Lab Safety & Equipment Use

Air Washington Electronics ~ Direct Current Lab

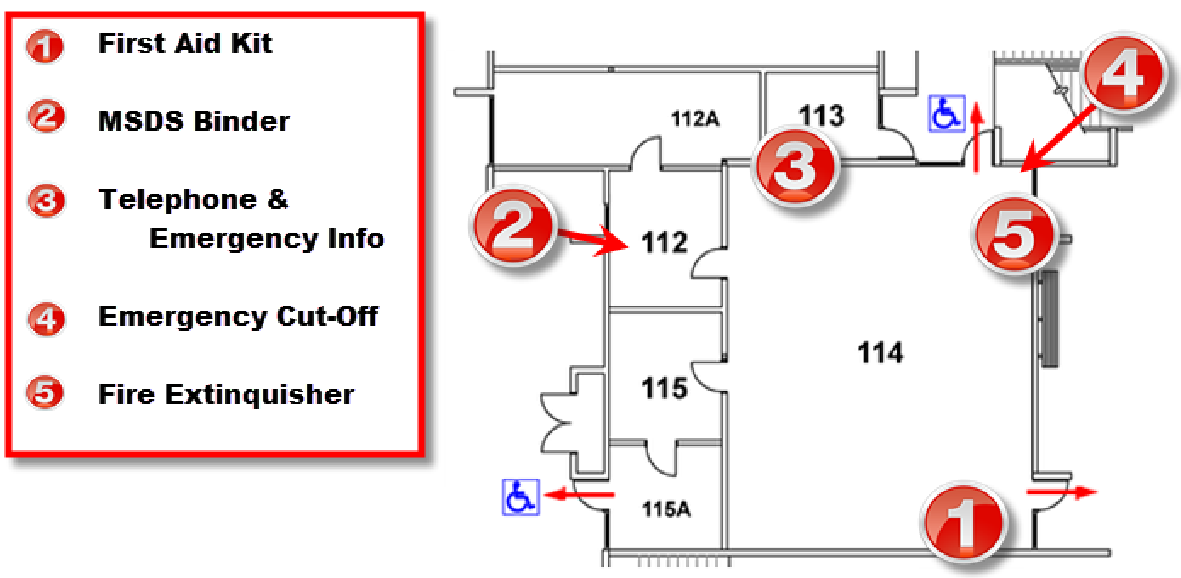
Safety & Electric Shock Hazard

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 milliampere (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.

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.

AC 60 Hz (mA)	DC (mA)	Effects
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 fist of <u>probable</u> 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, 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.

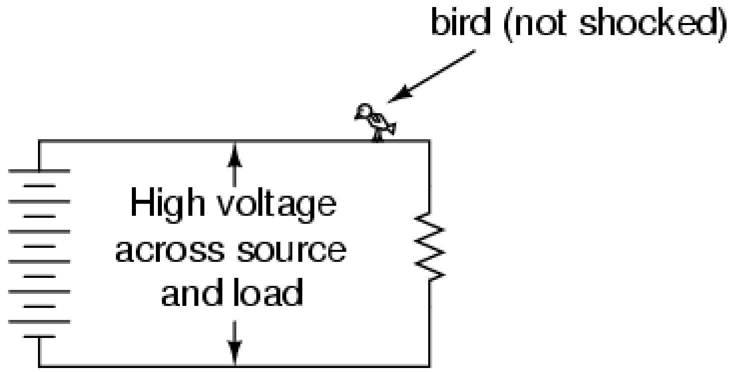
In addition, you should be aware of the following situations:

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.

Shock current path, or Why Birds Don't Get Electrocuted

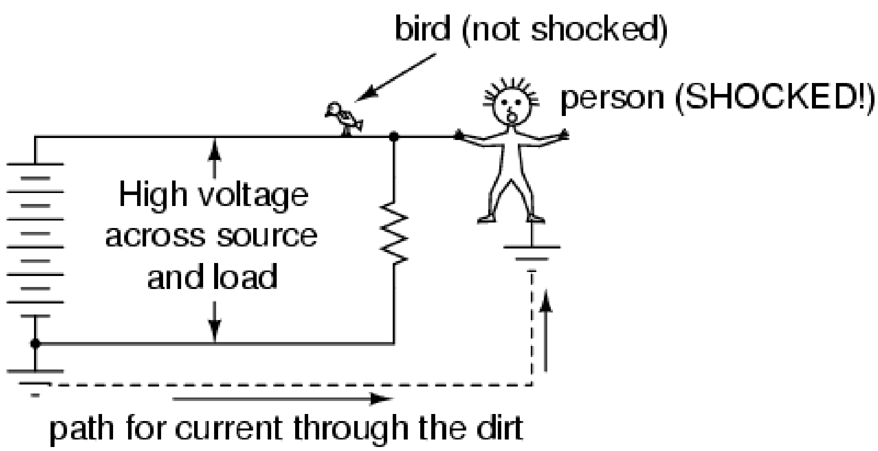
As we've already learned, electricity requires a complete path (circuit) to continuously flow. This is why the shock received from static electricity is only a momentary jolt: the flow of electrons is necessarily brief when static charges are equalized between two objects. Shocks of self-limited duration like this are rarely hazardous.

