

# Review of Lab Safety & Equipment Use

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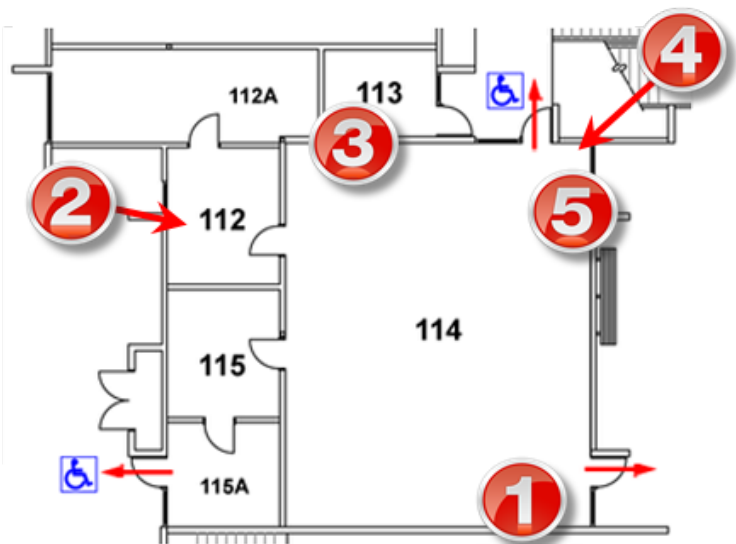
# Safety & Electric Shock Hazard

## Lab Safety

Safety should be the number one priority in an Electronics Lab. It is important that students understand the rules, know what to do in an emergency, and how to ensure their personal safety and that of those around them.

Students should be familiarized with the location and operation of the following items:

1. **First Aid Kit**
2. **MSDS Binder**
3. **Telephone & Emergency Procedures**
4. **Emergency Shut Off Switch**
5. **Fire Extinguisher**



## Chemical Safe Handling

Material Safety Data Sheets (MSDS) should be available for every chemical used in the Electronics lab. If there are any questions about safe handling, disposal, or emergency response, the MSDS will contain the answers.

## Electric Shock Hazard

Electric shock is a jarring, shaking sensation you receive from contact with electricity. You usually feel like you have received a sudden blow. If the voltage and resulting current are sufficiently high, you may become unconscious. Severe burns may appear on your skin at the place of contact; muscular spasms may occur, perhaps causing you to clasp the apparatus or wire which caused the shock and be unable to turn it loose.

The danger of shock from a high-voltage system is well recognized as shown by the relatively low number of reports of serious shock received from this voltage, despite its widespread use. On the other hand, a number of fatalities have been reported due to contact with low-voltage circuits. Despite a fairly widespread, but totally unfounded, popular belief to the contrary, low-voltage circuits (115 volts and below) are very dangerous and can cause death when the resistance of the body is lowered.

Fundamentally, **current**, rather than voltage, is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can cause death. The voltage necessary to produce the fatal current is dependent upon the several factors, including resistance of the body, contact conditions, and the path through the body. For example, when a 60-hertz alternating current, is passed through a human body from hand to hand or from hand to foot, and the current is gradually increased, it will cause the following effects:

At about 1 milliamperes (0.001 ampere), the shock can be felt.

At about 10 milliamperes (0.01 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles.

At about 100 milliamperes (0.1 ampere) the shock is fatal if it lasts for 1 second or more.

The above figures are the results of numerous investigations and are approximate because individuals differ in their resistance to electrical shock. It is most important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or less— fatalities from voltages as low as 30 volts have been recorded. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms from temple to temple if the skin is broken.

***All live electric circuits should be treated as potential hazards at all times.***

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## **Effects of Electric Current on the Human Body**

Before learning safety precautions, you should review of the possible effects of electrical current on the human body. The following table lists some of the probable effects of electrical current on the human body.

<b>AC 60 Hz (mA)</b>	<b>DC (mA)</b>	<b>Effects</b>
0-1	0-4	Perception
1-4	4-15	Surprise
4-21	15-80	Reflex action
21-40	80-160	Muscular inhibition
40-100	160-300	Respiratory failure
Over 100	Over 300	Usually fatal

Note in the above chart that a current as low as 4 mA can be expected to cause a reflex action in the victim, usually causing the victim to jump away from the wire or component supplying the current. While the current should produce nothing more than a tingle of the skin, the quick action of trying to get away from the source of this irritation could produce other effects (such as broken limbs or even death if a severe enough blow was received at a vital spot by the shock victim).

It is important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from a voltage as low as 115 volts or even less. Fatalities caused by human contact with 30 volts have been recorded. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms (from temple to temple) if the skin is broken. Generally direct current is not considered as dangerous as an equal value of alternating current.

This is evidenced by the fact that reasonably safe "let-go currents" for 60 hertz (alternating current) are 9.0 milliamperes for men and 6.0 milliamperes for women, while the corresponding values for direct current are 62.0 milliamperes for men and 41.0 milliamperes for women. Remember, the above table is a list of probable effects. The actual severity of effects will depend on such things as the physical condition of the work area, the physiological condition and resistance of the body, and the area of the body through which the current flows. Thus, based on the above information, you should consider every voltage as being dangerous.

## **Precautionary Steps**

One should constantly be on the alert for any signs which might indicate a malfunction of electric equipment. Besides the more obvious visual signs, the reaction of other senses, such as hearing, smell,

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and touch, should also make you aware of possible electrical malfunctions. Examples of signs which you must be alert for are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor.

Other signs of possible malfunction:

- Frayed and damaged cords or plugs.
- Receptacles, plugs, and cords which feel warm to the touch.
- Slight shocks felt when handling electrical equipment.
- Unusually hot running electric motors and other electrical equipment.
- An odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly.
- Electrical equipment which produces excessive vibrations.

In addition, you should be aware of the following situations:

1. Warning Signs: These in place for your protection and to disregard them is to invite personal injury as well as possible damage to equipment.
2. Working Near Electrical Equipment: When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid any potential hazards of which you may not be immediately aware.
3. Authorized Personnel Only: Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment should be done only by authorized persons. Keep your hands off of all equipment for which you have not been specifically authorized to handle. Particularly stay clear of electrical equipment opened for inspection, testing, or servicing.
4. Circuit Breakers and Fuses: Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Failure to do so may result in injury to personnel or damage to equipment in the event accidental contact is made with exposed live circuits.

## Rescue & First Aid Procedures

### Symptoms of Electric Shock

When you find someone who has received a severe electric shock, the person's skin is usually very white or pale blue. In the case of victims with dark skin, it may be necessary to rely primarily on the color of the mucous membranes on the inside of the mouth or under the eye lid or under the nail bed. A person in or going into electric shock has a bluish color to these membranes instead of a healthy pink. The victim's pulse is very weak or absent. The person is unconscious, and usually the skin is burned. A stiffness of the body may happen in a few minutes. This is caused by the muscles reacting to shock. You should not consider this condition as rigor mortis. You should make sure the victim is no longer touching the live circuit and then start artificial respiration. People have recovered after body stiffness has set in.

## Rescue and Care of Shock Victims

The rescue of a shock victim depends on your immediate administration of first aid.

***Do not attempt to administer first aid or come in physical contact with an electric shock victim before the power is shut off or, if the power cannot be shut off immediately, before the victim has been removed from the live conductor.***

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Each school or work place will have specific emergency procedures in place. Be sure to follow the procedures in place in case of emergency. There are, however, several important steps that will be very similar.

If you come upon somebody being shocked, the following procedures are recommended for rescue and care of electric shock victims:

- Turn off the power if possible.
- Call 911 and/or other emergency responders.
- Remove the victim from electrical contact at once, but DO NOT endanger yourself. You can do this by:
  - Throwing the switch if it is nearby
  - Using a dry stick, rope, belt, coat, blanket, shirt or any other nonconductor of electricity, to drag or push the victim to safety
- Determine whether the victim is breathing. If the victim is not breathing, you must apply artificial ventilation (respiration) without delay, even though the victim may appear to be lifeless. Do not stop artificial respiration until relieved by emergency responders.
- Lay the victim face up, with the feet about 12 inches higher than the head. Chest or head injuries require the head to be slightly elevated. If there is vomiting or if facial injuries have occurred which cause bleeding into the throat, the victim should be placed on the stomach with the head turned to one side and 6 to 12 inches lower than the feet.
- Keep the victim warm. The injured person's body heat must be conserved. Keep the victim covered with one or more blankets, depending on the weather and the person's exposure to the elements. Artificial means of warming, such as hot water bottles should not be used.
- Drugs, food, and liquids should not be administered if medical attention will be available within a short time. If necessary, liquids may be administered. Small amounts of warm salt water, tea or coffee should be used. Alcohol, opiates, and other depressant substances must never be administered.
- Send for emergency responders at once, but do NOT under any circumstances leave the victim until medical help arrives.

## Safety Precautions for Preventing Electric Shock

Working safely is the most important thing you can do. Because of their importance, several precautions are listed below. Of course there are more precautions, but these are some you should think about. The keyword here is *think*. Think safety.

- Never work alone. Another person may save your life if you receive an electric shock.
- Never receive an intentional shock.
- Work on energized circuits ONLY WHEN ABSOLUTELY NECESSARY.
- Deenergize equipment prior to hooking up or removing test equipment.
- Discharge power capacitors before working on deenergized equipment. Remember, a capacitor is an electrical power storage device.
- Work with only one hand inside the equipment. Keep the other hand clear of all obstacles that may provide a path, such as a ground, for current to flow.
- Only work on, operate, or adjust equipment if you are authorized.
- Keep loose tools, metal parts, and liquids from above electrical equipment. Never use steel wool or emery cloth on electric and electronic circuits.
- Keep protective closures, fuse panels, and circuit breaker boxes closed unless you are actually working on them.
- Keep a cool head and think about the possible consequences before performing any action. Carelessness is the cause of most accidents. Remember the best technician is NOT necessarily the fastest one, but the one who will be on the job tomorrow.

# Equipment Use and Safety

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## Introduction

In addition to the multimeter and DC power supply, this class will make use of the oscilloscope and function generator. Please review the precautions below on protecting yourself from injury when using the multimeter and power supply. Following this section, the necessary precautions for using the oscilloscope and function generator will be discussed.

## Protecting Yourself

### Measuring Current

When you use an ammeter, certain precautions must be observed to prevent injury to yourself or others and to prevent damage to the ammeter or the equipment on which you are working. The following list contains the **MINIMUM** safety precautions to observe when using an ammeter.

- Ammeters must always be connected in series with the circuit under test. That means they must be inserted into the circuit at the point being measured.
- Always start with the highest range of an ammeter.
- Deenergize and discharge the circuit completely before you connect or disconnect the ammeter.
- In dc ammeters, observe the proper circuit polarity to prevent the meter from being damaged.
- Never use a dc ammeter to measure ac.
- Observe the general safety precautions of electrical and electronic devices.

### Measuring Voltage

Just as with ammeters, voltmeters require safety precautions to prevent injury to personnel and damage to the voltmeter or equipment. The following is a list of the **MINIMUM** safety precautions for using a voltmeter.

- Always connect voltmeters in parallel.
- Always start with the highest range of a voltmeter.
- Deenergize and discharge the circuit completely before connecting or disconnecting the voltmeter.
- In dc voltmeters, observe the proper circuit polarity to prevent damage to the meter.
- Never use a dc voltmeter to measure ac voltage.
- Observe the general safety precautions of electrical and electronic devices.

### Measuring Resistance

The following safety precautions and operating procedures for ohmmeters are the **MINIMUM** necessary to prevent injury and damage.

- Be certain the circuit is deenergized and discharged before connecting an ohmmeter.
- Do not apply power to a circuit while measuring resistance.



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- When you are finished using an ohmmeter, switch it to the OFF position if one is provided and remove the leads from the meter.
- Always adjust the ohmmeter for zero (or  $\infty$  in shunt ohmmeter) after you change ranges before making the resistance measurement. (Analog)

### Protecting the Equipment

The electrical measuring instruments included in test equipment are delicately constructed and require certain handling precautions to prevent damage and to ensure accurate readings. While it is possible to find very inexpensive handheld DMMs, bench top models and higher quality handheld models can be very expensive. Analog meters can also be expensive.

To prevent damage to electrical measuring instruments, you should observe the precautions relating to three hazards: mechanical shock, exposure to magnetic fields, and excessive current flow.

**MECHANICAL SHOCK.**—Instruments contain permanent magnets, meters, and other components that are sensitive to shock. Heavy vibrations or severe shock can cause these instruments to lose their calibration accuracy.

**EXPOSURE TO STRONG MAGNETIC FIELDS.**—Strong magnetic fields may permanently impair the accuracy of a test instrument. These fields may impress permanent magnetic effects on permanent magnets, moving-coil instruments, iron parts of moving-iron instruments, or in the magnetic materials used to shield instruments.

**EXCESSIVE CURRENT FLOW.**—this includes various precautions, depending on the type of instrument. When in doubt, use the maximum range scale on the first measurement and shift to lower range scales only after you verify that the reading can be made on a lower range. If possible, connections should be made while the circuit is de-energized. All connections should be checked to ensure that the instrument would not be overloaded before the circuit is reenergized.

### Other Instrument Precautions

Precautions to be observed to prevent instrument damage include the following:

- Never leave an instrument connected with its pointer off-scale or deflected in the wrong direction. (analog)
- Never attempt to measure the internal resistance of a meter movement with an ohmmeter since the movement may be damaged by the current output from the ohmmeter.
- Before measuring resistance, always discharge any capacitors in the circuit to be tested. Note and record any points not having bleeder resistors or discharge paths for capacitors.
- Always disconnect voltmeters from field generating or other highly inductive circuits before you open the circuit.

## **Power Supplies**

A direct current (DC) power supply can be either a variable triple output bench model or a battery. For most modules, a 9 V battery will be a sufficient power source for your experiments. Be aware that some functionality will be lost when using a battery and that variable DC power supplies can be purchased at low cost.

## **Bench Power Supplies**

A bench power supply normally provides 0 – 24 V of DC voltage. For safety reasons, the amount of current is usually limited to not more than 1 Amp. As you have read, it is the current that is of greater concern. In future modules, you will learn that even with a steady low voltage, as you incorporate resistance into your circuits, the amount of current will vary.

## **Triple Output DC Power Supply**

The triple output DC power supply is commonly found in electronics labs due to its ease of use, relative safety and multiple outputs. Shown below is a typical triple output power supply. The triple output is due to it having two variable outputs and one fixed output. The variable outputs typically supply 0-30 V of DC with the current limited to help protect equipment, components, and especially, people. As you will learn in later modules, voltage, current, and resistance form a relationship called “Ohm’s Law.” In short, when one of those changes, the other two will either change directly or inversely proportionate in response. For working with digital electronics and other applications requiring 5 V, there is an output with fixed voltage and current settings. In future modules, the specifics of how to set up the power supply will be discussed.

## **DC Power Supply**

The Triple Output Power Supply as shown in the figure is fairly common and the directions following should be generic enough for a variety of models.

In the figure, a box is drawn around the set of controls for one of the variable outputs. The C.V. and C.C indicator lights let you know whether current or voltage is being held constant. For our purposes, we want a constant voltage. The output also has three input jacks, one labeled “-,” one labeled “+,” and one labeled “GND.” When setting up your circuit, you will use the “-” and “+.” In future modules, you will need to insert a ground point into your circuit. At that time, you will use the “GND” input.

Notice that each of the two variable outputs is labeled Master and Slave. In the center, there are a set of buttons which allow you to set whether the two outputs operate in series (additive), in parallel (supply the same current/voltage), or independently. For most purposes, the power supply needs to be set as independent.

## **Safety Considerations**

Normal lab safety procedures should always be observed when using a power supply. Ensure that the settings for current and voltage are both set to zero before connecting a circuit and turning on the power. If you are working with a sensitive circuit, it could be damaged by excessive current or voltage.

## **Signal Generator**

A signal generator is also referred to as a function generator. It is used to produce a signal in the form of a wave (sine, square, saw toothed, etc.) that can be controlled in regard to frequency and amplitude. Frequency is measured in cycles per second, or Hertz (Hz). It refers to how fast the wave is oscillating from positive to negative. Amplitude is measured in voltage and refers to how high the wave is going from positive to negative.

## **Oscilloscope**

The oscilloscope is used to measure frequency and amplitude and is primarily used in this course to measure AC signals and voltage. The actual techniques for measuring frequency and amplitude in a circuit differ significantly from the multimeter and will be covered separately.

## **Safety Considerations**

Safety considerations when working with signal generators and oscilloscopes relate more to the safety of the equipment than to the user. For both, the most important things to remember are to ground the probes and to be familiar with the capabilities and limitations of the equipment you are using. Both pieces of equipment, particularly the oscilloscope, can be very expensive. The measurement of current with the oscilloscope requires additional steps to protect the equipment. Failure to do so can permanently damage it.

## **Additional Equipment**

In future modules, there will be discussion of several new concepts and the specialized tools that are used for measurement. There are “Z-Meters” for measuring capacitors and inductors, counters, network analyzers, spectrum analyzers, True RMS Meters, and much more.

## **Conclusion**

The multimeter and the power supply are the two basic pieces of test equipment that are needed when working with DC. For AC, more specific pieces of equipment will be used. The function generator is to AC what the power supply is to DC. It provides the voltage. The multimeter will measure resistance, voltage and current in both AC and DC circuits. The oscilloscope provides for greater range of accuracy

# References

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Kuphaldt, Tony R. Shock Current Path. In *All About Circuits Volume 1 – DC*. Retrieved from [http://www.allaboutcircuits.com/vol\\_1/chpt\\_3/3.html](http://www.allaboutcircuits.com/vol_1/chpt_3/3.html)

Kuphaldt, T. (n.d.). *Safe Meter Usage*. Retrieved December 2012, from All About Circuits: <http://www.allaboutcircuits.com/pdf/DC.pdf>

United States Navy. (September 1998). Module 1 – Introduction to Matter, Energy, and Direct Current (NAVEDTRA 149173). In *Naval Electricity & Electronics Training Series (NEETS) (NAVSUP Logistics Tracking Number: 0504-LP-026-8260)*. Prepared by ETCS (SW) Donnie Jones. Naval Education and Training - Professional Development and Technology Center.

United States Navy. (1998). *Navy Electricity and Electronics Training Series - Module 3 Circuit Protection, Control, and Measurement* (Vol. 3). (F. J. Hicks, Ed.) Pensacola, Florida, USA: Naval Education and Training Professional Development and Technology Center.

United States Navy. (September 1998). Module 2 - Introduction to Alternating Current and Transformers (NAVEDTRA 14174). In *Naval Electricity & Electronics Training Series (NEETS) (NAVSUP Logistics Tracking Number: 0504-LP-026-8270)*. Prepared by DSC Ray A. Johnson. Naval Education and Training - Professional Development and Technology Center.

United States Navy. (September 1998). Module 19 – The Technician’s Handbook (NAVEDTRA 14191). In *Naval Electricity & Electronics Training Series (NEETS)*. Prepared TMCM Jack L. Formyduval. Naval Education and Training - Professional Development and Technology Center.

## Additional Resources

### Websites

All About Circuits (<http://www.allaboutcircuits.com/>)

### Multimedia

Naked Scientists at the Naked Science Scrapbook: “Why Are Birds Not Electrocuted on Power Lines?” (<http://www.youtube.com/watch?v=rN3QhtnICSw>)

# Breadboarding Review

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# Basic Lab Skills

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## Overview

In this exercise, students are introduced to the breadboard as a tool for building circuits. The set up and simple use of breadboards will be covered as well as basic schematic reading.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions.

