Lab 1 - Introductory Experiments and Linear Circuits I

University of California at Berkeley

Donald A. Glaser Physics 111A

Instrumentation Laboratory

Lab 1

Introductory Experiments and Linear Circuits I

Before starting the lab, complete this list of tasks:

· Watch the 4 quick-start videos on the lab equipment. These are available for download, but it is best to watch these in lab so you can use the equipment as you learn about it.

Check the manuals for the new digital equipment and look at the XYZ's of scopes [1].

- Completely read the Lab Write-up
- Answer the pre-lab questions utilizing the references and the write-up
- Perform any circuit calculations or anything that can be done outside of lab. Example 1.4 - 1.6
- Plan out how to perform Lab tasks.
- **Introduction video on Instrumentation and equipment** [2]
- **Soldering techniques video** [3]
- **Soldering Techniques Manual** [4]

NOTE: You can check out and keep the portable breadboards, VB-106 or VB-108, from the 111-Lab for yourself (Only one each please)

References:

Hayes & Horowitz	Chapter 1, p 1–31 and p 32–60
Horowitz & Hill	Chapter 1.01–1.06, 1.07–1.11, 1.12–1.24 1.32–1.34, 5.01–5.02, 5.04–5.05 and Appendixes A, B, C and H (You'll read the rest of Ch. 1 for the next two weeks, so you might want to get started now.)
Sedra & Smith	Chapter 1.1–1.3, 1.6, Scan Appendixes B, C1 and E[1]

A good web source is Wikipedia.org

Physics 111-Lab Library Reference Site

Reprints and other information can be found on the **Physics 111 Library Site.** [5]

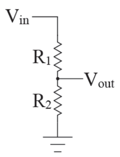
The beginning of this lab introduces you to the equipment you will be using throughout the BSC lab and most of the other labs in Physics 111. We want everyone to have a working knowledge of the equipment before continuing with the rest of the BSC course.

In part two of this lab you will study circuits made from linear components such as resistors, and capacitors. You will build filters and learn the concept of frequency dependent impedance and its importance in circuit analysis and electrical measurements. You will also learn why we use scope probes and terminators for scope measurements. Please ask questions if you don't understand something (or you think you know something that we don't) at any time during the course!.

Pre-lab

Pre-lab questions (Part 1):

1. Explain how the breadboard, power supply, multimeter, oscilloscope, and the signal/pulse generator are used.
2. What is the difference between the common and the ground of a circuit?
3. Derive the voltage divider equation ($\frac{V_{out}}{V_{in}} = \frac{R_2}{R_2+R_1}$) for the following circuit:



Pre-lab questions (Part 2):

1. What is impedance? Input impedance? Output impedance?
2. What are the interesting properties of a coaxial cable and transmission lines? (hint: wikipedia.org)
3. What is a low-pass circuit? A high pass circuit? Draw an example of each. Derive the transfer function for each of these circuits.
4. Derive the "arcsine" phase shift formula given in problem 1.2.7: $\delta = \sin^{-1}(\frac{y_{int}}{y_{max}})$

Background: In this lab you familiarize yourself with the usage of the digital multimeter (DMM), breadboard, power supplies, oscilloscope, and the signal/pulse generator. The breadboard, power supplies and some other components are integrated into a box found at each lab station.

Important safety habits:

1. ***When you are done for the day, make sure you power down all equipment.***

2. ***Never place food or drink next to any apparatus. Accidental spills can damage or destroy the equipment and your experiment.***

Five minutes notice will be given at the end of class. At that time, please return all unused components to their proper drawers.

In the lab:

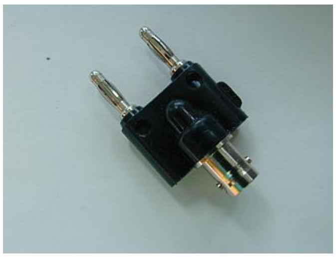
Now let's play with the equipment.

(A) Keithley 2110 Digital Multimeter[3]

The DMM is used to measure voltages, currents, resistances and several other more complicated quantities. The DMM is a relatively simple instrument.

Turn on the digital multimeter by pressing the power button located to the left on the front panel. To make a measurement with the DMM, first connect a double banana plug to one end of a BNC cable and a pair of mini-grabbers to the other end. The outer shield of the BNC is traditionally at ground; the inner wire carries the signals. When the BNC cable is attached to a double banana plug, one of the plugs will be attached to the outer shield, i.e. the ground, and the other to the signal. Figure out which of the banana plugs is labeled ground. Look for the little black tab on the banana plug pair; this tab will the ground.

Double Banana Plug



MiniGrabber

BNC Cable

Voltage

Find the pair of red and black inputs on the DMM that indicate where to insert the banana plugs to make a voltage measurement; remember that red is positive and black is ground and hook up the banana plug accordingly. You have two different voltage measuring options: DCV and ACV. DCV measures voltage created by a DC current and ACV for an AC current. **You can change the DMM's range to maximize your measurement's resolution by pressing the up and down arrows labeled "Range +" and "Range – ".**

Resistance

Be sure to disconnect the electronics component you wish to measure from the circuit before making the resistance measurement (think about why it is better to do so). You also have two options for measuring resistance. One is the standard 2 wire measurement and the other is a 4 wire measurement. The 4 wire measurement method is used for measuring very small resistances when even the resistance in a copper wire is important. Because this lab won't be dealing with such low resistances, the majority of the measurements you make will be done with the standard 2 wire method. To make the measurement, hook up the banana plug to the correct red/black inputs for measuring resistance, indicated by the Ω symbol, and select the 2 wire resistance option indicated by the Ω^2 symbol.

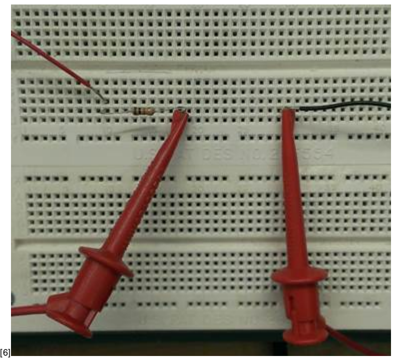
Capacitance

Same setup as the voltage and resistance measurements. The capacitance measurement option is indicated by the capacitor symbol.

Current

Current measurements also have two options: DCI and ACI. DC current measurements using this DMM are tricky because the appropriate jacks, the black jack on the right and the white jack on the left, are too far apart to have a single banana plug inserted into them. To compensate for this problem, we will be using **two** banana plugs and **only use the center conducting wire** of the BNC cables to perform the measurement. Consult the picture below for how this is done.

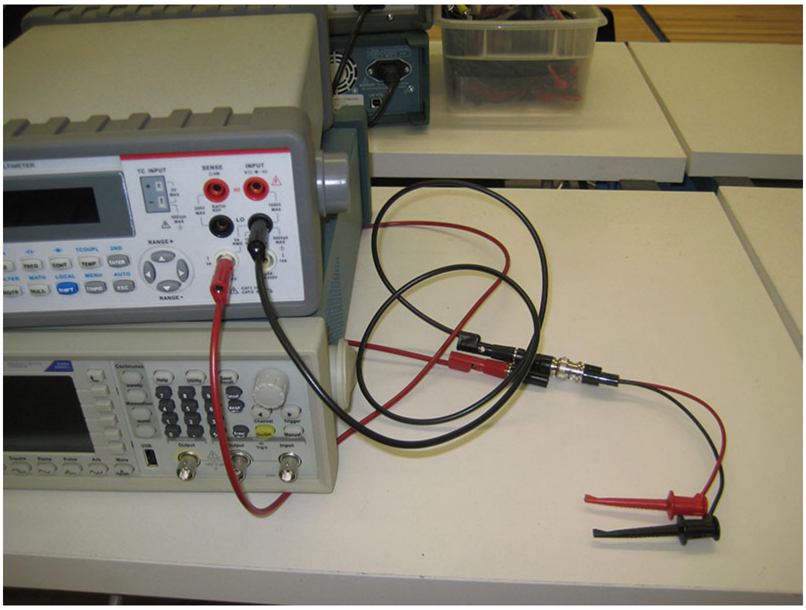
[6]


[7]