Without two contact points on the body for current to enter and exit, respectively, there is no hazard of shock. This is why birds can safely rest on high-voltage power lines without getting shocked: they make contact with the circuit at only one point.



In order for electrons to flow through a conductor, there must be a voltage present to motivate them. Voltage is *always relative between two points*. There is no such thing as voltage "on" or "at" a single point in the circuit, so the bird contacting a single point in the above circuit has no voltage applied across its body to establish a current through it. Even though they rest on *two* feet, both feet are touching the same wire, making them *electrically common*. Electrically speaking, both of the bird's feet touch the same point; hence there is no voltage between them to motivate current through the bird's body.

This might lend one to believe that it’s impossible to be shocked by electricity by only touching a single wire. Like the birds, if we're sure to touch only one wire at a time, we'll be safe, right? Unfortunately, this is not correct. Unlike birds, people are usually standing on the ground when they contact a "live" wire. Many times, one side of a power system will be intentionally connected to earth ground, and the person touching a single wire is actually making contact between two points in the circuit (the wire and earth ground):

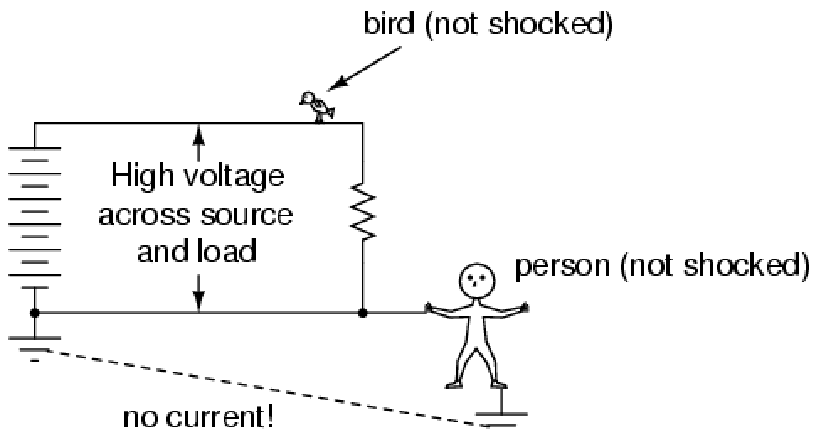


The ground symbol is that set of three horizontal bars of decreasing width located at the lower-left of the circuit shown, and also at the foot of the person being shocked. In real life the power system ground consists of some kind of metallic conductor buried deep in the ground for making maximum contact with the earth. That conductor is electrically connected to an appropriate connection point on the circuit with thick wire. The victim's ground connection is through their feet, which are touching the earth.

A few questions usually arise at this point in the mind of the student:

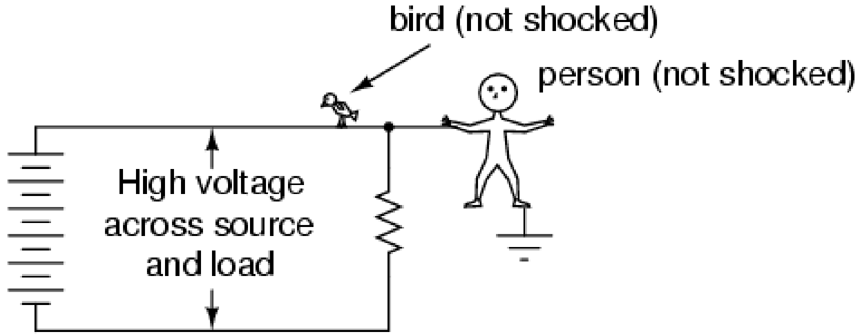
- If the presence of a ground point in the circuit provides an easy point of contact for someone to get shocked, why have it in the circuit at all? Wouldn't a ground-less circuit be safer?
- The person getting shocked probably isn't bare-footed. If rubber and fabric are insulating materials, then why aren't their shoes protecting them by preventing a circuit from forming?
- How good of a conductor can *dirt* be? If you can get shocked by current through the earth, why not use the earth as a conductor in our power circuits?

In answer to the first question, the presence of an intentional "grounding" point in an electric circuit is to ensure that one side of it *is* safe to come in contact with. Note that if our victim in the above diagram were to touch the bottom side of the resistor, nothing would happen even though their feet would still be contacting ground:

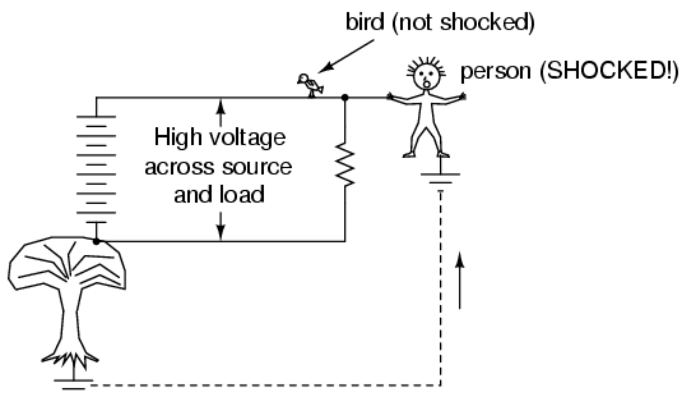


Because the bottom side of the circuit is firmly connected to ground through the grounding point on the lower-left of the circuit, the lower conductor of the circuit is made *electrically common* with earth ground. Since there can be no voltage between electrically common points, there will be no voltage applied across the person contacting the lower wire, and they will not receive a shock. For the same reason, the wire connecting the circuit to the grounding rod/plates is usually left bare (no insulation), so that any metal object it brushes up against will similarly be electrically common with the earth.