## Course Objectives

Upon completion of this course students will be able to:

- Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
- Demonstrate ability to document a breadboard circuit
- Demonstrate ability to document a schematic
- Demonstrate ability to document a pictorial layout
- Demonstrate ability to describe different wire size and type

## Module Objectives



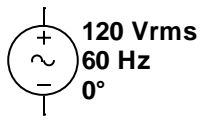




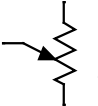

Upon completion of this module, students will be able to:

- Identify basic parts of a breadboard.
- Recognize and identify basic schematic symbols.
- Construct a very simple circuit from a schematic.
- Draw a schematic from a breadboard.
- Identify uses and qualities of different wire size and type.

## Reading a Schematic

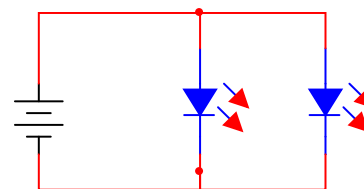
The basic concepts of schematics are the same for both AC and DC circuits.

### Schematic Symbols and Terms

<p>+ (positive)</p>  <p>- (negative)</p> 	DC Voltage	This symbol is used in this course to indicate a DC voltage source such as a DC Power Supply or a battery. The voltage level will indicated in units of volts, V. The longer lines are positive and the shorter lines are negative.
<p>V1</p> 	AC Voltage Source	This symbol is used to indicate an AC voltage source such as a signal generator. The $V_{rms}$ is number that represents AC voltage in terms of DC (oversimplification) and is found through a formula. The 60 Hz indicates the frequency. And the $0^\circ$ indicates phase. Many of these concepts will be covered in the future.
	Ground	This symbol indicates ground.
	Resistor	This is the symbol for resistors. The resistance will be indicated in units of ohms, $\Omega$ .
<p>C1</p>  <p>1<math>\mu</math>F</p>	Capacitor	Capacitors are used for many different functions. This symbol indicates that a non-polarized capacitor is to be used. It can be placed in the circuit without regard to positive/negative polarity.
<p>C2</p>  <p>1<math>\mu</math>F</p>	Electrolytic Capacitor	This symbol indicates that a polarized capacitor is to be used. Attention must be paid to how it is placed in the circuit in order to prevent damage to the cap, the circuit, and yourself.
 <p>50 %</p>	Potentiometer	A potentiometer is a variable resistor. The “pot’s” total resistive value will be indicated in ohms. In this image, the percentage of that value is indicated. 50% indicates that only half of the resistance is being used.
<p>L1</p>  <p>1mH</p>	Inductor	The inductor is another commonly used component.

### Bread Boarding Review

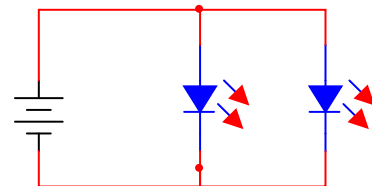
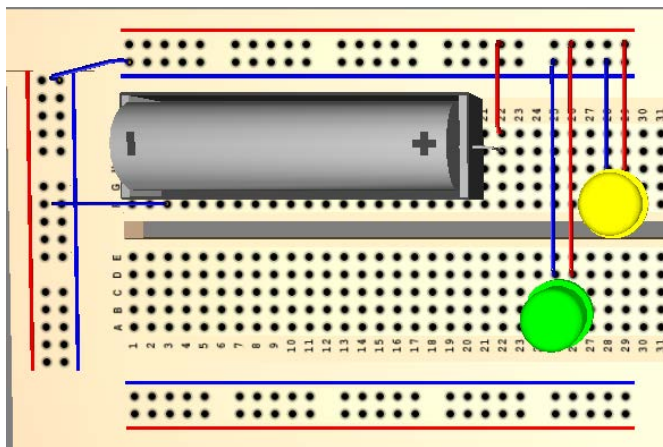
A simple circuit that allows two lamps to be powered by the same power source would look like the schematic shown. There is a power source, wire for the path, and two bulbs connected in parallel. The concept is the same for AC as it is for DC.



In this class, lab circuits are built on a bread board and the rest of this module will discuss how to use a breadboard in your labs.

Electricity needs a path to follow. Using the design of the breadboard, you can build that path. There must be an applied voltage and there must be a ground point. Between those two points all that is needed is a conductive path. In this case, the path is a wire. Watch the video in this module for detailed information how to set up a simple circuit on a breadboard.

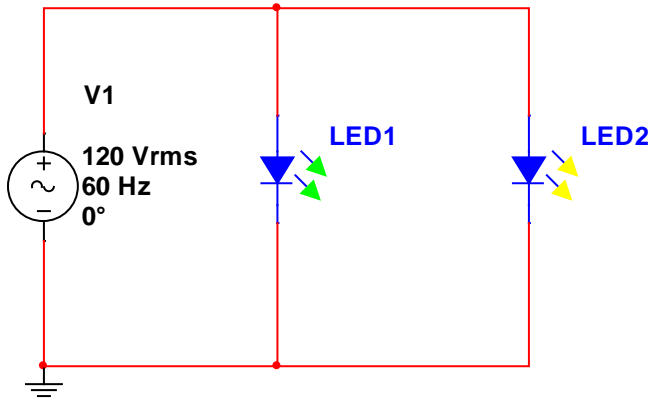
Below is shown a simple circuit with a battery and two lamps. This is the same circuit as is shown in the schematic. Note that the battery is attached to each of the bus lines. The negative side is attached to the blue bus line and the positive side to the red. Because each bus line has an electrically common connection, wires can connect to components from anywhere along their length. But since the bus connection does not go around the corner, a jumper wire was used to connect the two bus lines together.





## Basic AC Bread Boarding

Setting up a circuit on the breadboard for an AC circuits is essentially the same as for DC. The major difference is from where the voltage is coming from. If the circuit above was redrawn for AC, it would look like this:

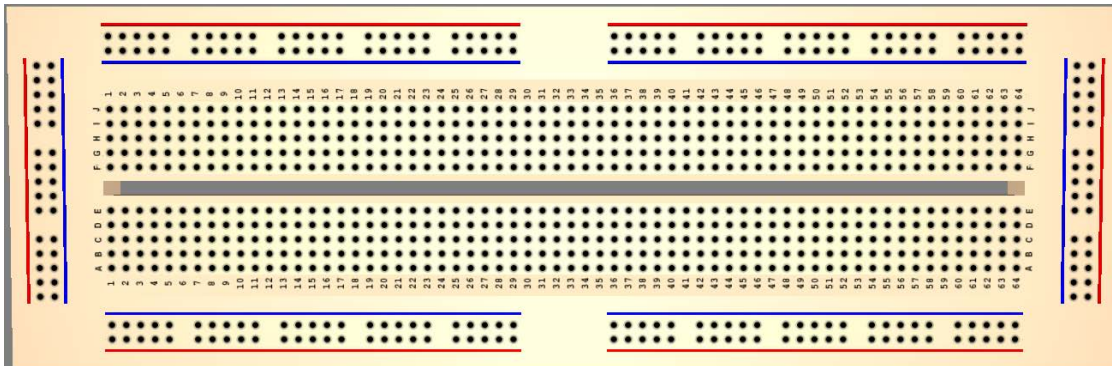


As for bread boarding, it would look the same EXCEPT that rather than a battery, there would be a connection going to a signal generator.

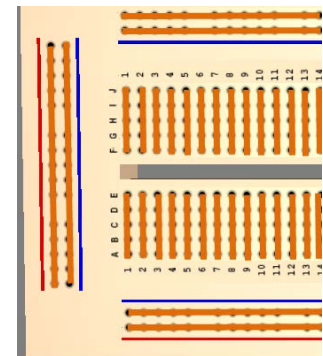
A signal generator uses a cable with a BNC connector (like for television cables) with a positive (red) lead and a negative (black) lead. Just like the battery or DC power supply, the positive goes to the positive bus on the bread board and the negative goes to the negative.

## The Bread Board

As a review, the bread board is basically just a convenient place to insert wires and components. Without it, you would need to figure out a way to hold all the components and wires together while designing a circuit. When you needed to make a change, you would have to disconnect all the connections, change the part, and then connect it all together again. With a bread board, you merely lift out the component you wish to change and insert a new one. If wires must be moved, you simply unplug the wire and move it to the new location.



If you could see inside the breadboard, it would look like the image in the second figure. This image shows how the holes on the breadboard are connected on the inside. Any hole that lies on the same line (or wire) are said to be electrically common. Any connection along that same set of holes is essentially the same connection. The areas that are outlined with red and blue stripes are bus lines. The area in the center is where circuits are built.



## Bus Lines

Bus lines are essentially areas from which connections can be made anywhere along the line. They are not required for use, but do allow for flexibility and convenience. On the bread board, locate the sections with blue and red lines. These indicate the buses. The red is normally used for positive (voltage) and the black for negative (or ground). Once again, this is not a requirement, but it is generally expected and accepted that red represents positive or “hot” and black or dark blue represents negative.

In the center area of the bread board, there are numbered rows and lettered columns with a channel that goes down the middle of each side. The center channel isolates one set of rows and columns from the next and is used with integrated circuit (IC) chips. When circuits are built, it is this area that is used.

## Wires & Jumpers

Copper wire creates the path that connects components together in an electric circuit. In later modules, you will learn more details about wire, but for now, it is important to have only a basic understanding. Standard wire sizes are measured in AWG (American Wire Gauge). Unlike most measurements, for wire the larger the gauge, the smaller the wire.

The wire used for bread boarding is single strand 22 AWG, or 22 gauge. Most of the components have pins or legs of the same or smaller size. For larger wattage resistors, the legs will be a bit larger. If you are having difficulty inserting a wire or component into the holes on a breadboard, please stop and ask for assistance. Forcing the wire or component into the breadboard will damage it.

Because the bread boarding wire is single strand, it is not as tolerable of bending and twisting as stranded wire. The test leads and cables used for the power supplies are made of stranded wire and as such are much better suited to being manipulated. If you start to experience trouble with a bread board wire, it could be that it has been bent and reused one time too many. As you progress through the program, you will find that you will amass a collection of color coded jumpers. Inspect them occasionally for damage such as crimps, bends, missing insulation. Missing insulation can become a shock hazard. Dispose of and replace any wire that has insulation missing and have exposed copper.

Wire in the lab will be called by several different names: jumper, wire, cable. It also comes in a variety of color. Color coding wire makes complex circuitry easier to follow. Some basic color coding is red for positive and black for negative / ground.

Preparing wire for use in the breadboard is simple and involves the use of wire strippers:

1. Cut off the amount of wire needed
2. Using the wire strippers, insert one of the wires into the slot labeled "22." You only need about 1/8" of bare wire. While squeezing the handles, pull the long end of the wire away from the strippers
3. Repeat on the other end.
4. Dispose of the insulating material in the trash.

## Additional Resources

### Websites

Vanderbilt University: “The Breadboard” (<http://eecs.vanderbilt.edu/courses/ee213/Breadboard.htm>)

TechDose: “How to use Solderless Breadboards,” by Wayne

Eggert (<http://www.techdose.com/electronics/How-to-Use-Solderless-Breadboards/252/page1.html>)

### Multimedia

Collin’s Lab: The REAL Breadboard (<http://www.youtube.com/watch?v=HrG98HJ3Z6w>)

SNMU: How Breadboards Work (<http://www.youtube.com/watch?v=lqw6ask5HK0>)

# Electromagnetism I

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# Electromagnetism I

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## Overview

In this lab, students create three different magnets using nails, 22 AWG insulated wire, a 9 V battery and different numbers of windings. They are asked to measure voltage and current and to calculate the flux density of each magnet. Students must discuss loading effects and the reasons for the steps taken to eliminate them in this experiment.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions. Compile all results into an APA formatted lab report and submit on line.

## Course Objectives

1. Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
2. Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
3. Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
4. Understand the loading effects and limitations of various types of test equipment.

## Module Objectives

- Analyze current in an electromagnet.
- Calculate flux density from measurements and known constants.
- Explain loading effects and limitations of the ammeter in this experiment.

## Activities

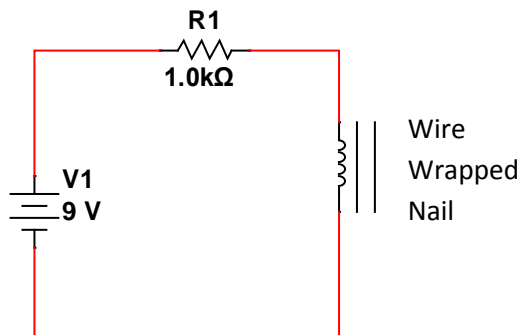
1. Electromagnetism
2. Critical Thinking

## 1: Electromagnetism

### Components & Equipment Needed

- 1 k $\Omega$ , 2 W Resistor
- 9V battery and holder
- 3 each “18 Penny” Nails
- Lengths of 22 AWG Wire: 12”, 24”, 36”
- Assorted leads
- Compass

### Schematic



**IMPORTANT:** Because of the potential for high current in this lab, it is essential that when measuring current flow that a shunt resistance is used. This helps eliminate loading effects.

### Procedure

**You will be using 3 different nails using the specified wire lengths. Record all measurements in the table. If you have excessive wire left after wrapping the nail, snip it off.**

- Step 1:** Measure the voltage of the battery.
- Step 2:** **Nail 1:** Using the 12” length of wire, measure the resistance of the wire and record in the table. Then, wrap about 1/3 of the nail in 22 AWG wire. Ensure that the windings are very tight and start at the head (flat side) of the nail.
- Step 3:** Connect the circuit as shown in the schematic. Measure the voltage drop of the resistor.
- Step 4:** Measure the current, taking care to follow correct procedures for measuring current.

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## Air Washington Electronics – Alternating Current Lab

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- Step 5:** Disconnect the circuit and measure the voltage of the battery.
- Step 6:** **Nail 2:** Using the 24" length of wire, measure the resistance of the wire and record in the table. Then, wrap the nail so that about 2/3 of the nail is wrapped in wire. Make sure the windings are tight.
- Step 7:** Reconnect the circuit as shown in the schematic. Measure the voltage drop of the resistor.
- Step 8:** Measure the current, taking care to follow correct procedures for measuring current.
- Step 9:** Disconnect the circuit and measure the voltage of the battery.
- Step 10:** **Nail 3:** Using the 36" length of wire, measure the resistance of the wire and record in the table. Then, wrap the entire nail, ensuring that it is tightly wound from head to point in wire.
- Step 11:** Connect the circuit as shown in the schematic. Measure the voltage drop of the resistor.
- Step 12:** Measure the current, taking care to follow correct procedures for measuring current.
- Step 13:** Disconnect the coil from the DMM, resistor, and ammeter. Using the Left-Hand Rule, determine towards which end of the nail (pointed or flat) the North end of a compass would point. Indicate your answer in the space below:
- Step 14:** Reconnect the coil to the battery and have your instructor test your assumption using a compass. In your observations and conclusions support, why or why not, your determination.

Using the measured values from above, complete the following table and submit with your lab report. Calculate the voltage of the coil for each set of windings using Ohm's Law. The voltage of the coil is too small to be measured, and will need to be calculated.

Nail 1: 1/3 of Nail		Nail 2: 2/3 of Nail		Nail 3: Total Nail	
$V_{\text{battery1}}$		$V_{\text{battery2}}$		$V_{\text{battery3}}$	
$V_{\text{Resistor1}}$		$V_{\text{Resistor2}}$		$V_{\text{Resistor3}}$	
$I_{\text{coil1}}$		$I_{\text{coil2}}$		$I_{\text{coil3}}$	
$R_{\text{coil1}}$		$R_{\text{coil2}}$		$R_{\text{coil3}}$	
$V_{\text{coil1}}$ (Calculated)		$V_{\text{coil2}}$ (Calculated)		$V_{\text{coil3}}$ (Calculated)	





## References and Resources

Georgia State University. (n.d.). *Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at 20°C*. Retrieved January 8, 2013, from HyperPhysics: <http://hyperphysics.phy-astr.gsu.edu/HBASE/tables/magprop.html>

# Electromagnetism II

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# Electromagnetism II

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## Overview

In this lab, students are introduced to datasheets and how to use them to determine specific features, limitations, and operating ranges. Using an electromechanical relay, students will measure current and voltage and make

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions. Compile all results into an APA formatted lab report and submit on line.

## Course Objectives

1. Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
2. Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
3. Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
4. Understand the loading effects and limitations of various types of test equipment.

## Module Objectives

- Identify specifications of a relay based on part number and data sheet.
- Identify state of contacts of an electromechanical relay.
- Measure voltage and current of an electromechanical relay at various points of operation.
- Define pickup voltage, pickup current, holding current, and drop out voltage.
- Explain the electromagnetic and switching properties of an electromechanical relay.

## Activities

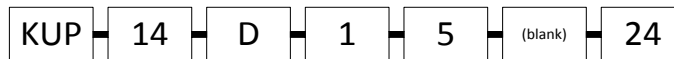
1. Deciphering the Data Sheet
2. Continuity & Resistance Tests
3. Voltage & Current Tests
4. Critical Thinking

## **Components & Equipment Needed**

- Digital Multimeter (DMM)
- Adjustable DC Power Supply
- 24 Vdc 3PDT Relay (KUP-14D15-24)
- Datasheet for Potter & Brumfield KUP Series Panel Plug-In Relay

### **1: Deciphering the Data Sheet**

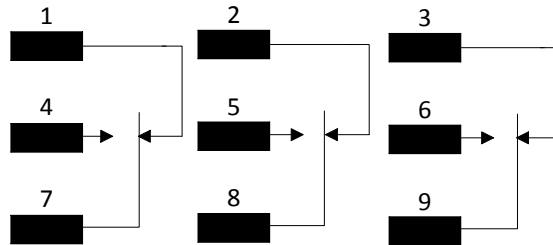
Familiarize yourself with the attached datasheet. Note the kinds of information presented. Think about how this information would be useful to a technician.



**Step 1:** Using the data sheet, decipher the part number of the relay used in this experiment. Answer the following questions using the data sheet.

- What is the relay's rated voltage?
- What is the relay's operating voltage?
- What is the coil resistance?
- What is the rated coil power?
- What is the recommended ambient temperature range?

**Step 2:** Based on the operational schematic below, identify by pin numbers the pairs of connections that are NO (normally opened) and those that are NC (normally closed).



Normally Opened (NO) Pairs	Normally Closed (NC) Pairs

## 2: Continuity & Resistance Tests

The connections on the relay are numbered 1 through 8 with the exception of two connectors. These are points A and B. For purposes of this lab, it is of no matter which you designate as A or B.

**Step 1:** Using the continuity checker on the DMM, test your answers to the above question.

Do they agree or disagree?

**Step 2:** Measure the resistance of the coil (between points A and B).

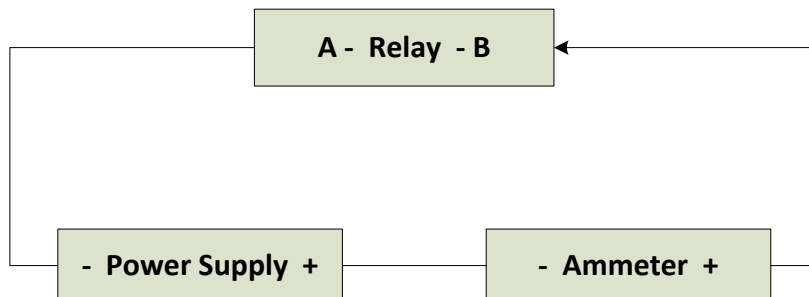
How does it compare to the coil resistance stated in the datasheet?

