Laboratory Manual
Everyday Electronics
GSCI 104

Syllabus
Notes & Handouts
Laboratory Projects
Weekly Note Sheets

PHYSICS DEPARTMENT JAMES
MADISON UNIVERSITY

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GSCI 104 Overview

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Course Description: Basic Electricity and Electronics

Text: This is provided, but you do need a calculator. You can use your cell-phone calculator.

Course Goal: Learn as much about electricity and electronics as possible primarily through hands-on projects, in a two-hour laboratory meeting once a week. The spirit of the course is to explore, play, and have fun. I expect learning to occur, and in learning about electronics we will learn about dynamics of systems in general, including such things as pressure, response, amplification, information, and simulation of electronic circuits through NI software MultiSim. You should keep a notebook (provided to you), noting in it the things you have learned.

Grading: Grades will be based on class attendance and a final project: You should come to class on time, and work until excused or until the scheduled end of class. Be sure I’ve recorded you. There are about 14 classmeetings during the semester. Each class you miss will reduce your final grade. If you come to class 15 minutes late, that’s one eighth of a class or one point. You’ve got to BE HERE. If you must miss a class, you must convince the instructor that you have a valid reason, and proofs may be required. For unexcused missed classes, the maximum grade will be 0=B, 1=B-, 2=C, 3=D, 4=F. If you want to get an A, you must complete a Final Project. You can make up a missed class by attending another section, with that instructor’s consent. There will be minimal homework and testing, focusing on very basic principles and subject matter every adult should know, or which you must learn to make the course viable. If the class has a good attitude, and shows interest in learning, then quizzes will not be necessary. If quizzes prove necessary, then 10% of the grade will be based on quiz scores.

Equipment: Equipment will be provided for work in the lab. This equipment is to be used exclusively in the lab. NO EQUIPMENT MAY BE TAKEN FROM THE LAB WITHOUT WRITTEN PERMISSION OF THE INSTRUCTOR.

Laboratory Safety: As with any lab safety is an issue. This lab is not subject to many hazards but accidents result whenever people become careless. Common sense and care are mandatory in any laboratory.

Safety Specifics:

Circuits may become very hot! The most common hazard in this lab is from circuits that over-heat when improperly connected. Wiring elements in a circuit invariably involves mistakes. You may fry some components. Components can burn and smoke. LEDs can pop. Components may become hot enough to burn your finger. Be aware of this and look for signs that components may be overheating. Often, the first warning is that you smell it. UNPLUG YOUR POWER SUPPLY if you think a circuit is overheating.

No bare feet in the lab. Occasionally integrated circuits are dropped on the floor, and they nearly always land with the pins pointing up. If you should step on one in bare feet, you will regret it.

Soldering Irons Melt Solder and Skin! Allow adequate space, and use a well-controlled and comfortable work area, with good ventilation. Turn off the iron when done. Be aware that solder and the iron become very hot and burn quickly. Also, be sure to keep the electric cord of the iron away from the hot tip.

No food or beverages in the lab: This is a rule recently imposed by OHSA.
# GSCI 104 Everyday Electronics, Spring 11 Class Tentative Schedule, Dr. Constantin

