Theory 2

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Units of Measure
Engineering Units
Pictorial vs. Schematic Symbols
Measuring Instruments
Analog & Digital Multimeters
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Units of Measure

VOLTAGE: We generally credit the first practical battery "voltage pile" to Alessandro Volta (Italy). In his honor, we call the unit of electrical pressure the volt.

Voltage is a measure of how much "pressure" or energy is contained within an electric charge. You can never ask "What is the voltage at point A?" without specifying what you are measuring the voltage with respect to. For example, in a thunderstorm you may have millions of volts inside of a cloud with respect to the earth, but with respect to another cloud you might have a small or zero voltage difference. It is always the voltage DIFFERENCE that we are measuring. A good water analogy is the water pressure (in pounds per square inch) in your house pipes. You may have 40 or 50 psi relative to an open sink, but zero psi with respect to another pipe within the same system.

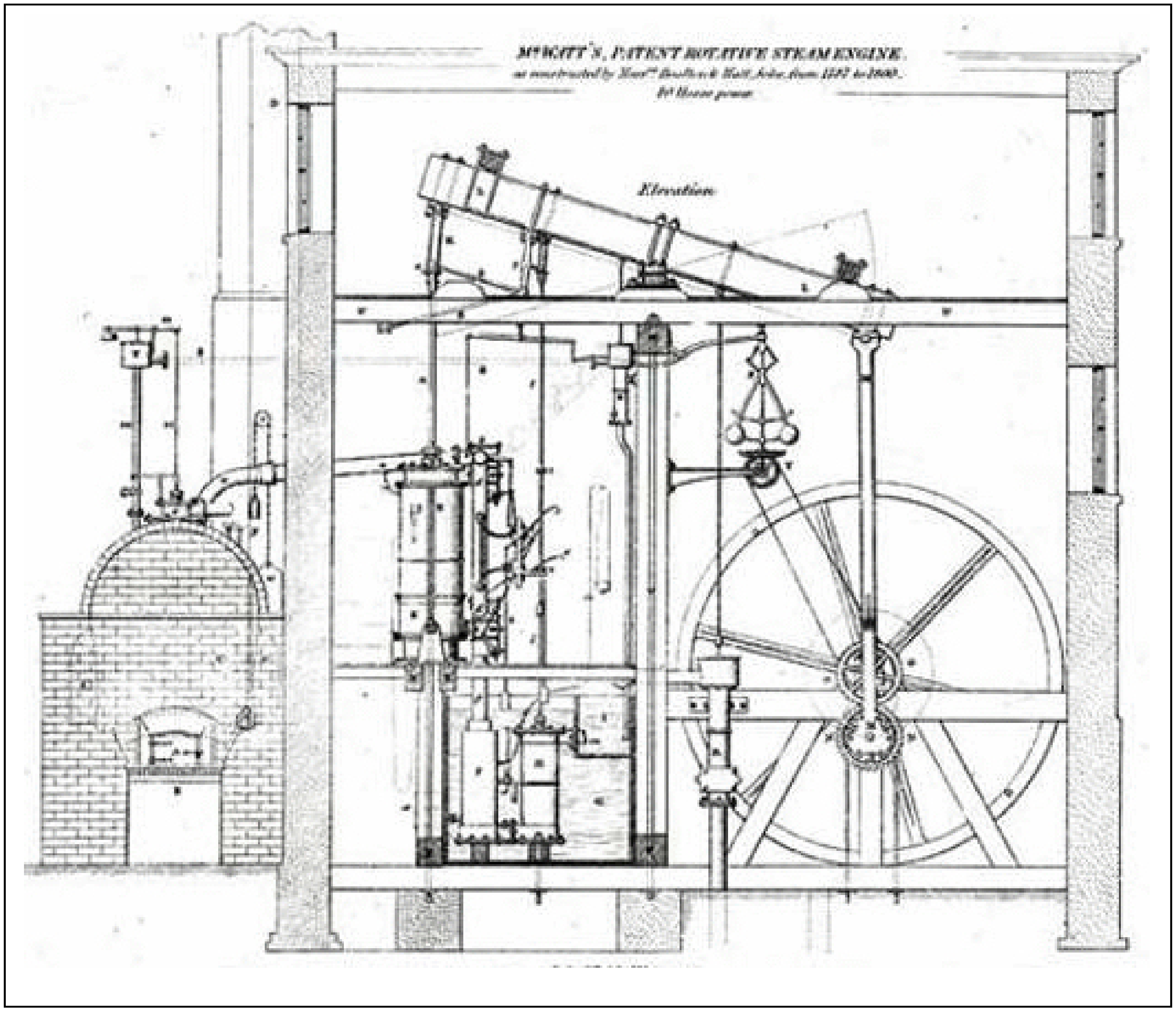
CURRENT: Andre Ampere (France) was the first to make a quantitative measurement of electrical current. We therefore give the name ampere to the measure of electrical current.

Current is defined as one COULOMB of electrons flowing by a given spot in one second. A COULOMB is a LOT of electrons (624 followed by 16 zeroes, or in better mathematical terms 6.24 E+18 or $6.24 * 10^{18}$).

In electronics, the ampere is usually too big a slug of current to use, so we conveniently divvy the ampere up by a thousand and talk about milliamperes or by a million and talk about microamperes.

RESISTANCE: Georg Ohm (Germany) discovered (or defined) the relationship between voltage and current. He said that if a substance (like carbon) connected across a voltage caused a current to flow, then the resistance of that substance was simply the value of the voltage divided by the value of the current, or in mathematical form $R = E / I$ where R is the resistance, E is the electromotive force or voltage, and I is the current in amperes.

This is one half of Ohm's Law. We'll see the other half below when we talk about POWER.



POWER: While James Watt (Scotland) did not invent the steam engine, his improvements on the original design were so great that he is credited with the making of the steam engine a practical working device. We take the name for electrical power, the watt, from Mr. Watt. His price for a steam engine was based on how many HORSEPOWER the engine produced, then calculated how much it would take to buy and feed those horses, and then sold the engine for one-third of the cost of the horses every year for as long as the engine was in service. He amassed a great deal of wealth this way.

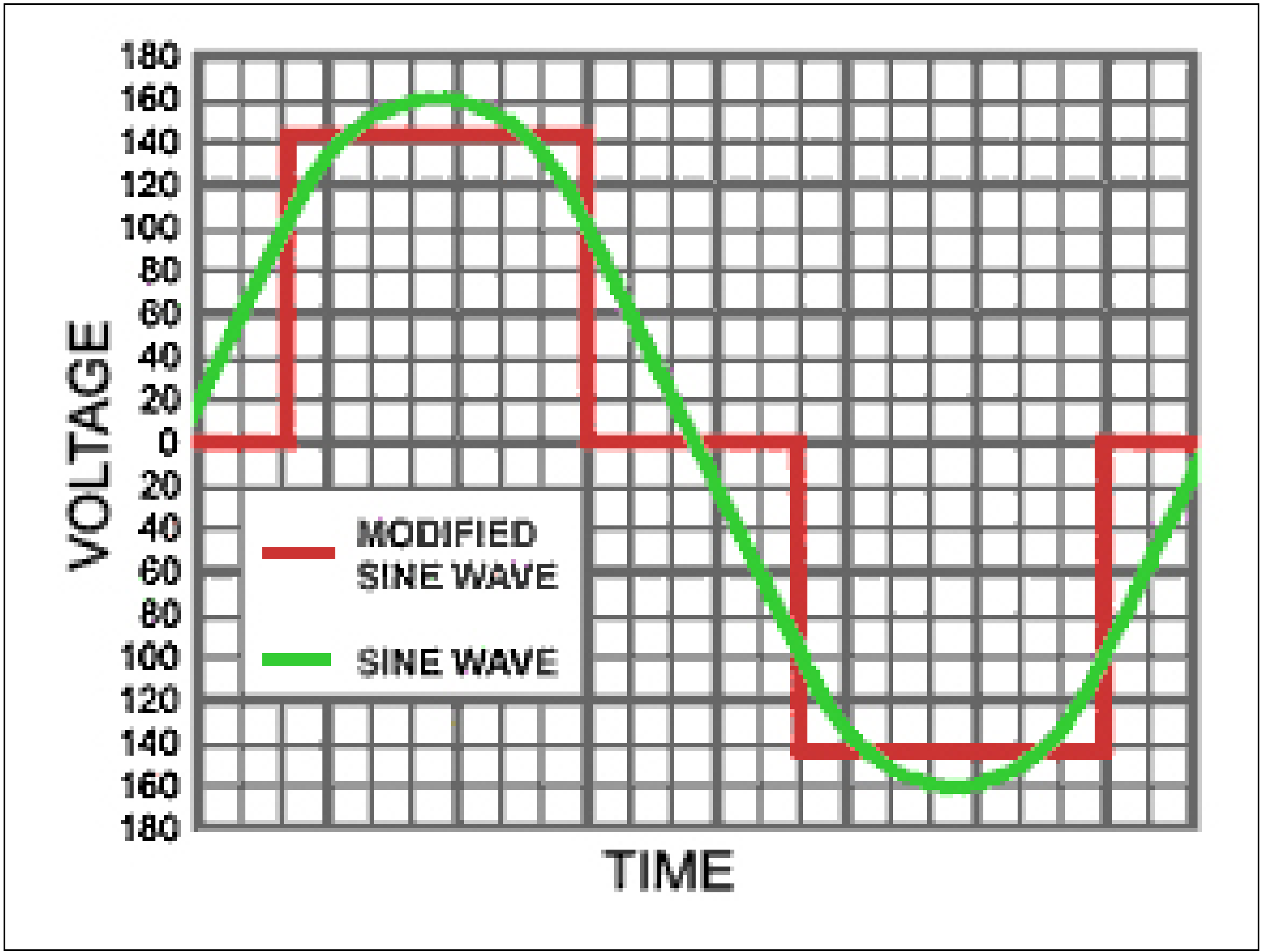
Heat is always produced by passing an electrical current through a resistor. Ohm tells us that this amount of heat (in watts, or P for power) is calculated by using either one of these formulas:
$P = E * I$ or $P = {E^2}/{R}$.