### 3: Voltage & Current Tests

**Step 1:** Connect the power supply to points A and B. You may need to unscrew the connectors and use alligator clips. Tighten the screw to ensure a good connection. Use the voltmeter to measure the voltage drop between points A and B.

- ☐ **Pickup Voltage:** Start with 0 volts and slowly increase voltage until the relay activates. Record the voltage: \_\_\_\_\_
- ☐ **Dropout Voltage:** Reduce the voltage gradually until the relay deactivates. Record the voltage: \_\_\_\_\_

**Step 2:** Reconfigure your set up so that an ammeter is now in series with the relay and power supply as shown in the block diagram below. The arrow indicates a probe end. Adjust the power supply to 0 V and ensure that the ammeter is set to read DC current.



- ☐ **Pickup Current:** Hold the probe to the relay as shown and gradually increase the voltage until the relay activates. Record the current: \_\_\_\_\_
- ☐ **Holding Current:** This step requires some trial and error. Reduce the voltage gradually until the relay deactivates. Make note of the current, then adjust the voltage gradually until it activates again. Once again, reduce voltage gradually until JUST before it deactivates. Record the current: \_\_\_\_\_

#### **4: Critical Thinking**

1. List at least three (3) reasons why datasheets are useful for technicians.
  
  
  
  
  
  
  
  
  
  
2. From what you have observed and measured, define the following terms:
  - a. Pickup Voltage
  
  
  
  
  
  
  
  - b. Dropout Voltage
  
  
  
  
  
  
  
  - c. Pickup Current
  
  
  
  
  
  
  
  - d. Holding Current
  
  
  
  
  
  
  
  
  
  
3. Explain the concept of “3PDT” as it relates to the relay used in this lab.

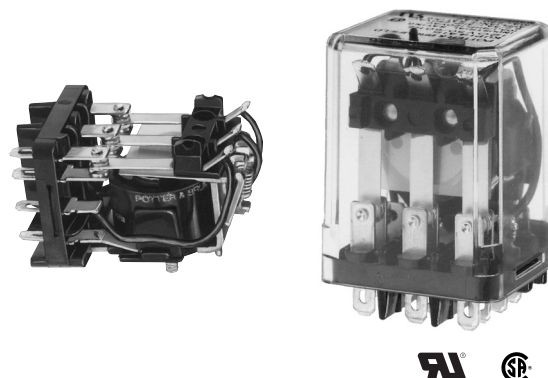


## KUP Series Panel Plug-in Relay

- AC coils: 5-240VAC, 50/60 Hz.; DC coils 6-110VDC
- Contact arrangements of 1 form X, 1-3 form A and 1-4 form C
- Wide selection of termination and mounting styles
- PC terminals available
- Push-to-test button and indicator lamp options
- Sockets available for panel, DIN rail or PCB mounting
- Class B coil insulation

### Typical applications

Vending, commercial sewing, tool/die equipment, robotics, timers, welding, HVAC, medical, power generators



### Approvals

UL E22575; CSA LR15734

Technical data of approved types on request

### Contact Data

Contact arrangement	1 Form X (NO-DM); 1-3 Form A (NO); 1-4 Form C (CO)		
Rated voltage	240VAC		
Rated current	10A		
Contact material	Ag	AgCdO	AgSnInO
Min. recommended contact load	100mA, 12VDC	300mA, 12VDC	300mA, 12VDC
Frequency of operation	360 ops./hr	360 ops./hr	360 ops./hr
Operate/releases time max.	15/10ms		
Bounce time max.	17ms		

### Contact ratings

Type	Load	Cycles
<b>UL 508</b>		
Ag, 1, 2 and 3 pole		
	5A, 240VAC	
	5A, 28VDC	
	1/6HP, 120VAC	
	2.5A, 120VAC, tungsten	
	1/3HP, 240VAC	
	0.5A, 120VDC	
	5FLA, 15LRA, 250VAC	
Ag, 4 pole		
	5A, 240VAC	
	2.5A, 120VAC, tungsten	
	0.5A, 120VDC	
	1/6HP, 120VAC	
	1/3HP, 240VAC	
AgCdO, 1, 2 and 3 pole		
	10A, 240VAC	
	10A, 32VDC	
	5FLA, 15LRA, 250VAC	
	1/3HP, 120VAC	
	5A, 120VAC, tungsten	
	1/2HP, 250VAC	
	0.5A, 125VDC	
	10FLA, 40LRA, 125VAC	
	3A, 600VAC	
	1/2HP, 480VAC	
	1/2HP, 600VAC	
	1HP, 480 VAC, 3 phase	
AgCdO, 4 pole		
	10A, 240VAC	
	5A, 120VAC, tungsten	
	0.5A, 120VDC	
	10A, 28VDC, resistive	
	10FLA, 30LRA, 125VAC	
	5FLA, 15LRA, 250 VAC	30x10 <sup>3</sup>
	125VA, 250 VAC	

AgCdO, 4 pole (continued)

1/3HP, 120VAC

1/2HP, 250VAC

Total load not to exceed 30 A, 28 VDC, 120 VAC and 20 A, 250 VAC

AgSnInO

10A, 277VAC, pf = 0.8

100x10<sup>3</sup>

Mechanical endurance 10x10<sup>6</sup> ops.

### Coil Data

Coil voltage range	5 to 110VDC
	6 to 240VAC

Coil insulation system according UL Class B

### Coil versions, DC coil

Coil code	Rated voltage VDC	Operate voltage VDC	Coil resistance $\Omega \pm 10\%$	Rated coil power W
1, 2 and 3 pole				
5	5	3.75	21	1.2
6	6	4.5	32.1	1.125
12	12	9.0	120	1.2
24	24	18.0	472	1.25
48	48	36.0	1800	1.3
110	110	82.5	10000	1.25
4 pole				
5	5	3.75	14	1.8
6	6	4.5	20	1.8
12	12	9.0	80	1.8
24	24	18.0	320	1.8
48	48	36.0	1250	1.85
110	110	82.5	6720	1.8

All figures are given for coil without preenergization, at ambient temperature +23°C.

### Coil versions, AC coil

Coil code	Rated voltage VAC	Operate voltage VAC	Coil resistance $\Omega \pm 15\%$	Rated coil power VA
1 and 2 pole				
6	6	5.1	6	2.0
12	12	10.2	24	2.0
24	24	20.4	85	2.0
120	120	102.0	2250	2.1
240	240	204.0	9110	2.1
3 and 4 pole				
6	6	5.1	4.2	2.8
12	12	10.2	18	2.8
24	24	20.4	72	2.8
120	120	102.0	1700	2.9
240	240	204.0	7200	2.9

All figures are given for coil without preenergization, at ambient temperature +23°C.

**KUP Series Panel Plug-in Relay (Continued)**

**Insulation Data**

Initial dielectric strength	
between open contacts	1200V <sub>rms</sub>
between contact and coil	2200V <sub>rms</sub>
between adjacent contacts	2200V <sub>rms</sub>
Initial insulation resistance	
between insulated elements	100MΩ, 500VDC

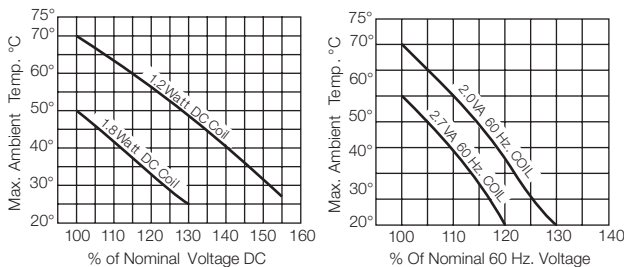
**Other Data**

Material compliance: EU RoHS/ELV, China RoHS, REACH, Halogen content refer to the Product Compliance Support Center at [www.te.com/customersupport/rohssupportcenter](http://www.te.com/customersupport/rohssupportcenter)

**Ambient temperature**

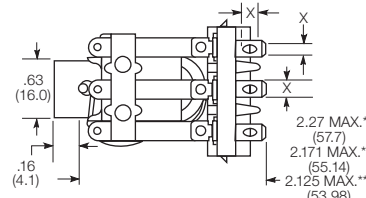
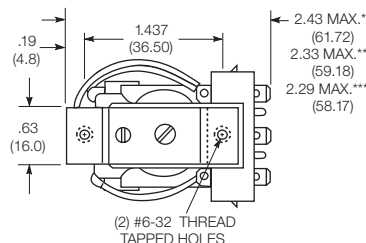
DC coil	Enclosed relays, 4 pole: -45°C to 50°C
	Enclosed relays, 1-3 pole: -45°C to 70°C
	Open relays: 15°C higher maximum
AC coil	Enclosed relays, 3 and 4 pole: -45°C to +45°C
	Enclosed relays, 1 and 2 pole: -45°C to +55°C
	Open relays: 15°C higher maximum

**Maximum allowable ambient temperature vs voltage (KUP enclosed)**

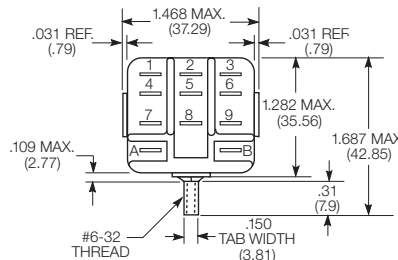
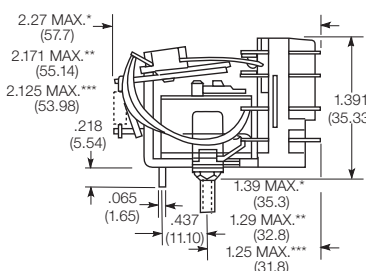


**Dimensions**

**KU bracket type**

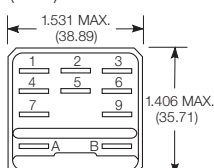


**KU stud type**

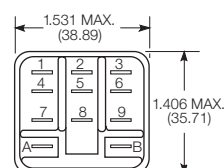


**Relay front diagrams**

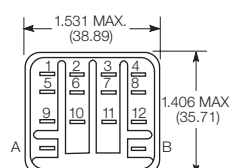
**Models with 6.35mm (.250) QC terminals**



**1-3 pole models with all other terminals**



**4 pole models**



**Other Data (continued)**

Category of environmental protection	IEC 61810	RT0 - open relay; RTI - dust protected
Terminal type	Quick connects (QC), .187, .205 or .250; PCB-THT	
Terminal retention, push force		
QC .205	17 lbs for 3s	
QC .187, QC .250, PCB	25 lbs for 3s	
Weight	85g	
Packaging/unit	tray/25 pcs., box/150pcs.	

**Accessories**

For details see datasheet	Sockets and Accessories, KUP Relays
---------------------------	-------------------------------------

Product Code	Description
27E893	DIN socket (use 20C318 clip)
27E121	Track mount socket (use 20C314 clips)
27E043	Chassis mount/solder eyelet socket (use 20C254 clip)
27E046	Chassis mount/PCB socket (use 20C254 clip)
27E067	Chassis mount/quick connect socket (use 20C254 clip)
27E396	Snap-in/quick connect socket (use 20C254 clip)

**Seated Heights For KU (open) Relays**

1.391" (35.33mm) for #6-32 stud with .218" (5.54mm) locating tab.

1.52" (38.6mm) for bracket with 2-#6 32 tapped holes.

1.282" (32.56mm) for #6-32 tapped core with .125" (3.18mm) or .218" (5.54mm) locating tab.

2.046" (51.97mm) for relay with printed circuit terminals.

STUD TYPE also available with .125" (3.18mm) tab, as well as without stud and locating tab. Models without stud have core tapped #6-32 THREAD, .25" (6.4mm) minimum depth.

\*Dimensions with .250" (6.35mm) terminals.  
\*\* Dimensions with .110" (2.79mm) or .205" (5.21mm) terminals.  
\*\*\* Dimensions with .187" (4.75mm) terminals.

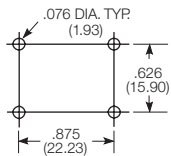


**KUP Series Panel Plug-in Relay** (Continued)

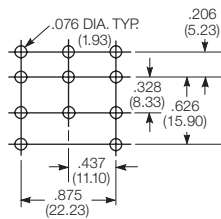
**PCB layout**

Bottom view on solder pins

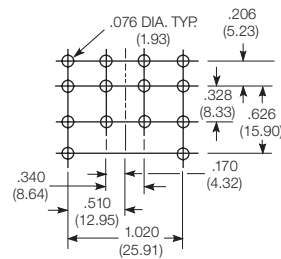
1 form X version



3 pole version  
(Omit unnecessary holes for form A and 2 pole types)



4 pole version



**Product code structure**

Typical product code

**KUP -14 A 1 5 -120**

**Type**

**KU** Open style relay

**KUP** Enclosed relay

**Contact arrangement**

<b>1</b>	1 form A (1 NO)	<b>3</b>	1 form X (1 NO-DM)	<b>5</b>	1 form C (1 CO)
<b>7</b>	2 form A (2 NO)	<b>11</b>	2 form C (2 CO)	<b>12</b>	3 form A (3 NO)
<b>14</b>	3 form C (3 CO)	<b>17</b>	4 form C (4 CO)		

**Coil Input**

<b>A</b>	AC, 50/60Hz	<b>D</b>	DC
----------	-------------	----------	----

**Mounting and options**

**KU**

- 1** #6-32 mounting stud, 5.54mm (.218in) locating tab
- 3** #6-32 tapped core, 3.18mm (.125in) locating tab
- 4** #6-32 tapped core, 5.54mm (.218in) locating tab
- 5** #6-32 tapped core, no locating tab

**KUP**

- 1** Socket mount (plain) case
  - 2** Socket mount (plain) case with push-to-test button 1)
  - 3** Socket mount (plain) case with indicator lamp 2)
  - 4** Socket mount (plain) case with indicator lamp and push-to-test button 1) 2)
  - 5** Bracket mount case
  - A** Plain case with #6-32 stud and locating tab
  - E** Plain case with #6-32 tapped core and locating tab
  - T** Top flange case 1)
- 1) Not available with four pole models (Contact arrangement 17).  
2) Indicator lamps are available on models with the following coils: 6-24VAC and VDC, 110VDC and 120-240VAC. Only models with 120-240VAC coils are UL recognized.

**Terminal and contact material**

**1 and 2 pole models**

<b>1</b>	4.75mm (.187in) quick connect/solder; Ag, 5A	<b>3</b>	1.19mm (.047in) PCB; Ag, 5A
<b>5</b>	4.75mm (.187in) quick connect/solder; AgCdO, 10A	<b>7</b>	1.19mm (.047in) PCB; AgCdO, 10A
<b>J</b>	6.35mm (.250in) quick connect/solder; Ag, 5A	<b>K</b>	6.35mm (.250in) quick connect/solder; AgCdO, 10A
<b>P</b>	4.75mm (.187in) quick connect/solder; AgSnInO, 10A	<b>S</b>	1.19mm (.047in) PCB, AgSnInO; 10A
<b>W</b>	6.35mm (.250in) quick connect/solder; AgSnInO, 10A		

**3 pole models**

<b>1</b>	4.75mm (.187in) quick connect/solder; Ag, 5A	<b>3</b>	1.19mm (.047in) PCB; Ag, 5A
<b>5</b>	4.75mm (.187in) quick connect/solder; AgCdO, 10A	<b>7</b>	1.19mm (.047in) PCB; AgCdO, 10A
<b>P</b>	4.75mm (.187in) quick connect/solder; AgSnInO, 10A	<b>S</b>	1.19mm (.047in) PCB, AgSnInO; 10A

**4 pole models**

<b>1</b>	4.75mm (.187in) quick connect/solder; Ag, 5A 3)	<b>3</b>	1.19mm (.047in) PCB; Ag, 5A
<b>4</b>	2.79mm (.110in) quick connect/solder; Ag, 5A	<b>5</b>	4.75mm (.187in) quick connect/solder; AgCdO, 10A 3)
<b>7</b>	1.19mm (.047in) PCB; AgCdO, 10A	<b>9</b>	2.79mm (.110in) quick connect/solder; AgCdO, 10A
<b>P</b>	4.75mm (.187in) quick connect/solder; AgSnInO, 10A 3)	<b>S</b>	1.19mm (.047in) PCB, AgSnInO; 10A
<b>U</b>	2.79mm (.110in) quick connect/solder; AgSnInO, 10A 2)		

3) 4 pole KUP with 4.75mm (.187in) terminals will not plug into sockets. Must use 2.79mm (.110) terminals for socket mounting.

**Au flashed contact option**

- Leave Blank** No Au flashing on contacts
- F** Optional Au flashing on contacts

**Coil voltage**

Coil code: please refer to coil versions table

### KUP Series Panel Plug-in Relay (Continued)

Product Code	Arrangement	Material	Coil	Terminals	Mounting	Part Number		
KUP-5A15-24	1 form C, 1 CO	AgCdO	24VAC	4.75mm (.187in) QC	Socket mount, plain case	6-1393118-0		
KUP-5A15-120			120VAC			5-1393119-9		
KUP-5A15-240			240VAC		Bracket mount case	6-1393118-1		
KUP-5A55-120			120VAC			6-1393118-3		
KUP-5D15-12			12VDC			Socket mount, plain case	6-1393118-6	
KUP-5D15-24			24VDC			6-1393118-7		
KUP-5D55-12			12VDC		Bracket mount case	7-1393118-0		
KUP-5D55-24			24VDC			7-1393118-1		
KUP-11A11-120	2 form C, 2 CO	Ag	120VAC		Socket mount, plain case	1-1393117-7		
KUP-11A15-12			AgCdO			12VDC	1-1393117-8	
KUP-11A15-24			24VAC		2-1393117-1			
KUP-11A15-120			120VAC		1-1393117-9			
KUP-11A15-240			240VAC		2-1393117-2			
KUP-11A35-120			120VAC		Socket mount case w/ indicator lamp	2-1393117-5		
KUP-11A55-24			24VAC		Bracket mount case	3-1393117-0		
KUP-11A55-120			120VAC			2-1393117-9		
KUP-11AT5-120					Top flange case	1-1393117-4		
KUP-11D11-24			Ag		24VDC	Socket mount, plain case	4-1393117-2	
KUP-11D15-5			AgCdO		5VDC		4-1393117-8	
KUP-11D15-12					12VDC		4-1393117-4	
KUP-11D15-24					24VDC		4-1393117-5	
KUP-11D15-36					36VDC		4-1393117-6	
KUP-11D15-110					110VDC		4-1393117-3	
KUP-11D35-24					24VDC	Socket mount case w/ indicator lamp	5-1393117-3	
KUP-11D55-6					6VDC	Bracket mount case	6-1393117-0	
KUP-11D55-12					12VDC		5-1393117-6	
KUP-11D55-24			24VDC			5-1393117-8		
KUP-11D55-48			48VDC			5-1393117-9		
KUP-11D55-110			110VDC			5-1393117-5		
KUP-14A11-120		3 form C, 3 CO	Ag		120VAC		Socket mount, plain case	7-1393117-3
KUP-14A15-12					AgCdO			12VAC
KUP-14A15-24					24VAC		7-1393117-9	
KUP-14A15-120					120VAC		7-1393117-8	
KUP-14A15-240					240VAC		8-1393117-0	
KUP-14A25-120					120VAC		Socket mount w/ test button	8-1393117-3
KUP-14A35-120							Socket mount w/ indicator lamp	8-1393117-7
KUP-14A35-240			240VAC		8-1393117-9			
KUP-14A35F-120	AgCdO w/ Au flash		120VAC		9-1393117-0			
KUP-14A45-120	AgCdO			Socket mount w/ test button, indicator lamp	9-1393117-4			
KUP-14A55-24			24VAC	Bracket mount case	1393118-2			
KUP-14A55-120			120VAC		9-1393117-9			
KUP-14A55-240			240VAC		1393118-3			
KUP-14D11-24	Ag		24VDC		Socket mount, plain case		1-1393118-0	
KUP-14D15-6	AgCdO		6VDC		1-1393118-8			
KUP-14D15-12			12VDC		1-1393118-3			
KUP-14D15-24			24VDC		1-1393118-4			
KUP-14D15-48			48VDC		1-1393118-7			
KUP-14D15-110			110VDC		1-1393118-2			
KUP-14D25-24			24VDC		Socket mount w/ test button		2-1393118-3	
KUP-14D35-24					Socket mount w/ indicator lamp		2-1393118-7	
KUP-14D35-110				110VDC			2-1393118-6	
KUP-14D35F-110	AgCdO w/ Au flash				2-1393118-9			
KUP-14D45-110	AgCdO				Socket mount w/ test button, indicator lamp		3-1393118-1	
KUP-14D55-12				12VDC	Bracket mount case		3-1393118-7	
KUP-14D55-24			24VDC				3-1393118-8	
KUP-17A19-120	4 form C, 4 CO			120VAC	2.79mm (.110in) QC		Socket mount, plain case	4-1393118-2
KUP-17A55-24				24VAC			Bracket mount case	4-1393118-6
KUP-17D19-24			24VDC	Socket mount, plain case		5-1393118-0		
KUP-17D55-24			24VDC	Bracket mount case		5-1393118-3		

# Alternating Voltage & Current

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# Alternating Voltage & Current

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## Overview

In this lab, students are introduced to the TENMA 72-6805 Oscilloscope with built in function generator. By experimenting with different settings, students will gain knowledge allowing them to successfully use the oscilloscope throughout term.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions.

