Introduction to Laboratory

Tools and Equipment

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ELECTRICAL STANDARDS AND NOTATIONS

Each field of study adopts standard terms and symbols. The electrical sciences are international in scope, and for many years have had an international committee to agree on units and terminology. In the U.S.A., the Institute of Electrical and Electronics Engineers (IEEE) takes the lead in establishing and publicizing electrical standards.

About 40 years ago, the electrical sciences adopted the meter-kilogram-second-ampere (MKSA) system of units that has now become part of the International System of Units (SI) used by all scientists throughout the world. Thus, the electrical sciences have had a consistent, widely used system of units for many years.

Standard Magnitudes (Powers-of-Ten Notation)

Many of the measured quantities in electronics are very large or very small in terms of the basic units of measurement. For convenience, a standard system of multiple powers-of-ten is used along with standard magnitude prefixes and symbols.

It was intended that the symbols for magnitude multipliers greater than unity be upper-case letters and those for magnitude multipliers less than unity be lower-case letters. However, the letter "K" had already been used for decades as the symbol for Kelvin temperature, and so the lower-case "k" is used as the 10^3 multiplier symbol. In digital electronics, particularly in regard to computer circuits, the upper-case "K" is used to mean $2^{10} = 1024$ rather than "k = 1000". The standard multipliers, prefixes and symbols are shown in Table 1. Compound prefixes, such as "micro-micro" are discouraged.

Table 1: Standard multipliers, prefixes, and symbols

Multiplier	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Standard Electrical Units

The electrical sciences have also agreed upon standard names and definitions for its units of measurements. The standard abbreviations will become familiar through daily use; their proper use is required for adequate communication in electronics.

Most of the units in electricity are named after an eminent physicist closely associated with the quantity being measured: Ampere, Ohm, Faraday, Volta, etc. When a proper name is spelled out and used as a name for a unit of measurement, it is **not** capitalized. Thus, Ampere means the man; ampere means 6.24 X 10^{18} electrons per second. However, when the unit named after a famous person is abbreviated, the single or first letter of the proper name IS capitalized; lower-case letters are used for other terms. For example: ampere is abbreviated A while gram is abbreviated g.

The use of hertz (Hz), for the unit of frequency deserves special comment. While "cycle per second" is also correct, the name hertz is preferred because of the widespread misuse of "cycle" alone as a unit of frequency. Table 2 gives a list of standard unit names and abbreviations often used in electronics.

Table 2: Names and abbreviations commonly used in electricity and electronics

Quantity	Name	Symbol
frequency	hertz	Hz
force	newton	N
energy	joule	J
power	watt	W
electric charge	coulomb	C
electric potential	volt	V
electric current	ampere	A
capacitance	farad	F
resistance	ohm	Ω
conductance	siemens	S
magnetic flux	weber	Wb
magnetic field	tesla	T
inductance	henry	H

Standard Resistor and Capacitor Values

The commonly used resistors and capacitors are manufactured with standard values. These standard values are chosen so that each value has nearly a constant percentage increase over the preceding value. The constant percentage increase is based on the tolerance of the component. The most commonly used components in everyday circuits typically have tolerances of ±5%, ±10% or ±20%. Table 3 shows one complete decade of values for each tolerance. The sequence of number repeats itself over each decade. For example, resistors with a 5% tolerance can be found in standard values of 18 Ω, 180 Ω, 1.8 kΩ, etc. However, there are no standard 20% tolerance resistors in these values. The closest nominal value would be 15 Ω, 150 Ω. etc.

Table 3: Standard component values over one decade

20% Tolerance	10% Tolerance	5% Tolerance
10	10	10
		11
	12	12
		13
15	15	15
		16
	18	18
		20
22	22	22
		24
	27	27
		30
33	33	33
		36
	39	39
		43
47	47	47
		51
	56	56
		62
68	68	68
		75
	82	82
		91
	… repeat …	
100	100	100
		110
	120	120
		130

Resistor Color Codes

As shown in Figure 1, discrete resistors are color coded to indicate the value and tolerance of the resistor. The three bands clustered toward one end of the resistor body indicate the value. The tolerance indicating color band is located beyond the three value bands. The value of a resistor can be determined by decoding the color-band sequence into resistance values using the color-number coding listed in Table 4. The end band represents the first significant digit of the resistance value. The next band represents the second significant digit of the resistance value. The third band represents the decimal multiplier, or the number of zeros to the right of the two significant digits. A fourth color band is used to indicate the tolerance of the resistance value. A gold band means a 5% tolerance. A silver band means a 10% tolerance. No band means 20% tolerance. As an example, consider a resistor with the color band sequence: brown, black, orange, gold. These bands indicate the value 1, 0, 10^{+3} (000), 5%; that is a value of 10,000 ohms ±5%. Occasionally a resistor has a fifth band. If present, this band will have one of several meanings depending on the type of resistor. One usage is to indicates the failure rate or quality of the resistor. Another usage is to add a third significant digit. In most cases, you can ignore the fifth band if there is one.