WATT-HOUR is the term used to calculate how much energy is used or consumed. You pay your PG&E bill every month by the watt-hour. Let's calculate how much it would cost to leave a 100 watt light burning all (30 days) month. Let's also assume that PG&E bills you 13¢ per ***kilo***watt hour. In the first day, you burn 2400 (24 hours times 100 watts) watt-hours of energy. In the month, then, you would burn (2400 * 30) or 72,000 watt hours. To convert from watt hours to kilowatt hours, simply divide watt hours by 1000. You therefore consumed 72 kwh of energy that month. At 13¢ per kilowatt hour, you paid $9.36 just to leave that one light burning.

Another energy unit you may be familiar with is the British Thermal Unit, or btu. The btu is the amount of energy it takes to raise one pound of water one degree Fahrenheit. One watt-hour is approximately 3½ btu.

AC VOLTAGE: In most of the discussion up to this point, we have been talking about batteries and voltage piles, all of which produce DIRECT CURRENT, where the polarity of the voltage does not change over time.

Another type of voltage is ALTERNATING CURRENT made famous in the Edison-Tesla-Westinghouse wars of the early 1900s. In this type of voltage the current is continuously changing over time from positive to negative and back to positive. The green trace to the right is a SINE WAVE (from the trigonometric relationship called the sine function). The red trace is what some "modified sine wave" generators in solar power systems generate. We will discuss generators and inverters in more detail when we talk about generating electricity in a future class.



Engineering Units

In the engineering world, we live on what are called "powers of three". That is, the difference between mega and kilo is a thousand, which is ten to the third power. The difference between giga and milli is a trillion, which (besides being a lot of zeroes) is simply ten to the twelfth (four times three). At some point in time, you will have this committed to memory. Don't worry if you have to look at a chart for a few months or years. You'll eventually get it.

By the way, this is what the ENG key on the calculator lets you do.

A "buck" is slang for a dollar bill. Here you go:

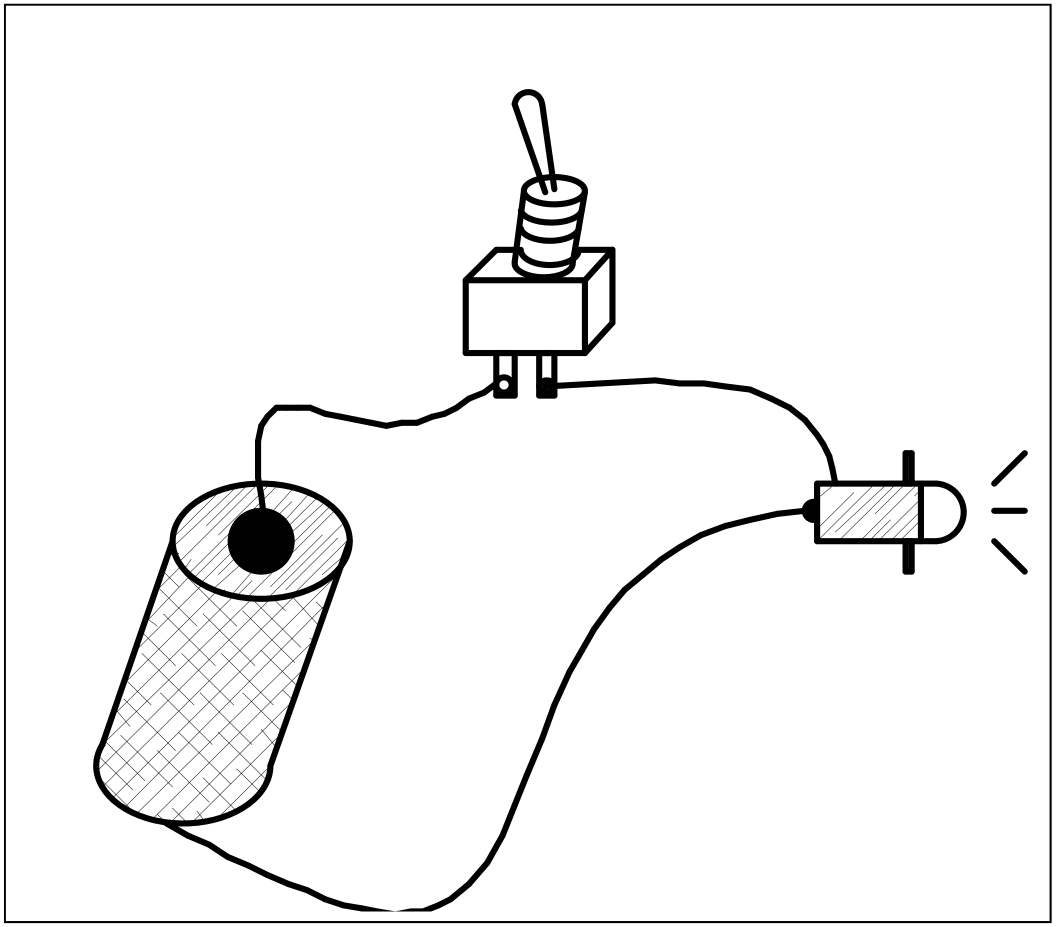
	(THE LIST GOES ON)		**Abbreviation**
.000000000000001	**FEMTO- BUCK**	**10^{15}**	**f**
.000000000001	**PICO-BUCK**	**10^{-12}**	**p**
.000000001	**NANO-BUCK**	**10^{-9}**	**n**
.000001	**MICRO-BUCK**	**10^{-6}**	**u or µ (note SMALL u)**
.001	**MILLI-BUCK**	**10^{-3}**	**m (note SMALL m)**
0	**BUCK**	**10^{0}**	
1000	**KILO- BUCK**	**10^{3}**	**K or k**
1000000	**MEGA- BUCK**	**10^{6}**	**M**
1000000000	**GIGA- BUCK**	**10^{9}**	**G**
1000000000000	**TERA- BUCK**	**10^{12}**	**T**
	(THE LIST GOES ON)		

Pictorial & Schematic Symbols

When we deal with electrical circuits, we could do what most beginners want to do, and that is deal with a PICTORIAL drawing of the circuit. For example, the common flashlight can be drawn like this:

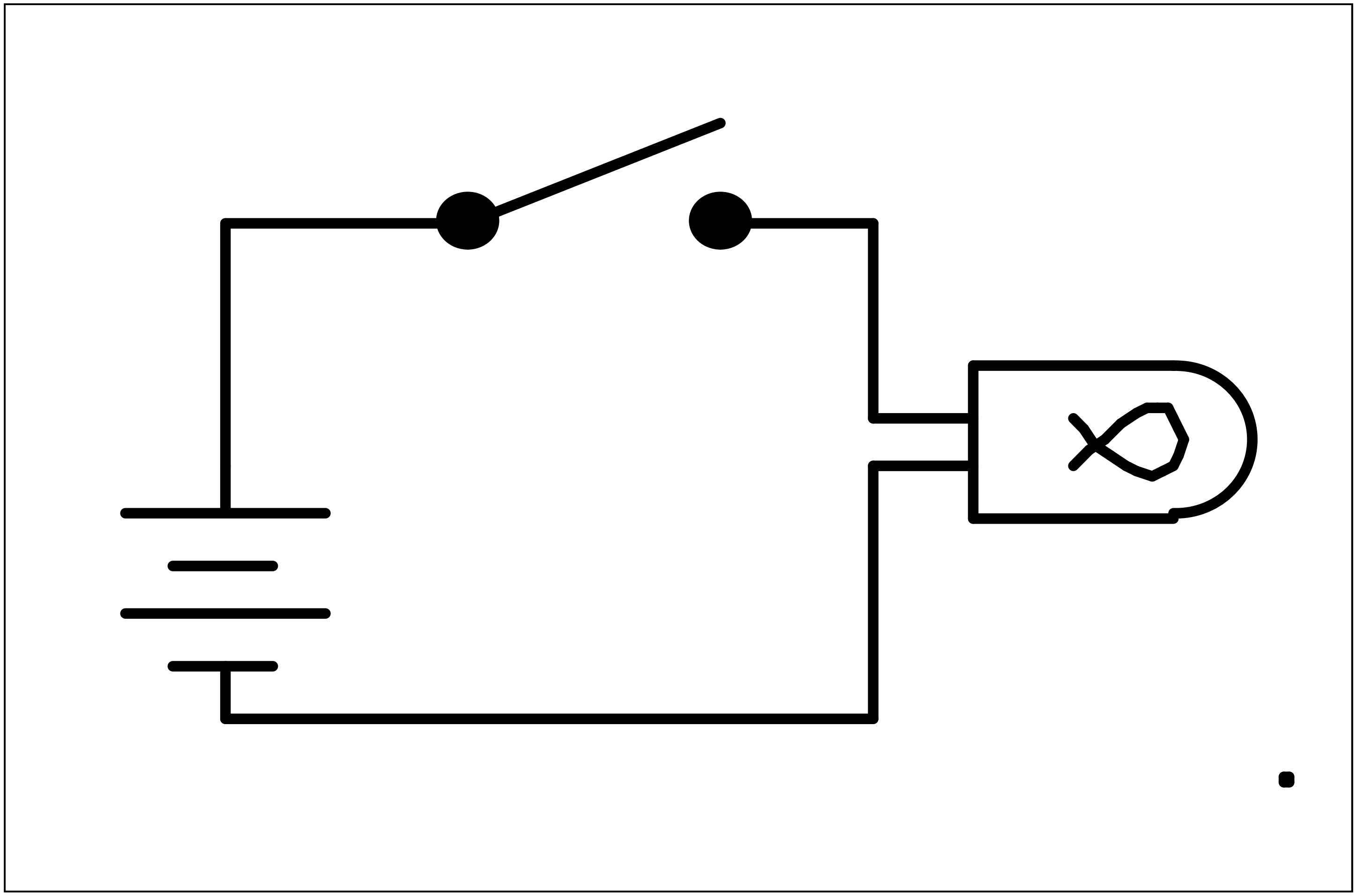
Here we see a battery on the left going through an on-off switch, then through the bulb, and then completing the circuit back to the bottom of the battery.

For relatively simple circuits such as this, pictorials aren't too bad. However, can you just imagine what the schematic drawing of a typical Pentium class home computer might look like? The drawing wouldn't fit inside of Yankee Stadium.



The answer to this dilemma is to use SCHEMATIC symbols for the drawing, where the symbol is SOMEWHAT representative of what the component does, but does not necessarily resemble the component physically. For example, inside the battery we have a series of carbon and zinc (or other conductors) plates separated by a liquid called the electrolyte. The symbol for a battery is a series of straight lines intended to represent the plates of the battery.

Similarly, a switch is nothing more than two pieces of metal that touch one another when you "throw" the switch. The schematic symbol for a switch is a circle representing one of the metal contacts, and a line from the other contact that is going to connect the two contacts when the switch is "thrown". A light bulb is a coil of metal inside a glass envelope, and the symbol shows a coil inside a bulb-shaped structure.



Back in the old days (BC – Before Computers) any large company worth its salt had a HUGE room full of people sitting at large drawing tables (called drafting tables) with pen and ink, templates, white gloves (to keep from smearing the ink), ammonia (to erase ink before it completely dried) and very sour dispositions when they spilled ink on a drawing that had taken all week to produce. They were making schematic drawings of the company products, and woe be the engineer who took a first look at a drawing and said, "You know, this would work better if this resistor went to this point over here instead of where I first put it." Many a young engineer was told in no uncertain terms where he could "put that resistor".

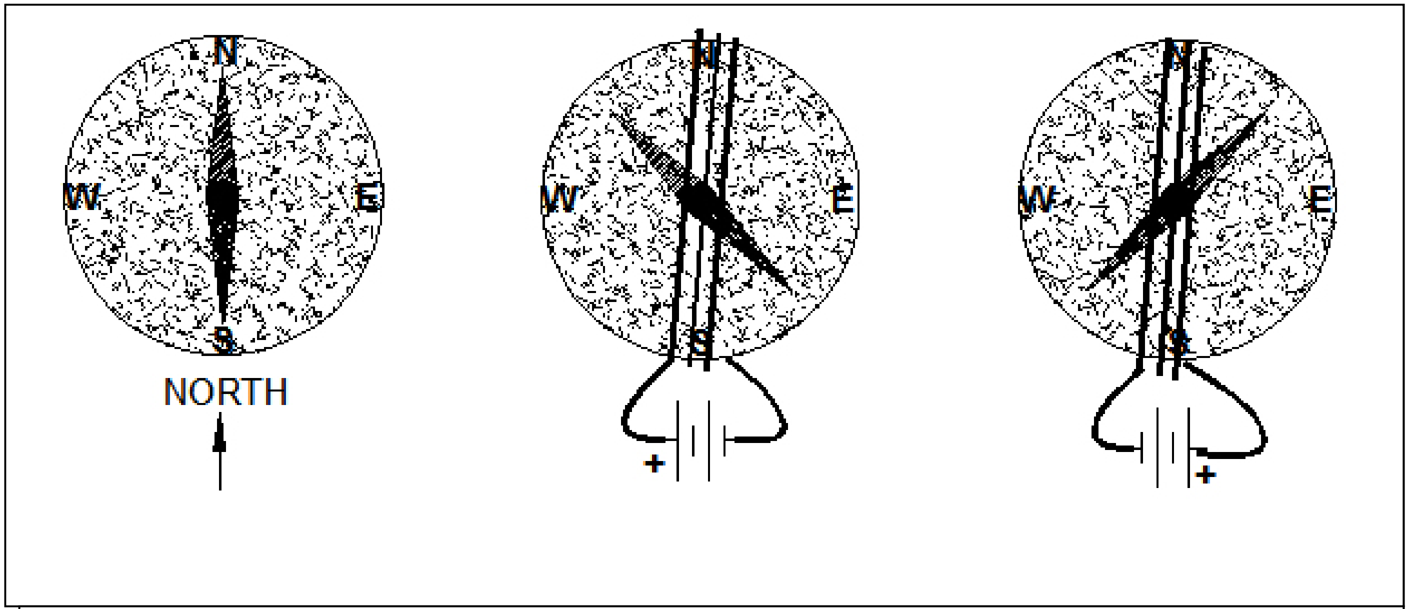
At any rate (you knew this was headed somewhere, didn't you?) the advent of the computer relegated the pen and ink artist to a byte twiddler. In my experience, except for the preliminary SKETCHES of a design, there hasn't been a formal pen and ink schematic (or mechanical drawing, for that matter) made in the last 10 years.

Most schematic drafting packages are combined with another routine called a "layout" package. That is, once the circuit is laid out on a schematic page, the "cadastral delineator" (you KNEW a draftsperson wanted another title when they got computer-smart, didn't you?) simply pushes a button, and out the other end of the computer pops a full circuit board artwork all ready to go to the camera.