## Course Objectives

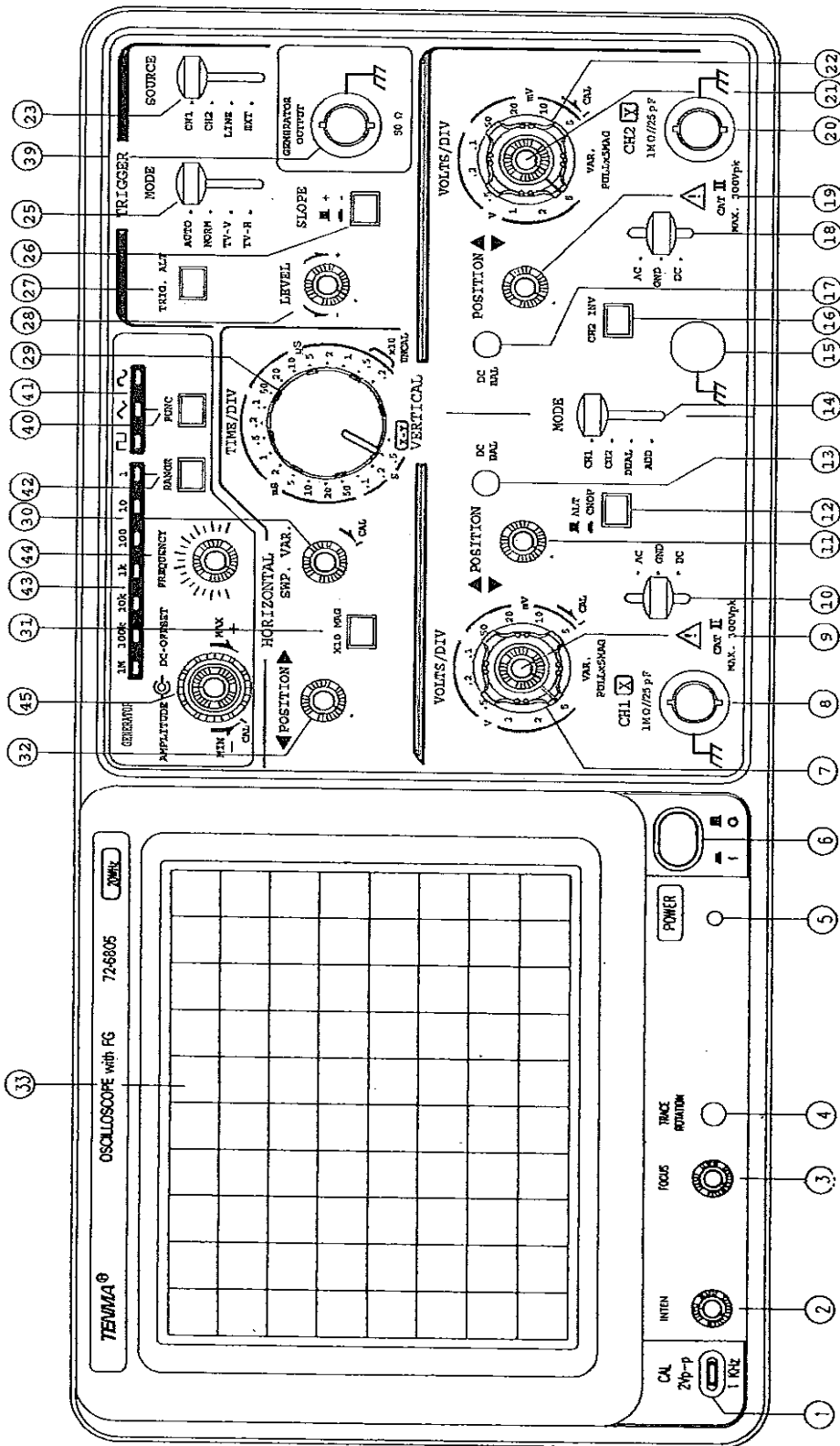
- Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
- Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
- Understand the loading effects and limitations of various types of test equipment.

## Module Objectives

- Demonstrate proper calibrating techniques for oscilloscope probes.
- Demonstrate proper setup procedures for the signal generator.
- Calculate time and frequency from a displayed wave form.
- Measure voltage, time, and frequency from a displayed wave form.

## Activities

1. Introduction to the Oscilloscope
2. Measuring Alternating Voltage





## 1: Introduction to the Oscilloscope

### Components & Equipment Needed

- Oscilloscope (Example used is TENMA 72-6805)
- Signal Generator (built-in)
- Oscilloscope Probes (1x/10x capable)

### Part 1: Calibrating the Oscilloscope

#### Procedure

*Before proceeding, review the video demonstration on the use of the TENMA 72-6805 Oscilloscope*

- Step 1:** Review diagram of TENMA 72-6805 oscilloscope. The location numbers of inputs, dials, etc., when referenced, will be indicated parenthetically in the steps below.
- Step 2:** Attach probe to Channel 1 (8).
- Step 3:** Turn on power; set AC/GND/DC (10) to GND.
- Step 4:** Use horizontal position (32) and Ch. 1 vertical position (11) to center the green beam on the centerline of the screen.
- Step 5:** Set probe to 10x and attach to calibration post (1)
- Step 6:** Set AC/GND/DC (10) to DC. You should see a square wave similar to the below picture:

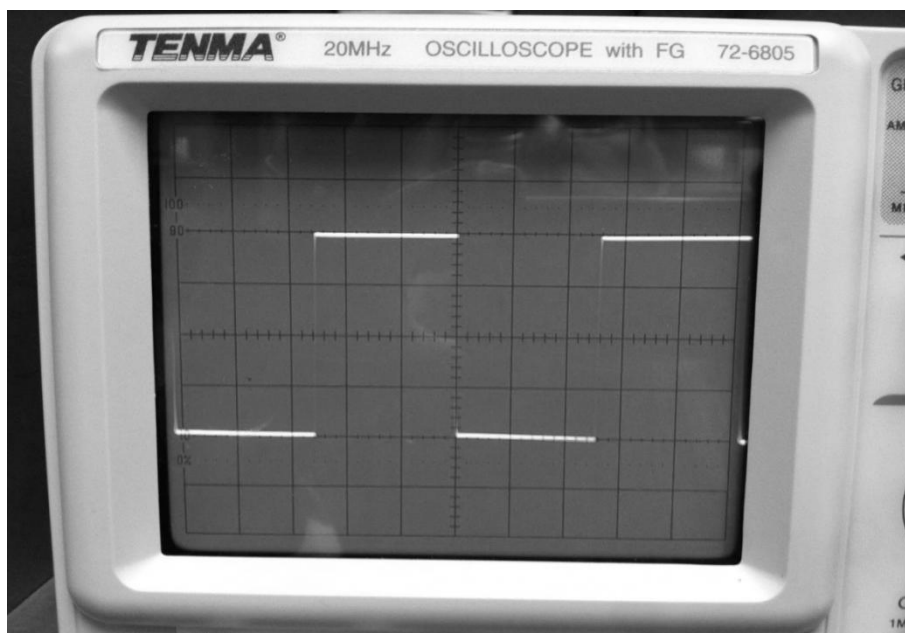


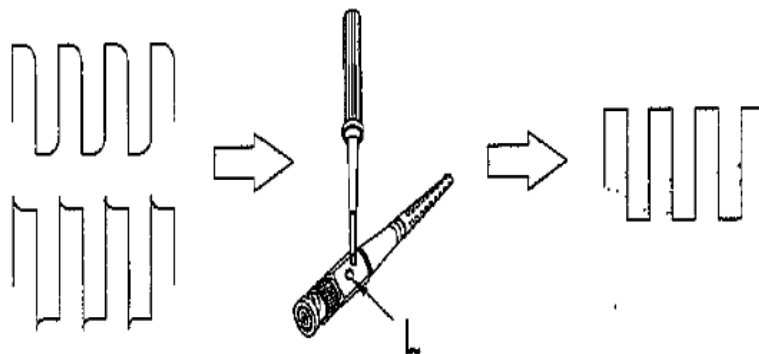
Figure 1: Calibrated Probe

If the wave does not look correct, adjust as per these directions:

## Maintenance

### Low-Frequency probe Compensation

Before taking any measurements using a probe, first check the compensation of the probe and adjust it to match the channel inputs. Most oscilloscopes have a square wave reference signal available at a terminal on the front panel used to compensate the probe. Connect the probe to the signal source to display a 1KHz test signal on your oscilloscope. Set the probe to 10X position.



Adjust trimmer L until seeing flat-top square wave on the display.

Figure 2: Calibration Instructions TENMA 72-6805

## **Part 2: Adjusting the Signal Generator**

Note: These instructions are for the built-in signal generator of the TENMA 72-6805. For a standalone signal generator, please note that the locations and labels of the amplitude and frequency adjust will be different. The basic premise will hold true, however.

### **Procedure**

- Step 1:** Now that the probe is calibrated, remove it from the calibration post (1).
- Step 2:** Attach the signal generator cable to the generator output (39).
- Step 3:** Set the generator range to 1 kHz by pushing the RANGE button (42) repeatedly until the light for “1k” is lit. Set the wave function for square wave function by depressing the FUNC button (40) until the first option is lit. The symbols shown are square wave, saw-toothed wave, and sine wave.
- Step 4:** Set SOURCE (23) to CH1 and MODE (25) to AUTO.
- Step 5:** Adjust AMPLITUDE (45) and FREQUENCY (44) for a  $2 V_{pk}$ , 1 kHz signal. Be sure that the DC-OFFSET is not set.
- Frequency is determined by using the formula  $f=1/T$  where  $f$  is frequency and  $T$  is the period, or time.
- Step 6:** Set FUNC (40) to square wave
- Step 7:** Set FUNC (40) to saw-toothed.
- Step 8:** Set FUNC (40) to sinusoidal wave.
- Note the differences and or similarities between the three different wave types. Include these observations and any conclusions you draw in your lab report.

**Step 9:** Maintain the 2 V<sub>pk</sub> setting and sinusoidal wave, and:

- ☐ Set signal generator to the values shown in the table below and calculate both time and frequency for the displayed sinusoidal wave and record.
- ☐ Measure the time and frequency for the displayed wave and record.

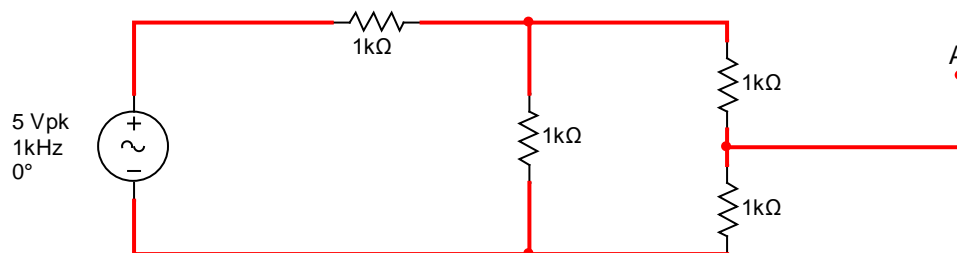
Frequency Setting	Calculated		Measured	
	Time	Frequency	Time	Frequency
350 Hz				
2.5 kHz				
1 Mhz				

## 2: Measuring Alternating Voltage

### Components & Equipment Needed

- Oscilloscope
- Signal Generator
- Oscilloscope Probes (1x/10x capable)
- Resistors : 1 k $\Omega$  (3) and 3 k $\Omega$  (3)

### Schematic



**Procedure**

Step 1:           Using the schematic, calculate the following and record in the chart below:

	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>
<b>V<sub>pp</sub></b>				
<b>V<sub>rms</sub></b>				

Step 2:           Breadboard the circuit as shown in the schematic.

Step 3:           Using the oscilloscope, measure the peak to peak voltage drop at each resistor and record in the chart below:

	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>
<b>V<sub>pp</sub></b>				

Step 4:           Using a digital multimeter, measure the effective voltage of each resistor and record in the chart below. Make sure the DMM is set for AC voltage.

	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>
<b>V<sub>rms</sub></b>				

Step 5:           Using the oscilloscope, set it up to read the voltage at Point A. Include a drawing of the waveform with volts/division and time/division clearly indicated.

# Capacitors and Capacitive Circuits

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# Capacitors and Capacitive Reactance

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## Overview

In these experiments, students will become familiarized with capacitors and how to measure them and students will observe and analyze the effect of capacitance and capacitive reactance in an RC circuit.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, plus observations and conclusions.

## Course Objectives

- Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
- Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
- Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
- Understand the loading effects and limitations of various types of test equipment.

## Module Objectives

After completing this module, the student will be able to do the following:

- Determine capacitance and tolerance of ceramic type capacitors by visual inspection.
- Demonstrate ability to use a digital multimeter to test and analyze capacitors out of circuit.
- Demonstrate ability to safely use a capacitor-inductor analyzer to test and analyze capacitors out of circuit.
- Connect, calculate, and measure capacitance in series and parallel.
- Analyze effects of capacitor in an RC circuit

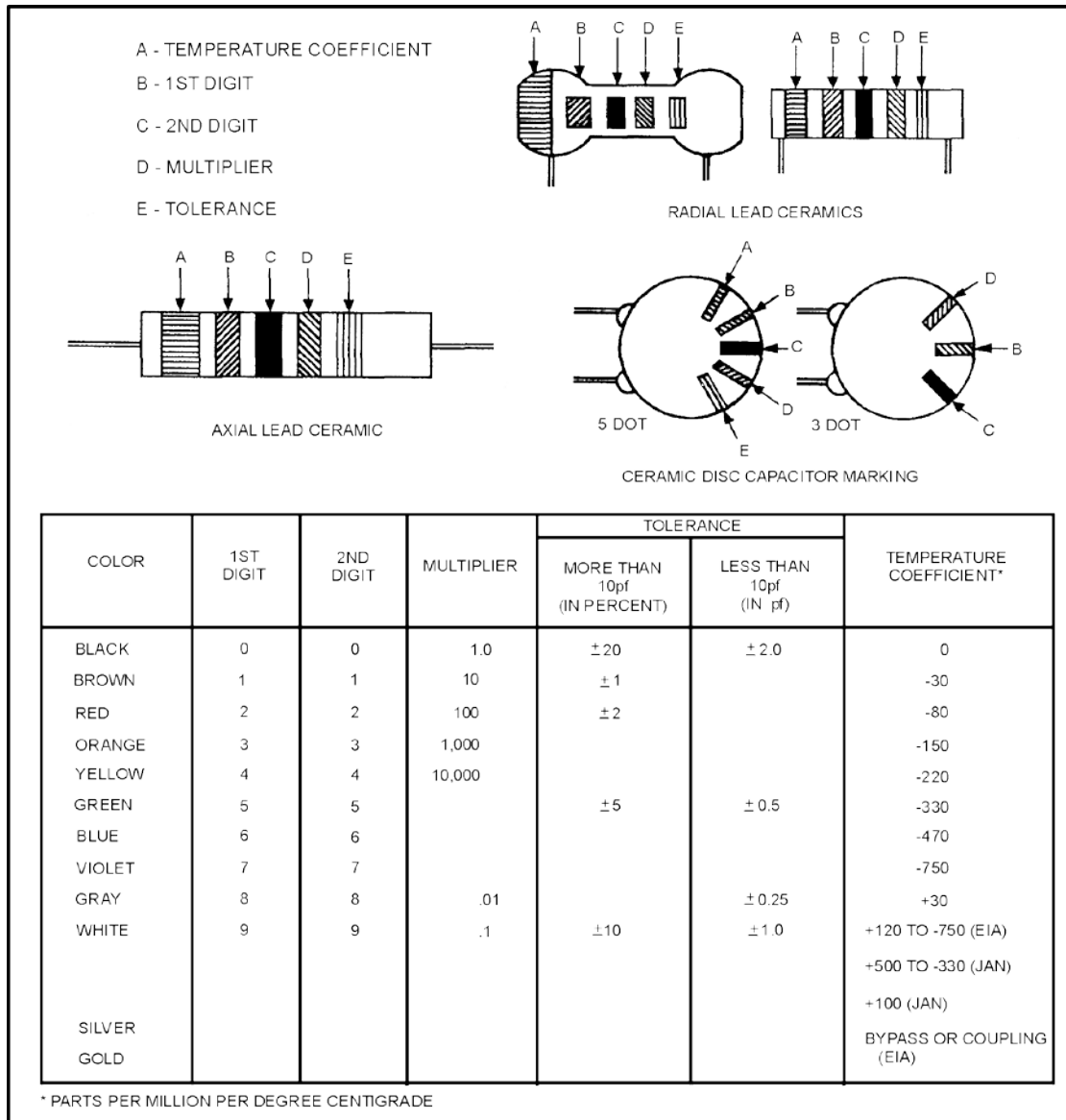
## Activities

1. Introduction to Capacitors
2. Capacitance in Series and Parallel
3. Effect of Capacitance and Capacitive Reactance in an RC circuit

## 1: Introduction to Capacitors

### Components & Equipment Needed

- Packet of various capacitors
- Digital Multimeter (DMM)
- Sencore LC 103 Capacitor & Inductor Analyzer

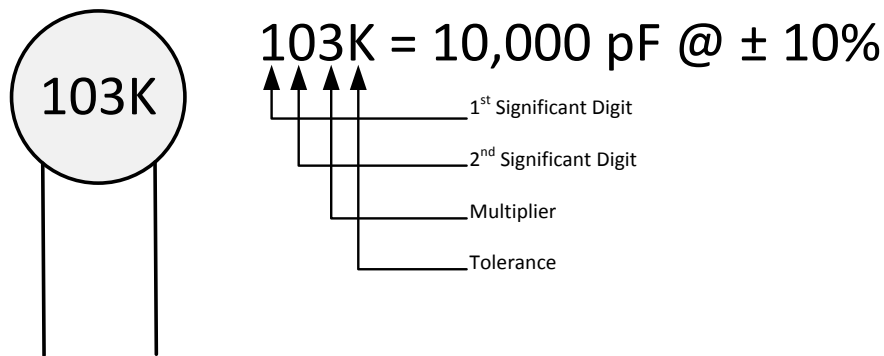




## Identification of Capacitor Value

Unlike resistors, there is no international standard for color-coding on capacitors. There are various organizations that have set their own color codes, but they are not valid outside of that particular organization. However, like resistors, for them most part, the colors do correspond to the same numbers. Shown at the start of this activity is a color chart for ceramic capacitors (US Navy, NEETS Module 2).