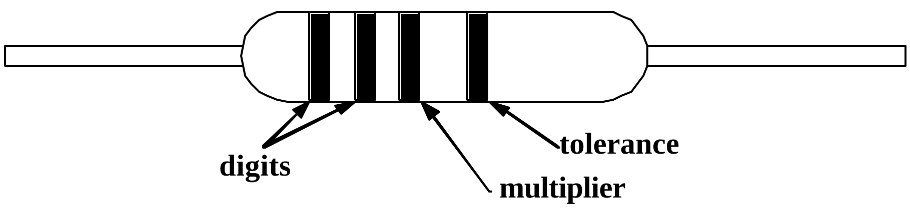

Figure 1: Color code bands on a resistor

Table 4: Color code values

Color		Digit	Multiplier	Tolerance
Black	(Bk)	0	10^{+0}	–
Brown	(Bn)	1	10^{+1}	–
Red	(Rd)	2	10^{+2}	–
Orange	(Oe)	3	10^{+3}	–
Yellow	(Yw)	4	10^{+4}	–
Green	(Gn)	5	10^{+5}	–
Blue	(Be)	6	10^{+6}	–
Violet	(Vt)	7	10^{+7}	–
Gray	(Gy)	8	10^{+8}	–
White	(We)	9	10^{+9}	–
Gold	(Gd)	–	10^{-1}	5%
Silver	(Sr)	–	10^{-2}	10%
None		–	–	20%

CIRCUIT BOARDS

Most of the electrical circuits built in the laboratory will be wired on "solderless breadboards" or circuit boards. The term "breadboard" originated in the early days of electronics when temporary circuits were literally wired on wooden boards about the size commonly used for slicing bread. While breadboarding electronic circuits with wire-patch circuit boards is largely a matter of common sense, a few simple guidelines can help you work faster and more efficiently. The time these hints can save you can be worth many times the few minutes it takes to read them.

Solderless Breadboards

A typical breadboard is shown in Figure 2. The breadboard consists of a series of holes, or sockets, into which wires or leads of electrical components can be placed. There are strips of spring metal underneath the plastic that serve as "tie-points", connecting individual sockets into groups. All sockets in a group will have the same electrical connection.

The rectangular boxes shown in Figure 2 illustrate the socket groupings, or tie-points, on the breadboard. The tie-points along the outside of the breadboard are referred to as “busses”. These busses provide a mechanism for distributing signals along the entire breadboard, i.e. making it easy to connect to the signals from anywhere on the breadboard. Some breadboards have a screw in the middle of these busses, resulting in a break in the connection. To have a continuous connection along the entire length of the circuit board, the gap must be bridged with short jumper wires. The inner tie-points consist of groups of five sockets, running perpendicular to the busses. Down the middle of the breadboard is a ridge or gap.