Standard component reference designators are:

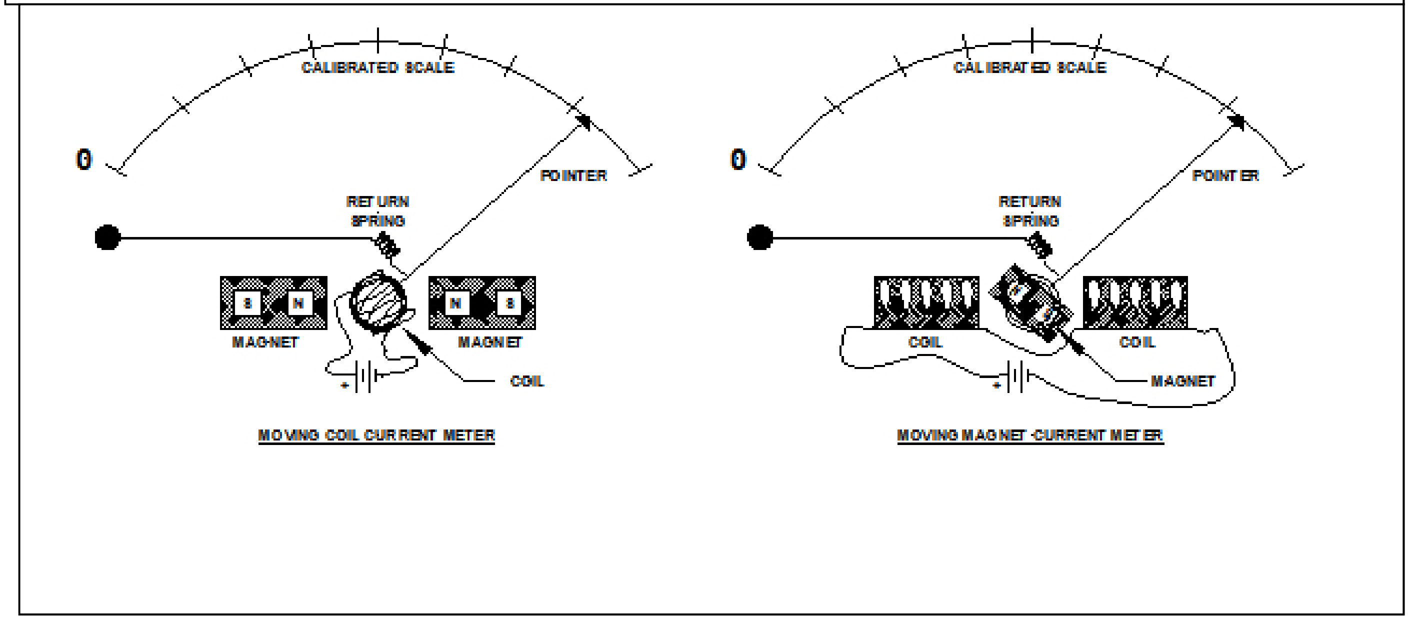
A	Antenna
B	Battery, including single cells
C	Capacitor, including variable capacitors
D	Diode, including multiple diodes in one package (bridge rectifiers), reference diode (zener), variable capacitance diode, and light emitting diode
E	(not used)
F	Fuse
G	Ground
H	(not used)
I	Lamp or Display, other than light emitting diode
J	Jack. For power connectors, the female half of a connector set as defined by the shell. For RF connectors, the female half of a connector set as defined by the center pin.
K	Relay
L	Inductor, including speaker and earphone driver
M	Meter or Motor
N, O	(not used)
P	Plug. For power connectors, the male half of a connector set as defined by the shell. For RF connectors, the male half of a connector set as defined by the center pin.
Q	Transistor, including field effect, thyristors, triac, and SCR
R	Resistor, including variable resistor
S	Switch, mechanical
T	Transformer
U	Integrated Circuit
V	Vacuum Tube
W	Wire
X	Otherwise Undefined
Y	Crystal, including crystal filter
Z	Ferrite

Measuring Instruments



a. A very long time ago, when we were just learning what "electricity" was all about, we found out that if we wrapped a few turns of wire around a compass and passed an electrical current through the wire that the compass needle swung away from magnetic north. If we reversed the current the compass needle also swung away from magnetic north, but in the opposite direction.

The problem with measuring electrical current this way is that you had to point the compass at north, wind the wire parallel to the needle, and then take your measurement. While this was clumsy to say the least, it was all we had for a few dozen years.