In addition, for ceramic capacitors, a standardized numbering system is used. Learning to read this will help you be able to identify capacitors that might not be otherwise labeled. Be aware that the result will be in pico-farads (pF). Some older non-electrolytic capacitors may have the value written on them, but rather than use the mu ( $\mu$ ) symbol to indicate micro, a capital M is used. It can be confusing to see 470  $\mu$ F written as 470 MF. There are ultra-capacitors which are in the mega-farad range, but you are not likely to encounter one of these in a basic AC Lab. These are used in hybrid automobiles and other devices requiring large storage capacity.



Multiplier Table		Temperature Coefficient					
Multiplier	Multiply by	Code	Tolerance	Temp. Coefficient	Operating Temp Range	Capacitance Change	Min Capacitor Tolerance
0	None	C	$\pm 0.25$ pF	Y5E	-30°C ~ +85°C	$\pm 4.7\%$	$\pm 10\%$
1	10	J	$\pm 5\%$	Y5F	-30°C ~ +85°C	$\pm 7.5\%$	$\pm 20\%$
2	100	K	$\pm 10\%$	Y5P	-30°C ~ +85°C	$\pm 10\%$	$\pm 10\%$
3	1,000	M	$\pm 20\%$	Y5U	-30°C ~ +85°C	+22% / -56%	$\pm 20\%$
4	10,000	D	$\pm 0.5\%$	Y5V	-30°C ~ +85°C	+22% / -82%	$\pm 20\%$
5	100,000	Z	+ 80% / - 20%	Z5U	+10°C ~ +85°C	+ 22% / -56%	$\pm 20\%$
6	1,000,000			Z5V	+10°C ~ +85°C	+ 22% / -82%	+80% / -20%

Very often the temperature coefficient is marked on the capacitor. Many of the types seen in this lab will be marked “NPO,” indicating that they are stable over a broad range of operating conditions, including frequency and temperature. For electrolytic capacitors, the necessary information is printed directly on the capacitor, including polarity, voltage rating, and capacitance.

## Procedure

### Visual Identification of a Capacitor

**Step 1:** For each of the seven capacitors in your packet, identify the capacitance. If unable to do so, write “Unknown” for the capacitance. Indicate your answers in either uF or pF.

	#1	#2	#3	#4	#5	#6	#7	#8
Capacitance								

### Analyzing Capacitors with a Digital Multimeter

A DMM can be used to check a capacitor when a “cap checker” is not available. Most DMMs do not have the capacity to check the capacitance, but can check the general health of a capacitor.

Because there are no perfect conductors, a charged capacitor will have some leakage of charge over time. Heat and high voltage can have a detrimental effect on capacitors and this can manifest as a variety of troubles. Electrolytic capacitors, like dry cell batteries, are also affected by time. Ceramic capacitors will not deteriorate with age, however.

When first connected, the capacitor will charge itself from the battery of the DMM. From this action, it is possible to determine if the capacitor is short-circuited, open, or leaky. The resistance value will start out at infinity (or OL) and then change gradually. How the resistance changes determines the state of the resistor.

- Good – Ohmmeter goes to zero, and then goes to infinity (OL) as it charges.
- Short-Circuited - Ohmmeter Reading goes directly to zero and does not change.
- Leaky - The capacitor charges, but the resistance goes to a low value. For electrolytic capacitors, reverse the leads and measure a second time. The higher of the two values is going to be more accurate.

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- Open – Reads a very high resistance. But because very high resistance is the natural state of a capacitor, reverse the leads to discharge the capacitor and measure again.

**Step 1:** Set the ohmmeter range to the highest setting.

**Step 2:** Measure the resistance of each capacitor. Make sure you are not touching the leads or contacts as this creates a parallel resistance with your body. In the chart below, indicate both the leakage resistance and your determination of the state of the capacitor (Good, Open, Short, Leaky).

	#1	#2	#3	#4	#5	#6	#7	#8
Leakage Resistance								
State of Capacitor								

#### Questions

1. Explain why a leaky capacitor has low resistance.

### Analyzing Capacitors with a Capacitor-Inductor Analyzer

A more accurate method to check the functionality of a capacitor is to use a capacitor-inductor analyzer. Some handheld and bench digital multimeters do have the ability to check capacitance, but are not able to check for many other factors.

A capacitor-inductor analyzer also referred to as a cap checker, such as the Sencore LC 103, offers the ability to check capacitors both in and out of circuits. Because special precautions must be taken when working with capacitors, the meter has instructions and safety precautions located in a pull out tray from the front of the meter. It is very important to follow these instructions as capacitors have capacity for causing harm. Polarity must be observed when working with electrolytic capacitors. If connected without regard to polarity they can explode. Negative is indicated by a lighter colored strip with “0” repeated in the strip. Ceramic, film, and mica capacitors are not polarized.

For the following steps, be sure to follow the directions at the cap checker and to be mindful of polarity for electrolytic capacitors. Indicate the type of capacitor being checked by pressing the correct button on the left side. The capacitors you have for testing are either electrolytic (the “can” variety) or ceramic (several varieties). During some tests, the capacitor will be charged. You will be asked to enter a voltage. Do not disconnect the leads from the capacitor until the checker indicates that it has been discharged. Also, calibrate the leads after each use. The instructions indicate how to perform this.

**Step 1:** Using a Cap Checker, check capacitance, leakage resistances, dielectric absorption, and equivalent series resistance (ESR) of the seven capacitors and record below. Also, indicate whether the state of the capacitor is good, open, short, or leaky.

	#1	#2	#3	#4	#5	#6	#7	#8
Capacitance								
Leakage Resistance								
Dielectric Absorption								
ESR								
State of Capacitor								

**Questions**

1. Compare the results from the tests with the DMM to the results with the cap checker. Which do you think is more accurate?
2. Calculate the series capacitance of all eight capacitors.
3. Calculate the parallel capacitance of all eight capacitors.

## 2: Capacitance in Series and Parallel

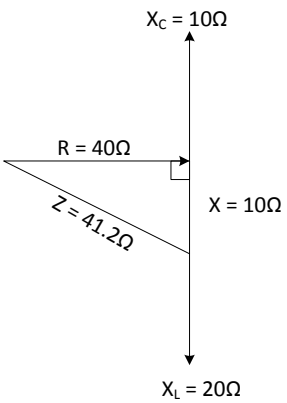
Capacitance in series behaves as resistance in parallel. And capacitance in parallel behaves as resistance in series. Measuring capacitors in series or parallel takes a special tool, such as a “Z – Meter” or a cap checker with the ability to measure “in-circuit.”

- Step 1:** Connect all eight capacitors in series on a breadboard. No power supply is needed. Have two long wires available for measuring with the meter.
- Step 2:** Using the Sencore cap checker, follow the directions included with the cap checker to measure the capacitors in series.
- Step 3:** Connect all eight capacitors in parallel on a breadboard. No power supply is needed. Have two long wires available for measuring with the meter.
- Step 4:** Using the Sencore cap checker, follow the directions included with the cap checker to measure the capacitors in series.

### Questions

1. How does the series capacitance measurement compare to your calculation? What is the percentage of difference?
2. How does the parallel measurement compare to your calculation? What is the percentage of difference?

### Fact Sheet for Capacitive and Inductive Circuits

Resistive Impedance	$\theta = 0^\circ$	$Z_R = R\Omega \angle 0^\circ$	
Capacitive Impedance	$\theta = -90^\circ$	$Z_C = Z_C\Omega \angle -90^\circ$	$Z_C = -j\frac{1}{\omega C}$
Capacitive Reactance	$X_C = \frac{1}{2\pi fC} \text{ or } \frac{1}{\omega C}$		
Inductive Impedance	$\theta = +90^\circ$	$Z_L = Z_L\Omega \angle +90^\circ$	$Z_L = j\omega L$
Inductive Reactance	$X_L = 2\pi L \text{ or } \omega L$		
RC Impedance	$\theta = 0^\circ \text{ to } (-90^\circ)$	$Z_{RC} = R - j\frac{1}{\omega C}$	
RL Inductance	$\theta = 0^\circ \text{ to } (+90^\circ)$	$Z_{RL} = R + j\omega L$	
Total Impedance Series RC	$Z_T = \sqrt{R^2 + X^2}$		
Total Impedance Parallel RC	$Z_{EQ} = \frac{V_A}{I_T}$		
Current Formula	$I_Z = \sqrt{I_R^2 + I_X^2}$		

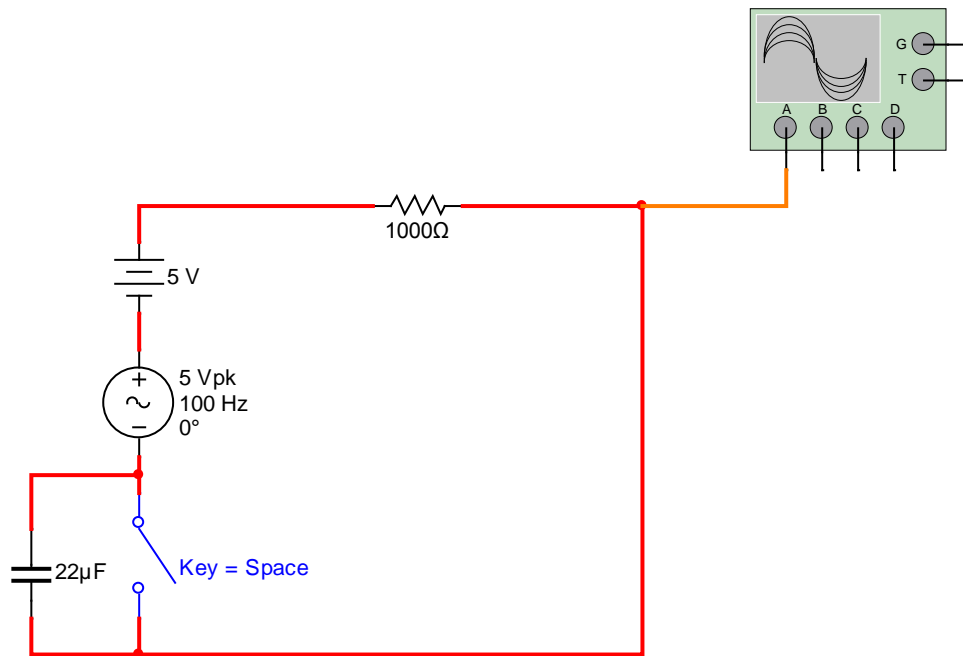
- $\omega$  is the symbol for “angular velocity,” which is also expressed as:  $2\pi f$
- Resistance (R), Reactance (X), and Impedance (Z) are all expressed in ohms ( $\Omega$ )
- Net Reactance, or total reactance:  $X = X_L - X_C$  -or-  $X = X_C - X_L$
- Ohm’s Law for AC Circuits (note that impedance is used rather than resistance):
  - $V = IZ$
  - $I = V/Z$
  - $Z = E/I$

### 3: Effects of Capacitance and Capacitive Reactance in an RC circuit: Blocking DC

#### Components & Equipment Needed

- Multisim

#### Schematic



#### Procedure

- Step 1: Build the circuit shown above in Multisim.
- Step 2: With the oscilloscope screen open and the switch in closed position, run the circuit.
- Step 3: Toggle the switch between opened and closed about 4 times then stop the simulation.
- Step 4: Using the slider bar under the oscilloscope screen to adjust the view so the transition is in the center of the screen. Copy and paste this screen into your lab report. You can use Tools >> Capture Screen Area, then drag the window to desired area and adjust the size.



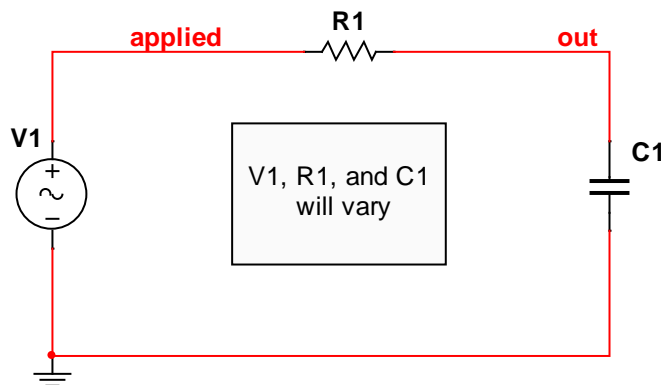
- Step 5: In your lab report, be sure to address the following points:
- a. Describe what is happening in the circuit when the switch is opened; why does the waveform look the way it does?
  - b. Describe what is happening in the circuit when the switch is closed; why does the waveform look the way it does?
  - c. When the switch goes from closed to opened, why does it take time for the voltage to level out?
  - d. Calculate  $X_C$ .
  - e. Calculate  $Z$ .

## 4: Effects of Capacitance and Capacitive Reactance in an RC circuit: Phase & Current

### Components & Equipment Needed

- Multisim

### Schematic



### Procedure

- Step 1: Build the circuit as shown the read the Multisim Tutorial on Transient Analysis.
- Step 2: Use the chart below to set  $f$ ,  $V$ ,  $R$ , and  $C$ . Refer to the TSTOP setting for the Transient Analysis end time parameter. For all, the start time will be 0 seconds. You will need to print the Transient analysis for each setting.

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	Frequency	Voltage (pk)	Resistor	Capacitor	TSTOP	Notes
A	1 Hz	40	500 $\Omega$	1 $\mu$ F	1 s	
B	100 Hz	40	500 $\Omega$	1 $\mu$ F	0.01 s	
C	1 kHz	40	500 $\Omega$	1 $\mu$ F	2 ms	
D	1 MHz	40	500 $\Omega$	1 $\mu$ F	2 $\mu$ s	Unclick $I_C$ to view $V_{out}$
E	1 Hz	40	10 $\Omega$	1800 $\mu$ F	1 s	
F	100 Hz	40	10 $\Omega$	1800 $\mu$ F	0.01 s	
G	1 kHz	40	10 $\Omega$	1800 $\mu$ F	2 ms	
H	1 MHz	40	10 $\Omega$	1800 $\mu$ F	2 $\mu$ s	

Step 5: For A through D, compare and contrast the changes in  $V_{applied}$ ,  $V_{out}$ , and  $I_C$  as frequency is increased. Be sure to include measurements for the voltages and current and to discuss changes in phase and amplitude, including why these changes are occurring. Use the CURSOR feature with the Transient Analysis tool to measure the voltages and current. Repeat for circuits E through H.

In some configurations, the current is very small and does not register on the graph. Be aware that it is still there, however. If you would like to measure it, you can adjust the y-axis by double-clicking on it and adjusting the min. and max. under "Range."

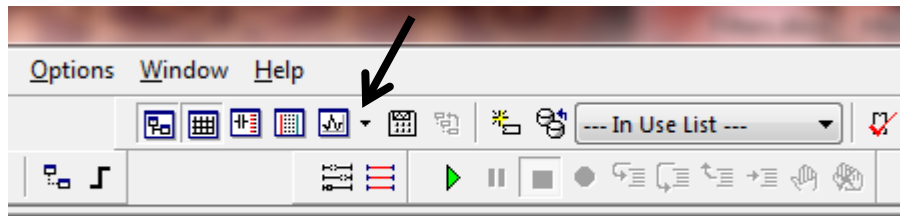
For each circuit configuration, A through H, calculate:  $I_C$ ,  $X_C$ , and  $Z$ .

Circuit Configuration	Measurements			Calculations		
	$V_{applied}$	$V_{out}$	$I_C$	$I_C$	$X_C$	$Z$
A						
B						
C						
D						
E						
F						
G						
H						

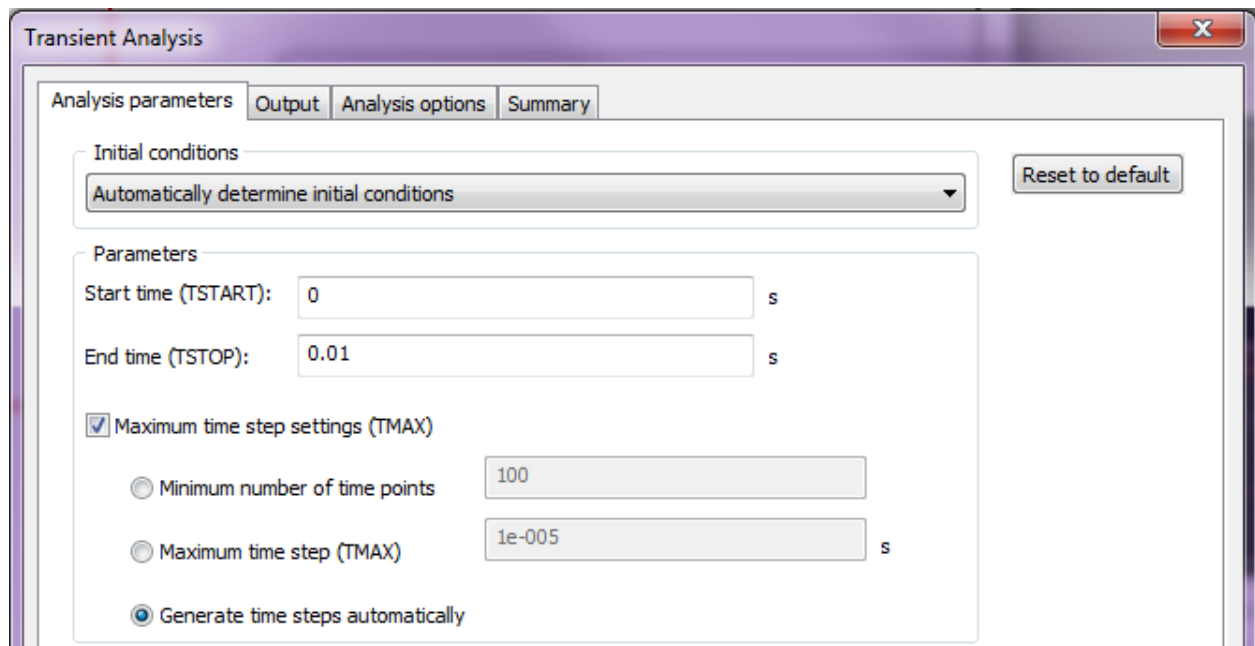
## Multisim Tutorial: Grapher and Transient Analysis

The Grapher contains many analysis tools, such as Transient Analysis. The Transient Analysis gives a detailed view of a waveform over specific time frames. This tool can be set to output various measurements over a set period of time