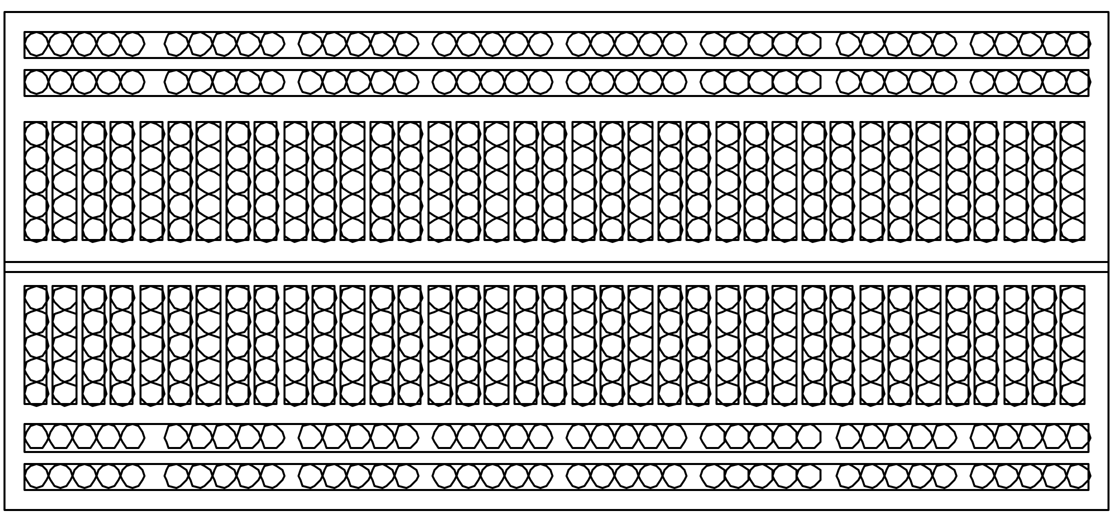

Figure 2: Solderless breadboard

Power Distribution

When wiring electronic circuits, it is desirable to follow schematic drawing conventions. This makes the wiring process easier and facilitates later circuit analysis. The convention in drawing a schematic diagram is to place the common or ground line at the bottom of the diagram and main power supply line (usually positive), at the top. When using the circuit boards, a similar convention comes in handy. The busses running parallel to the length of each circuit board are for electrical power distribution: + 5 volts and ground. Use the outside buss strips on the circuit board as the positive power line (+5 volts) and the inside buss strips as the common or ground line.

Wire Jumpers

From the first time you hook-up a circuit, you will probably need to "jump" two or more tie-points. Jumpers can be anything from #22 to #30 solid insulated wire. This wire comes in a variety of colors. You will find it helpful to color-coordinate your wiring (all ground connections black, all +5 volt connections red, etc.). This will greatly assist in trouble-shooting your circuit. A few basic rules are important in using the jumper wires so as to avoid damage to the circuit board and prevent short circuits:

- Do not use wire that is larger than #22 gauge. Do not use stranded wire.
- Never use wire that is bent, kinked, nicked or rough on its stripped ends as it will tend to break off in the holes and plug the connectors.
- To prevent short circuits, do not strip the ends of the wires more than 3/8 inches. Be certain, however, that the wires are stripped long enough to make good contact with the sockets on the breadboard.

Using Components

To make an electronic circuit, various components such as resistors, capacitors, diodes, transistors and integrated circuits will have to be interconnected. The breadboarding sockets are compatible with a wide range of circuit components. Table 5 provides a guide to some of the types of more frequently-used components that are directly compatible with the breadboarding sockets.

Table 5: Breadboard compatible circuit components

Component	Type	Lead Diameter (in)
Resistors	1/8 Watt	0.015
	1/4 Watt	0.025
	1/2 Watt	0.031
Diodes	IN4148, 914, etc.	0.015
	IN4001-4007 series	0.025
Transistors	TO-5, TO-92,	0.017
	TO-18, etc.	0.021
Integrated Circuits	The sockets accommodate all standard dual in-line packages (DIPS)	

A wide variety of potentiometers, switches, transformers, etc., can also be accommodated. Generally speaking, if a component is made for mounting on a printed circuit board, then it probably will fit directly into the circuit board (except for surface mount packages). Otherwise, it may be necessary to solder short lengths of wire to the leads.

When laying out components, short lead length, neat bending, etc., make component insertion faster and easier, as well as providing a neater overall layout. Avoid building a "rat's nest" of wires or you will pay for it when you try to trouble shoot a non-working circuit.

If you should burn-out, break-off a lead, or otherwise damage a component, please inform your instructor and do not return the damaged component to the parts bins. If you are uncertain whether a part is working correctly, give it to your instructor for testing. There is no charge or penalty for damaging these components (it can happen to anyone) and we do want to keep functioning components and all equipment ready to use so that your valuable laboratory time is not wasted.

When using dual in-line packaged (DIP) integrated circuit (IC) chips, they should be placed across the trench the runs along the middle of the breadboard such that each pin is placed into a separate tie-point. A special "chip puller" is available for removing the ICs from the circuit board. Place the blades of the chip puller into the circuit board's trench, under both ends of the DIP; then gently squeeze and rock the chip puller to pry the IC from the socket. Be careful not to bend the leads on the chips, as they will eventually break off if they are bent. When inserting chips on the breadboard, try to leave enough room between chips so that the chip puller can be inserted.

If new hook-up wires are needed, they can be made from the spools of wire provided in the laboratory. Along with the spools of wire are wire strippers that will allow the insulation to be removed from the wire without nicking or otherwise damaging the wire. Be careful to strip enough insulation from the wire to ensure that the wire will seat completely into the breadboard (about 3/8") but do not strip too much insulation or adjacent wires on the breadboard may short out.