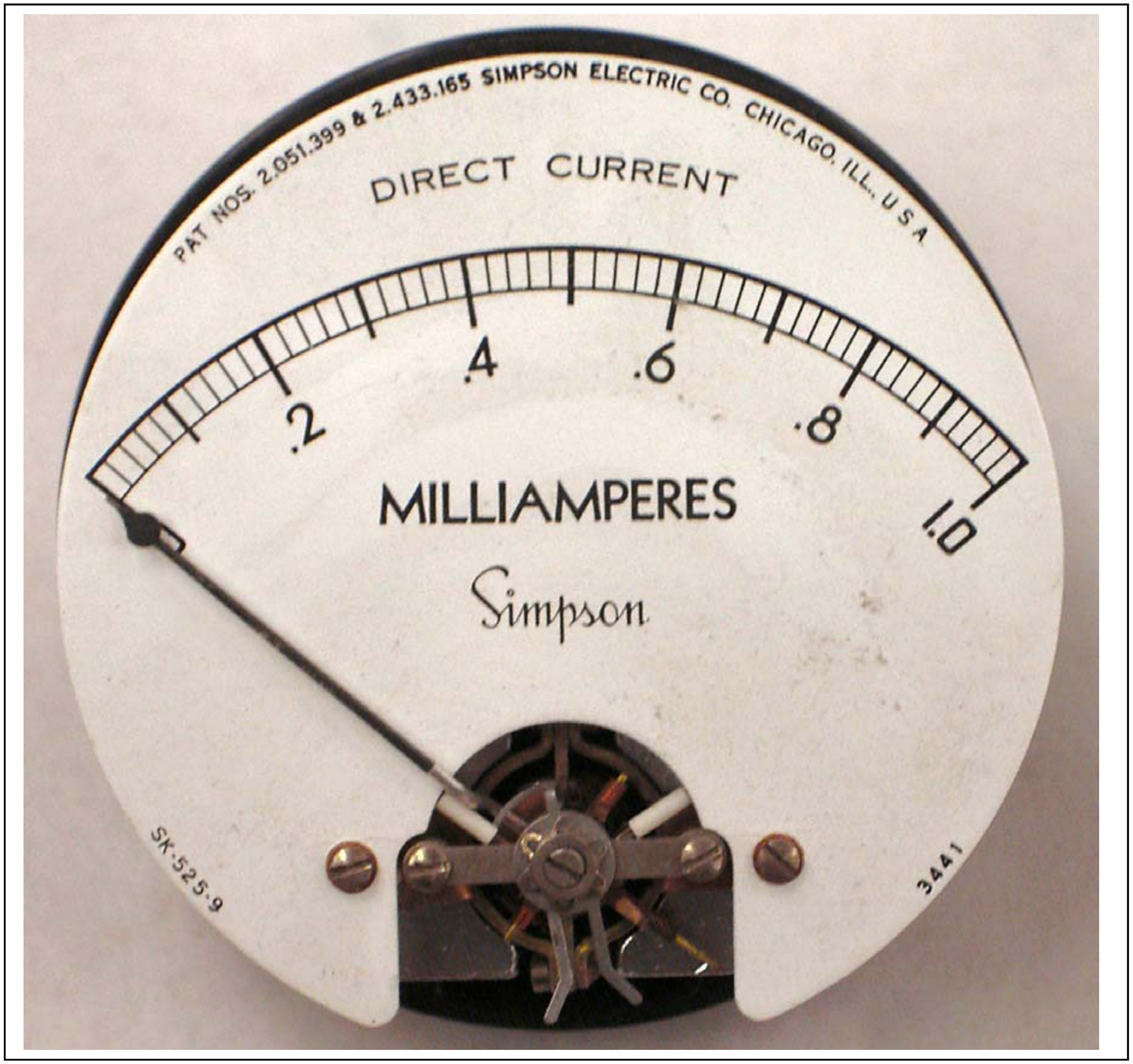
MOVING COIL CURRENT METER

MOVING MAGNET CURRENT METER

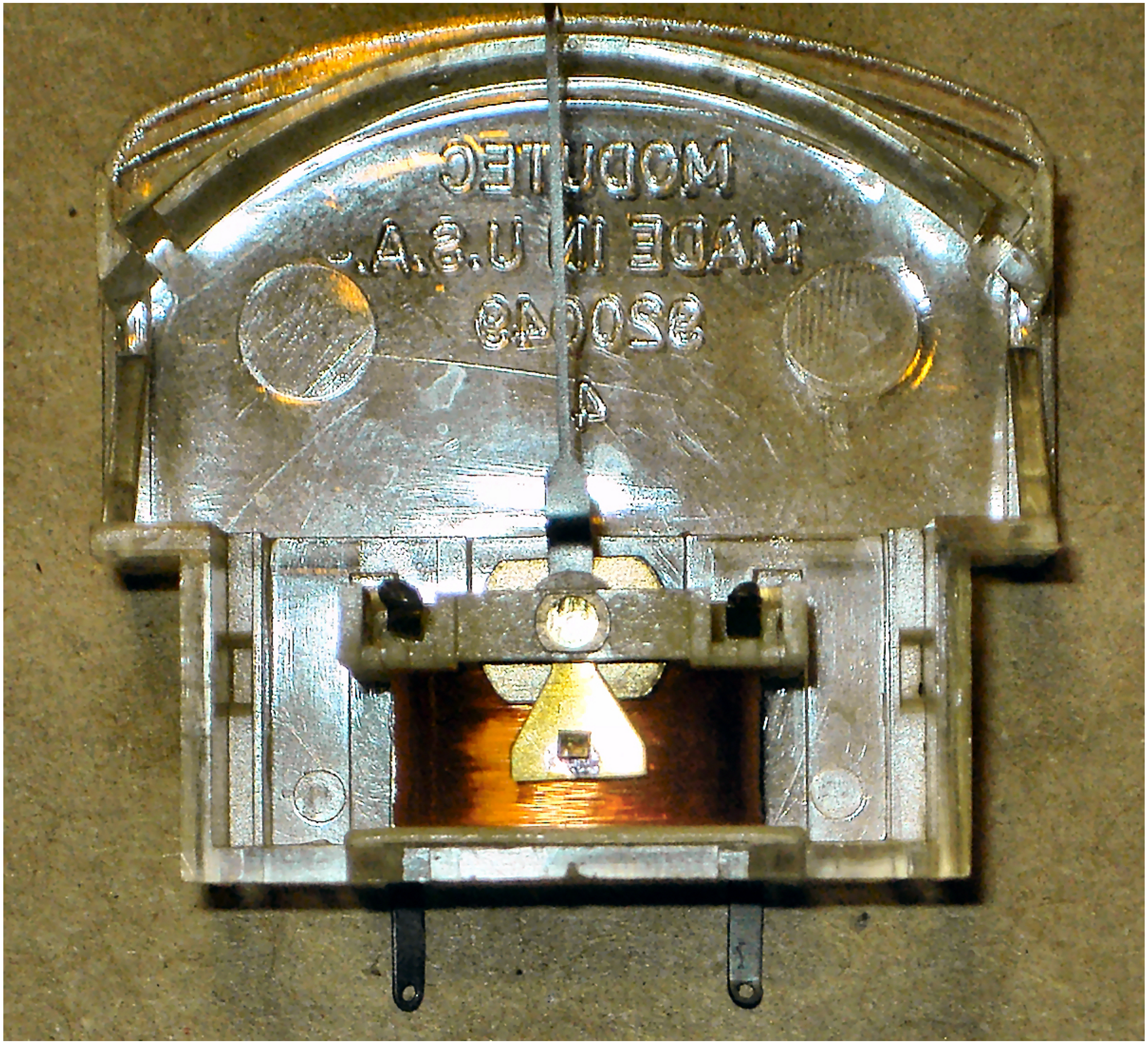
b. When we became a little more knowledgeable about electricity, we found that we could take a relatively strong magnet that completely overwhelmed the earth's magnetic field, fasten a needle to that magnet, wind a coil of wire on either side of the magnet, fasten a spring to the needle and make a true moving magnet current meter. This was a great advance in the state of the current measuring art. No longer were we tied to a compass and the earth's magnetic field.

c. Things haven't changed much over the last couple of hundred years except for the fact that we found a good way to fasten the needle to the coil of wire and have a fixed magnet provide the magnetic field. Thus today we have moving-magnet and moving-coil versions of a current meter.

Here is a picture of one of those moving-coil meters. This meter goes from zero to one milliampere full scale of current.



d. Here is a close-up of the "coil" end of a moving magnet meter. Note the orange copper coil; the magnet is hidden inside the coil of wire and attached to the needle pivot.



e. Up until the late 1980s, these pointer (or ANALOG) meters were the standard. When we perfected the DIGITAL readout to where it was a tenth of the cost of an analog meter, the digital meter became the standard.

Here is a photo of an analog "multimeter". A multimeter uses internal circuitry to allow us to read current PLUS voltage PLUS resistance.

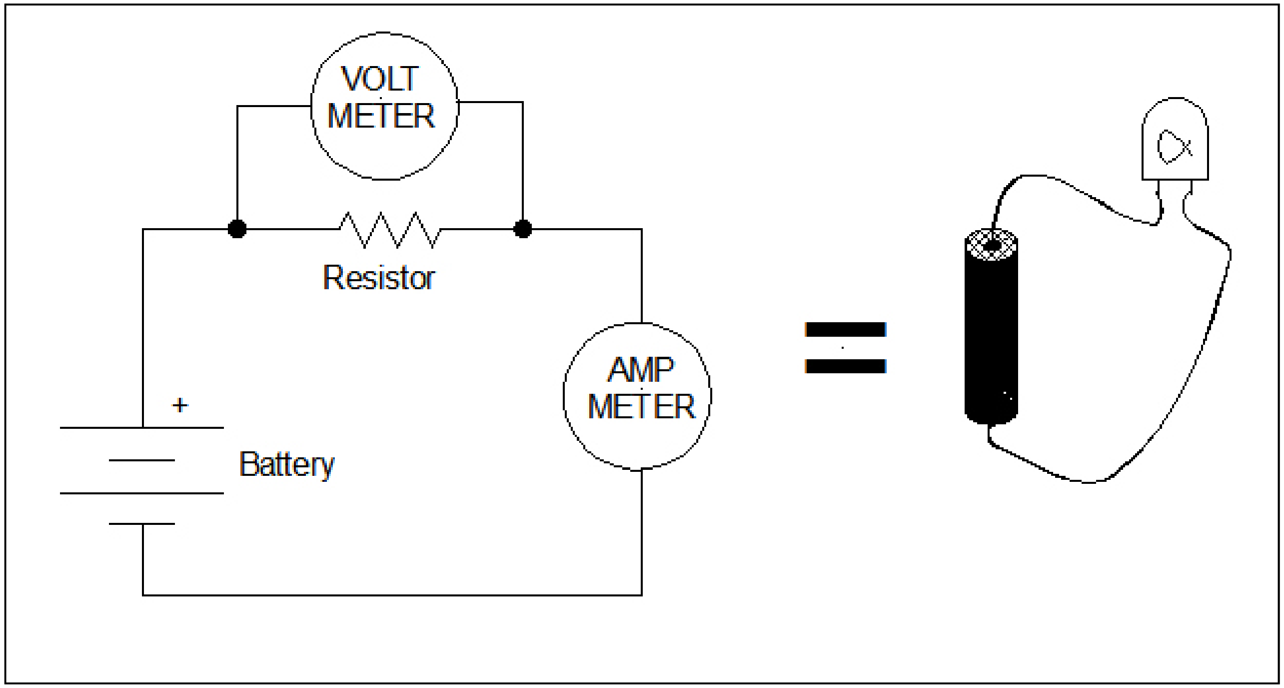
The digital "multimeter" (more later) shown here sells for less than $4. A comparable analog meter (as shown above) will sell for $75 or more. Note that the digital meter is reading 33.4 milliamperes.

Current is measured in AMPERES. A milli-ampere is $^{1}/_{1000}$ of an ampere.

Ohm's Law

f. There are three basic quantities in Ohm's Law -- Current (measured in amperes), Voltage (measured in volts) and Resistance (measured in ohms). (Andre Ampere, French, 1775-1836; Alessandro Volta, Italian, 1745-1827; Georg Ohm, German, 1789-1854)

   Ohm was the first to recognize the relationship between voltage and current. He said that the voltage in a circuit divided by the current flowing in that circuit was the resistance. Or, to put it in mathematical terms, $R = E/I$ where R is the resistance (in ohms), E is the voltage (E lectromotive force) in volts, and I is the current in amperes. A bit of algebra allows us to rearrange this equation to solve for voltage if we know resistance and current $E = I * R$ and current if we know voltage and resistance $I = E/R$.