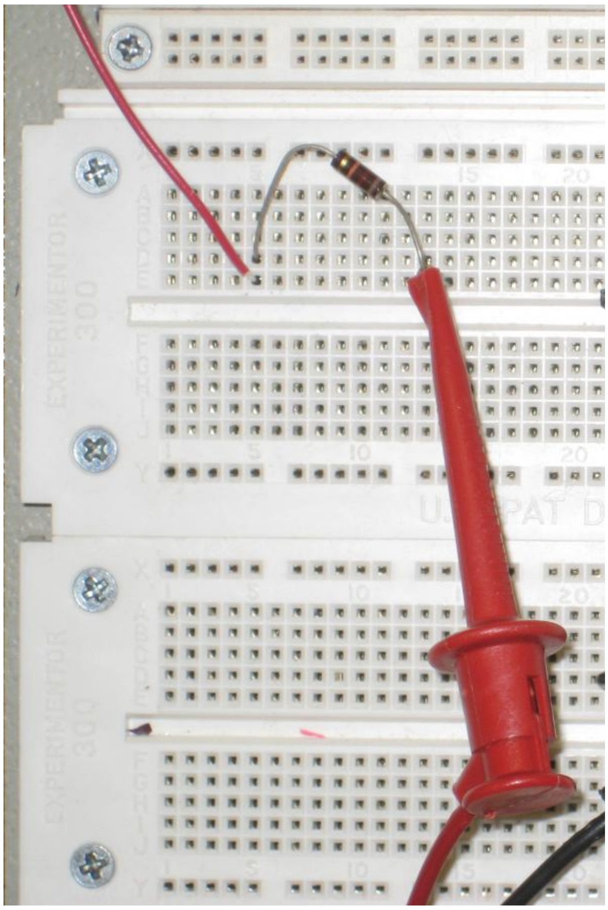
Here we are measuring the current flowing across a resistor. Notice how the banana plugs are inserted in and how we are only using the red grabbers, or the center conducting wires, to make the measurement. Conversely, we could flip the orientation of both banana plugs and only use the grounding (black) wires to make the measurements instead. The important thing to note is that **any DC current measurement requires the left white jack and the right black jack to work**; you can insert the banana plugs in any orientation you want but you must remember to use the correct BNC grounding or conducting wires.

ACI measurements are easy because we only need one banana plug. The jacks for an ACI measurement are the black and white jacks on the right. Be sure to hook up the banana plug with the correct polarity.

Alternate method to measure current:



[8]Click on Picture to enlarge in another window

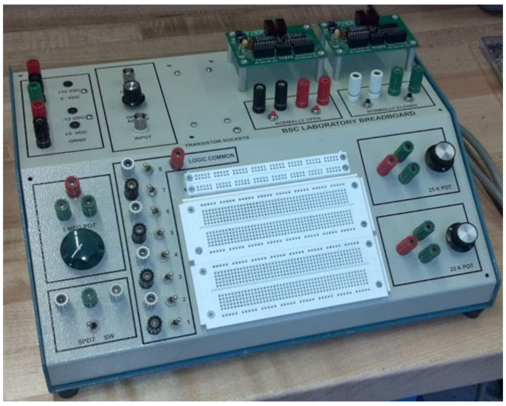


[9]Click on Picture to enl

DMM Hookup connections for current measement

Note black and red leads are in series with the resistor to measure current.

Connect the DMM leads in parallel with a component to measure voltages across it, and in series with a component to measure currents through it (Refer to the drawings in Appendix II.) When measuring the resistance of a component, the element must be isolated from the rest of the circuit. Also, when connecting the banana to BNC adapter to the DMM, make sure that the common of the adapter matches the common of the DMM.



(B) BSC Laboratory Breadboard Box

Back To Top

Breadboard

Commercial electronic equipment is constructed on printed circuit boards; “wires” are photo-etched onto a sheet of copper, and components are soldered into place. To save time and effort, we will build our prototype circuits[2] on solderless breadboards. A breadboard is an insulating board with a regular pattern of holes that are actually sockets. The sockets are interconnected with hidden wires, and electronic component leads or wires pushed into the socket holes will make contact with the interconnecting wires below. The interconnecting wires on our breadboards follow the pattern shown by the heavy lines in the drawing below; the gray squares indicate the positions of the sockets.

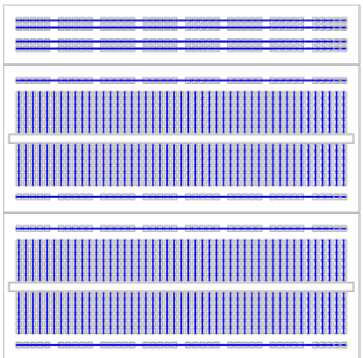


Figure 1 Breadboard

Breadboard Practice:

· Use 22-gauge solid (not stranded) wire to make connections. Cut interconnecting wires to the right length. Strip ~3/8” of insulation from each end, and poke the bare wires into the breadboard socket holes until they bottom out. The breadboards are delicate! Forcing wires or component leads into the board can damage the sockets or make a poor connection. Wires or leads that do not fit easily into the breadboards may be too thick. (Wire gauges [thicknesses] are listed in Appendix IV.)

· Use the buses (the long horizontal strips shown in Figure 1) for power and ground connections. Good bus habits will save you lots of time and trouble with complicated circuits by making your circuit wiring more transparent and by removing unnecessary clutter.

· Build your circuits **compactly**. Long leads between components introduce stray capacitance and can result in oscillations or high frequency [e.g., radio frequency (RF)] pickup.

· For clarity, signals should flow from left to right; place input signals on the left side of the board, circuitry in the middle, and output signals on the right side.

· Use color-coding to make your wiring clear: try to use *red* wire for power connections, and *black* for ground connections. This will help enormously when working with complex circuits later in this course.F[3]

Problem 1.1.1

Use the Digital Multimeter (DMM) in resistance-measuring mode to check some of the internal connections in the breadboard. Make sure you understand how the breadboard is set-up: what is connected and what is not. **Sketch** a simple diagram showing what connects where on the breadboard, as if to make it clear to someone who is using it for the first time.

Commons and Grounds

Recall that voltage is a measure of the potential *difference* between two points. Although we say “the voltage at point A”, we really mean “the voltage at point A with respect to the local zero-potential reference point.”

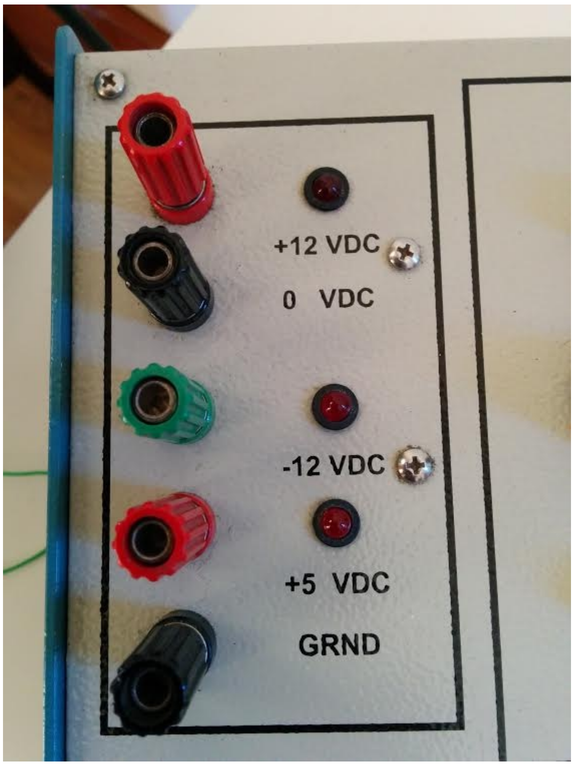
The most useful zero-potential reference point is the earth itself—the “ground.” The earth is a potential grounding system. The ground in any circuit is defined to be any wire, lead or bus somehow connected to the earth. The power company thoughtfully provides a wire connected to the earth in all three-pronged power outlets[4]F, and that wire is usually connected to a ground lead in electrical equipment. Thus the potential of a point in a grounded circuit is the same as the potential difference between that point and the earth.

Why do most electrical wall sockets have three leads? The electric company intends current to flow between the hot and neutral wires in the wall socket, the two rectangular slots. No current should flow in the ground wire. The electrical company arranges its transformers so that the hot lead is approximately 120V from ground, and the neutral is approximately at ground. But things are rarely perfect, and the neutral lead is often a few volts from ground. As for the ground lead itself (the horseshoe shaped hole), the electric company grounds the lead by actually attaching it to a long conducting rod stuck into the earth. Look for the ground wire the next time you walk by a transformer on a pole! Other good grounds are available. Cold water pipes, for example, are well connected to the earth, and are often used as grounds.

The electric company doesn’t supply the ground as a courtesy for electronic circuits builders; they supply it for shock prevention. Electrical shocks occur when a sufficiently high voltage drives a sufficiently high current through the victim’s body. Most dangerous are shocks in which currents travels through the victim’s heart; only 50mA can be lethal. Grounding the outer case of a piece of equipment greatly reduces the chance of shocks by shielding the user from any high internal voltages. It is difficult (but not impossible!) to get a serious shock with voltages less than about 70V. While you should always think before touching a bare wire, shocks should not be a problem with any of the circuits in the BSC lab.