Building a Circuit

A well-built circuit is a piece of art. It takes careful planning and extra time, but it is well worth it. Think before you place a component on the breadboard. When building a circuit out of components like capacitors and resistors, it is helpful to place them on the breadboard in the same configuration and orientation as they appear on the schematic. This makes locating individual components easy. However, this strategy is not possible when using IC chips because each chip contains multiple gates that may be used all over the circuit. Therefore, it is important to have a well-documented schematic to be able to identify and locate the gates. The following is a list of some good wiring habits.

- Be color coordinated. Black is for ground and red is for power. Do not use other colors, or worse, switch the colors. These are the standard colors used in all electrical wirings. Get used to it.
- Use the long rows at the top and bottom of the breadboard for the power and ground connections. These signals are used a lot. The long rows provide many connection points that are easily accessible from anywhere on the breadboard.
- Use short wires. Long wires get in the way and are more likely to get dislodged. Use masking tape to label wires of interest.
- Place IC chips across the center gap between the short columns. Place all the IC chips in the same orientation. Use the orientation that matches your power and ground connections. If the power is on the top row, then the chips should be placed such that the V_{cc} pin is towards the top. Make sure they are well seated in the breadboard. Don't forget to use a chip extractor when removing the chips to avoid damaging the pins. As soon as you place the chips in the breadboard, connect the power and ground wires lest you forget. Figure 3 shows the basic wiring configuration for a single IC chip.

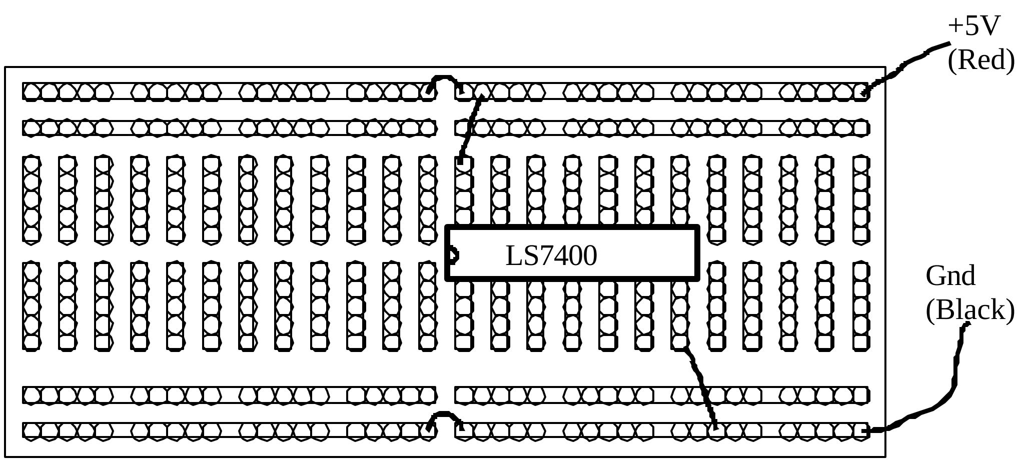

Figure 3: Sample breadboard wiring.

Schematics and Wiring Diagrams

Before building a circuit, you should create a schematic / wiring diagram. A schematic typically shows just the circuit elements and does not contain any wiring information. Schematics are typically used to design and analyze a circuit. On the other hand, a wiring diagram shows the actual device packages, pin numbers, and all the connections. Wiring diagrams are typically used to build a circuit. Since you are both designing and building a circuit, it would be beneficial to sketch a "wiring schematic". This type of schematic includes both the circuit elements (using standard symbols) along with the chip and pin numbers. Recording this information ahead of time will greatly assist you in building and debugging the circuit.

Figure 4 illustrates a sample schematic. Only the signal names and circuit symbols are used. Figure 5 illustrates the corresponding wiring schematic. The chip numbers IC1 and IC2 designate the two distinct IC chips. The A or B designation after the chip number indicates the particular gate on the chip. The pin numbers associated with that gate are written on the input and output lines.