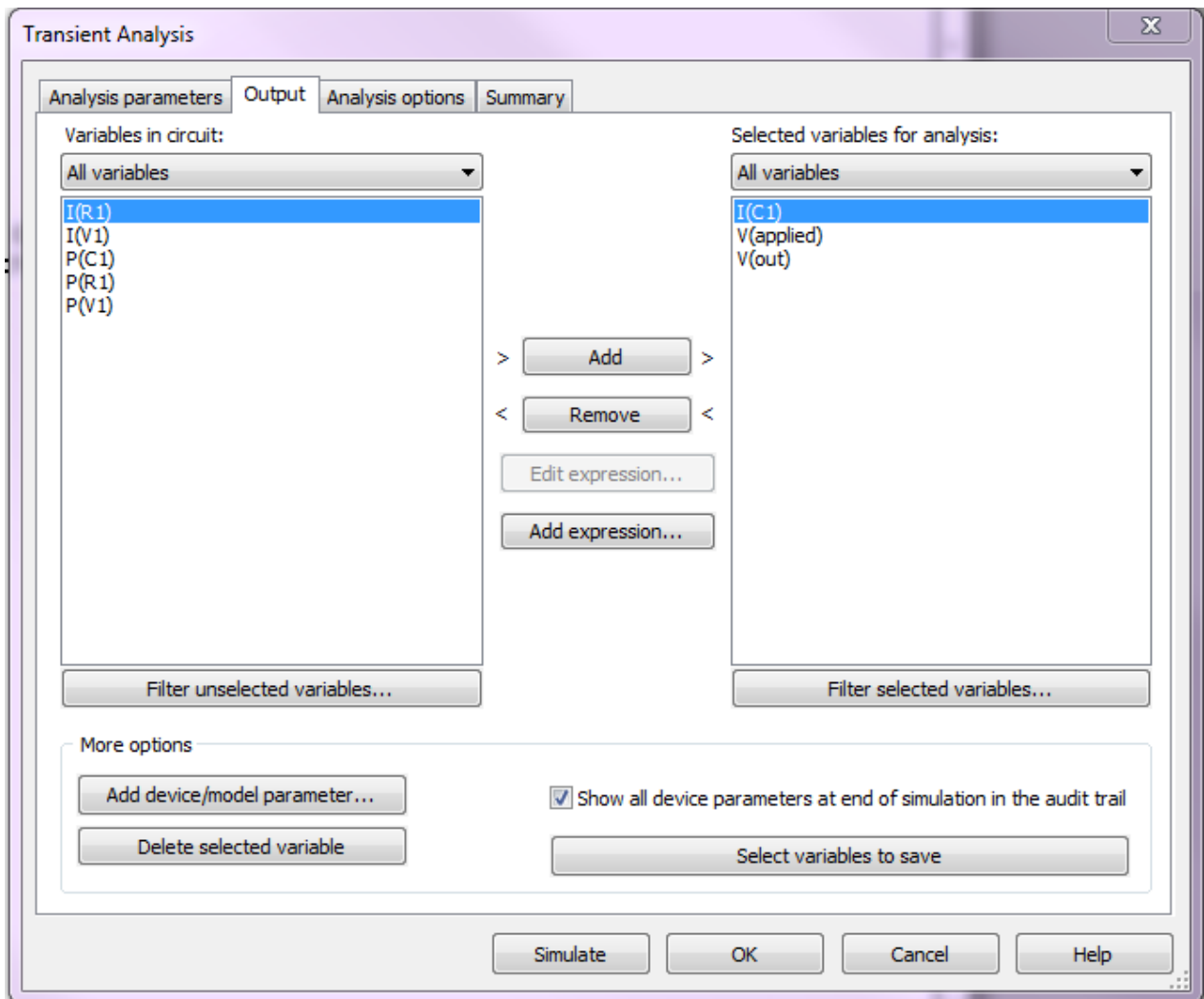
1. **To access the Transient Analysis Tool**, click the little “down” arrow next to the Grapher Icon in the Multisim Toolbar and select Transient Analysis:



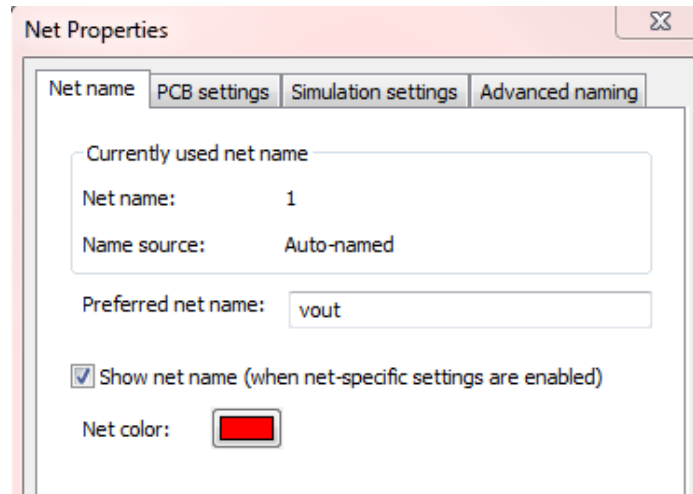
2. **Parameter Settings** For each lab experiment; you will be given the settings for starting and stopping times. The time step settings will be left at the default.



3. **Output Settings** For each experiment, the output variable s will be  $v_{\text{applied}}$ ,  $v_{\text{out}}$ , and  $I_C$ . After you have selected the outputs, click the SIMULATE button at the bottom. As you can see, there can be a long list of variables available from which to choose. At this point, we are only interested in the applied and output voltages and the current. However, there can be several different voltages referenced in the available variables list. To make it easier to choose the correct voltage, use the “Net Properties” to name the output. How to do this will be covered in the next step.

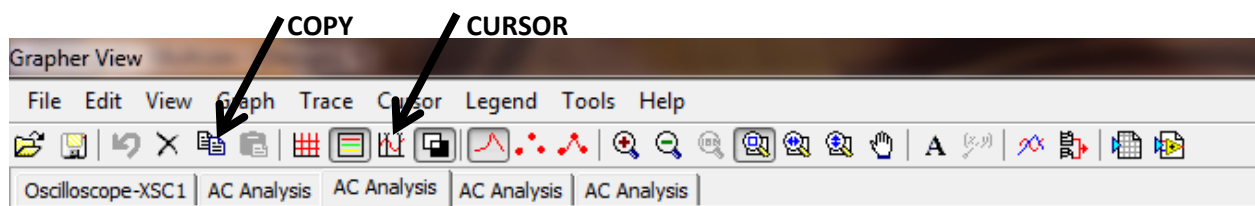


4. **Naming the Net** To name a net (or wire), double click on the wire and under “Preferred net name:” type “vout.” You can select the “Show net name...” option if you want it to appear on your circuit. Note that you can also change the color of the wire.



Once you have selected “SIMULATE,” the Transient Analysis Tool will run the analysis and provide you with a graph. There is a legend at the bottom of the graph with the titles of the waveforms. For some of the outputs, the current waveform will be very small compared to the voltage waveform and you will need to run two graphs. For the current graph, uncheck the applied and output voltages in the legend and then adjust the x- and y-axes to get a better look at the current waveform. To adjust an axis, double click on it and adjust the min/max range settings.

### The Grapher Toolbar



Many of the icons are images only, but if you hover over them, text does appear. The most important one that you will use is the CURSOR and COPY icons.

**CURSOR**: This will allow you to move cursors over the graph to indicate specific points of measurement.

**COPY**: Copies the selected graph to the clipboard for easy pasting to your lab report. It copies and pastes with a white background, so no worries about the the black background that is used in Grapher.

# Inductors and Inductive Circuits

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# Inductors and Inductive Reactance

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## Overview

Students will be introduced to inductors and inductance, including the instruments used to measure them. In addition students will analyze series and parallel inductance as well as the ac waveforms.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, plus observations and conclusions.

## Course Objectives

- Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
- Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
- Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
- Understand the loading effects and limitations of various types of test equipment.

## Module Objectives

After completing this module, the student will be able to do the following:

- Demonstrate ability to safely use a capacitor-inductor analyzer to test and analyze inductors out of circuit.
- Connect inductors in series and parallel.
- Calculate inductance in series and parallel.
- Discuss the effect of reactance in an inductive circuit.
- Compare and contrast waveforms of series and parallel RL Circuits

## Activities

1. Introduction to Inductors
2. Inductance in Series and Parallel
3. Inductance and Inductive Reactance in an RL circuit
4. Series RL Circuits
5. Parallel RL Circuits

## 1: Introduction to Inductors

### Components & Equipment Needed

- Packet of various inductors
- Sencore LC 103 Capacitor & Inductor Analyzer

### Identification of Inductor Value

Unlike capacitors, inductors are relatively easy to identify as the values are printed directly on the inductor. There are cases, however, where an inductor, such as a choke, will consist of nothing more than a core and wire. For these, one needs to rely on other means for identification. One thing to note is that a similar numbering system as seen with capacitors is used. However, rather than the default being “pico-Farads,” the default is “pico-Henries.” For example, an inductor labeled “104” is 100,000 pico-Henries, or 100  $\mu\text{H}$ .

### Procedure

**Step 1:** For each of the inductors in your packet, identify the inductance. If unable to do so, write “Unknown” for the inductance. Please put your answers in millihenries (mH).

	#1	#2	#3
Inductance			

### Analyzing Inductors with a Capacitor-Inductor Analyzer

Just as with capacitors, there is an easy way to check the functionality of an inductor. The capacitor-inductor analyzer offers the ability to check inductors. Because special precautions must be taken when working with inductors, the meter has instructions and safety precautions located in a pull out tray from the front of the meter.

**For the following steps, be sure to follow the directions at the cap checker.** Indicate the type of inductor being checked by pressing the correct button on the left side. The inductors you have for testing are all coils. **Also, calibrate the leads after each use.** The instructions indicate how to perform this.



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The “Inductor Ringer” tests for the most common defect: shorted turns. This defect can occur from insulation break down due to high voltage. It also tests the non-iron core coil by testing the Q Factor. The Q Factor is the inductor’s quality factor and is calculated:

$$Q = \frac{X_L}{R}$$

As shown in the equation the Q Factor is a ratio of inductive reactance to resistance. An ideal inductor would have an infinite Q and zero resistance. As an aside, Q in this usage is not related to coulombs or charge. Generally, 10 or more rings indicate that the coil is good. This kind of test should not be performed on coil with laminated iron cores, such as power transformers, filter chokes, and audio output transformers. If there is no ringing, the coil is open.

**Step 2:** Using a Cap Checker, check inductance and the inductor ringer.

	#1	#2	#3
Inductance			
Ringer			

1. Calculate the series inductance using all the inductors in the packet.
2. Calculate the parallel inductance using all the inductors in the packet.

## 2: Inductance in Series and Parallel

### Components & Equipment Needed

- Packet of various inductors
- Sencore LC 103 Capacitor & Inductor Analyzer

Inductors in series and in parallel are calculated the same as for resistors. Measuring inductors in series or parallel takes a special tool called a Z-Meter. In addition to its many other features, the Sencore LC 103 can also measure series and parallel inductance. Because there is no power supply in this circuit, it is not necessary to consider mutual inductance.

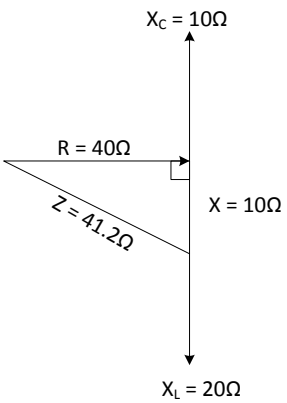
### Procedure

- |                |   |
|----------------|---|
| <b>Step 1:</b> | Connect all inductors in the packet in series on a breadboard. No power supply is needed. Have two long wires available for measuring with the meter.   |
| <b>Step 2:</b> | Using the Sencore cap checker, follow the directions included with the cap checker to measure the inductors in series.                                  |
| <b>Step 3:</b> | Connect all inductors in the packet in parallel on a breadboard. No power supply is needed. Have two long wires available for measuring with the meter. |
| <b>Step 4:</b> | Using the Sencore cap checker, follow the directions included with the cap checker to measure the inductors in series.                                  |

### Questions

1. How does the series inductance measurement compare to your calculation? What is the percentage of difference?
  
2. How does the parallel measurement compare to your calculation? What is the percentage of difference?

## Fact Sheet for Capacitive and Inductive Circuits

Resistive Impedance	$\theta = 0^\circ$	$Z_R = R\Omega \angle 0^\circ$	
Capacitive Impedance	$\theta = -90^\circ$	$Z_C = Z_C\Omega \angle -90^\circ$	$Z_C = -j\frac{1}{\omega C}$
Capacitive Reactance	$X_C = \frac{1}{2\pi fC} \text{ or } \frac{1}{\omega C}$		
Inductive Impedance	$\theta = +90^\circ$	$Z_L = Z_L\Omega \angle +90^\circ$	$Z_L = j\omega L$
Inductive Reactance	$X_L = 2\pi L \text{ or } \omega L$		
RC Impedance	$\theta = 0^\circ \text{ to } (-90^\circ)$	$Z_{RC} = R - j\frac{1}{\omega C}$	
RL Inductance	$\theta = 0^\circ \text{ to } (+90^\circ)$	$Z_{RL} = R + j\omega L$	
Total Impedance Series RC	$Z_T = \sqrt{R^2 + X^2}$		
Total Impedance Parallel RC	$Z_{EQ} = \frac{V_A}{I_T}$		
Current Formula	$I_Z = \sqrt{I_R^2 + I_X^2}$		

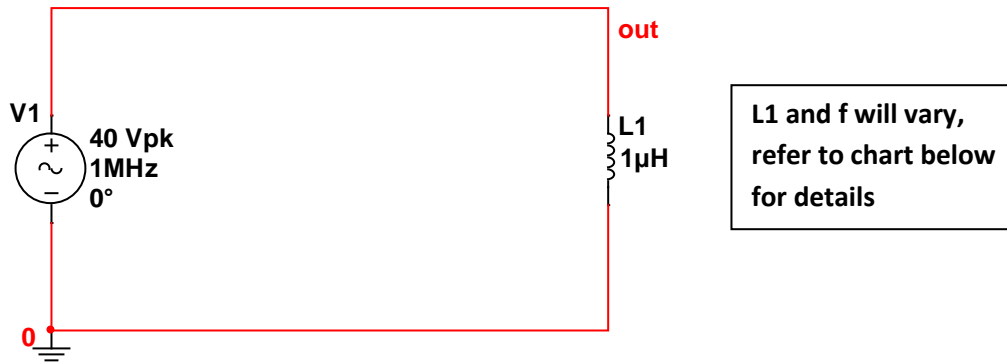
- $\omega$  is the symbol for “angular velocity,” which is also expressed as:  $2\pi f$
- Resistance (R), Reactance (X), and Impedance (Z) are all expressed in ohms ( $\Omega$ )
- Net Reactance, or total reactance:  $X = X_L - X_C$  -or-  $X = X_C - X_L$
- Ohm’s Law for AC Circuits (note that impedance is used rather than resistance):
  - $V = IZ$
  - $I = V/Z$
  - $Z = E/I$

### 3: Inductance and Inductive Reactance in an RL circuit

#### Components & Equipment Needed

- Multisim

#### Schematic



#### Procedure

- Step 1:** Build the circuit with the L and f settings per the chart below.
- Step 2:** Use the chart below to set frequency and inductance. Refer to the TSTOP setting for the Transient Analysis end time parameter. For all, the start time will be 0 seconds. You will need to print the Transient analysis for each setting.

For Output, you will want to look at  $v_{out}$  and the current at the inductor,  $I_L$ .

	Frequency	Inductor	TSTOP
A	1 Hz	1 H	2 s
B	100 Hz	1 H	0.01 s
C	1 kHz	1 H	2 ms
D	1 MHz	1 H	2 $\mu$ s
E	1 Hz	1 $\mu$ F	2 s
F	100 Hz	1 $\mu$ F	0.01 s
G	1 kHz	1 $\mu$ F	2 ms
H	1 MHz	1 $\mu$ F	2 $\mu$ s

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**Step 3:** For A through D, compare and contrast the changes in  $V_{out}$ , and  $I_L$  as frequency is increased. Be sure to include measurements for the voltages and current and to discuss changes in phase and amplitude, including why these changes are occurring. Use the CURSOR feature with the Transient Analysis tool to measure the voltages and current. Repeat for circuits E through H.

In some configurations, the voltage is very small in comparison to the current and does not register on the graph. Be aware that it is still there, however. If you would like to measure it, you can adjust the y-axis by double-clicking on it and adjusting the min. and max. under “Range.”

For each circuit configuration, A through H, calculate:  $I_L$ ,  $X_L$ , and  $Z$ .

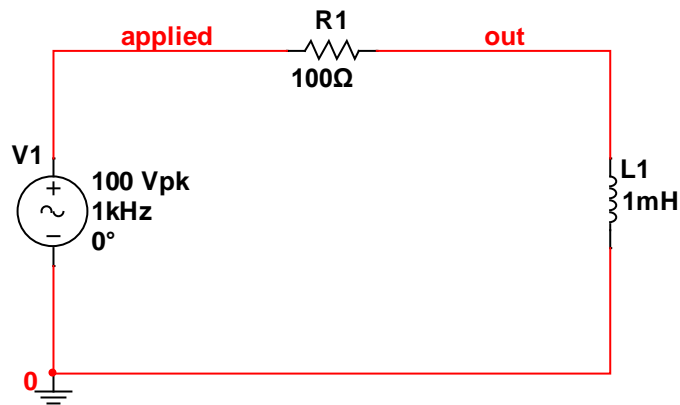
Circuit Configuration	Measurements		Calculations		
	$V_{out}$	$I_L$	$I_L$	$X_L$	$Z$
A					
B					
C					
D					
E					
F					
G					
H					

## 4: Series RL Circuit

### Components & Equipment Needed

- Multisim

### Schematic



### Procedure

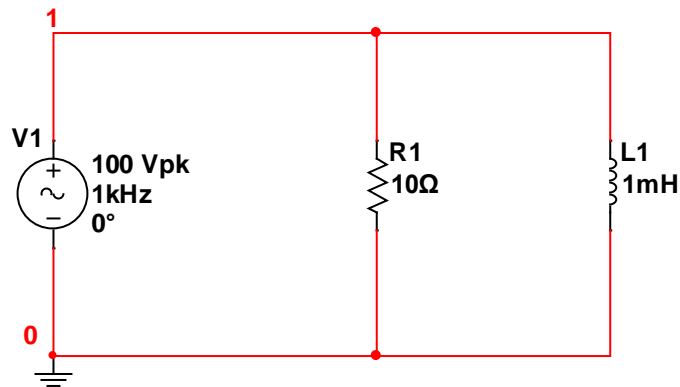
- Step 1:** Build the circuit as shown.
- Step 2:** Using the Transient Analysis Tool, graph each of the following SEPARATELY:
- Voltage Applied ( $V_{\text{applied}}$ )
  - Voltage out ( $V_{\text{out}}$ )
  - Current ( $I_L$ )
- Step3:** Compare and contrast the three graphs, paying close attention to phase. Be thorough in your discussion of the relationships.
- Step 4:** Calculate  $Z_T$

## 5: Parallel RL Circuit

### Components & Equipment Needed

- Multisim

### Schematic



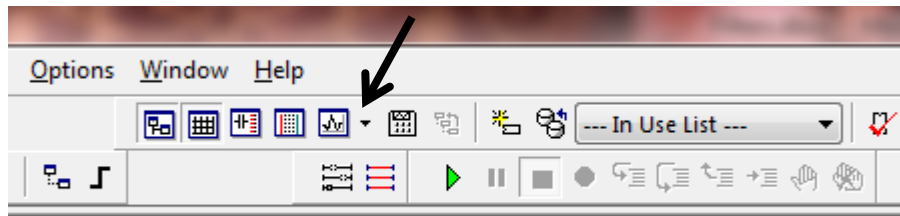
### Procedure

- Step 1:** Build the circuit as shown.
- Step 2:** Using the Transient Analysis Tool, graph the following on the same graph:
- Total Current –  $I(V1)$
  - Current through Resistor –  $I(R)$
  - Current through Inductor –  $I(L)$
- Step3:** Compare and contrast the three waveforms, paying close attention to phase and amplitude. Be thorough in your discussion of the relationship.
- Step 4:** Calculate  $Z_T$