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Discussion Subject</th>
<th>Activity</th>
<th>Learn this for quizzes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jan 10-14</td>
<td>Electricity, AC &amp; DC current</td>
<td>Assign bins, and listen to the discussion about Circuits, Batteries, Voltage, Current, AC, DC, ground, house wiring and safety. Learn Ohm’s Law, P=IV and Metric Prefixes</td>
<td>Ohm’s Law, P=IV, and the metric prefixes¹</td>
</tr>
<tr>
<td>2</td>
<td>17-21</td>
<td>Protoboards</td>
<td>Wiring simple circuits: Distribute the power around the protoboard, and install an LED power indicator (LED with 150 ohm power resistor)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>24-28</td>
<td>Resistance</td>
<td>Use multimeters to measure voltage, current, and resistance. Combine resistances in series and parallel.</td>
<td>Know how resistances combine in series and parallel</td>
</tr>
<tr>
<td>4</td>
<td>Jan 31- Feb 4</td>
<td>Introduction to Circuit simulation software MultiSim</td>
<td>How to simulate with MultiSim circuits: series, and parallel resistor and capacitors. How to measure in MultiSim: voltages, and currents.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7-11</td>
<td>Voltage Dividers &amp; MultiSim</td>
<td>How to simulate and construct a resistance based voltage divider.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>14-18</td>
<td>Switches &amp; LEDs</td>
<td>Understand switches (SPST, DPDT, etc). Control a lamp with one, two, or three switches.</td>
<td>Know about SPST, DPDT, SPDT, etc, Switches</td>
</tr>
<tr>
<td>7</td>
<td>21-25</td>
<td>Op Amps</td>
<td>Understand basic properties of Op Amps</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Feb 28-Mar 4</td>
<td>Op Amps applications</td>
<td>Simulate and construct a Digital to Analog Converter</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>7-11</td>
<td>Break</td>
<td>Spring Break</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>21-25</td>
<td>Oscilloscopes</td>
<td>Measure wave-forms from a function generator, and a mike</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Mar 28-Apr 1</td>
<td>Final Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>4-8</td>
<td>Final Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>11-15</td>
<td>Final Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>18-22</td>
<td>Final Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>25-29</td>
<td>Final Project</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹**Quizzes**: If I say know Ohm’s law, that means you should be able to write V= IR, and know what the letters stand for. Or if I give you P=IV, you should know what this equation is about.

Lab overview: In most experiments, I will first lead you in a discussion, and then demonstrate what I want you to do. You are welcome to ask questions, but we'll cover a lot in two hours per week, so don't feel upset if there are some things you don't understand. Just follow my lead, learn what you can, and learn by doing.
WEEK 1: Assign bins, and listen to the discussion about Circuits, Batteries, Voltage, Current, AC, DC, ground, house wiring and safety. Learn Ohm’s Law, P=IV and the Metric Prefixes. Also, learn how to use and convert units.

I. Electrons and Atoms: Atoms consist of three kinds of particles—neutrons, protons, and electrons. Electrons and protons carry electric charge, which means that these two kinds of particles attract each other, just like planets and stars attract each other. The attraction between planets we call gravity, and the attraction between an electron and a proton we call static electricity. Through gravity, all masses exert a pull on each other, and the attractive force increases with the mass of the two particles. The force of gravity between two masses \( m_1 \) and \( m_2 \) is

\[
F_G = -\frac{Gm_1m_2}{r^2}
\]

where \( G \) is a constant, and \( r \) is the separation of the two masses. (The – sign shows the force is attractive.) The form of electric attraction is similar:

\[
F_E = \pm \frac{kQ_1Q_2}{r^2} \quad (1)
\]

But here, instead of masses, we have the charges, and the plus or minus sign shows that the force can be either repulsive (+), or attractive (−). \( k \) is a constant like \( G \). The proton’s charge is +e, and the electron’s charge is –e, where \( e \) is called the elementary charge. We can use \( e \) as the fundamental unit of charge. If a particle has the same number of protons as electrons, then it has zero net charge. If it has a \( N_p \) protons and \( N_e \) electrons, then the net charge is \( Q = (N_p - N_e)e \), so it can be have either a positive or negative charge, depending on whether there are more protons than electrons in it. The rule for charges is that charges of the same sign repel, and opposites attract.

In an atom, the protons and neutrons are massive and compact, and stick together in a small blob called the nucleus, with the much more massive electrons flying around it, like planets going around the massive sun. Since charges can be accelerated by nearby charges, without contact, we say that the space around each charge is filled with an electric field. When charges move they also create magnetic fields, which can deflect a compass needle.

2. Electric Current: In metals electrons can move easily from one atom to the next, so electrons can move through a copper wire like water flows through a pipe, and just like there is a current of water (gallons per second) flowing in the pipe, there is a current of electrons (charges per second) flowing in the copper wire. Since the electrons are moving, they make a magnetic field, and the deflection of a compass needle can measure how many charges per second are moving past the compass needle. There is also a small magnetic force between two wires carrying electric currents, and we define the unit of electric current in terms of this force. The international unit of electric current is the Ampere or amp, abbreviated A. The amount of charge flowing in the wire is the current multiplied by the time, just like the number of gallons coming out a hose nozzle is the current (gallons/second) multiplied by the time (seconds).