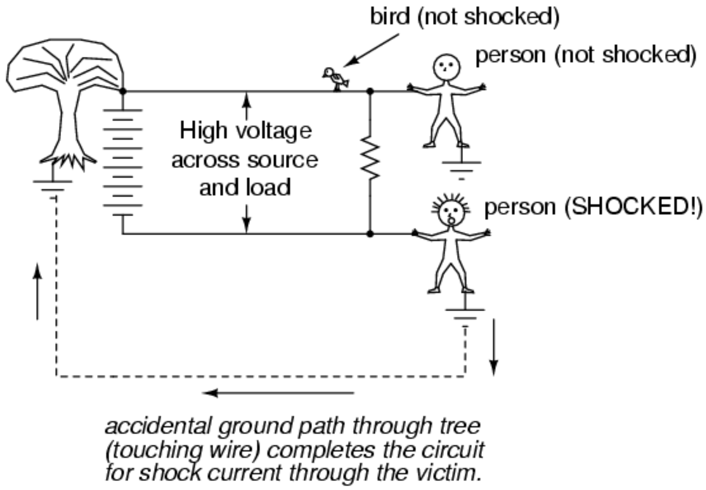
Circuit grounding ensures that at least one point in the circuit will be safe to touch. But what about leaving a circuit completely ungrounded? Wouldn't that make any person touching just a single wire as safe as the bird sitting on just one? Observe what happens with no ground at all:



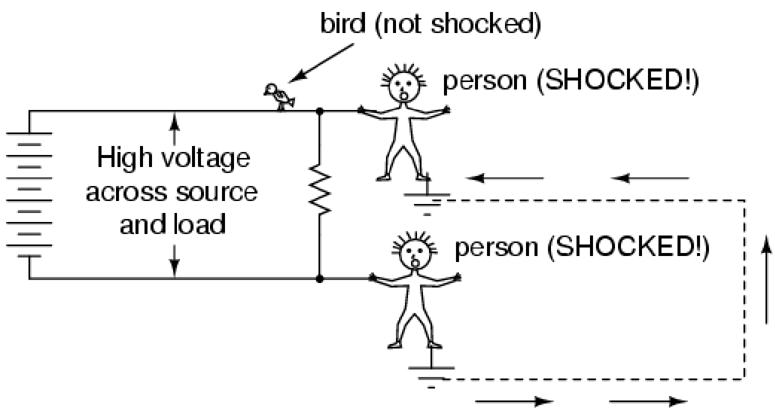
Despite the fact that the person's feet are still contacting ground, any single point in the circuit should be safe to touch. Since there is no complete path (circuit) formed through the person's body from the bottom side of the voltage source to the top, there is no way for a current to be established through the person. **However, this could all change with an accidental ground, such as a tree branch touching a power line and providing connection to earth ground:**



Such an accidental connection between a power system conductor and the earth (ground) is called a *ground fault*. Ground faults may be caused by many things, including dirt buildup on power line insulators (creating a dirty-water path for current from the conductor to the pole, and to the ground, when it rains), ground water infiltration in buried power line conductors, and birds landing on power lines, bridging the line to the pole with their wings. Given the many causes of ground faults, they tend to be unpredictable. In the case of trees, no one can guarantee *which wire* their branches might touch. If a tree were to brush up against the top wire in the circuit, it would make the top wire safe to touch and the bottom one dangerous -- just the opposite of the previous scenario where the tree contacts the bottom wire:



With a tree branch contacting the top wire, that wire becomes the grounded conductor in the circuit, electrically common with earth ground. Therefore, there is no voltage between that wire and ground, but full (high) voltage between the bottom wire and ground. As mentioned previously, tree branches are only one potential source of ground faults in a power system. Consider an ungrounded power system with no trees in contact, but this time with *two* people touching single wires:



With each person standing on the ground, contacting different points in the circuit, a path for shock current is made through one person, through the earth, and through the other person. Even though each person thinks they're safe in only touching a single point in the circuit, their combined actions create a deadly scenario. In effect, one person acts as the ground fault which makes it unsafe for the other person. This is exactly why ungrounded power systems are dangerous. The voltage between any point in the circuit and ground (earth) is unpredictable because a ground fault may appear at any point in the circuit at any time. The only character guaranteed to be safe in these scenarios is the bird, which has no connection to earth ground at all! By firmly connecting a designated point in the circuit to earth ground ("grounding" the circuit) safety can at least be assured at that one point. This is more assurance of safety than having no ground connection at all.

