

MUST 382 / EELE 491

Spring 2014

Basic Lab Equipment and Measurements

Electrical laboratory work depends upon various devices to supply power to a circuit, to generate controlled input signals, and for circuit measurements. The basic operation of these instruments may seem somewhat complicated at first, but you will gain confidence as your experience grows. Eventually the operation of an oscilloscope or multimeter should seem as natural to you as using a calculator or a mobile phone.

Electrical measurements, like all physical measurements, are subject to uncertainty. The sources of uncertainty include so-called *human* errors (like misreading a dial setting), *systematic* errors due to incorrectly calibrated instruments, and *random* errors due to electrical noise and interference, environmental changes, instrument resolution, or uncertainties in the measurement process itself.

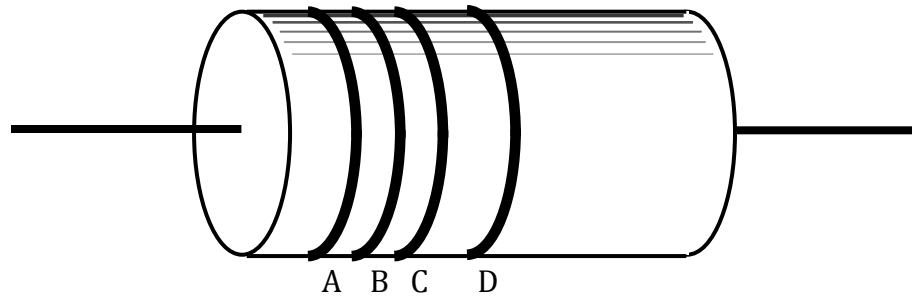
Frequently you may find that several possible approaches are available to make a particular measurement. By considering the shortcomings of each measurement technique you may discover that one of the possible methods is better (less prone to error) than the others. Moreover, you may be able to *verify* a questionable result by choosing alternate measurement methods. For example, a resistance can be measured by supplying a known current and measuring the voltage, or by supplying a known voltage and measuring the current, or by using a voltage divider or bridge containing a known resistance.

Basic Equipment: Resistors.

Real resistors are labeled with an approximate, or *nominal*, resistance value and a *tolerance* specification. For example, a resistor might be labeled as $1\text{k}\Omega \pm 5\%$, meaning that the manufacturer guarantees that the actual resistance will be between 950Ω ($1\text{k}\Omega - 5\%$) and $1,050\Omega$ ($1\text{k}\Omega + 5\%$). The nominal resistance value and its tolerance for 5, 10, and 20% resistors are either printed numerically on the resistor body (if the resistor is large enough), or indicated by four colored bands (ABCD) on the resistor body.

If we test many resistors with the same nominal (labeled) value we will find that the *actual* resistance varies from resistor to resistor within the tolerance range. On the other hand, the resistance value of a *particular* resistor is usually quite constant with time, staying close to its original measured value.

Resistors are also rated according to their maximum power dissipation. Most of the resistors used in this course are 0.25 watt devices, meaning that they can safely handle up to one-quarter watt of power. Resistors with lower and much higher power ratings are available, with the resistor size increasing with the power rating.



Value given by digits: $AB \times 10^C$ (D is the tolerance code)

The numerical values corresponding to the colors are:

0 = Black	5 = Green	Tolerance:
1 = Brown	6 = Blue	20% = No band
2 = Red	7 = Violet	10% = Silver
3 = Orange	8 = Gray	5% = Gold
4 = Yellow	9 = White	
	-1 = Gold	

For example, a $1\text{k}\Omega \pm 5\%$ resistor [10×10^2] is labeled BROWN:BLACK:RED:GOLD, a $220\Omega \pm 10\%$ resistor is labeled RED:RED:BROWN:SILVER, and a $1\Omega \pm 5\%$ resistor must be represented as [10×10^{-1}], or BROWN:BLACK:GOLD:GOLD.

Resistors are also available in 1% tolerance values. The 1% resistors have five colored bands (JKLMN) instead of four and indicate the resistance value as $JKL \times 10^M \Omega$, with the tolerance band (N) colored BROWN.