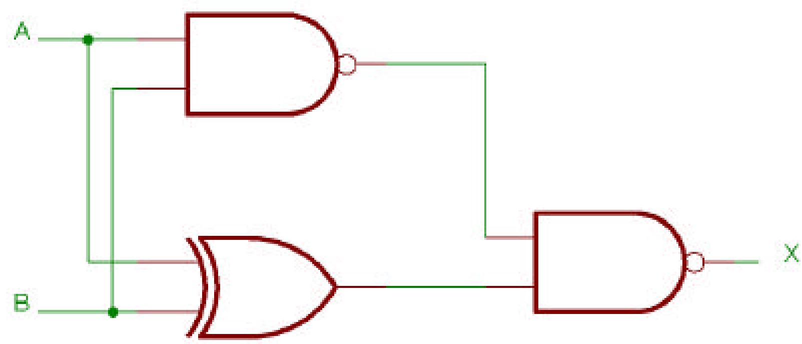

Figure 4: Sample schematic.

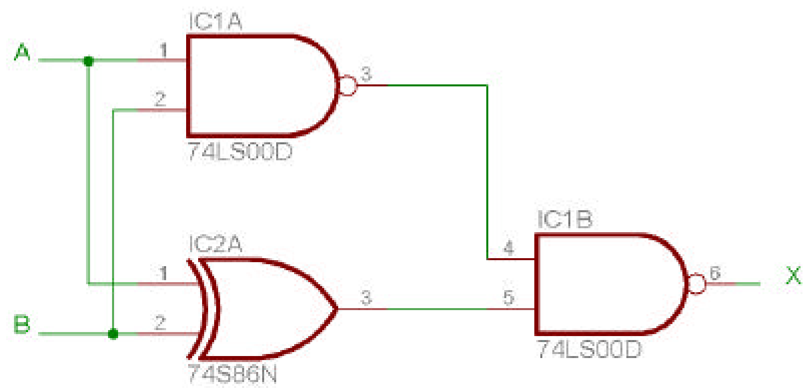

Figure 5: Sample wiring schematic.

Do not forget to connect the ground and 5-volt power supply to the IC chips. This is something that would normally appear on a wiring diagram but is not included on the "wiring schematic".

EQUIPMENT

There are several different types of measurement devices and power sources that you will typically encounter whenever you deal with electrical circuits. The most common pieces of equipment are the multimeter, oscilloscope, power supply, and function generator. There are a wide variety of models available for each of these devices, both analog and digital. A brief description of each device, its basic features, and how to use it, are provided in the next several sections. This information is appropriate and useful no matter what model you use.

Multimeter

The multimeter is the most commonly used instrument for engineers, technicians and electricians making electrical measurements. Originally, electrical work required multiple instruments for measuring voltage (voltmeter), current (ammeter) and resistance (ohmmeter). These instruments have been combined into a “multi” meter.

There are three connections available on the multimeter, typically labeled **A**, **COM**, and **V /** W. Two of the connections are required to make a measurement. The **COM** connection is used as one of the connections for all measurements. The **A** connection is only used for current measurements. The **V /** W connection is used for all other measurements. The dials and/or buttons on the multimeter are used to select the type of measurement, range, etc. How the connections are made with the element or system depends upon the type of measurement being made. **Using the wrong connections / measurement combination can cause serious damage to the multimeter and/or system.** The following sections discuss how to make each of the three basic types of measurements: resistance, voltage, and current.

Resistance Measurements

To measure resistance, the element to be measured must be removed from the circuit. **Do not apply power to the multimeter when it is set to measure resistance. Doing so can damage the multimeter.** The **COM** and **V /** W connections are used to make the measurement as shown in Figure 6. In most cases it doesn't matter the orientation of the connections (i.e. the **COM** and **V /** W connections can be reversed without affecting the measurement).

Resistance Measurement

- **Use COM and V /** W **connections**
- **Remove element from circuit**
- **Measure across element**

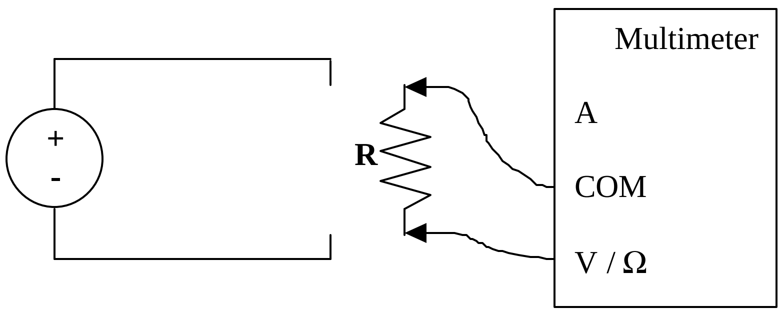

Figure 6: Multimeter connection for resistance readings

Voltage Measurements

To measure voltage, the element must remain in the circuit with power applied. The **COM** and **V /** W connections are used to make the measurement as shown in Figure 7. The multimeter is placed in parallel with the element to be measured. The voltage is measured at the **V /** W connection with respect to the **COM** connection. When measuring voltage, the orientation of the connections affects the sign of the measurement (see orientation of signs in Figure 4).