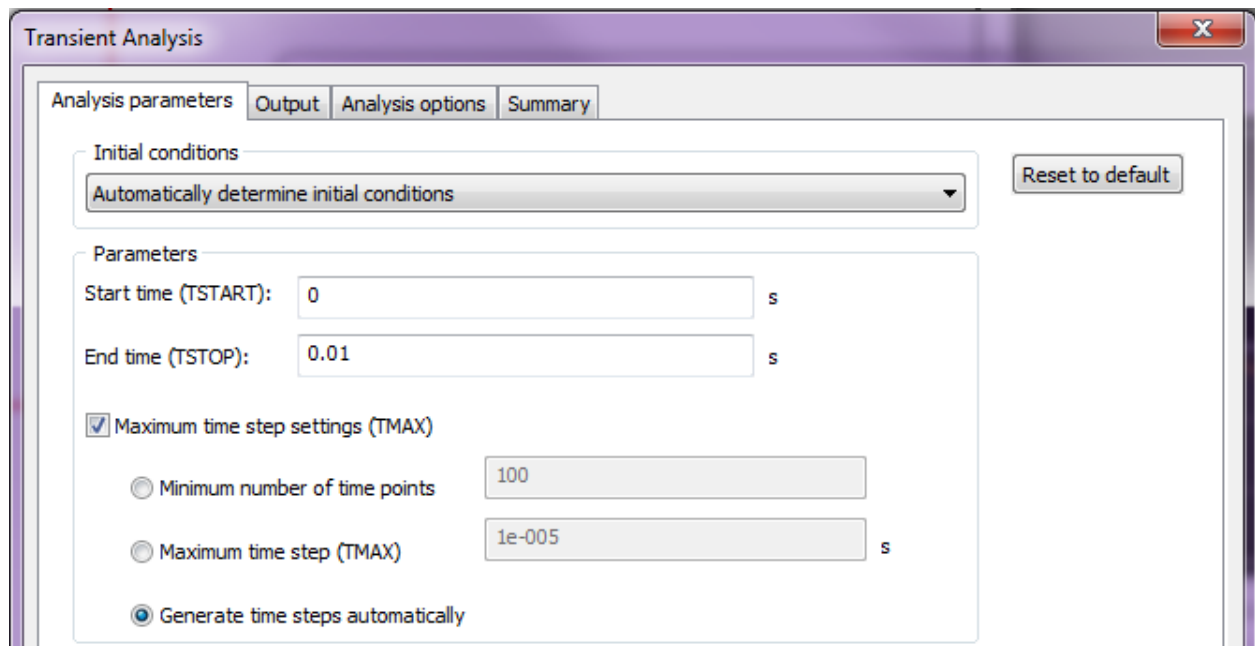
## Multisim Tutorial: Grapher and Transient Analysis

The Grapher contains many analysis tools, such as Transient Analysis. The Transient Analysis gives a detailed view of a waveform over specific time frames. This tool can be set to output various measurements over a set period of time

1. **To access the Transient Analysis Tool**, click the little “down” arrow next to the Grapher Icon in the Multisim Toolbar and select Transient Analysis:

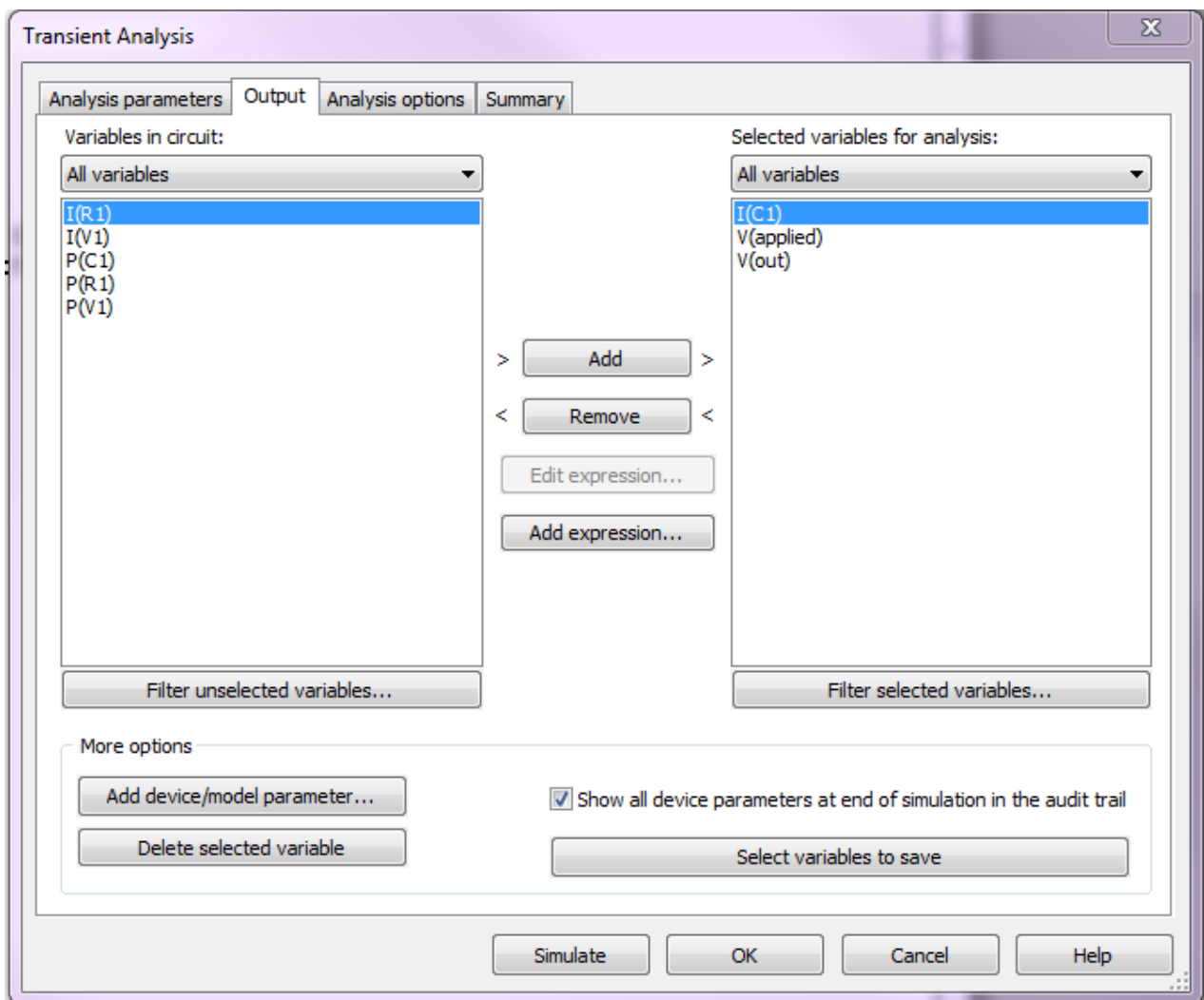


2. **Parameter Settings** For each lab experiment; you will be given the settings for starting and stopping times. The time step settings will be left at the default.

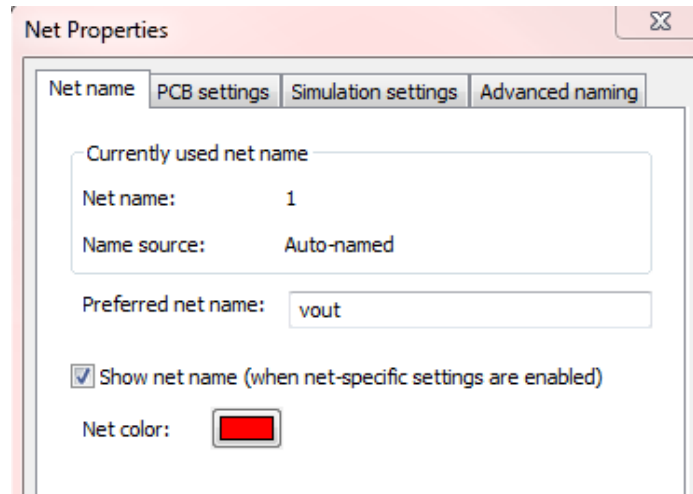




3. **Output Settings** For each experiment, the output variable s will be  $v_{\text{applied}}$ ,  $v_{\text{out}}$ , and  $I_C$ . After you have selected the outputs, click the SIMULATE button at the bottom. As you can see, there can be a long list of variables available from which to choose. At this point, we are only interested in the applied and output voltages and the current. However, there can be several different voltages referenced in the available variables list. To make it easier to choose the correct voltage, use the “Net Properties” to name the output. How to do this will be covered in the next step.

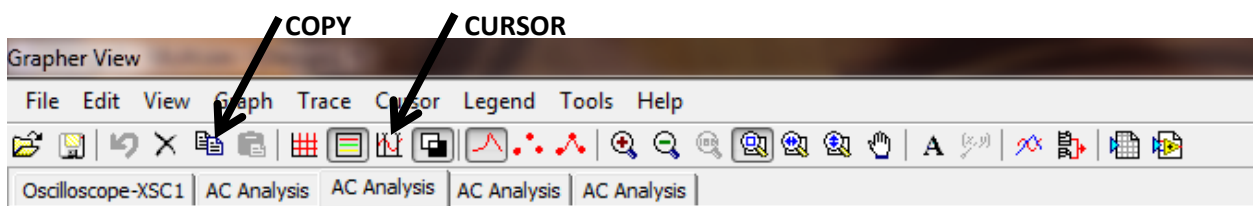


4. **Naming the Net** To name a net (or wire), double click on the wire and under “Preferred net name:” type “vout.” You can select the “Show net name...” option if you want it to appear on your circuit. Note that you can also change the color of the wire.



Once you have selected “SIMULATE,” the Transient Analysis Tool will run the analysis and provide you with a graph. There is a legend at the bottom of the graph with the titles of the waveforms. For some of the outputs, the current waveform will be very small compared to the voltage waveform and you will need to run two graphs. For the current graph, uncheck the applied and output voltages in the legend and then adjust the x- and y-axes to get a better look at the current waveform. To adjust an axis, double click on it and adjust the min/max range settings.

### The Grapher Toolbar



Many of the icons are images only, but if you hover over them, text does appear. The most important one that you will use is the CURSOR and COPY icons.

**CURSOR**: This will allow you to move cursors over the graph to indicate specific points of measurement.

**COPY**: Copies the selected graph to the clipboard for easy pasting to your lab report. It copies and pastes with a white background, so no worries about the the black background that is used in Grapher.

Critical Thinking Questions

**Questions**

1. Would the frequency of a circuit have any effect on the Q Factor?
2. What are possible sources of “stray” resistance in a circuit that could affect an inductor’s Q Factor?

# AC Troubleshooting

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# AC Troubleshooting

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## Overview

In this lab, students will analyze a Multisim AC circuit for the identification of a failed component. The student will support their hypothesis with an explanation of how and why the fault will create the symptoms displayed.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions.

## Course Objectives

- Troubleshoot AC Circuit.

## Module Objectives

- Analyze the output of an AC circuit to identify a faulty component.
- Create a hypothesis to explain the fault.
- Explain why the hypothesized fault would demonstrate the symptoms.

## Activities

1. Analyze faulty circuit
2. Create and support a hypothesis.

## 1: Analyze Faulty Circuit

### Components & Equipment Needed

- Multisim File (located online)

### Procedure

**Step 1:** Open the Multisim file:

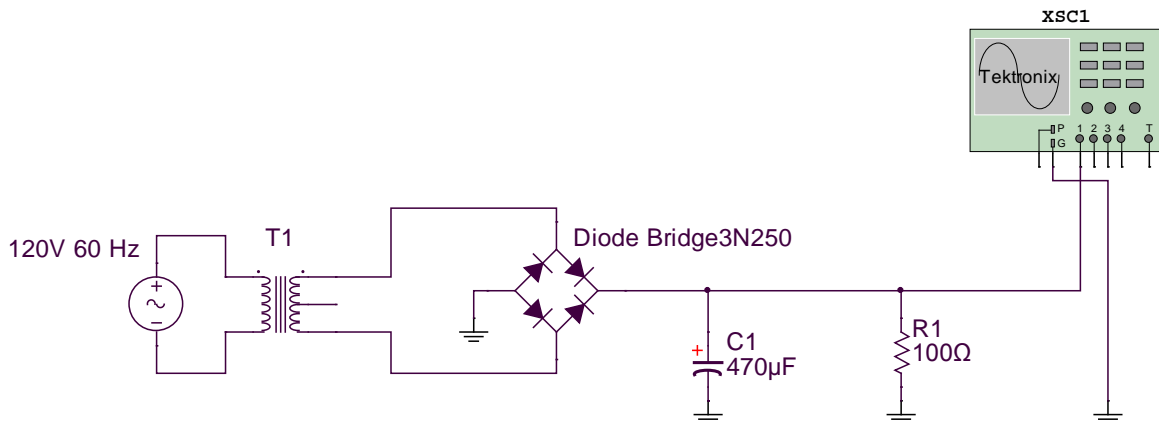


Fig. 1 Faulty AC Circuit

**Step 2:** The expected output of this circuit is shown in figure 2. Compare the actual output of the circuit to the expected output.

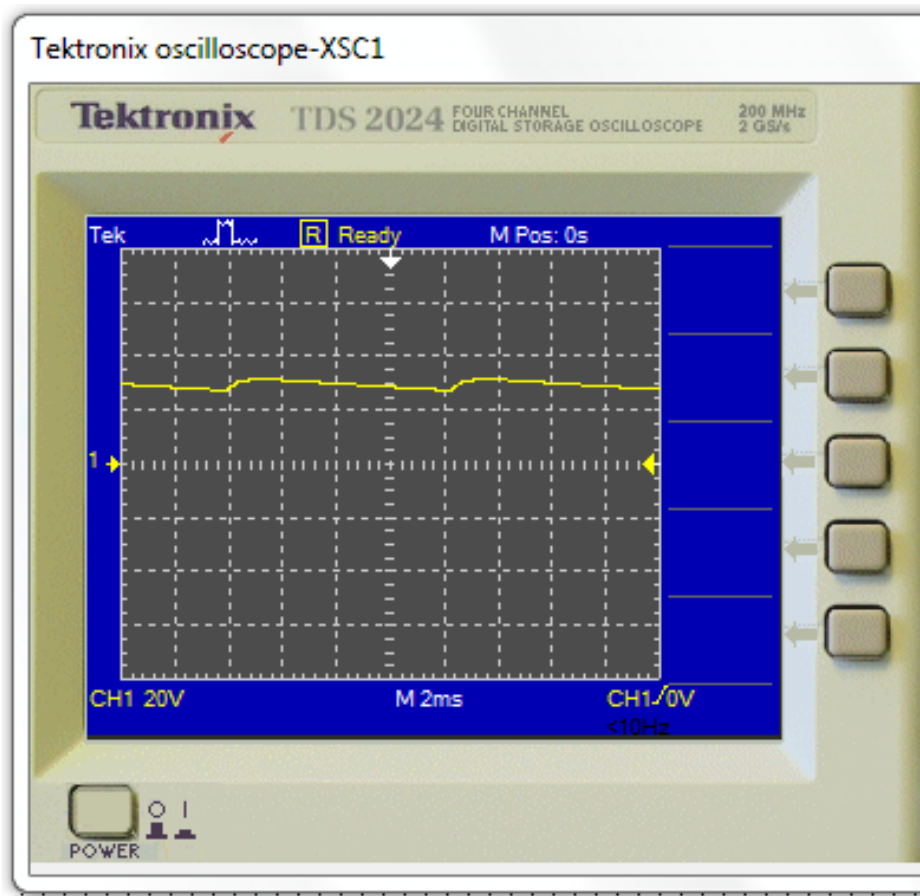


Fig. 2 Expected Output

**Step 3:** Measure the output of the circuit and compare with figure 2.

**Step 4:** **Answer the following question:** What is the intended function of this circuit and in what kind of equipment/device would we expect to see it?

## 2: Create and Support a Hypothesis

For this section, you are asked to discuss what you think the problem is and then to support this discussion using formulas or references. As an oversimplified example, if the voltage at the load on a simple series circuit was 15 V rather than 10 V as expected, you may suspect that the problem is another resistive element in the circuit. You would then discuss why this would cause the voltage to be higher than expected. To support your hypothesis, you discuss the effect of a shorted resistor in terms of Ohm's Law.

### Create a Hypothesis

1. Referring back to Figure 1 and the faulty output, create a hypothesis explaining the symptoms of the faulty circuit. *(Example: A shorted resistor in a series circuit can affect the voltage drops at other resistive elements in the circuit.)*
2. Explain why the fault of the hypothesis would create the output. *(Example: In a series circuit, Kirchhoff's Voltage Laws state that ... and as such, because of the failed resistor, the higher than expected voltage is being dropped at the load.)*

### Support a Hypothesis

1. Support the hypothesis by discussing why this fault would create this output, including any formulas or references. *(Example: Discuss and use mathematical references, such as Kirchhoff's and Ohm's Laws, to prove your hypothesis.)*
2. Given the circuit/device that you answered in Step 4 above, how would this fault affect it? *(Example: If the circuit had been for a control circuit, it could be stated that the failed resistor created a situation where the power rating of the load was exceeded, causing total failure of the system.)*



# Filter Circuits

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# Filter Circuits

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## Overview

Using Multisim, students will calculate, construct, and measure a variety of filter circuits. Using AC Analysis, students will confirm their calculations and compare and contrast the frequency response of each circuit.

## Requirements

To meet all requirements for this lab, you must complete all activities, questions, critical thinking activities and questions, and observations and conclusions.

## Course Objectives

- Demonstrate measurement and calculations of AC waveforms (peak, peak-to-peak, average, rms, time, period, frequency, wavelength)
- Calculate, construct and measure: Resonant circuits, Filter circuits, and Passive filters
- Demonstrate proper measurement techniques for voltage, current, resistance, time, frequency, duty cycle, and phase.
- Demonstrate proper operating techniques and evaluate for proper operation the following list of test equipment: DC power supply, signal generator, frequency counter, impedance meter, digital multimeter, oscilloscope, logic probe / LED.
- Understand the loading effects and limitations of various types of test equipment.
- Demonstrate acceptable techniques to construct circuits from schematic drawings on solderless and/or solder type breadboards.
- Demonstrate proper decoupling methods for work on breadboard proto-type circuits.