While grounding a circuit is usually beneficial, it is not actually necessary. Cell phones, for instance, are not grounded. For these circuits we define a “common” for the voltage—a local point that all measurements on the circuit refer to.

Power supply



R +12V

B 0V

G -12V

R +5V

B 0V

Each station has two power supplies[5]F built into the box carrying the breadboard. The first supply (bottom two terminals) has an output voltage of 5 V and is used mainly with digital circuits. The common of the 5V supply is marked 0V, and is connected to the metal chassis of the breadboard box, which is in turn connected to ground. **Thus the common of the 5V supply is also a ground.**

The other supply, the top three terminals, supplies 12V between adjacent terminals. This power supply "floats", i.e. it is not connected to ground. A floating supply maintains its rated voltage difference between its terminals, but its absolute potential can float up or down. Usually ground is attached to the 0V terminal, but it may be useful to attach it to either of the other two terminals. Watch out: leaving the power supply floating, or inappropriately grounding the supply, can lead to subtle circuit failures. If you use both the 5V and the ±12V power supplies in a circuit, make sure that the ±12V supply is referenced to the 5V supply

Problem 1.1.2

How should you hook up the power supplies to get the following voltages ***with respect to ground***:

a) +24V, **b)** –24V, **c)** +12V, **d)** –12V, **e)** +17V?

Sketch a simple diagram for each one. Remember that ground is a zero voltage point reference.

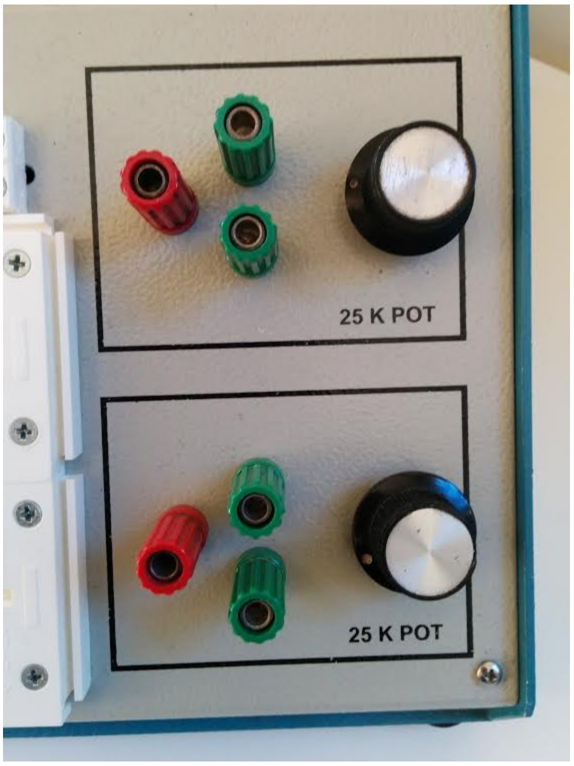
Problem 1.1.3

Setup, measure, and record the power supply voltages required in Question 1.2. What does the DMM read when you measure the potential between the +12V output and 5V supply ground (the GND terminal) if you don't hook up any other wires? **Explain** why you don't measure 12V!

Offset Adder

The Offset Adder adds a constant to the input signal. By turning the Offset Adjust knob, the signal can be either raised or lowered.

This now inside the breadboard chassis. You will see the same connections on the top of the breadboard chassis



Potentiometers

There are two 25k and one 1M potentiometers on the breadboard. The potentiometer has three terminals, so turning the knob changes the resistance between the red and the green terminal from 0 to the designated resistance. Between the two green terminals the resistance is constant.

Buttons

There are two normally open buttons, two normally closed buttons, and one SPDT switch. The normally open button means the circuit is open and pressing the button closes it. The normally closed button works exactly the same except the circuit is left closed and the button opens it. The SPDT (single pull double throw) completes one of two circuits when it is thrown.

Logic Switches

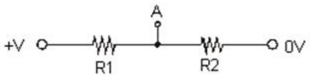
The eight logic switches are all referenced to a single logic common. Throwing the switch puts it in either a HIGH or LOW state. These can be connected to a circuit to easily switch the voltage from high to low or vice versa.

Printed Circuit Boards (PCB)

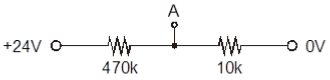
There are two PCBs on the breadboard. Each PCB has two 9368 chips and two FND357 chips along with various other components. When viewing a digital display, power the chips make the connections to the 9368. The 9368s are already soldered to the FND357s, where the digits are displayed.

Problem 1.1.4 - Voltage Divider

Calculate the voltage at point A with respect to 0V in the general case shown here. You will use this “resistor divider” formula in every lab in the course!



Now use the breadboard, the power supplies and the DMM to do a simple experiment. Build the following voltage divider: [6]



Note that the ohm symbol (Ω) is traditionally suppressed when showing resistor values in a circuit diagram. Hence, the label "470k" means a resistor with value 470 $\mathrm{k\Omega}$.

Problem 1.1.5

Calculate the current through each resistor, using its nominal[7] resistance and the nominal supply voltage (24V). **Show** the circuit and calculations in your notes.

Problem 1.1.6

Calculate the voltage at point A with respect to 0V using the nominal values and the formula you derived in 1.4.

Problem 1.1.7

How should you connect the DMM in order to measure **a)** the current through the 10k resistor, **b)** the voltage drop across the 470k resistor? **Sketch** the corresponding circuit diagrams for each of these measurements, showing the connections to the DMM.

Problem 1.1.8

Measure the actual values of the 10k and 470k resistors with the DMM. (be sure to remove them from the circuit before measuring them). What are the tolerances of the resistors? Do the measured and nominal (nominal means labeled value) resistances agree to within the specified tolerances? Also measure the 24V power supply voltage. **Record** your measurements and note if the components are within 5% of the nominal values.

Problem 1.1.9

Repeat the calculations of Question 1.1.5 and 1.1.6 using the actual measured resistances and voltages rather than the nominal ones. Note the difference between nominal and those calculated using the measured quantities.

Note: This uncertainty on this calculated value for the current will depend on the uncertainties in both the measured resistance and measured voltage. You do not have to do this uncertainty propagation, but be mindful that this is not an exact value for the current and that a difference between this value and the nominal value could be within uncertainties.

Problem 1.1.10

Measure the voltage at point A as precisely as possible. **Note that this is one of the few times in this course when you should write down many significant figures. Bench electronics is generally a 10% science.**

Record values and range and calculate the error using the example below, which comes from the manual for the Kiethley DMM:

Accuracy (error) = 0.012% of value + 0.004% of range (i.e. 1mV, 10mV, 10 volts)
As an example of how to calculate the actual reading limits, assume that you are measuring 5V on the 10V range.

Accuracy = 0.012% of value + 0.004% of range
*0.012% * 5 V + 0.004% * 10 V*
0.0006 V + 0.0004 V
0.0010 V
Thus, the actual reading range is 5 V ± 1 mV or from 4.999 V to 5.001 V.

DC current, AC voltage, AC current, and resistance calculations are performed in exactly the same manner using the pertinent specifications, ranges, and input signal values.

Does the voltage at point A agree with the value calculated in Section 1.9? **Comment** on how close your calculation and measurement are. Do they agree to within the measurement uncertainty?

Problem 1.1.11

Measure the current through the resistors. Is your result within calculated values? (Specify its uncertainty.)

Problem 1.1.12

Using the nominal values for simplicity:

a) Calculate how much power each resistor dissipates. Are your resistors rated for this power? (hint: look up the power rating for the 1/4 watt)

b) Keeping the same 24V supply and keeping the ratio of the resistors the same, would you increase or decrease the resistor values to approach the maximum power rating of the resistors?

c) Which resistor would reach its max power rating first?

d) Calculate how much larger or smaller (5 times smaller? 100 larger?) would you have to make the resistor values until one exceeded its maximum power rating?

e) Would it be difficult to make such a circuit in this lab with the available resistors?

(C) Digital Oscilloscope

The oscilloscope is the most important instrument in any electronics lab, and in many physics labs as well. To do well in this lab and in later 111 semesters you must be fluent with its operation.

Oscilloscopes are used to take a picture of a signal — a time-history or "scope trace" of the amplitude of the signal. A "scope" is one of the most complicated instruments in the lab. The BSC scopes have over thirty controls…and are relatively simple scopes. Fortunately most of these controls are rarely or never adjusted while taking routine measurements; only four controls determine the scope's basic operation. These primary controls are shown on the simplified scope front panel drawn below.

