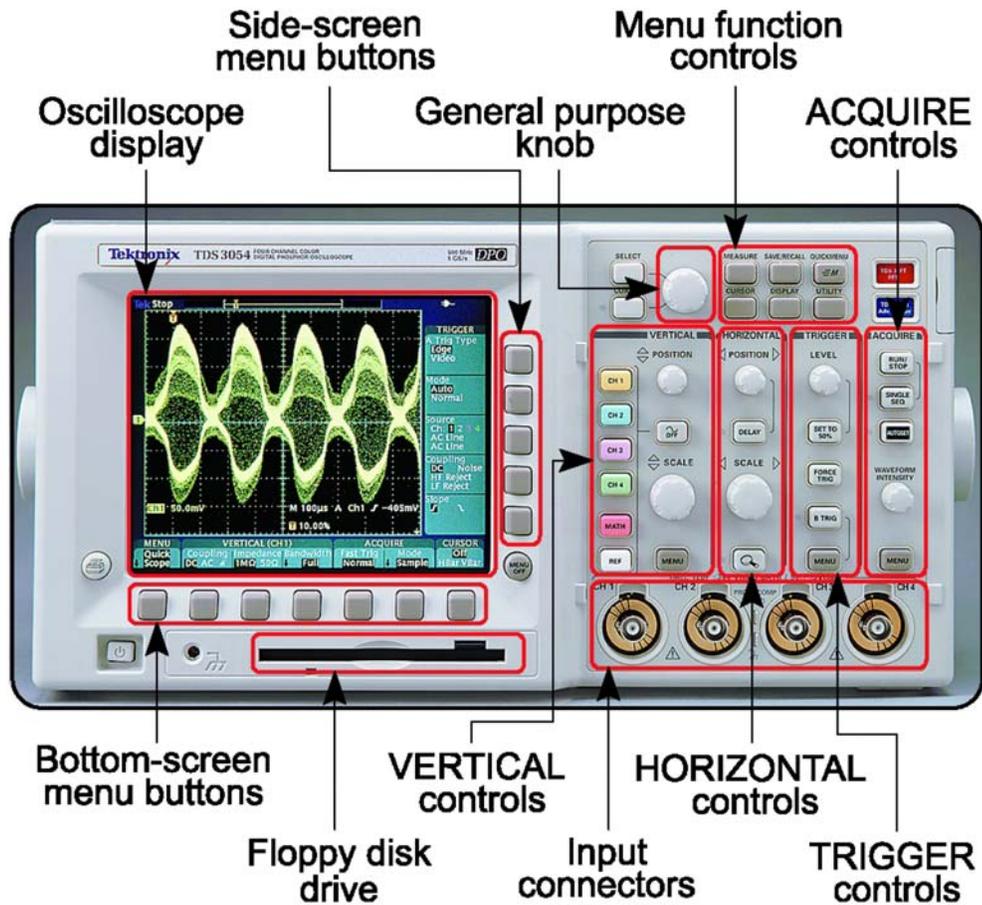


Figure 1.1: A TDS3054 digital phosphor oscilloscope

The scope can be controlled remotely using a computer, and the information on the scope can be transferred back to the computer using the protocols described below. They are copied from the user manual, which is posted on the website.

Control your TDS3000B Series Oscilloscope over the Internet: How to Activate e*Scope™

- 1.) Assign your oscilloscope an IP address. The address should contain 4 sets of up to three numbers, separated by periods (i.e. 128.181.240.94). Ask your organization's network administrators for an address.

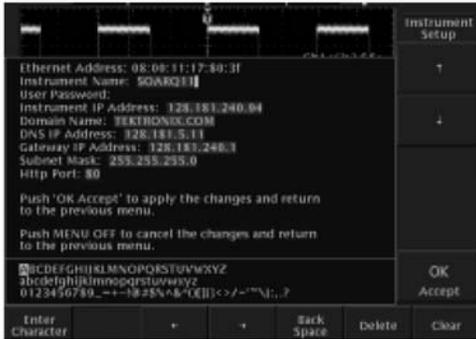


Figure 1. TDS3000B IP address menu. From your oscilloscope's front panel, then select menu options in this order: Utility, System, I/O, Ethernet Network Settings, Change Instrument Settings.

- 2.) If your PC is connected to the Internet and your oscilloscope and PC are on the same side of your company's firewall, select either Method 1 or 2.

Method 1: Basic control option

Enter your oscilloscope's IP address into your Web browser window. This will take you to the e*Scope home page housed in your oscilloscope. Click on the Data tab at the top of the page. From the Data page you can type in commands and control the oscilloscope (see figure 2).



Figure 2. Data page housed on your TDS3000B oscilloscope. Type commands here. Or go into the Control Tab to download your oscilloscope's graphical user interface.

To control your TDS3000B through its graphical user interface, click the Control tab at the top of the browser window. When you click this tab, your oscilloscope will retrieve the Control Page from <http://www.tektronix.com> (see figure 4). The Control page is cached on your Web browser, your connection with the Tektronix web site ends, and commands and data go directly between your PC and oscilloscope.

Method 2: Advanced control option

From your browser, go to <http://connect.tek.com/escape>. Enter your oscilloscope's IP address (see figure 3). This will take you to the e*Scope home page housed in your oscilloscope. Click the Control tab at the top of the page. Your oscilloscope will then retrieve the Control page, as described in the previous paragraph (see figure 4). The Control page reproduces the oscilloscope's graphical user interface.

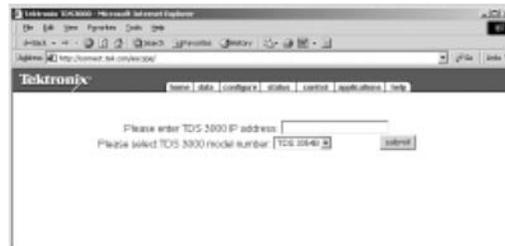


Figure 3. <http://connect.tek.com/escape>.

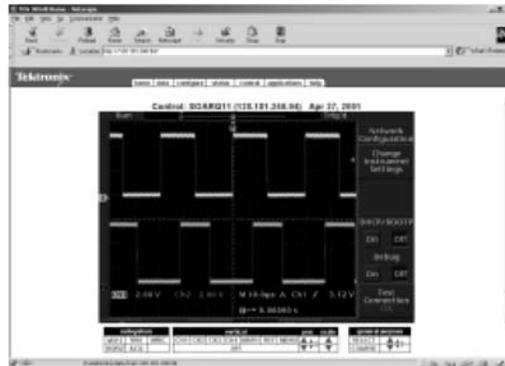


Figure 4. Control page from www.tektronix.com/escape cached on your Internet browser. Using your mouse or computer keyboard, you can control your oscilloscope.

(Continued on reverse side)