Voltage Measurement

- **Use COM and V /** W **connections**
- **Keep element in circuit**
- **Measure across element**

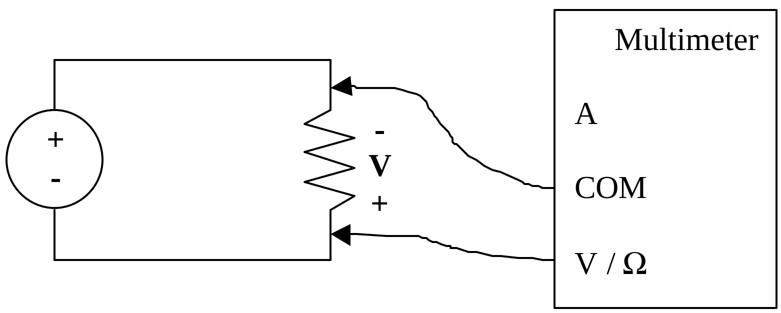

Figure 7: Multimeter connection for voltage readings

Current Measurements

To measure current, the element must remain in the circuit with power applied. The **COM** and **A** connections are used to make the measurement as shown in Figure 8. The multimeter is placed in series with the element to be measured. This implies that you must disconnect something in the circuit, and connect the multimeter between the disconnected ends, as shown in Figure 8. When the multimeter is in the current measuring mode it has a very low resistance. If the multimeter is placed across a circuit element in this mode it effectively "shorts out" the circuit element. Therefore, when using the multimeter to measure current, its placement in a circuit must be done with caution so that a power supply or other circuit element is not "shorted". Because breaking a circuit can affect the behavior of the circuit, the power should be turned off first, then break the circuit, insert the multimeter, and finally turn the power back on. **When measuring current, make sure the multimeter is set to measure current, the A connection is used, and the multimeter is placed in series. Failure to do so can cause damage to the circuit elements or the multimeter.** When measuring current, the orientation of the connections affects the sign of the measurement (see direction of arrow in Figure 8).

Current Measurement

- **Use COM and A connections**
- **Break circuit**
- **Measure in series with element**

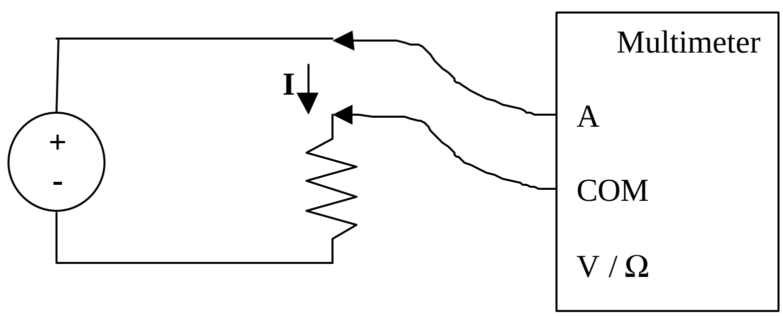

Figure 8: Multimeter connection for current readings

It is good practice to leave the multimeter set up for reading voltages and the cables connected to the **COM** and **V /** W connections. Leaving the multimeter set up for reading current is more likely to accidentally create a short circuit.

Oscilloscope

to be completed…

The most convenient instrument available to measure and display time varying voltage signals is the oscilloscope or “scope”. The oscilloscope graphs the voltage on the vertical (Y) axis versus time on the horizontal (X) axis.

DC Power Supply

to be completed…

A DC power supply is used to provide either a constant voltage (CV) or constant current (CC). Hence, it can be used as either a DC voltage or DC current source. They are referred to as power supplies because they are capable of supplying several amps of current while maintaining a constant voltage. Most IC chips can only handle currents in the range of milliamps before their output voltages begin to drop off.

Function Generator

to be completed…

The function generator is used to produce time varying voltage signals. The basic waveforms that can be produced by any function generator are the sine wave, square wave, and triangular wave. In addition, some function generators can produce random noise, amplitude and frequency modulated signals, and even more complex waveforms. The user has the ability to adjust the amplitude, frequency, and offset of the output waveform.