Basic scope operation is as follows: The signal to be analyzed is connected to the input BNC jack, and is displayed on screen. Two of the controls make up the vertical controls of the scope. The volts/div knob[8]F controls the vertical size of the scope trace. For instance, the 20mV peak-to-peak[9]F (p-p) triangular wave shown on the simplified scope screen below takes up two divisions on the 10mV/div scale. The position knob shifts the scope trace up and down.

Turning on the scope

The power button is located on the front in the lower left hand corner. The scope will take some time to start up it has a computer processor; do not press any buttons during this time.

Viewing an electronic signal

Using a BNC cable, connect the signal's source to one of the channels on the scope. The channels are located in the front on the bottom right of the scope and are labeled "1,2,3,4". If you are connecting the signal from a function generator or any other device that **does not have an impedance of 50 Ohm**, then be sure to terminate your signal with a 50-Ohm terminator. In other words, connect a BNC tee to the output of the source, then connect a 50-Ohm terminator to one end of the tee and the BNC cable to the other end. If you were to plug the signal directly into the oscilloscope without terminating it as explained previously, the signal can be unintentionally doubled in amplitude due to impedance mismatching (a topic that you will explore later).

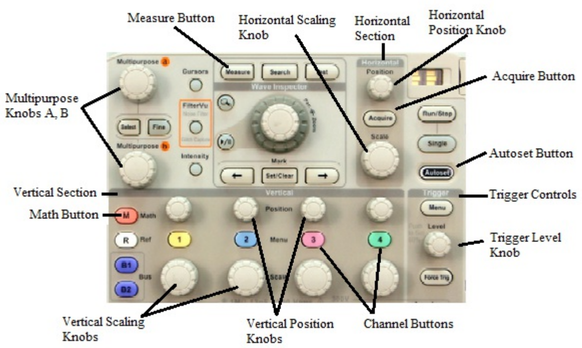
Do not plug the signal into the "Aux In"; the use for this input will be discussed later. After you hook up the signal to the scope, you should see a trace of it appear on the screen. If you do not, play around with the scope's viewing controls. Here is a list of the various controls you can use to help you better view the signal.

Vertical and Horizontal Scaling and Position Controls

The vertical scale for each of the scope's channels is set with the knobs labeled "Scale" in the Vertical section of the scope controls and has units of volts/division. The horizontal scale for all of the channels is set similarly in the Horizontal section of the scope controls and has units of seconds/division. For example, a 100Hz 10 volt peak to peak triangle wave will take up two divisions on the 5V/division scale and one period will take up 10 divisions on the 1 ms/division scale. The current value of the vertical and horizontal scales is displayed at the bottom of the scope's screen.

You can also adjust the position of the signal on the screen with the position controls. These are the smaller sized knobs located in the Vertical and Horizontal sections of the scope controls. The arrows on the left side of the screen indicate where ground is for each channel.

XY mode can be accessed by pressing the "Acquire" button in the Horizontal section of the scope controls and then turning on the "XY Display" option. XY mode will display two signals at the same time, the amplitude of one of the signals will make up the x-axis and the amplitude of the other will make up the y-axis. Consequently, if you put an equal amplitude sine wave as the y-axis and cosine wave as the x-axis, in XY mode the resulting trace would be a circle.

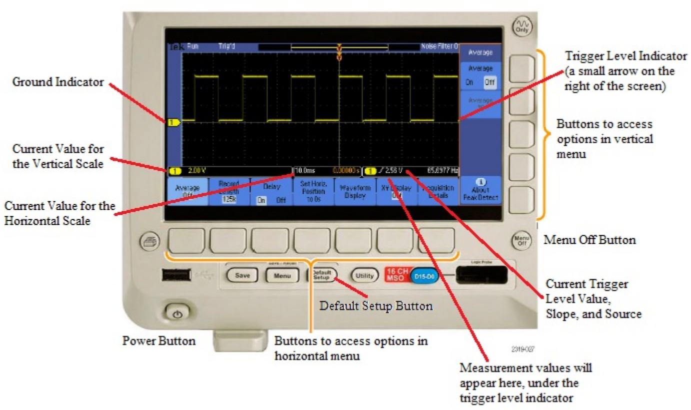


The sec/div (time-base) knob is the primary horizontal control, and controls the rate at which the scope trace sweeps (from left to right) across the screen. A scope trace of a 1ms period sine wave, displayed on the 0.5ms/div scale, would show five complete cycles of the wave.

Try this exercise: turn on the power switch, set the trigger to AUTO, to CH1, and both channel's input switches (AC GND DC) to ground (GND). Set the horizontal time-base to 0.1ms/div. Move the vertical "position" knob slowly for channel 1 until you obtain a line at the center of the screen. Adjust the "focus" and "intensity if needed." Now slow the time-base to 0.1s/div. See how the trace sweeps across the screen?

Look at the scope's "TRIGGER" section. The "trigger circuit" determines when the scope starts its horizontal display sweep, but it needs an input. The source for this input is set by the position of the TRIGGER SOURCE switch,F[10]F and the operating mode by the "A TRIGGER" switch. Look up what each switch does.

One other control deserves special mention: the **Autoset** button. If you cannot find the scope trace, just push this button and the trace will be pulled onto the screen and set to the correct voltage setting.



Individual Channel Configuration

You can turn individual channels on/off for viewing by pressing the corresponding channel buttons which are color coded yellow, blue, magenta and green. The menu for each channel is also accessed through these same buttons. In the menu you can configure an individual channel's coupling, bandwidth, label, etc. To exit out of the menu, press the "Menu Off" button. (Note: A common mistake is to measure the amplitude of a low frequency signal with the channel on AC coupling. AC coupling is mainly used to measure small AC signals on top of large DC signals. Always use DC coupling unless there is a specific reason to use AC coupling.)

Triggering

Triggering on the scope will be one of the more difficult controls to understand. Recall that the scope displays a trace of the signal by constantly redrawing the signal on top of itself. The scope does this by selecting a certain amplitude for the signal to reach and once the signal reaches that amplitude the scope begins drawing the signal trace from left to right on the screen. If the signal is periodic, then the scope produces the same trace every time it draws. If the scope had selected random points along the signal to begin drawing, the resulting image would be a smear of all the differently timed traces. As a result, the scope needs to be "synched" to produce a readable signal which can be done with the trigger controls located to the far right of the scope controls.

The triggering circuit needs to know at what amplitude the signal needs to reach to begin drawing. This can be set with the "level" knob; an arrow on the right of the screen indicates the trigger level. Additionally, it needs to know which signal it is using to trigger, a.k.a. the "source", and it must know whether to trigger when the signal has an increasing or decreasing slope. Other features include the triggering coupling, the mode, type, etc. which can all be configured in the trigger menu.

Furthermore, the scope does not need to rely on the input signal itself to tell it when to trigger. It can accept an auxiliary signal to tell it when to trigger instead. This auxiliary signal is fed into the "Aux In" channel and the source must be set to "Aux" in the trigger menu. With these settings the scope will begin drawing the trace whenever the auxiliary source triggers the scope to do so.

Making Measurements

The digital oscilloscope is capable of making measurements of the input signals such as measuring the frequency. You can configure the scope to perform a measurement by pressing the "Measure" button at the top of the scope controls. From there, select "Add Measurement" and then use the multipurpose A knob (located to right of the screen) to indicate the measurement type and the source. Afterwards, select "OK Add Measurement" and the scope will continuously perform the measurement and display the result at the bottom of the screen.

Other mathematical operations on the signals can be accessed by pressing the red "Math" button. Selecting the "Dual Wfm Math" option lets you add, subtract, or multiply two signals. The "FFT" option performs a Fourier transform. The data used to perform the transform is less than one screen width of the signal and the range can be viewed by turning on the "Gating Indicators" in the "FFT" menu; use the horizontal position control to move the boundaries over the region of the signal you want the transform to be performed. The horizontal scaling (in units of Hz/division) of the transform is indicated in the "FFT" menu to the right of the screen and can be adjusted using the multipurpose B knob.

Helpful tips for when you can't get a good signal trace

- Sometimes the signal you see may be ridiculously larger than expected due to the "Probe Setup" being configured to "10X" which multiplies the signal seen on the scope trace by a factor of 10. Access the menu for that channel and take a look at the "Probe Setup" option to see if it is set to "10X" and change it accordingly using the Multipurpose A knob.

- If you have accidentally changed one of the settings on the scope which messed up the signal trace and do not know how to reset it, you can always return the scope to its default settings by pressing the "Default Setup" button located below the scope screen.