In answer to the second question, rubber-soled shoes *do* indeed provide some electrical insulation to help protect someone from conducting shock current through their feet. However, most common shoe designs are not intended to be electrically "safe" as the soles are too thin and not made of the correct substance. Also, any moisture, dirt, or conductive salts from body sweat on the surface of or permeated through the soles of shoes will compromise what little insulating value the shoe had to begin with. There are shoes specifically made for dangerous electrical work, as well as thick rubber mats made to stand on while working on live circuits, but these special pieces of gear must be in absolutely clean, dry condition in order to be effective. Suffice it to say, normal footwear is not enough to guarantee protection against electric shock from a power system.

Research conducted on contact resistance between parts of the human body and a point of contact (such as the ground) shows a wide range of figures (see end of chapter for information on the source of this data):

- Hand or foot contact, insulated with rubber: 20 MΩ typical.
- Foot contact through leather shoe sole (dry): 100 kΩ to 500 kΩ
- Foot contact through leather shoe sole (wet): 5 kΩ to 20 kΩ

As you can see, not only is rubber a far better insulating material than leather, but the presence of water in a porous substance such as leather *greatly* reduces electrical resistance.

In answer to the third question, dirt is not a very good conductor (at least not when it's dry!). It is too poor of a conductor to support continuous current for powering a load. However, as we will see in the next section, it takes very little current to injure or kill a human being, so even the poor conductivity of dirt is enough to provide a path for deadly current when there is sufficient voltage available, as there usually is in power systems.

Some ground surfaces are better insulators than others. Asphalt, for instance, being oil-based, has a much greater resistance than most forms of dirt or rock. Concrete, on the other hand, tends to have fairly low resistance due to its intrinsic water and electrolyte (conductive chemical) content.

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.***

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.

Questions

1. What can cause a ground fault?
    a. Dirt build-up on power lines
    b. Ground water
    c. Tree branches
    d. All of the above
2. Electric shock can cause:
    a. Burns.
    b. Muscles to constrict and freeze.
    c. Death.
    d. All of the above.
3. When working on electrical equipment, why should you use only one hand?
    a. To allow for greater ease of eating or drinking while working on equipment.
    b. To ensure that the other hand cannot provide a path for current to flow.
    c. To allow for waving at your friend when the walk by.
    d. None of the above.
4. A effect of electric shock hazards can be:
    a. Muscular inhibition or inability to move.
    b. Death.
    c. Respiratory failure.
    d. All of the above.
5. Why don't birds get shocked when they sit on the high-voltage power lines?
    a. Because they have super-insulated feet.
    b. Because they are extraordinarily lucky.
    c. Because both of the bird's feet touch the same point of the wire, or are electrically common.
    d. Because their bones are hollow.

Equipment Use and Safety

Introduction

There are two basic pieces of equipment that will be used throughout this course: the multimeter and the power supply. The multimeter is a tool for measurement and the power supply is what provides direct current (DC) to the experiments. Multimeters are digital or analog and are available in either bench or handheld models. Power supplies can range from feature rich bench top models to a common household battery. In this module, you will become familiarized with the various types of multimeters and power supplies and how to safely operate them.

Multimeters

One of the most commonly used tools in an electronics technician's tool bag is the multimeter. This tool is used to measure voltage, current, resistance, and to check components such as diodes. There are essentially three types of meters that are commonly encountered. These are the bench top digital multimeter, the handheld digital multimeter, and the handheld analog meter. The bench top DMM provides ease of use and a high level of accuracy. Handheld DMMs offer affordability and portability as well as ease of use. The analog multimeter, while not as common, offers an alternative to digital measurement and is also portable and provides real time measurement.

Digital Multimeter (DMM)

Using an electrical meter safely and efficiently is perhaps the most valuable skill an electronics technician can master, both for the sake of their own personal safety and for proficiency at their trade. It can be daunting at first to use a meter, knowing that you are connecting it to live circuits that may harbor life-threatening levels of voltage and current. This concern is not unfounded, and it is always best to proceed cautiously when using meters. **Even for experienced technicians, it is carelessness, more than any other factor, which causes electrical accidents.**

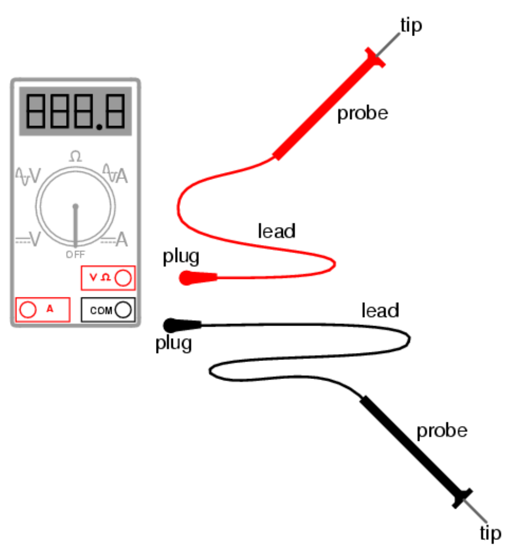


Figure 1: Digital Multimeter

The digital multimeter, or the DMM, comes in both handheld and bench versions. They have the ability to measure resistance, voltage, and current. The bench meter is slightly different, having pushbutton selections rather than a knob, and having a few more features, but overall bench and hand held meters have the same functions and safety considerations.