## Module Objectives

- Calculate, construct and measure the following:
  - RC Low-Pass Filter Circuit
  - RL High-Pass Filter Circuit
  - RC Band-Pass Filter Circuit
  - RC Band-Stop Filter Circuit
  - RLC Band-Pass Resonant Filter Circuit

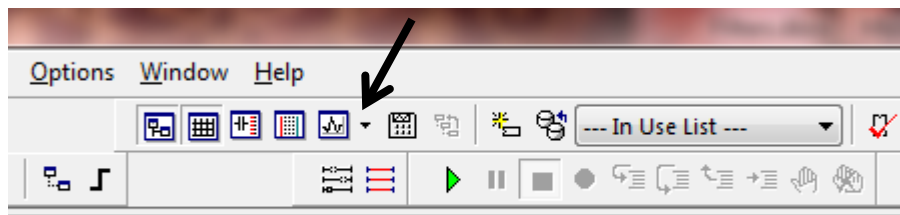
## Activities

1. RC Low-Pass Filter Circuit
2. RL High-Pass Filter Circuit
3. RC Band-Stop Filter Circuit
4. RC Band-Pass Filter Circuit
5. RLC Band-Pass Resonant Filter Circuit

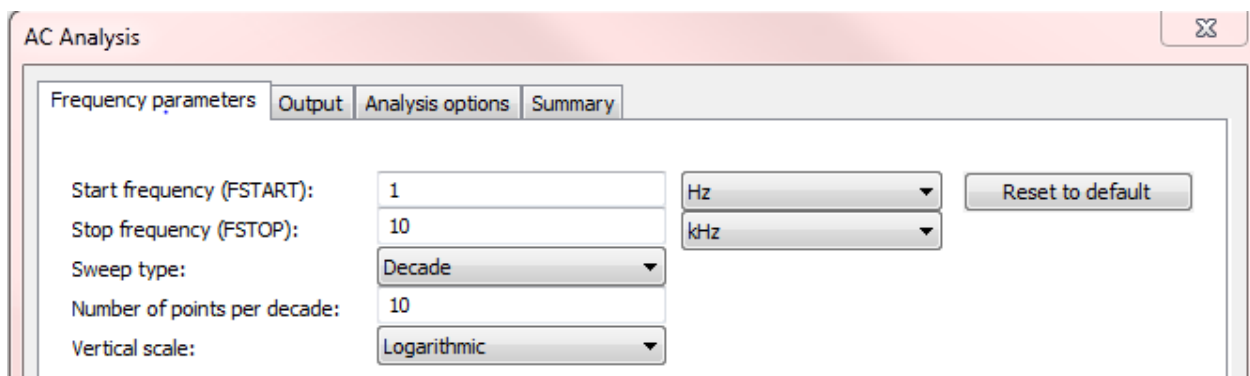
## Multisim Tutorial: Grapher and AC Analysis

The Grapher contains many analysis tools, such as AC Analysis. The AC Analysis tool can be set to take voltage readings over a series of frequencies. It eliminates the tedious work of setting the frequency, starting the circuit, recording a voltage measurement, and repeat. Another feature is that it takes MANY samples, thus allowing for smoother graphs that are more representative of the frequency response being measured.

1. **To access the AC Analysis Tool**, click the little “down” arrow next to the Grapher Icon in the Multisim Toolbar and select AC Analysis:

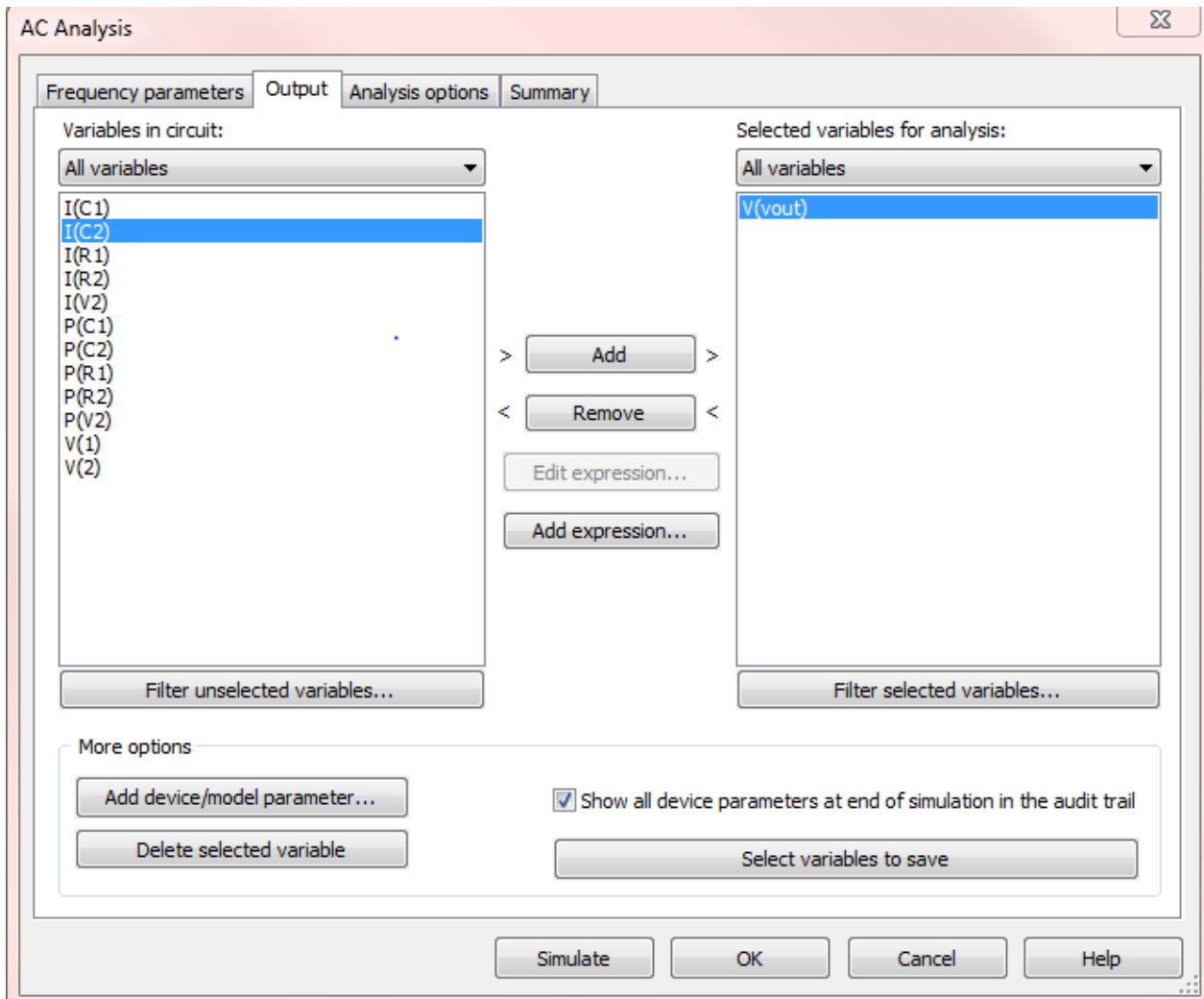


2. **Frequency Parameter Settings** For each lab experiment, you will be given the settings for starting and stopping frequency and the vertical scale.



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3. **Output Settings** For each experiment, the output variable will be  $v(out)$ . After you have selected the output, click the SIMULATE button at the bottom. As you can see, there can be a long list of variables available from which to choose. At this point, we are only interested in the output voltage. However, there can be several different voltages referenced in the available variables list. To make it easier to choose the correct voltage, use the “Net Properties” to name the output. How to do this will be covered in the next step.

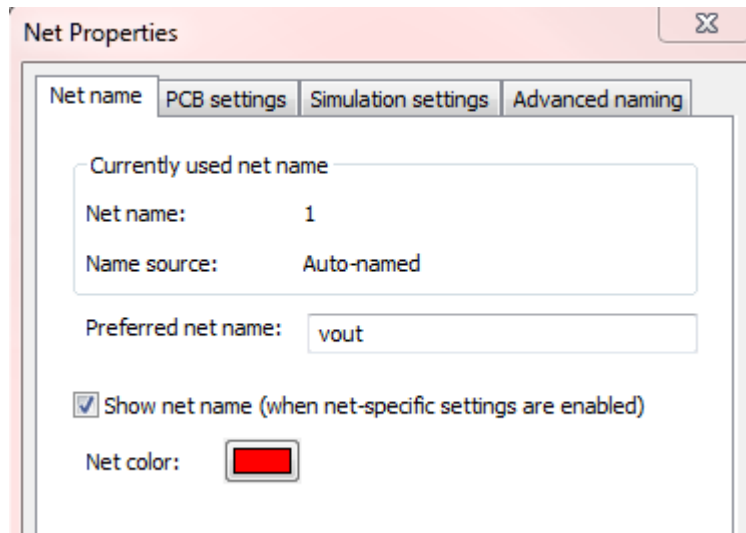


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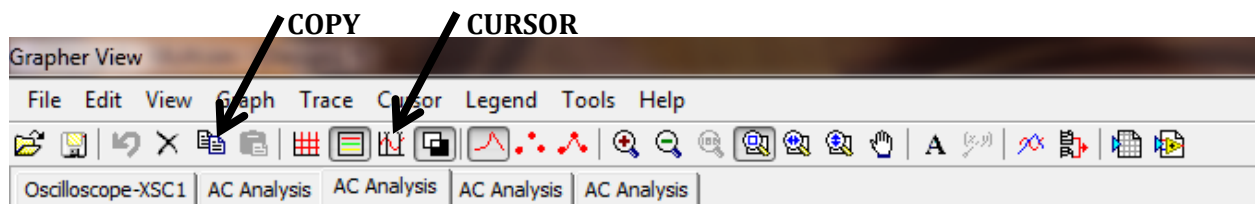
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4. **Naming the Net** To name a net (or wire), double click on the wire and under “Preferred net name:” type “vout.” You can select the “Show net name...” option if you want it to appear on your circuit. Note that you can also change the color of the wire.



Once you have selected “SIMULATE,” the AC Analysis Tool will run the analysis and provide you with a graph of both Magnitude vs. Frequency and Phase vs. Frequency. The Grapher treats these as two separate entities though they are on the same page. This means that you have to click in the area of which ever graph to which you want to add cursors or to copy.

### The Grapher Toolbar



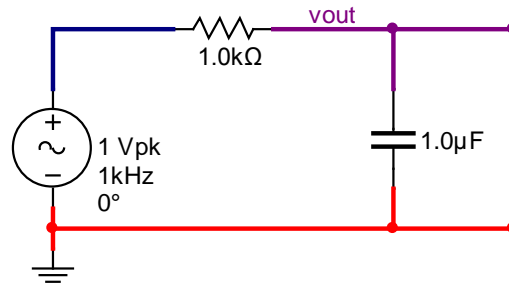
Many of the icons are images only, but if you hover over them, text does appear. The most important one that you will use is the CURSOR and COPY icons.

**CURSOR**: This will allow you to move cursors over the graph to indicate specific points of measurement.

**COPY**: Copies the selected graph to the clipboard for easy pasting to your lab report. It copies and pastes with a white background, so no worries about the the black background that is used in Grapher.

## 1: RC Low-Pass Filter Circuit

### Schematic



### Formulas

$$X_C = \frac{1}{2\pi fC}$$

$$f_c = \frac{1}{2\pi RC}$$

$$Z_T = \sqrt{R^2 + X_C^2}$$

$$\theta_{f_c} = \arctan\left(-\frac{R}{X_C}\right)$$

$$v_{out} = \left(\frac{X_C}{Z_T}\right) v_{in}$$

### AC Analysis Settings

Starting Frequency	1 Hz
Stopping Frequency	100 kHz
Sweep Type	Decade
Vertical Scale	Linear

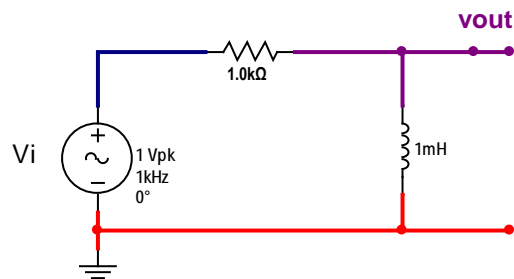
### Procedures

- Step 1: Complete the calculations shown in the table below for both input frequency and cut-off frequency.
- Step 2: Build the circuit using Multisim. Run the AC Analysis using the settings above. Use the cursors to find the values of  $v_{out}$ ,  $f_c$ , and  $\theta$ . Record those measurements in the table below.

	Calculated	Measured
<b>Based on input frequency</b>		
$X_C$		
$Z_T$		
$v_{out}$		
$f_c$		
<b>Based on cut-off frequency</b>		
$X_C$		
$Z_T$		
$v_{out}$		
$\theta$		

## 2: RL High-Pass Filter Circuit

### Schematic



### Formulas

$$X_L = 2\pi fL$$

$$f_c = \frac{R}{2\pi L}$$

$$Z_T = \sqrt{R^2 + X_L^2}$$

$$\theta_{f_c} = \arctan\left(\frac{R}{X_L}\right)$$

$$v_{out} = \left(\frac{X_L}{Z_T}\right) v_{in}$$

### AC Analysis Settings

<b>Starting Frequency</b>	1 kHz
<b>Stopping Frequency</b>	10 MHz
<b>Sweep Type</b>	Decade
<b>Vertical Scale</b>	Linear

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### Procedures

- Step 1: Complete the calculations shown in the table below for both input frequency and cut-off frequency.
- Step 2: Build the circuit using Multisim. Run the AC Analysis using the settings above. Use the cursors to find the values of  $v_{out}$ ,  $f_c$ , and  $\theta$ . Record those measurements in the table below.

	Calculated	Measured
Based on input frequency		
$X_L$		
$Z_T$		
$v_{out}$		
$f_c$		
Based on cut-off frequency		
$X_L$		
$Z_T$		
$v_{out}$		
$\theta$		

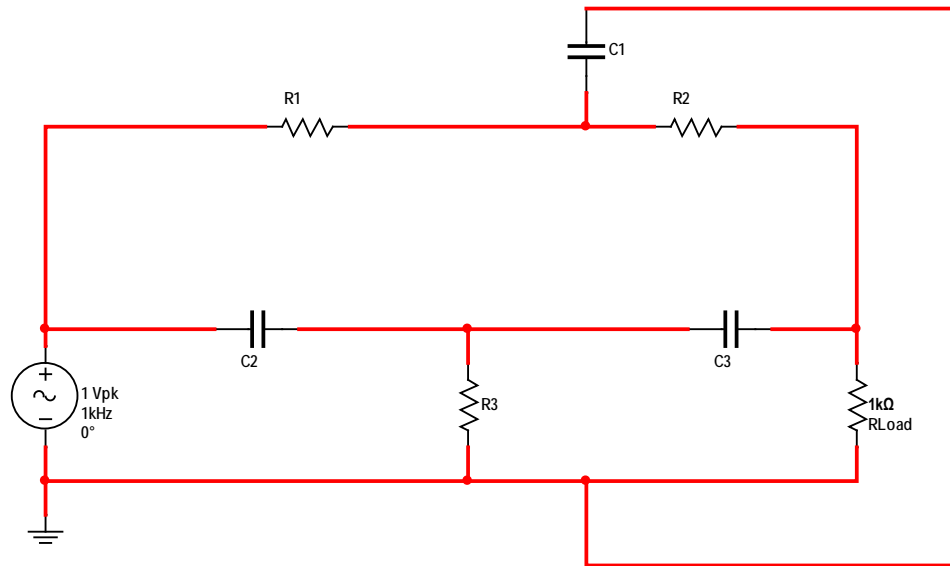
### Questions

1. Explain the significance of the voltage at  $f_c$  being approximately 0.707 V for both filters?
2. Explain the significance of the difference in phase angle,  $\theta$  at  $f_c$  for both filters?
3. For a low-pass filter, what is the approximate phase angle,  $\theta$  for frequencies significantly below cut-off frequency?
4. How would raising the inductance in the RL High-Pass Filter affect the cut-off frequency?



### 3: RC Band-Stop Filter Circuit

#### Schematic



#### Formulas

$$R_1 = R_2 = 2R_3$$

$$C_2 = C_3 = 0.5C_1$$

$$f_{notch} = \frac{1}{4\pi R_3 C_3}$$

#### AC Analysis Settings

Starting Frequency	10 Hz
Stopping Frequency	100 kHz
Sweep Type	Decade
Vertical Scale	Linear

#### Procedures

- Step 1: Complete the calculations shown in the table below for both input frequency and cut-off frequency. For your calculations, set  $R_3 = 100\Omega$  and  $C_3 = 1\mu F$ .
- Step 2: Build the circuit using Multisim. Run the AC Analysis using the settings above. Use the cursors to find the values of  $v_{out}$ ,  $f_{notch}$ , and  $\theta$ . Record those measurements in the table below.

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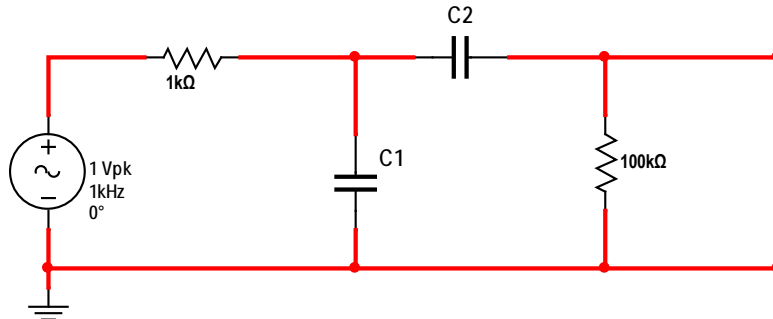
	Calculated	Measured
Based on input frequency		
$V_{out}$		
$f_{notch}$		
Based on cut-off frequency		
$V_{out}$		
$\theta$		

### Questions

5. The notch frequency is another name for the frequency with maximum attenuation. Explain that term.
6. Examine the phase vs. frequency graph and explain what is happening to the phase angle at the point of maximum attenuation.

#### 4: RC Band-Pass Filter Circuit

##### Schematic



##### AC Analysis Settings

Starting Frequency	10 Hz
Stopping Frequency	500 kHz
Sweep Type	Decade
Vertical Scale	Linear

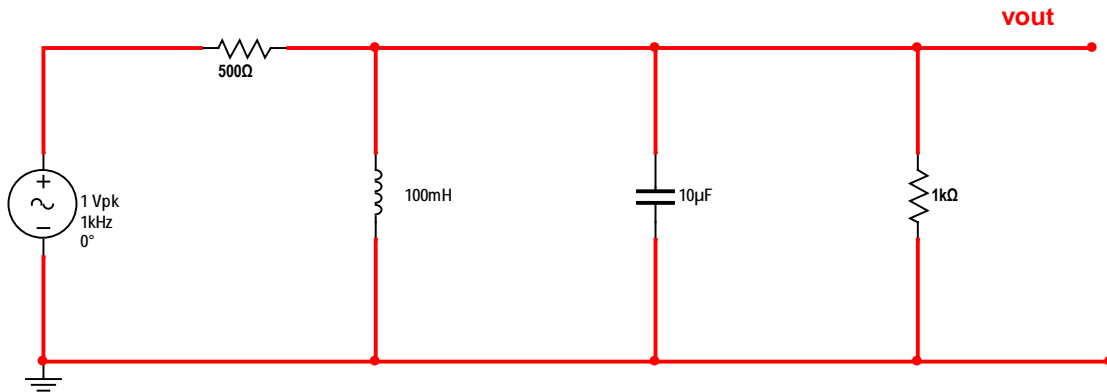
##### Procedures

- Step 1: Calculate the values for C1 and C2 that would be needed to allow frequencies between 250 Hz and 2.5 kHz to pass. Record in the table below.
- Step 2: Calculate the lower and upper cut-off frequencies and record in the table below.
- Step 3: Build the circuit using Multisim. Run the AC Analysis using the settings above. Use the cursors to find the values of  $f_c$ , and  $\theta$ . Record those measurements in the table below.

	Calculated	Measured
<b>Based on input frequency</b>		
$C_1$		
$C_2$		
$f_{c(Low)}$		
$f_{c(High)}$		
<b>Based on cut-off frequency</b>		
$\theta_{(Low)}$		
$\theta_{(High)}$		

## 5: RLC Band-Pass Resonant Filter Circuit

### Schematic



### Formulas

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

### AC Analysis Settings

Starting Frequency	1 Hz
Stopping Frequency	100 kHz
Sweep Type	Decade
Vertical Scale	Linear

### Procedures

- Step 1: Calculate the resonant frequency for this circuit. Include this in the Results section of your lab report.
- Step 2: Build the circuit using Multisim. Run the AC Analysis using the settings above. Answer the questions below.

### Questions

7. Compare the graphs of the two band-pass filter circuits. Based on your observations and measurements, explain the significance of the differences in bandwidth and slope of phase vs. frequency.