- If you have been playing around with the viewing controls for a while and cannot get a clear trace to appear on the screen, then press the "Autoset" button located above the Trigger controls. This will have the scope configure itself to what it thinks are the best settings for viewing the signal. (Note: The "Autoset" settings may not always be the best settings to use. Use Autoset to first get a readable signal on the screen and from there configure the viewing controls yourself to improve the trace further.)

- More information on the scope's controls can be found on the manual online.

On the work bench and available from the course website is a manual, **"***The XYZ's of Using a Scope,***"** that you can refer to for more information.

Back To Top

Problem 1.1.13

Practice finding a trace of a simple sine wave on the scope. Take turns with your partner- one scrambling the controls of the scope and signal generator until no trace appears- and the other recovering the signal. When you are ready, a GSI will scramble the controls and sign you off when you recover the signal. You do not need to write anything down.

(D) Arbitrary Waveform Function Generator Tektronix AFG2021 Function Generator[2]

Turn on the function generator

The power button is the green button located in the lower left hand corner on the front. Like the scope, the function generator will take some time to start up; do not press any buttons during this time.

Configuring a continuous wave signal

To output a waveform, begin by selecting one of the six available waveform types using the buttons under the screen. Next, be sure that the "Continuous" button is turned on if you want to produce a pure, unmodulated waveform of the appropriate type. The current attributes of the waveform are displayed on the screen.

To change the attributes, do as follows: press the back button, the button with the arrow located to the left of the "Continuous" button, until the menu on the right side of the screen shows the options: "Frequency/Period/Phase Menu", "Amplitude/Level Menu", etc. Then, select the appropriate menu and the attribute you wish to adjust. You can also use the knob on the right instead of the number pad to change the attribute's value and the right/left arrow beneath the knob to select which digit to change.

To see the signal, hook up the output of the function generator with a BNC tee, 50 Ohm terminator, and BNC cable to an oscilloscope and remember to **turn on the channel on/off button** to output the signal. In addition, be sure you are using the **channel output** to view the signal. The other output is the trigger or "sync" output which produces TTL (transistor-transistor logic) pulses with the same frequency as the output waveform for synchronization purposes.

Modulated Signals

The function generator is capable of producing modulated waveforms as well as pure waveforms. To create a modulated waveform, first configure your carrier signal to the correct attributes as you would in continuous operation. Then, turn on the "Modulation" button at which point the modulation menu should show up on the right side of the screen. From here, you can select the appropriate attributes of your modulating signal such as the shape, frequency, etc. The amplitude of the modulating signal is set by adjusting the "depth" or "deviation" depending on what kind of modulation you are doing.

Sweep Signals

The function generator's "Sweep" option lets you perform a frequency sweep of a waveform. This means the waveform's frequency will start at some initial value, continuously increase until a certain limit, then continuously decrease back to the initial value within some allotted time. You can access the sweep attributes under the "Sweep" menu.

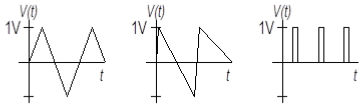
Helpful Tips

Some of the menus are not fully displayed on the screen so be sure to check the bottom right portion of the screen to see if there is a “more” option which will let you access the rest of the menu.

Warning: When hooking up the function generator, make sure that you confirm the connections before you attach the generator to your circuit. You can burn out the generator if you attach the output of the generator to another voltage souce (like the power supplies.)

Problem 1.1.14

To gain some familiarity with the scope and function generator, generate the following scope displays for a GSI. Make sure you are able to reproduce the right offsets and voltae levels. (You do not have to write anything.)



(E) Frequency and time measurements

Your measurements are unlikely to agree precisely. One of the hardest tasks in experimental work is reconciling seemingly contradictory or bizarre data. This takes experience and common sense. Here either of the two instruments (the scope and the signal generator) could be improperly calibrated, but it is much more likely that the oscilloscope is correct and the generator is incorrect[11]. Of course this assumes that the user-adjustable calibrations on the scope are in their proper positions.

Problem 1.1.15 - Measurement of DC and AC voltages

(Voltages can be measured using either the scope or the DMM. Connect the scope and DMM in parallel and measure the output voltage of the 5 V power supply using both devices. A good horizontal time-base setting to use is 1ms/div.

a) What are the result and the estimated error of the DMM measurement?

b) What are the result and the estimated reading error of the measurement using the scope?

c) Repeat the measurement for different settings of the V/div knob, and for the other channel of the scope. Are the results consistent with each other and with the DMM measurement?

d) Describe the best scope settings (0V level and V/div) to minimize the reading error.

Problem 1.1.16

Keeping the scope connected to the 5V supply, set the scope channel input switch to AC.

a) What does this setting do? Expand (increase the sensitivity) the vertical scale.

b) What do you see? Describe in detail the AC component of the output. Be sure to explore the full range of the time-scale knob.

Problem 1.1.17

The amplitude of an AC signal can be characterized in different ways: by the peak voltage (or amplitude), the peak-to-peak voltage, or the RMS[12]F voltage. **Derive** the coefficients that convert between these three quantities for **a)** sine waves, **b)** triangular waves, and **c)** square waves. Construct a conversation table showing your results. To verify the coefficients in the conversion tables, feed a 1kHz wave of each type into both the DMM and the scope, using the scope to measure peak and peak-to-peak voltages, and the DMM to measure the RMS voltage. Be sure to put the DMM into the AC/RMS mode. Compare your measured values to the calculated values. (Remember that any quantitative comparison requires consideration of errors on all the measured quantities.)

Problem 1.1.18

Using a sine wave of about 1V p-p (peak-to-peak), vary the frequency of the signal between 10Hz and 10MHz. Measure, as a function of frequency, the RMS voltage of the signal **a)** using the scope with the input switch on 'DC' (using the conversion constant calculated in Section 1.19), and **b)** using the DMM. **Plot** the results. Find the frequency range over which the DMM is accurate (i.e. where the two results agree to within 5%.). Does the DMM perform within specifications? Take at least two measurements per decade,F[13] taking a few more per decade at the low and high ends. You should take your data at geometrically rather than arithmetically (i.e. multiplying by a constant each time rather than adding a constant increment) spaced frequencies. Why?

Problem 1.1.19

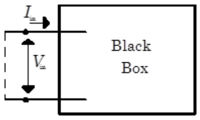
Now feed a square-wave into both channels of the scope, with one channel set on 'DC', the other on 'AC'. Compare and sketch the displayed signals for 10Hz, 100Hz and 10kHz square waves, and explain the distortion on the 'AC' channel.

Remember these results! A common mistake is to measure the amplitude of low-frequency signals using the ‘AC’ setting of the scope. ‘AC’ on the scope does **not** mean “use this setting if your signal has an AC component!” **Use ‘DC’ unless you have a specific reason to not use it.** The only common reason to use the AC setting is to look at a small AC signal riding on top of a large DC. Even then, better results are often obtained by using the DC setting and the vertical level knob to force the trace onto the screen.

Back To Top

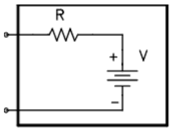
Part 2—Linear Circuits I

Background: Black Boxes and Thévenin's Theorem or Thévenin equivalent circuit http://en.wikipedia.org/wiki/Thevenin%27s_theorem [10]



Perhaps the simplest general circuit is a box containing some internal circuitry connected to two external leads. Such "thought experiment" boxes are known as black boxes. What can we deduce about the internal circuitry from measurements on the two leads? Let's assume that there are no frequency dependent elements in the box. The simplest measurements that we can make are the open-circuit voltage[14]F V_{open} , and the short-circuit current[15]F I_{short} . What internal circuit could generate these two parameters?

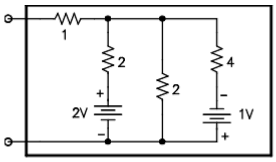
The simplest such circuit is shown to the right. If we set the battery voltage to the measured open-circuit voltage $V = V_{\text{open}}$ and set the resistance to $R = V_{\text{open}} / I_{\text{short}}$, the circuit reproduces the correct open-circuit voltage and short-circuit current. But is it identical to the original circuit for all other conditions? Thévenin proved that it is indeed identical if all the internal components are linear. Linear circuit components obey the linear relation:



$$V = ZI + V_{\text{constant}}$$

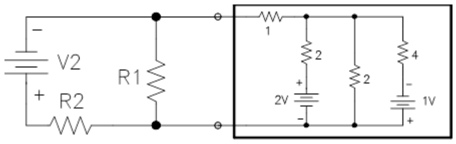
and include components like resistors, capacitors, inductors, and batteries. The simplified circuit is called the Thévenin equivalent circuit, and its internal components are called the "**Thévenin resistance**" and the "**Thévenin voltage**".