The basic concepts of the handheld and bench DMM are similar. There is an LED/LCD screen to show the measurement, and a method for choosing what is being measured. On the bench models, there are push buttons for DC Volts, DC Amps, AC Volts, AC Amps, and others. On the handhelds, there is a rotary selector switch with different measurement positions it can be set in: two "V" settings, two "A" settings, and one setting in the middle with an ohms (Ω) symbol on it representing resistance.

Of the two "V" settings and two "A" settings, you will notice that each pair is divided into unique markers with either a pair of horizontal lines (one solid, one dashed), or a dashed line with a squiggly curve over it. The parallel lines represent "DC" while the squiggly curve represents "AC." The "V" stands for "voltage" while the "A" stands for "amperage" (current). The meter uses different techniques, internally, to measure DC than it uses to measure AC, and so it requires the user to select which type of voltage (V) or current (A) is to be measured. Although we have not discussed alternating current (AC) in any technical detail, this distinction in meter settings is an important one to bear in mind.

It is important to set the proper range. If too high, the meter will display "OL," or sometimes "0." If too low, the meter will display a very small number (0.001) or 0.000. If it is auto-ranging (like the bench model), it will adjust where the decimal point is.

There are three different sockets on the multimeter face into which we can plug ***test leads***. Test leads are nothing more than specially prepared wires used to connect the meter to the circuit under test. The wires are coated in a color-coded (either black or red) flexible insulation to prevent the user's hands from contacting the bare conductors, and the tips of the probes are sharp, stiff pieces of wire.

The black test lead *always* plugs into the black socket on the multimeter: the one marked "COM" for "common." The red test lead plugs into either the red socket marked for voltage and resistance, or the red socket marked for current, depending on which quantity you intend to measure with the multimeter.

Measuring DC Voltage

To see how this works, let us look at a couple of examples showing the meter in use. First, we will set the meter to measure DC voltage from a battery. Figure 2 shows the two test leads plugged into the appropriate sockets on the meter for voltage, and the selector switch has been set for DC "V."

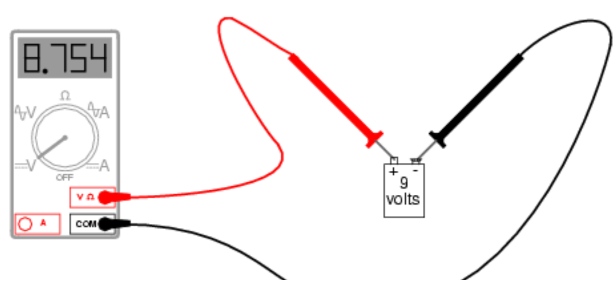


Figure 2: Measuring DC Voltage

Measuring AC Voltage

For measuring AC, only difference in the setup of the meter is the placement of the selector switch (figure 3). Because voltage is being measured, the test leads will remain plugged in the same sockets. In both of these examples, it is ***imperative*** that you not let the probe tips come in contact with one another while they are both in contact with their respective points on the circuit. If this happens, a short-circuit will be formed, creating a spark and perhaps even a ball of flame if the voltage source is capable of supplying enough current (figure 4).

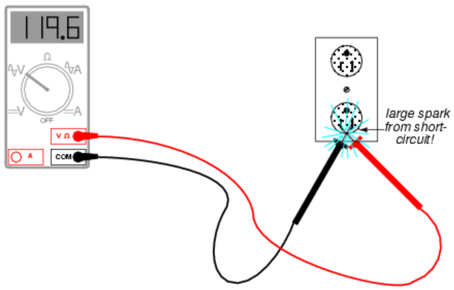


Figure 4: Short Circuit

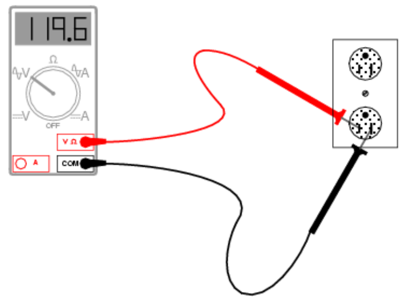


Figure 3: Measuring AC Voltage Correctly

Safety Considerations of Measuring Voltage

Voltage measurement is perhaps the most common function of a multimeter. Voltage is the primary measurement taken for safety purposes and needs to be understood by the operator. **Because voltage is relative between two points, the meter *must* be firmly connected to two points in a circuit before it will provide a reliable measurement.** To prevent possible shock, use test leads with a spring clip or other gripping device to connect to the circuit. This ensures that at least one hand is kept free and helps to prevent a path to ground through your body.

Measuring Resistance

Using a multimeter to check for resistance is a fairly simple task. The test leads will be kept plugged into the same sockets as for the voltage checks, but the selector switch will need to be turned until it points to the resistance (Ω) symbol. After touching the probes across the device whose resistance is to be measured, the meter should properly display the resistance in ohms, as shown in figure 5.