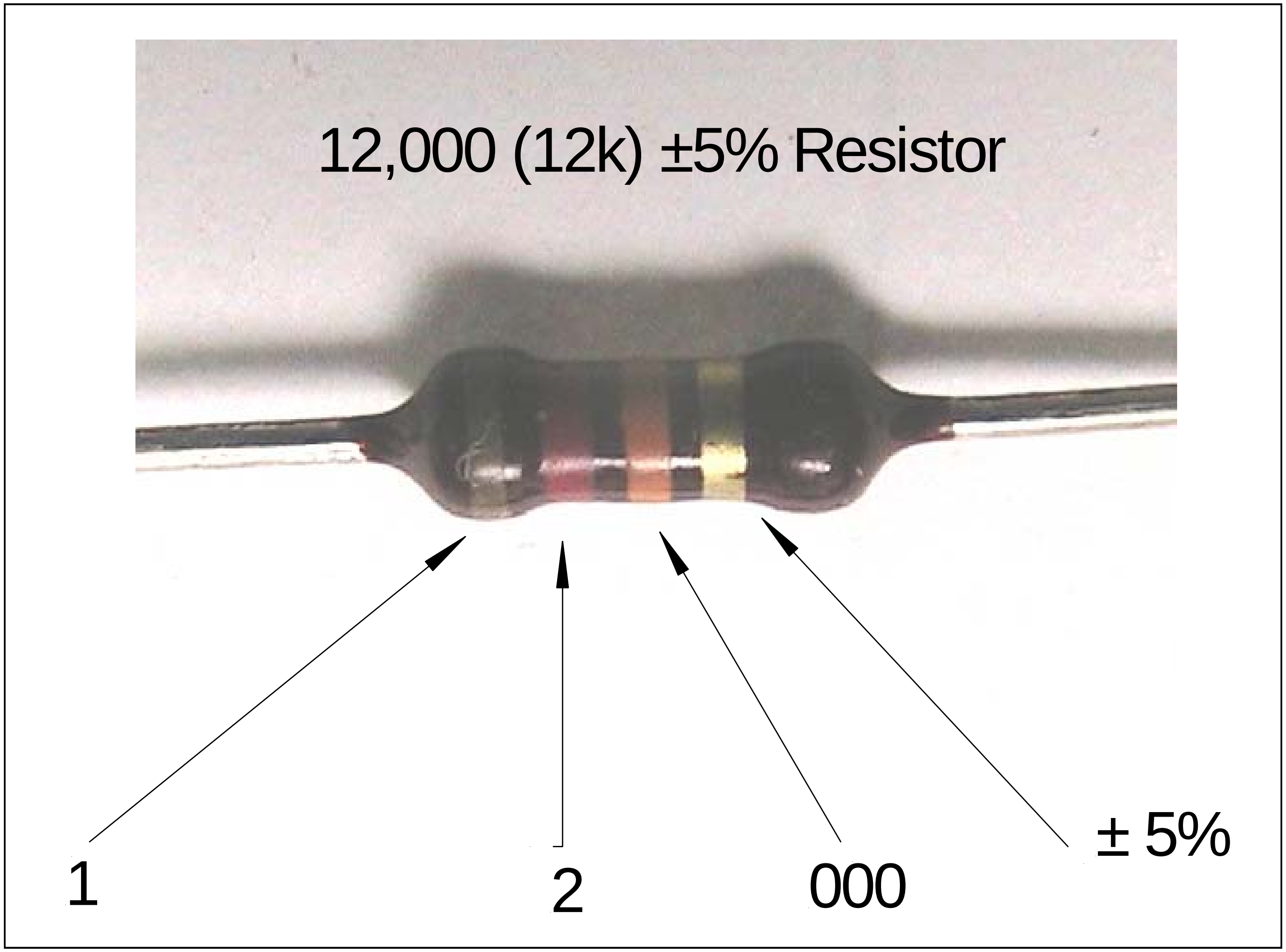
g. Take a look at the very simple circuit shown to the right. Here we see a battery going through a resistance of some sort with the current being measured by the AMMETER and the voltage being measured by the VOLTMETER.

   It is *IMPORTANT* to remember that an AMPMETER ("ammeter")measures current in SERIES with the circuit, and a VOLTMETER measures voltage in PARALLEL with the circuit.

   This SCHEMATIC (symbol) circuit on the left might be as simple as the PICTORIAL (picture) circuit on the right. Here on the right we see a light bulb being lit by a flashlight battery. If the flashlight battery measures 1.5 volts and the ampmeter (usually spelled "ammeter") measures 100 milliamperes, we can say that the bulb's resistance is $R = 1.5/0.100$ = 15 ohms (abbreviated 15**Ω**, where **Ω** is the Greek "omega").

Color Code

h. Many small parts, especially resistors, are color-coded for value and tolerance. Each number from 0 to 9 is given a specific color -- 0/black; 1/brown; 2/red; 3/orange; 4/yellow; 5/green; 6/blue; 7/violet; 8/gray; **9/white.** Note that this color coding somewhat resembles the coloring of a rainbow or a prism.



2. The Digital Multimeter

   a. As we noted above, digital multimeters have taken over the marketplace for instruments that measure voltage, current, and resistance (plus some other goodies that we couldn't come close to doing with analog instruments).

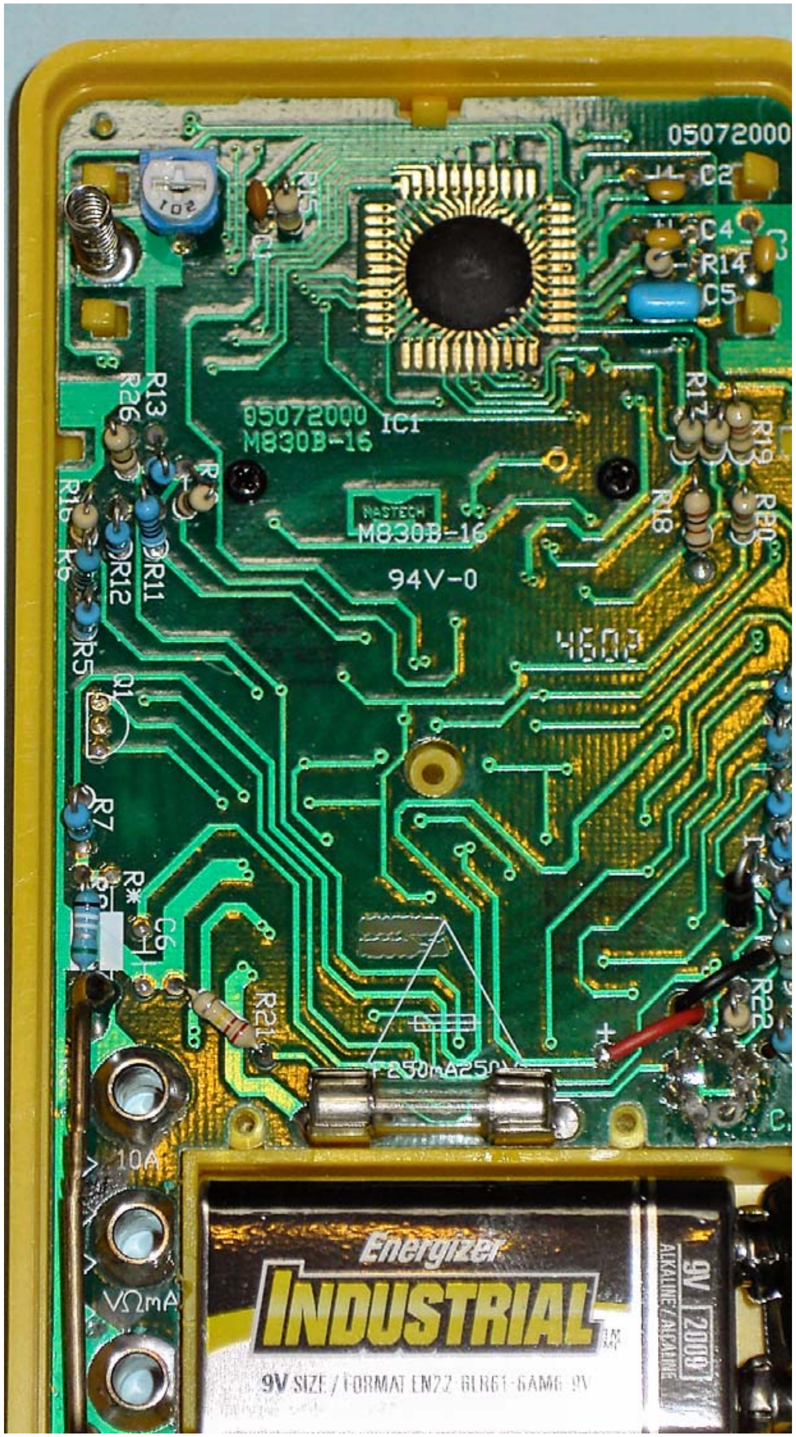
   b. The meter chosen (see next page) has scales for direct current voltage (DCV), alternating current voltage (ACV), direct current amperage (DCA), Ohms (Ω) and a few other goodies that we don't need to worry about (transistor and diode testing)

   c. It measures full scale dc voltage from 200 millivolts full scale to 1000 volts (one kilovolt) full scale, ac voltage from 200 volts full scale to 750 volts full scale, dc current from 200 microamperes (μA) full scale to ten amperes full scale, and ohms from 200 ohms full scale to 2000 kilohms (2 mega ohms more commonly written 2MΩ) full scale.

   d. .Note the RED (positive) and BLACK (negative) test leads exiting the bottom of the photo.

   e. Note also that this particular model has an "OFF" position. If you do not turn the multimeter off when you are through using it, the internal battery will slowly run down to where it is dead.

   f. Inside the meter (see page after next) you can see the battery (bottom of the picture) and immediately above it a little glass tube with metal ends. This is the meter fuse. If you try and measure volts on any of the amperage scales, you will blow the fuse. Not to worry; we've all done it. The important thing is to replace the fuse, not to put the meter back on the shelf hoping the next person will find the problem. (Look closely at the white triangle above the fuse for the current rating of the replacement fuse).