It is important to realize that only a limited number of nominal resistances are available. Manufacturers produce *standard* values that are spaced by approximately twice the tolerance specification (a logarithmic spacing) so that a wide range of resistances are covered by a minimum number of nominal values. The standard 5% resistors, for instance, follow the pattern:

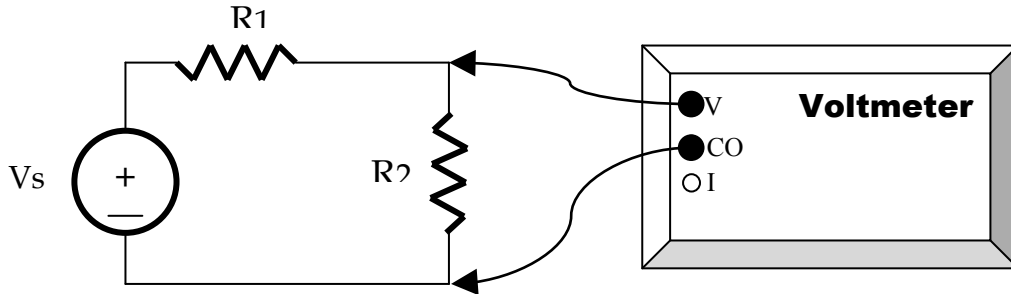
1.0	1.6	2.7	4.3	6.8
1.1	1.8	3.0	4.7	7.5
1.2	2.0	3.3	5.1	8.2
1.3	2.2	3.6	5.6	9.1
1.5	2.4	3.9	6.2	10.0

which then repeats for each greater power of 10.

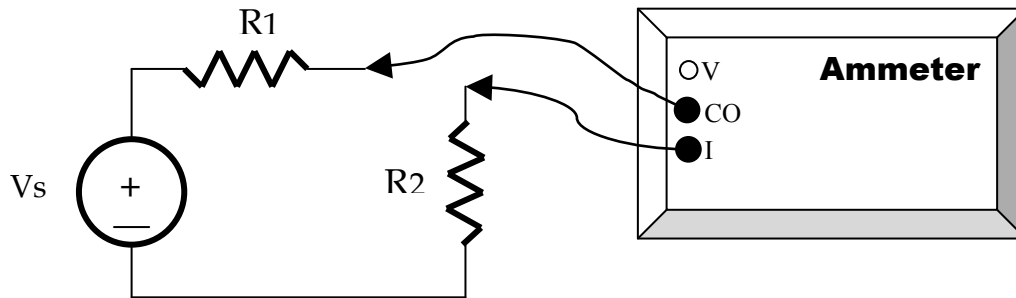
Basic Equipment: The multimeter.

Each lab station is equipped with a measurement instrument called a *multimeter*. It is called a multimeter because the same instrument can be used to measure voltage, current, and resistance: voltmeter, ammeter, and ohmmeter.

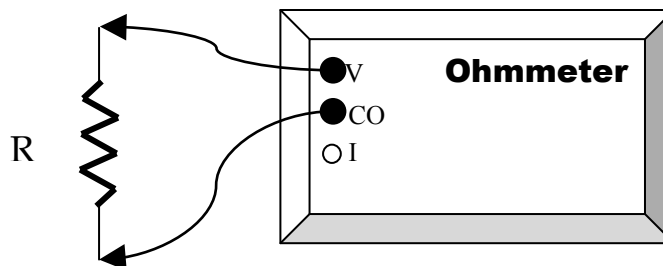
The **voltmeter mode** measures the voltage difference *between* two nodes in a circuit, i.e., the voltmeter is connected *in parallel* with a circuit branch. The meter leads are connected to the voltage input and the common (ground) input.



The **ammeter mode** must be connected *in series* with a circuit branch, which means that the circuit must be connected so that the current in the branch of interest passes through the meter. NOTE that the meter leads are connected to the current input (I) and the common input.



An internal battery in the **ohmmeter** is used to determine the resistance of a circuit element via Ohm's Law. Note that the ohmmeter is used to test *isolated* resistances: it is generally not possible to measure a resistance while it is hooked up to other components. The element should be removed from the circuit to avoid unwanted "stray" current paths. The meter leads for the ohmmeter mode are connected like the voltage measurement.



Although an "ideal" voltmeter would act like an open circuit (no current through the meter) and an ideal ammeter would act like a short circuit (no voltage across the meter), the instruments actually available for these measurements cannot be perfect. This means that the multimeter may actually *load* the circuit being measured by changing the resistance between the test points. This problem is particularly important when measuring circuits with resistances comparable to the meter resistance.

In order to obtain the best resolution from a multimeter several different sensitivity ranges are usually provided. This allows the limited number of digits available in the display to be used most effectively. For example, a voltmeter might have a smallest range setting to measure voltages from 0 to 500 mV with 100 μ V resolution, a largest range setting to measure voltages from 0 to 500 V with 100 mV resolution and several range settings in between. Thus, we would obtain the most accurate measurement of a voltage by choosing the *smallest* range setting that is still larger than the input voltage.