For example, this complicated circuit below

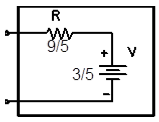


can be reduced to the Thévenin equivalent circuit on the right by determining that the original circuit's open-circuit voltage is 3/5V and its short-circuit current is 1/3A.

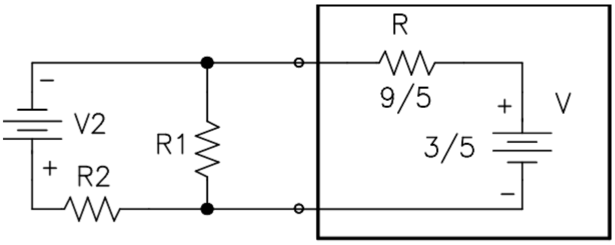
Textbooks describe sophisticated methods for calculating the Thévenin circuit parameters. While these methods are not very hard, it is more important for you to accept that the reduction can always be done then for you to be actually able to do it.



Thévenin's theorem would be just a curiosity if it only worked for isolated black boxes. Its power lies in the fact that the Thévenin equivalent circuit behaves exactly like the original circuit when inserted into *any* external circuit.



For example, this circuit
can be reduced to the circuit below independent of the values of V2, R1 or R2. Clearly the reduced circuit is easier to analyze and understand than the original.



Time Dependent Circuits

Circuit analysis is straightforward if all the signals are time independent, i.e. DC. The response of circuit to time dependent (AC) signals like sine waves is more complicated because the response to the signal may not be in phase with the signal, and may depend on frequency. For example, a circuit driven by a voltage source $V = V_1 \cos(\omega t)$ might produce an output current phase-shifted by ϕ, namely $I = I_1 \cos(\omega t + \phi)$. We can incorporate such phase shifts into Ohm's law by allowing the voltages, currents, and resistances to be complex. Thus, $I_1 \cos(\omega t + \phi)$ becomes[16] $\bar{I} \exp(j\omega t)$, where $\bar{I} = I_1 \exp(j\phi)$. While we do all our algebra with complex quantities, we have to take the real part in the end (e.g. $I = \text{Re}[\bar{I} \exp(j\omega t)]$) because we can measure only real quantities in the lab.

Since I and V are not necessarily in phase, the resistance can no longer be a pure real quantity. We use a new term for complex resistances: the ***impedance*** *Z*. The magnitude of the impedance has much the same function in Ohm's law (now $V = ZI$), as did the resistance *R*; it determines the relation between the magnitudes of *I* and *V*. The phase angle of *Z* determines the phase shift between *I* and *V*. Note that resistance is redefined to be the real part of the impedance, and the ***reactance*** is defined to be the imaginary part of the impedance.

Clearly, a resistor has pure real impedance $\boxed{Z_R = R}$ and induces no phase shifts. Capacitors have impedance $\boxed{Z_C = \frac{1}{j\omega C}}$ and inductors have impedance $\boxed{Z_L = j\omega L.}$

Capacitor impedance decreases with frequency; inductor impedance increases with frequency. Both capacitors and inductors induce 90° phase shifts, but the phase shifts are in opposite directions.

Any linear circuit[17]F can be analyzed using the impedance formulas. The familiar parallel and series resistor addition formulas carry over directly; just substitute the capacitative and inductive impedances for *R*. For example, the impedance of two capacitors in parallel is

$$Z = \frac{Z_{C1} Z_{C2}}{Z_{C1} + Z_{C2}} = \frac{\frac{1}{j\omega C_1} \frac{1}{j\omega C_2}}{\frac{1}{j\omega C_1} + \frac{1}{j\omega C_2}} = \frac{1}{j\omega (C_1 + C_2)}.$$

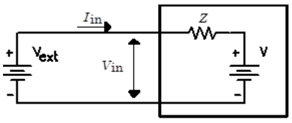
Analyze any circuit just as you would if all the components were resistors, but keep track of the complex parts, and you will get the right answer. Thévenin circuit reduction works as well, though the Thévenin resistance becomes a complex, frequency dependent impedance.

And that's all we need to know about complex impedances for this class. But as physicists we should understand the formal differential equations methods that underlie these simplifications, which can be found in most E&M texts.

Large Signal Impedance

To recapitulate, we can model any linear black box with its Thévenin equivalent. The black box's input impedance is defined to be the Thévenin impedance *Z*: the ratio of the **open-circuit voltage** to the **short-circuit current** $\left(V_{open} / I_{short} \right)$. The Thévenin impedance *Z* may be a function of frequency, but it is not (yet) a function of the amplitude of any signal. Such impedances are called “large signal” impedances.

For example, consider the circuit below.



The input current is related to the input voltage by the equation $I_{in} = (V_{in} - V)/Z$. The proportionality between the current and the input voltage V_{in} is the impedance *Z*, regardless of the amplitude of the external driving voltage $V_{in} = V_{ext}$.

It can be awkward to measure input impedances by varying the size of the external voltage source V_{ext}. A more common procedure employs the circuit below. Because the instrument typically doesn’t produce a voltage across its own input terminals, it is not necessary to include V_{th} in this box.

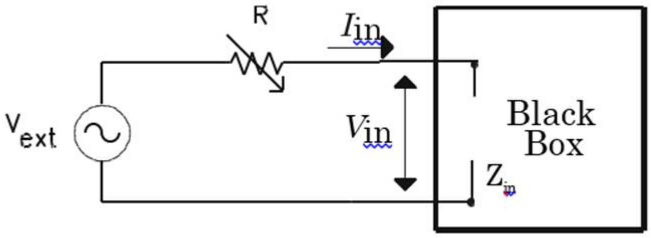
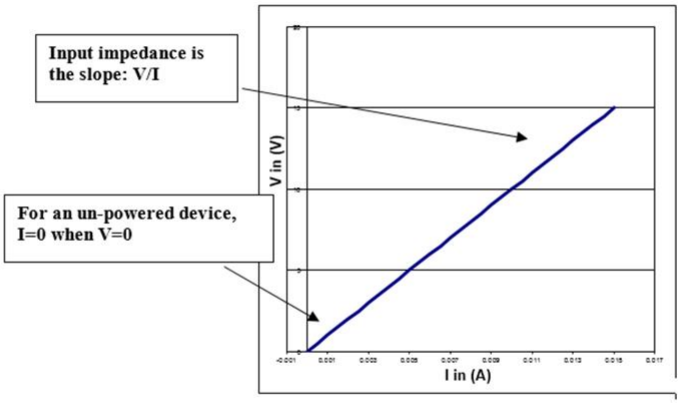


Figure 3: Measuring Input Impedance

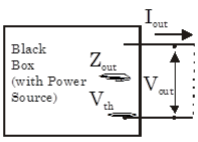
Here we fix the amplitude and frequency of V_{ext}, and vary *R*, while measuring the corresponding V_{in}. Then we determine the input current $I_{in} = (V_{ext} - V_{in}) / R$, as a function of V_{in}. If the circuit is linear, we need not bother with taking derivatives; the impedance reduces to

$$Z_{in} = \frac{V_{in}}{V_{ext} - V_{in}} R ,$$

If the circuit is not linear (as in later labs), we can find the impedance by taking the slope of the $V_{in}(I_{in})$ curve.



In principle, any set of values of *R* can be used to find Z_{in}. In practice values of *R* that are too large introduce errors because V_{in} will be too small to measure accurately. Values of *R* that are too small will introduce errors because calculating the denominator V_{ext} - V_{in} requires the subtraction of two imprecisely known, but nearly equal numbers.[18]F Values of *R* close to Z_{in} generally produce the most accurate results.



Output Impedance

Output impedance is defined similarly to input impedance: $\boxed{Z_{out} = -\frac{\partial V_{out}}{\partial I_{out}}.}$

Output impedances are used when the black box drives an external circuit. Consequently, we normally assume that the black box contains some sort of internal power source. Note that I_{out} is directed *out* of the box while I_{in} (used with input impedances) is directed into the box. (Keep track of which direction goes with which impedance by remembering that input and output impedances are normally positive.