00.0
DCV
1000
200
20
2000m
200m
OFF
750
ACV
200
DCA
200µ
2000µ
20m
200m
10A
2000k
200k
20k
2000
200
Ω
hFE
E
B
C
NPN
PNP
10ADC
10A max unfused
VΩmA
750VAC
1000VDC
200mA max
500V max
COM
CEN-TECH
P30756

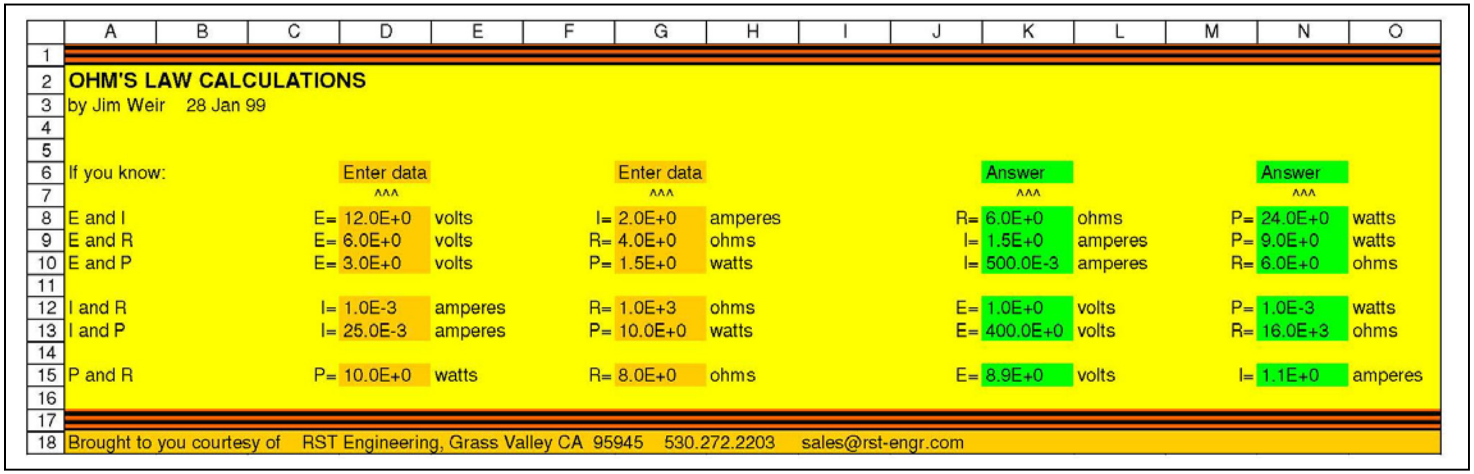
Excel

a. Whenever you have to do an equation TWICE, especially if the equation is long and/or has some very large or very small numbers, you will find it to your advantage to do a SPREADSHEET. It may take you twice the time to do the spreadsheet as to punch numbers in to a calculator, but once you have the spreadsheet done, it is a simple matter to plug in the variables and let the spreadsheet do the number crunching.

b. Let's take a very simple example of a spreadsheet used to calculate Ohm's Law for any combination of voltage, resistance, or current. You will find this spreadsheet in www.rstengineering.com/sierra, then General Links, then Spreadsheets, then open the zip file, then Ohmslaw.xls. The sheet should look something like this:

c. You can see over on the left hand side that if you know two things about a resistive circuit, you can easily calculate the other two:

1. E is electromotive force, or voltage, expressed in volts (sometimes abbreviated V)
2. I is current, expressed in amperes
3. R is resistance, expressed in ohms
4. P is power, expressed in watts (sometimes abbreviated W)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2	OHM'S LAW CALCULATIONS														
3	by Jim Weir	28 Jan 99													
4															
5															
6	If you know:			Enter data			Enter data				Answer			Answer	
7				^^^			^^^				^^^			^^^	
8	E and I		E=	12.0E+0	volts	I=	2.0E+0	amperes		R=	6.0E+0	ohms	P=	24.0E+0	watts
9	E and R		E=	6.0E+0	volts	R=	4.0E+0	ohms		I=	1.5E+0	amperes	P=	9.0E+0	watts
10	E and P		E=	3.0E+0	volts	P=	1.5E+0	watts		I=	500.0E-3	amperes	R=	6.0E+0	ohms
11															
12	I and R		I=	1.0E-3	amperes	R=	1.0E+3	ohms		E=	1.0E+0	volts	P=	1.0E-3	watts
13	I and P		I=	25.0E-3	amperes	P=	10.0E+0	watts		E=	400.0E+0	volts	R=	16.0E+3	ohms
14															
15	P and R		P=	10.0E+0	watts	R=	8.0E+0	ohms		E=	8.9E+0	volts	I=	1.1E+0	amperes
16															
17															
18	Brought to you courtesy of		RST Engineering, Grass Valley CA 95945				530.272.2203		sales@rst-engr.com						

d. What you do NOT see is the "behind the scenes" math. For example, in the row where you know E and I, you enter E into "cell" D8. You enter I into cell G8. "Behind the curtain" in cell K8 is the formula for Ohm's Law $R = E/I$. In this case, you use the CELL to come up with the answer $= D8/G8$ and the actual result of the math formula is shown on the screen as 6 ohms.

e. What's all this E+0 and E-3 stuff, anyway? In the context of a spreadsheet, E stands for 10^X, where X is the "exponent" of the number 10. Let's take an example. In cell G12, you see that the value is 1.0E+3. In better math form, this looks like $1.0 * 10^3$ or 1*1000, or 1000. Since this is the RESISTANCE of the circuit, we can say that the person who was working this problem had a circuit resistance of 1000Ω, or in better "engineerspeak", 1.0KΩ

f. One convention in algebra that you should be aware of is that $X^0 = 1$ for ANY value of X. Thus 12E+0 is simply 12 * 1 or 12.

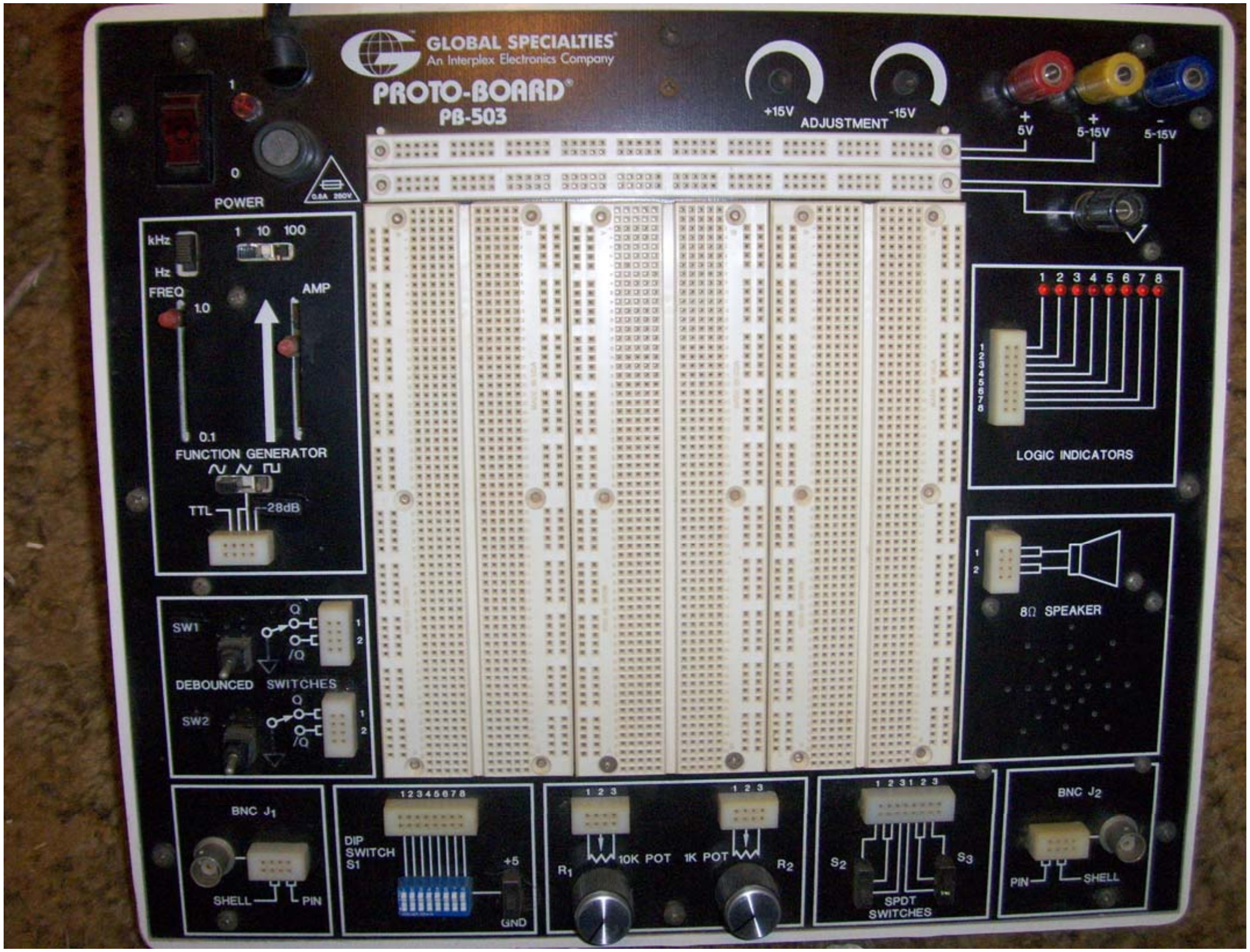
The "Trainer"