Some multimeters used in the lab are *autoranging*, which means that the meter will automatically choose the proper display range for the measurement being made once you select an appropriate setting such as "V", or "mV". You may encounter other meters that require you to manually set the proper range using a panel switch. To measure an *unknown* input signal with such a meter you should always start out with the highest range setting, determine the approximate value of the signal, then reduce the range setting to the optimum level. An autoranging meter performs most of this process automatically.

A typical multimeter has a digital readout, the volt-amp-ohm function selection dial or buttons, and the signal input jacks. The input jacks include "V Ω " for measuring volts and ohms, a separate jack for measuring current, and "COM" (*common*) which is used in conjunction with the other three jacks. The various jacks are required because of the multipurpose nature of the meter. Recall that a good voltmeter behaves like an open circuit, drawing negligible current from the circuit under test, while a good ammeter behaves like short circuit. There is a very high resistance between the "V Ω " jack and the "COM" jack (acts like an open circuit), while current inputs have a small resistance to the common jack (acts like a short circuit).

It is very important to connect the inputs properly. One common error is to connect the test leads to the current jacks, then attempt to measure a voltage source: the low resistance of the current inputs essentially short circuits the circuit being measured. **It is likely to blow the meter's internal fuse, damage the meter, or even damage the circuit being tested by this mistake!** Be familiar with the maximum and minimum limitations of this or any other meter *before* making any measurements.

Basic Equipment: The DC power supply.

Active electronic circuits require a power supply providing electrical energy to operate the circuit. The power supply can be a battery, a DC supply operating from the AC power line, or some other source such as a solar cell, fuel cell, generator, or thermoelectric element. Several experiments in this lab course will make use of a line-powered DC power supply.

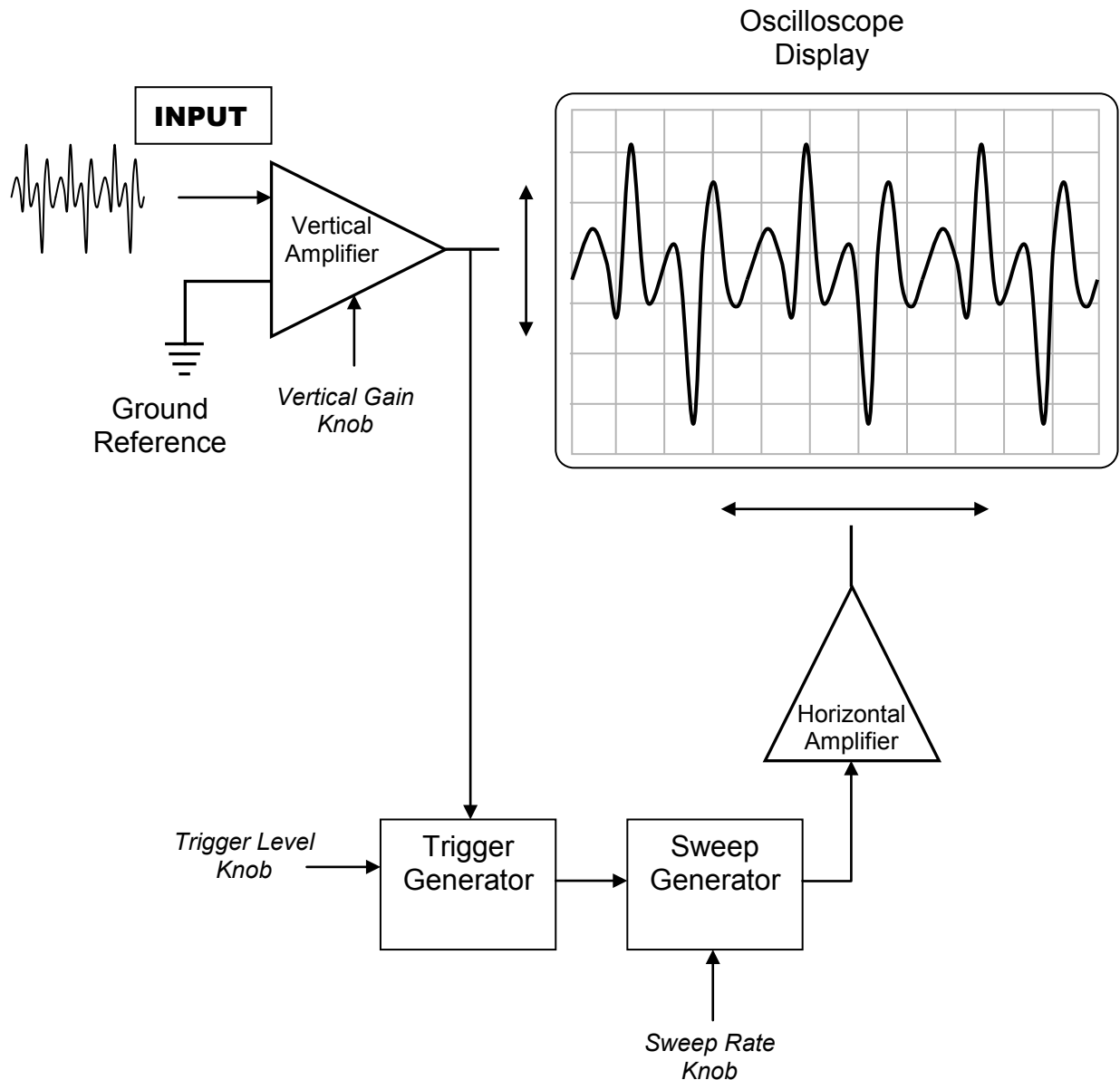
DC lab bench power supplies usually have so-called "floating" output. This means that the supply acts like a battery, producing X volts between its output terminals with neither terminal internally connected to chassis (earth) ground. Thus, you can choose to use the DC supply as a positive or negative voltage with respect to a circuit reference node. It should be noted that although DC lab bench supplies often contain an internal meter indicating the supply's DC output voltage and/or current, the internal meter is typically *not* extremely accurate: the output voltage should be adjusted using an accurate multimeter if the circuit requires a specific voltage.