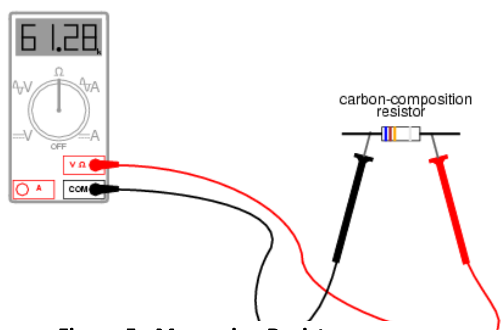


Figure 5: Measuring Resistance

Measuring resistance must be done on ***de-energized*** components. When the meter is in "resistance" mode, it uses a small internal battery to generate a tiny current through the component to be measured. By sensing how difficult it is to move this current through the component, the resistance of that component can be determined and displayed. If there is any additional source of voltage in the meter-lead-component-lead-meter loop to either aid or oppose the resistance-measuring current produced by the meter, faulty readings will result. In a worse case situation, the meter may even be damaged by the external voltage.

Measuring Continuity

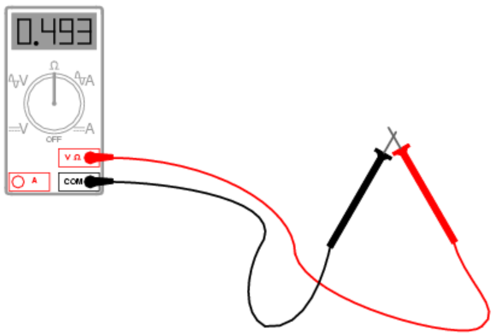


Figure 6: Measuring Continuity

The resistance mode of a multimeter is also useful in determining wire continuity. When there is a good, solid connection between the probe tips, simulated by touching them together as shown in figure 6, the meter shows almost zero Ω. If the test leads had no resistance in them, it would read exactly zero, however, since there is resistance in the wires, the meter will show a very small number.

If the leads are not in contact with each other, or touching opposite ends of a broken wire, the meter will indicate infinite resistance, usually by displaying dashed lines or the abbreviation "OL" which stands for "open loop," as shown in Figure 7.

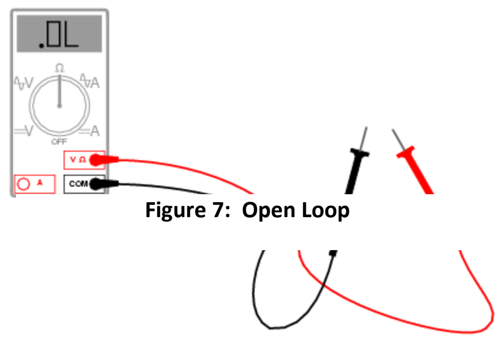


Figure 7: Open Loop

Measurement of Current

By far the most hazardous and complex application of the multimeter is in the measurement of current. The reason for this is quite simple: in order for the meter to measure current, the current to be measured must be forced to go *through* the meter. This means that the meter must be made part of the current path of the circuit rather than just be connected off to the side somewhere as is the case when measuring voltage. This configuration is known as "being in series." In order to make the meter part of the current path of the circuit, the original circuit must be "broken" and the meter connected across the two points of the open break. To set the meter up for this, the selector switch must point to either AC or DC "A" and the red test lead must be plugged in the red socket marked "A". Figure 8 illustrates a meter all ready to measure current and a circuit to be tested. Next, the circuit is broken in preparation for the meter to be connected (Figure 9).

Finally, the meter is inserted in-line with the circuit by connecting the two probe tips to the broken ends of the circuit, the black probe to the negative (-) terminal of the 9-volt battery and the red probe to the loose wire end leading to the lamp (Figure 10).

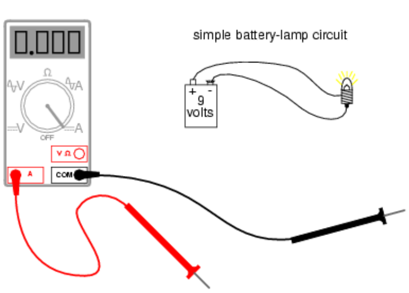


Figure 8: Measuring Current

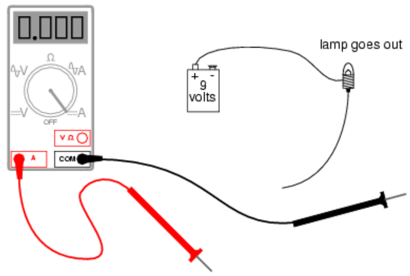


Figure 9: Break the Circuit

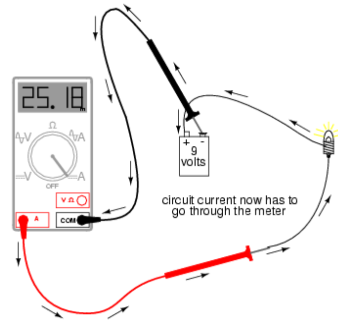


Figure 10: Insert the Meter

Safety Consideration When Measuring Current

A potential hazard of using a multimeter in its ***current-measuring*** ("ammeter") mode is failure to put it into a voltage-measuring configuration before measuring voltage. The reasons for this are specific to ammeter design and operation. When measuring circuit current by placing the meter directly in the path of current, it is best to have the meter offer little or no resistance against the flow of electrons. Otherwise, any additional resistance offered by the meter would impede the electron flow and alter the circuits operation. Thus, the multimeter is designed to have practically zero ohms of resistance between the test probe tips when the red probe has been plugged into the red "A" (current-measuring) socket. In the voltage-measuring mode (red lead plugged into the red "V" socket), there are many mega-ohms of resistance between the test probe tips, because voltmeters are designed to have close to infinite resistance (so that they *do not* draw any appreciable current from the circuit under test).