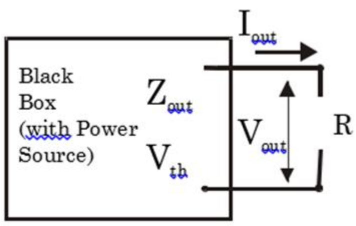
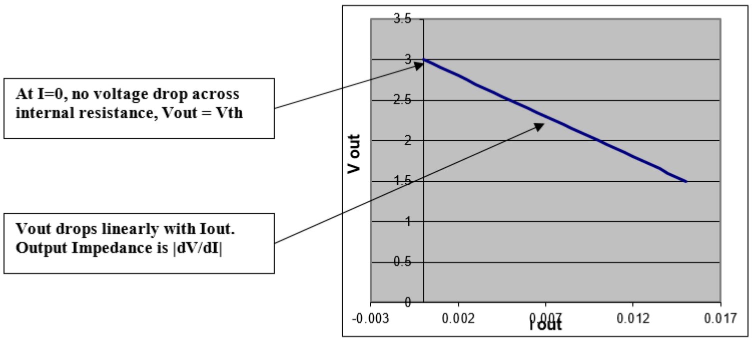


Figure 4: Measuring Output Impedance

Output impedances are often measured with variable resistors using the circuit above (Figure 4). An external power source is no longer needed because the black box provides its own power. Data is taken with different resistor values and analyzed in the same manner as for input impedances.



Don't forget that there is little actual difference between output and input impedances; which to employ depends on the context. For example, input impedance is defined for the input of a scope,F[19]F while output impedance is defined for the output of a signal generator.

Part 2 questions:

Problem 1.2.1 - Thévenin Analysis

Obtain a black box, and insert the two 9V batteries. Trace out the schematic. (The output connectors are the two spring loaded push pins.) Decode the resistor values ***by yourself.*** With the DMM measure the open-circuit voltage and the short-circuit current.[20]F Draw the Thévenin equivalent circuit and determine the value of the equivalent resistor (output impedance) by using $Z = \frac{V_{open}}{I_{short}}$. Now attach a 100$\Omega$ resistor to the output terminals, and measure the output voltage and current. Repeat for $1\mathrm{k}\Omega$, and $10\mathrm{k}\Omega$ resistors. **Plot** the measured current and voltage values. Does the Thévenin circuit predict these voltages accurately? Finally, remove the batteries and short each battery holder with a wire. (This replaces the 9V sources with 0V sources) Use the DMM to measure the resistance between the two terminals. Is it the same as the Thévenin resistance? **Remember to disconnect the 9V batteries when you are not using the black box.**

Note: While you do not have to do so for this problem, it *is* possible to predict the Thevenin V and Z for any arbitrary combination of linear circuit elements and ideal voltage supplies. This generally involves solving a system of linear equations. Ask a GSI if you're interested!

Problem 1.2.2

Connect a four-foot BNC cable to the oscilloscope input. Attach a minigrabber clip to the other end, and set the scope to 50mV/div and 5ms/div. Touch the end of the minigrabber signal (red) lead.

a) What is the origin of the signal you see on the scope?

b) Do you see a signal if you pinch the red insulation rather than the metallic connection?

c) Does pinching the BNC cable result in a signal?

Now short the minigrabber signal and ground leads together with a four-foot long (approximately) insulated wire. Set the scope to 2mV/div, the time base to 0.05ms/div. Also try other oscilloscope zoom settings with which you can see interesting features of the waveform. **Sketch** the scope trace.

d) What do you think the new signal's origin is?

Back To Top

Problem 1.2.3 - Cables and Oscilloscope Probes

Measure the input impedance of the scope using the circuit given in **Fig. 3**. Treat the scope as a unknown resistor. Use a frequency of 100Hz, a driving amplitude of 1V p-p, and several different resistors (for example 0Ω, 200$\mathrm{k}\Omega$, 470$\mathrm{k}\Omega$, 820$\mathrm{k}\Omega$, 1$\mathrm{M}\Omega$ and 2.2$\mathrm{M}\Omega$.) Record the scope's input voltage for each resistor, conveniently the scope's input voltage is displayed on the scope itself.

Plot the input voltage versus input current (determined from Ohm's Law). *As with all your plots, be sure to label your axes and scales clearly, and don't forget to give the units!* What is the dependence between input voltage, input current, and impedance? Does the data fit the theory? Determine the input impedance of the oscilloscope from the plot, and make a simple estimate of its uncertainty.

Scope Probe

Problem 1.2.4

Repeat the previous (1.2.3) measurement but this time connect a scope probe to the oscilloscope and feed the signal generator output into the scope probe.F[21]F You may need to use higher-valued resistors. Is the input impedance of the scope with the scope probe higher? (Note that the scope probe attenuates the signal by a factor of ten, so increase the channel gain to compensate.)

The advantage of using a scope probe should be clear from these results. An ideal voltage meter has infinite input impedance. The impedance without the probe is high, but the probe raises it further. The probe attenuates the signal, which can be inconvenient when measuring already small signals. It has one extra advantage for high frequency signals, which will be covered in later labs.

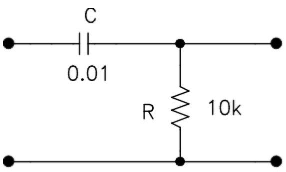
You should use a scope probe whenever you are looking at a fast, high voltage, or high output impedance signal.

Problem 1.2.5 - Output Impedance

Using the circuit given in Fig. 4. determine the output impedance of the signal generator at 1kHz. Use 47Ω, 82Ω, 100Ω, 150Ω, 220Ω, and 330Ω load resistors, as well as no load (infinite resistance.) Also try it with a potentiometer on your breadboard station, changing the resistance until the voltage drops in half. Is this easier? Why or why not? (Reminder: to measure the pots resistance it must be disconnected.)

Problem 1.2.6 - RC Circuits

Build the RC circuit shown below. The circuit follows the convention that signals flow left to right; the input terminals are the left and the output terminals are on the right. Confirm the values of your components using your DMM and the LCR22] meter. The LCR meter can be tricky to use. Ask for help if you're not sure about it. (Note that when units are not explicitly given for a capacitor, the assumed units are μF.)



Using 1V p-p sine waves in the frequency range 20Hz - 20kHz, measure the input and output amplitudes as a function of frequency (use 1-2-5-10... frequency steps). **Plot** Vout/Vin vs. frequency. (use a log scale for frequency) Measure the roll-off point, defined as the frequency f where $\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{2}}$ and mark it on the graph. (**Bonus question**: why $\frac{1}{\sqrt{2}}$ instead of the more straightforward $\frac{1}{2}$?) Because this circuit sharply attenuates low frequencies, but passes high frequencies unchanged, it is called a high-pass filter. Swapping the positions of the capacitor and resistor results in a low-pass filter in which high frequencies are attenuated.

Use the scope to measure the phase between the input and output signals. (The scope has a "measurement" that measures the phase automatically.)

Problem 1.2.7

A more elegant (though not necessarily more accurate) method displays the phase angle as an angle on the scope screen. First, set the time base to the XY mode. On this setting, the scope plots channel 2 (Y) against channel 1 (X); the time base sweep is disabled. Set both channels to GND, and make sure that the displayed dot is centered on the screen. Then feed the two signals into the two channels. If the signals are in phase, you will see a straight line at 45°; if they are out of phase, an ellipse. The phase difference between the two signals is given by the arcsine of the ellipse's Y intercept divided by its Y maximum:

$$\delta = \sin^{-1}\left(\frac{y_{int}}{y_{max}}\right)$$

Demonstrate a phase measurement with this "arcsine" method to a GSI.

Problem 1.2.8

For the circuit in 1.2.6, use whichever method you prefer to measure the phase shift between the input and the output over the same frequency range. **Plot** this data on the same graph as 1.2.6. **Find** the frequency or frequencies yielding approximate phase shifts of 0°, 22.5°, 45°, 67.5°, and 90° mark these values on the graph.

Analysis:

Problem 1.2.9

If the output voltage of a black-box decreases by 20% with a load of $1\text{k}\Omega$ as compared to the "no-load" output, what is the output impedance of the black-box?

Problem 1.2.10

The resistance of a 100W light bulb, as measured with the DMM, is 9Ω. Household power is 110V. Using a power equation, how much power would you expect the light bulb to use? What's going on here? Is the light bulb a linear circuit component? If not, what accounts for its nonlinearity? Which power number is right? Why is the other power number wrong?