A *dual* lab bench supply contains two independent DC supplies in a single chassis. A dual supply is often used to produce a *bipolar* or *split* supply providing both positive and negative voltages with respect to a reference node. Most of the bench power supplies in the lab are actually *triple* supplies: in addition to the dual variable DC, they have a fixed +5 volt output.

DC supplies often are equipped with a *current limiter* to prevent excessive current from flowing if the supply is incorrectly connected or if sensitive circuit components are used. The current limit setting is usually adjusted to allow the supply to provide the necessary *normal* circuit current at the chosen voltage, but to limit the current if the normal power level is exceeded sufficiently to possibly damage the circuitry.

Basic Equipment: The oscilloscope.

The oscilloscope is arguably the most fundamental measurement device in electrical engineering. The usefulness of the oscilloscope—or 'scope' for short—is due primarily to its ability to display electrical signal information directly in visual form. A simplified block diagram is shown here.



Although it may appear complicated, the basic oscilloscope is quite simple in concept:

- The vertical position, or *vertical deflection*, of the electron beam of a cathode ray tube (CRT) is linearly proportional to the input *voltage*. The input voltage is measured between a particular circuit node and the circuit *ground* reference. A calibrated variable amplifier is used to boost low-level signals in order to produce a visible

beam deflection. The input voltage can thus be determined by measuring the amount of beam deflection for a particular input amplifier gain. Vertical deflection calibration is usually indicated as *volts per division*, where "division" refers to the grid lines etched on the face of the CRT.

- The *horizontal deflection* is controlled either by another input signal or more commonly by a calibrated *sweep generator*. The sweep generator moves the electron beam at a selectable, constant rate from left to right across the CRT screen. The calibrated sweep rate is usually indicated as *time per division*, where "division" again refers to the CRT display grid lines.

The most important use of oscilloscopes is in the observation of periodic signals: repetitive waveforms (oscillations) can be viewed by synchronizing the sweep generator with the repetition rate of the input signal. This is accomplished using a *trigger generator* which starts the horizontal sweep when the input signal exceeds an adjustable voltage threshold. The trigger can be selected to occur for either a positive or negative slope at the threshold voltage.

Thus, by adjusting the vertical gain and the sweep speed, time varying input signals can be viewed directly as a voltage-vs.-time display.

Oscilloscopes have many other features for producing displays of particular types of signals. For example, most 'scopes have two or more independent input amplifiers for displaying two or more input signals simultaneously. Some special features will depend upon the instrument manufacturer and the sophistication of the 'scope itself. Some of these "advanced" features will be considered later in this course.

Basic Equipment: The signal generator or function generator.

A source of known waveforms—a *signal generator*—is another standard piece of laboratory gear. A basic signal generator produces a repetitive (periodic) output waveform, typically a sinusoidal signal or square wave, with adjustable frequency and amplitude. A *function generator* is a signal generator able to produce several different waveforms, typically sinusoidal, square, triangle, sawtooth, and pulse. Unlike the DC power supplies, the signal generator is usually used to provide circuit excitation only and not operating power.