When switching a multimeter from current- to voltage-measuring mode, it is easy to spin the selector switch from the "A" to the "V" position and forget to switch the position of the red test lead plug from "A" to "V." The result -- if the meter is then connected across a source of substantial voltage -- will be a short-circuit through the meter!

To help prevent this, some multimeters have a warning feature by which they beep if ever there's a lead plugged in the "A" socket and the selector switch is set to "V." While this can help avert damage, most meters have fuses to protect them from damage.

Fuses

Meters of all types are very likely to contain fuses. As you start to use meters, you will find that fuses will blow. Mistakes made while measuring current are common for new students and the fuse protects the meter from being ruined. When the fuse has blown, the meter will still operate, though you may get erroneous readings, particularly for current. If you get voltage and resistance measurements that are close to expected, but current readings are extremely low, suspect a blown fuse.

Checking a Fuse

You can visually inspect a fuse to see if the wire inside is broken. However, it is difficult to tell for certain. Because the wire provides continuity through the fuse, you can use an ohmmeter to check for continuity. Most DMM have a setting that looks like a speaker, this is the continuity checker. It provides an audible tone if the fuse is still functional, or will indicate “OL” or other visual indicator for no continuity.

A multimeter can also be used to check its own current fuse by setting the selector switch to the resistance position and creating a connection between the two red sockets like as shown in Figure 11:

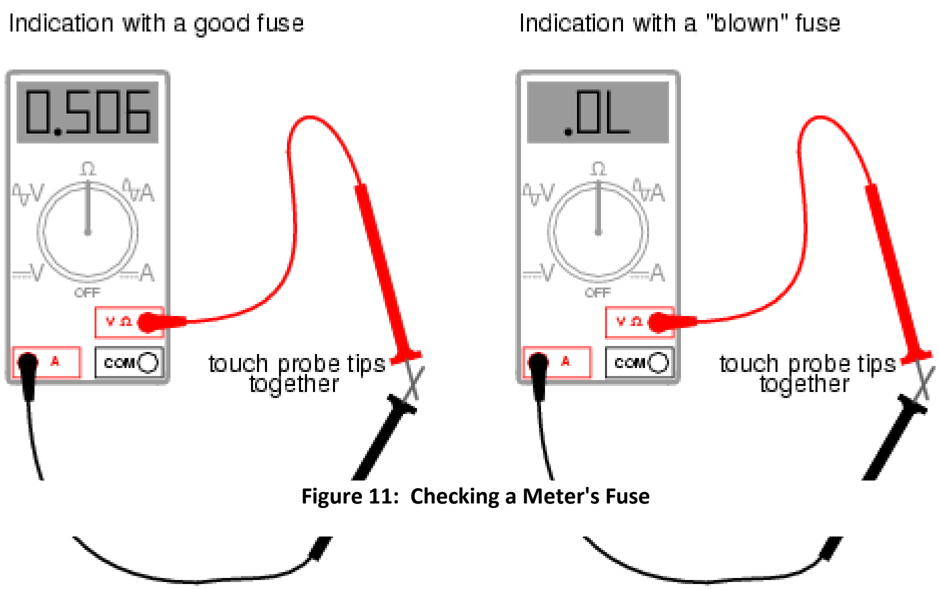


Figure 11: Checking a Meter's Fuse

A good fuse will indicate very little resistance while a blown fuse will always show "OL," or whatever indication that model of multimeter uses to indicate no continuity. The actual number of ohms displayed for a good fuse is of little consequence, so long as it is an arbitrarily low figure.

Replacement of Fuses

After an open fuse is found and the trouble that caused the fuse to open has been corrected, the fuse must be replaced. Before you replace the fuse, you must be certain the replacement fuse is the proper type and fits correctly.

To be certain a fuse is the proper type; check the technical manual for the equipment. The parts list will show you the proper fuse identification for a replacement fuse. If you cannot obtain a direct replacement, use the following guidelines:

Never use a fuse with a higher current rating, a lower voltage rating, or a slower time delay rating than the specified fuse.

The best substitution fuse is a fuse with the same current and time delay ratings and a higher voltage rating.

If a lower current rating or a faster time delay rating is used, the fuse may open under normal circuit conditions.

Substitute fuses must have the same style (physical dimensions) as the specified fuse.

Analog Multimeter

Other meters you may encounter are "VOM" (Volts-Ohm-Milliammeter) and "VTVM" (Vacuum Tube Voltage Meter). In the case of the VTVM, it is unlikely that you will encounter one, but the term is still used. The VOM is not as common, but is still used in some applications. This is an analog device that measures Resistance, Voltage, and Current using linear and nonlinear scales.