Problem 1.2.11

The gain of a circuit is defined to be the ratio of its output to input signal voltage amplitudes. It is usually expressed in decibels:

$$G = \left|\frac{V_{out}}{V_{in}}\right| \quad \text{(linear)}$$

$$G = 20\log_{10}\left|\frac{V_{out}}{V_{in}}\right| \quad \text{(dB)}$$

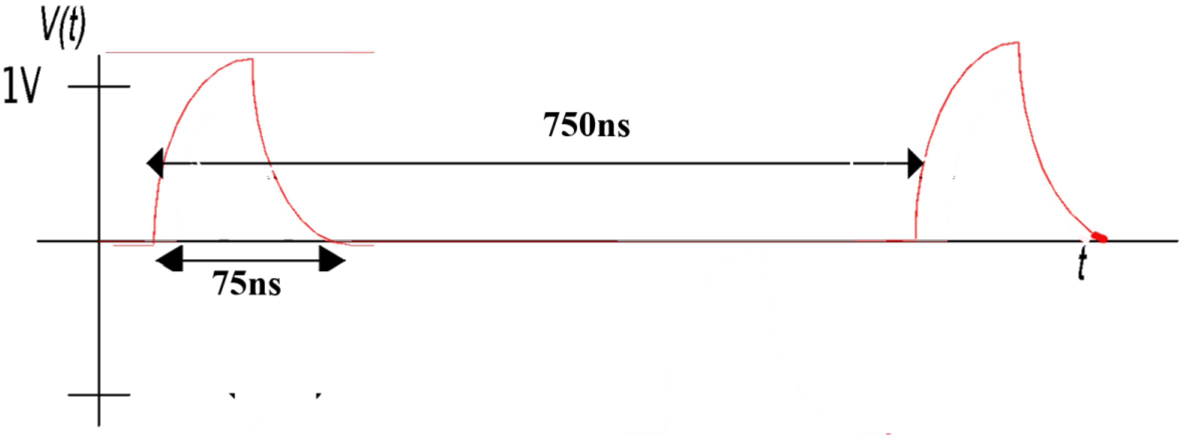
where "dB" is the abbreviation for "decibel". The frequency where $G = -3$dB (where $|V_{out}/V_{in}| = 1/\sqrt{2}$) is known as the "3 dB point" or the "rolloff point". Note that the 3dB point is the point at which the power (proportional to V^2) has gone down by a factor of two.

For the RC circuit analyzed in Sec. 1.2.6, **plot** the measured gain vs. frequency on a log-log scale (most plotting programs have an easy setting for this). Mark the gain axis in dB. This type of plot is sometimes called a Bode Plot. Next, on a new graph, plot the phase shift vs. frequency on a semi-log scale (i.e. with frequency on a log scale and the phase shift on a linear scale). Next, calculate and plot the expected transfer function and phase. (Put the theoretical and experimental curves on the same plots as the measured ones.) Do the theoretical and experimental rolloff points agree?

Additional Required Exercises:

Problem 1.2.12 (Note: this exercise can be completed at any point in the lab and does not rely on the previous exercises. We only have two long cables, so you will have to share.)

Clear your setup and connect a BNC T to the scope A input. Run a BNC cable from this T to the signal generator, and setup the generator sync signal to sync the scope (i.e. connect the generator trigger output to the AUX trigger input on the scope). Configure the generator on a square wave to produce an isolated, 75ns long pulse like that shown below.



(**Use the Pulse option on the signal generator, with the Duty (cycle) set to 1% to get the pulse.** It is not necessary to precisely reproduce this waveform.) Draw a picture of the signal. Connect a BNC 50Ω terminator to the BNC T. How does the signal change? Draw the signal. Next, remove the terminator and short the input signal by connecting a bare wire between the BNC T's inner and outer conductors. (Use the shortest possible wire.) What do you see? Draw it.

Now disconnect the bare wire and get a long (at least one hundred feet) BNC cable. Connect one end to the BNC T, and the other end to a T and the scope's B channel. Look at the A and B channels simultaneously. Surprised by what you see? Play with further separating the wave generator pulses by decreasing the frequency knob. Draw the resulting signals. Connect the 50Ω terminator to the B channel's T. What happens? Draw the signals. Finally, replace the 50Ω terminator with a shorting wire, and draw the signals.

Finally, discount the cable attached to the generator output, and reattach it with an interposed 200Ω series resistor. Use a T as shown in the photo below. (You may notice that the photo does not depict any connection of the outer conductors. This is OK for the purposes of this question, but not ideal in general. If this bothers you or if you would like a cleaner signal, you may use extra cables and minigrabbers to connect the outer conductors as well). Now what sort of signals do you see with the far end of the long cable (the cable attached to the scope) connected normally, connected with the 50Ω terminator, and shorted with the bare wire? Draw all the signals.

Problem 1.2.13

The resistors, capacitors, and inductors that we use in this lab are normally physical small compared to the distance traveled by a light (or radio) wave over the relevant circuit time scales, i.e. they are small compared to a wavelength. For example, a sine wave with a frequency of 1kHz has a 300km wavelength, certainly much greater than the size of any components. For high frequency signals, however, wavelengths can be comparable to the size of the components. Circuit analysis under these conditions is *much* more difficult because opposite ends of the components experience different signals.

Calculate how long it takes light to travel[23]F the length of the long cable you used in Sec. 1.2.13 (Signals propagate on the cable at about 2/3 the speed of light in vacuum.) Does this account for your measurements? Why do you see extra pulses on the A channel? And why, depending on what we put at the end of the coax line, are the extra pulses sometimes upright, sometimes upside-down, and sometimes not there at all? Hint – Think about what happens when light travels between two media with different indices of refraction.

Problem 1.2.14

A bandpass filter passes frequencies between high and low rolloff points, and attenuates all other frequencies. It can be constructed from sequential high and low-pass filters. Design, build, and demonstrate a bandpass filter with rolloff points at $f1$ = 500 Hz and $f2$ = 10kHz. Choose the impedances such that the first stage is not greatly affected by the loading of the second stage. Build the filter, and take enough measurements to explore its performance. (Note that this is not a good way to build a bandpass filter; later in the course, you will work with much better circuits.)

Back To Top

Please fill out the

Student Evaluation of Lab Report [11]

After completing the lab write up but before turning the lab report in, please fill out the **Student Evaluation of the Lab Report** [11].

[1] Fourth Edition: The material in these Appendixes is beyond the level of this course. Just get some idea of what's in them.

[2] Complicated prototype circuits are typically soldered with normal wire or wire wrapped. (Wire wrapping is a method of cold-welding wires to special gold-plated leads.) Both methods require skill, time, and equipment, but result in permanent circuits.

[3] BE CAREFUL: Standard electronic circuit construction always uses black for ground, red for power and other colors for signal leads. BUT building wiring, found in the walls of houses and labs, always uses white for neutral, BLACK FOR HOT (the dangerous lead) and green for ground.

[4] See Appendix IV.

[5] Make sure you plug in the breadboard station, and turn it on with the switch on the side!

[6] Resistors are often misfiled. Always check the value of the resister by reading its color code, given by the colored bands printed on the resistor. The resistor color code is printed in Appendix IV of this write-up, and is also posted in the lab.

[7] The spec'd or printed value of a component or voltage, as opposed to its actual value.

[8] Take a careful look at the volts/div knob. It has two setting indicators: a 1x-setting indicator for measurements taken without a scope probe, and a 10x-setting indicator for measurements taken with a probe.

[9] Peak-to-peak means the voltage difference between the maximum and minimum points on the waveform.

[10] "LINE" means that the trigger source is the power line voltage, oscillating at 60Hz.

[11] Scopes tend to be more accurate than generators for at least two reasons:

1. Since scopes cost about five times as as much as generators, they are designed and constructed with far more care. Newer model, digitally based signal generators are extraordinarily accurate.
2. The scope time base is varied by switch-selected precision resistors. The frequency ARB generator is controlled by a digital IC chip.

[12] Root mean square: the square root of the time-average of the square of the amplitude. An example is given in Appendix IV.

[13] Factor of ten.

[14] Open-circuit means that the leads are disconnected from all loads; i.e. no current flows in the leads.

[15] Short-circuit means that the leads are connected together with a zero resistance wire; i.e. the leads are "shorted" and there is no voltage drop between the two leads.

[16] To avoid confusion with the symbol for current, we often use *j* instead of *i* to denote $\sqrt{-1}$.

[17] More specifically, any circuit that consists only of resistors, capacitors, inductors, voltage sources, and current sources.

[18] For example, subtracting 2.1700 from 2.1701 is problematic if both numbers are not known to more than five digits.

[19] Obviously oscilloscopes contain power supplies, but these supplies are not connected to the inputs.

[20] Don't be greedy—Use the relatively insensitive 20mA scale. If you try the more sensitive scales, you will find that the current appears to decrease as you increase the sensitivity. This change is due to a design limitation of the meter called the voltage burden. Fortunately the measured signal converges to a single (and correct) answer as the scale sensitivity decreases.

[21] For best results, always attach the probe's ground clip (the short wire with the alligator clip) to a circuit ground.

[22] A LCR meter measures inductance, capacitance and resistance: hence LCR.

[23] Because of their capacitance and inductance, waves actually travel at about 2/3 the speed of light in coax cables. Try wikipedia.org for a more in depth source.