or

The "Mean Evil Machine" (quote from a CIE-1 student in Fall Semester '08)

a. The "Trainer" is a little like the multimeter. It has so many functions and so many "buttons" to push that it seems rather foreboding when you first look at it. However, if you break it up into its component parts, it isn't quite so overwhelming.

THE MEAN EVIL MACHINE



1. The On-Off switch is located in the upper left hand corner. When you turn it on, the switch body itself lights up red.

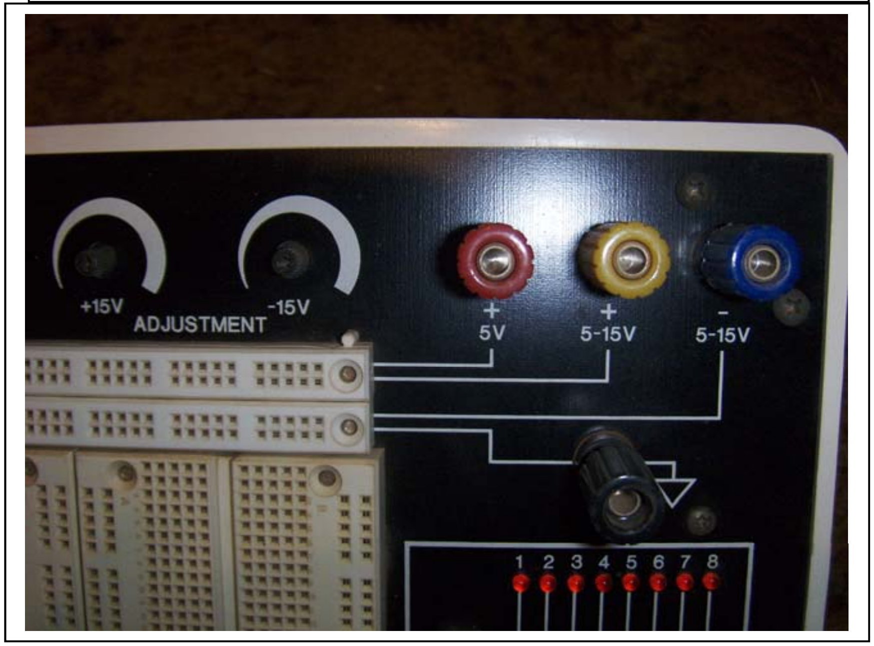
In the "1" position, the trainer is "on", in the "0" position the trainer is "off".

The little red light by the "1" is an indicator that the internal power supply has reached an overload.

There is a fuse to the right and below the red light that fuses the AC power supply (wall power).

2. In the upper right hand corner are the power supplies. Think of them as variable batteries that will power our projects for the semester.

From top to bottom, we have a RED binding post (connector) that has a constant positive (+) 5 volts.



Then a YELLOW binding post that has a variable 5 to 15 volts that is controlled by "ADJUSTMENT +15" knob to the far left of the picture.

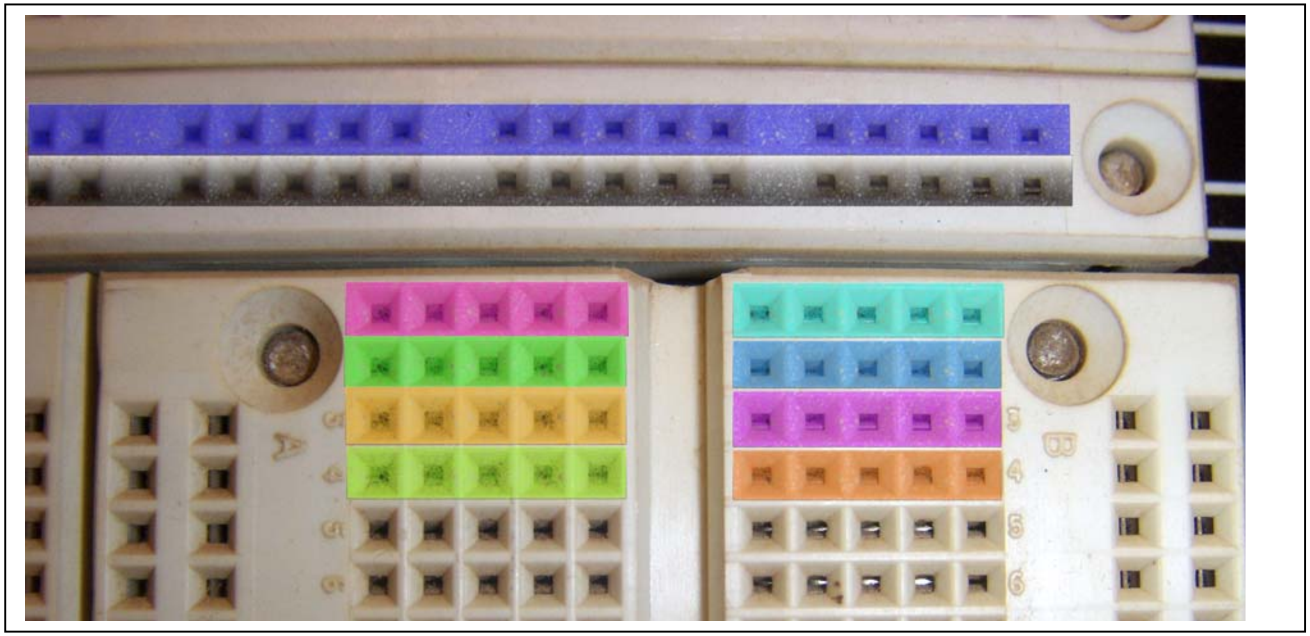
Then a BLUE binding post that similarly has an output of - 5 to -15 volts. You can FORGET about this output until at LEAST the first semester of your second year in CIE.

Then a BLACK binding post that we call by many names: Common, Ground, Chassis, and a few other less common names. You will notice to the right of the black binding post there is a small triangle (▼). This is the common symbol you will find on a schematic diagram for Common. Common is the reference point for all the other voltages and functions of the trainer. It is what we use when we measure (for instance) the +5, the +5 to 15, and the -5 to -15 supplies above.

If any of the voltages is accidentally shorted to common, the little red light by the on-off switch will light and the internal circuitry will protect the power supply from being damaged. We call this "current-limiting"

3. Note that each of the power supply binding posts has a line connecting it with a row of holes on the top two rows of wire connectors. The red binding post is connected to the top row, the yellow binding post is connected to the second row, the blue binding post is connected to the third row, and the black binding post is connected to the fourth row. What this means is that anywhere along the top row you wish, you can insert a wire and connect your circuit to the +5 supply. Likewise the yellow row will get you +5 to +15 volts, and the black row will get you common, or ground.

4. There are 384 5-hole rows on the main body of the trainer arranged in 3 columns of 128 double-rows. Here's the deal. On the picture to the right, you see the blue power supply row and the black ground row at the top. Just below that you see 7 rows of 10-hole connections. Those 10 hole connections are further divided by a white vertical column. On the top row, the 5 pink holes are connected ("tied") together and the 5 aqua holes are tied together. The pink and aqua holes are NOT tied together. In the second row on the left you have lime green on the left and pale blue on the right. Again, all the green holes are tied together ad all the blue holes are tied together but NOT to each other. And so on for 128 more rows on the board.



5. Now for the tricky one. Vertically next to each of the 5/10 hole rows are a double row of vertical holes (note that the camera was rotated 90° so that I could show the rows clearer.

Exactly as we have shown above, all the orange holes are tied together, all the green holes are tied together, all the purple holes are tied together and all the pink holes are tied together. However, they are NOT tied to each other or to any other points on the trainer.