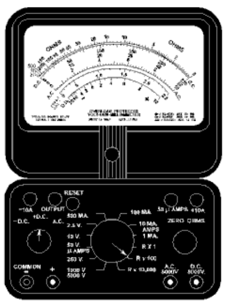


Figure 12: Simpson 260

There are several advantages in using the Simpson 260: instantaneous results and portability. Instantaneous because as the technician makes adjustments, the needle will move without the delay, albeit small, that exists in the digital multimeter due to the process of analog to digital conversion. Analog multimeters are relatively small and can be carried easily. However, there are disadvantages. They lack the precision and accuracy of a digital multimeter and are susceptible to damage caused by environment factors and human errors. A major disadvantage is parallax error. Parallax error is defined as the apparent displacement of the position of an object because of the difference between two points of view. In the case of meters, this means the position of a meter's pointer will appear to be at different positions on the scale depending on the angle from which the meter is viewed.

Analog and digital multimeters differ slightly when measuring voltage and current. However, when measuring resistance, there are significant differences. Measuring resistances with the analog multimeter requires making the appropriate range setting using a multiplication factor. Always set the meter to a higher range than anticipated, then touch the leads together and zero the meter using the ZERO dial. This must be done each time you change the range. It is also important to understand that for very small or very large resistances, you may not be able to get an accurate reading. In addition, when measuring very small resistance, it is possible that the meter will load the resistance. This means that the small voltage used by the meter when measuring resistance can negatively affect the component being measured.

In comparison, the handheld digital multimeter has a dial with settings at 200 Ω, 2,000 Ω, 20,000 Ω, 200,000 Ω, 2,000,000 Ω, and 20,000,000 Ω. The bench top digital multimeter has auto ranging, which simplifies measurement readings as it automatically adjusts to the amount of resistance being measured. It also has internal protections to prevent the adverse effects of taking measurements on the wrong setting or using the incorrect range. Below is a chart comparing the range settings for each type of meter. You can see that they are essentially the same, but the DMM settings are more intuitive than the multiplication factor used by the analog meters.

Table 1: Analog Meter Multiplication Factors

Ohmmeter Settings – Analog Meter	
Multiplication Factor	Range of Resistance
R x 1	0 - 200 Ω
R x 100	200 – 20,000 Ω
R x 1000	Over 20,000 Ω

Table 2: DMM Resistance Range Settings

Ohmmeter Settings – Handheld Digital Multimeter	
Range Setting	Range of Resistance
200	0 - 200 Ω
2,000	200 – 2,000 Ω
20,000	2,000 - 20,000 Ω
200,000	20,000 – 200,000 Ω
2,000,000	200,000 – 2,000,000 Ω
20,000,000	Over 2,000,000 Ω

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.
- 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 ∞ 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 loss 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.

Batteries

Batteries are an alternative to a DC Power Supply as described above. Regular batteries (AAA, AA, C, and D) are 1.5 V. For most DC experiments, however, a single regular 9 V batter would be sufficient. They are very simple to use and relatively safe as well.

Safety Considerations

When using a battery, it is important to inspect it to ensure there is no leakage or corrosion. Also, because they are a finite source, it is necessary to test them with a voltmeter to ensure that you are still getting the nominal voltage. Use a DMM to measure the voltage. A battery with less than 9V will not provide expected results.

Conclusion

The multimeter and the power supply are the two basic pieces of test equipment that are needed to successfully complete a DC lab course. You will find you need a variety of components (resistors, potentiometers, bulbs), but the need for the meter and power supply will not vary. You should now have a basic understanding of multimeters and power supplies and how to safely use them in future lab experiments.

Questions

1. When measuring AC voltage, if the test leads come into contact with one another while measuring the live circuit, there will be a(n):

    a. open circuit.

    b. short circuit.

    c. long circuit.

    d. nothing will happen.

2. The most hazardous and complex application of the digital multimeter (DMM) is the measurement of:

    a. current.

    b. resistance.

    c. voltage.

    d. power.

3. When measuring current,

    a. connect the ammeter in series, or in line, with the circuit being tested.

    b. always start with the highest range on the ammeter.

    c. de-energize or discharge the circuit completely before connecting the ammeter.

    d. all of the above.

4. When measuring voltage,

    a. connect the voltmeter in parallel, or across, the component being tested.

    b. always start with the highest range on the voltmeter.

    c. never use the DC voltage setting to measure AC voltage

    d. all of the above.

5. When measuring resistance,

    a. de-energize or discharge the circuit completely before connecting the ohmmeter.

    b. do not apply power when measuring resistance.

    c. set the selector dial or switch to “Resistance.”

    d. all of the above.

References

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List of Sources

- Safety & Electric Shock Hazards
  - Adapted primarily from the US Navy's *NEETS Modules 1, 2, and 19*.
  - "Shock Current Path, Or Why Birds Don't Get Electrocuted" adapted from *All About Circuits* by Tony Kuphaldt. All figures also by Tony Kuphaldt.
- Equipment Use and Safety
  - Figures
    - Figures 1- 11 are from *All About Circuits* by Tony Kuphaldt
    - Figure 12 is from *NEETS Module 3*
    - Figure 13 created by Rebecca Evenhus
  - Text
    - Multimeters
    - "Digital Multimeters" has been adapted primarily from *All About Circuits* by Tony Kuphaldt with further adaptations from the US Navy's *NEETS Module 3*.
    - "Analog Multimeter" by Rebecca Evenhus, Olympic College.
    - "Protecting Yourself" Adapted from the US Navy's *NEETS Module 3*.
    - "Power Supplies" Created by Rebecca Evenhus, Olympic College

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=rN3QhtnlCSw)