3. Electric Charge: The international unit of charge is the Coulomb (abbreviated C).

One Coulomb = 1C = 1 Amp x 1 second = 1As.
One Coulomb is a lot of electrons—approximately 6250000000000000000. This is too big a number to see, so we use exponential notation: \( 1C = 6.25 \times 10^{18}e \), where \( e \) is the charge of one electron. If we divide both sides of this equation by the big number, we can also write it as

\[
e = 1.6 \times 10^{-19} \text{ C} \quad (2)
\]
One Coulomb is a lot of charge. In fact the constant K in equation (1) above is $9 \times 10^9 \text{ N m}^2/\text{C}^2$. (N stands for Newtons, a unit of force, and m stands for meter.) A pound is 4.44N, so the force between two 1C charges separated by 1 cm is huge.

How big is this force in tons? _______________________________

A car battery can put out 1 A of current for 80 hours. How many seconds is this? ____ s. How many Coulombs can the battery send out? ____________C

3. Electrical Circuits: If the electrical forces are so large, then the electricity coming out of a battery CANNOT accumulate anywhere. If we just took a thousandth of a coulomb of charge from a battery, the attractive forces would easily be so big that no more charges could leave. So the only way to have electric current in a wire is for the wire to flow around a closed loop, called a “circuit” For every electron that flows out of a battery, another must flow into the battery.

Lesson: When your circuit isn’t working, look and be sure that there is a closed loop in which the current can flow.

4. Voltage: If there is a fire hose with water in it, the water doesn’t squirt out unless there is something to push the water through the hose. The water will only flow if there is a pressure difference between the ends of the hose. In electricity, the electrical pressure which pushes charge through, say a light bulb, is called the voltage. The electricity might be pushed by a battery, so the battery is doing work on the electrons, pushing them through the lightbulb. Energy is the ability to do work, so the battery must contain some energy.

In the metric system, the unit of energy is called a Joule (J), so if a 3 V battery pushes 5 coulombs of charge through a light bulb, then the amount of energy required is

Energy = voltage x charge = $3 \text{V} \times 5 \text{C} = 15 \text{J}$

A typical car battery produces 12 V, and it can produce 80 A for one hour. How many Joules of energy are in a typical fully-charged car battery? ________________J

If we have a fire truck with a pump, the pump can push the water through the hose with great force and speed. If $m$ is the mass of the water, and $v$ is its velocity, then the kinetic energy of the water is $E = \frac{1}{2} \text{mv}^2$, so the pump gives energy to the water. The “electrical pressure” which pushes electricity through, say, a light bulb, is called the voltage. You are used to think of pressure as a force divided by an area, as in pounds per square inch. In the metric system, the unit of force is the Newton, which is about a fifth of a pound, and the unit of area is the square meter, so the metric unit of pressure is the Newton per square meter. If you push on something with a force of 1 N, and you push it a distance of 1 m, then you have done an amount of work equal to 1 Nm, which is the force multiplied by the distance. The amount of work you did equals the amount of energy you expended, so energy is also force times distance. The metric unit of energy is the Joule (J), so if you push an object 3 m with a force of 2 N, how much work did you do? ________________J. How much energy is this? ________________J

5. Power: Power is the rate of doing work. The international unit of power is the Watt (abbreviated W).

$1 \text{W} = 1 \text{joule per second} = 1 \text{ J/s}$. If we let P be the power, then $P = \text{Work}/\text{time} = \text{energy}/\text{time}$. If the 12V 80A-hr car battery described above is discharged in 20 minutes, how much power is it producing? ____________________W

Note that Power = Energy/time = voltage x charge / time = voltage x current. That is, $P = IV$ where $I$ is the current and $V$ is the voltage. If the voltage in your house is 115 V, what is the current through a turned-on 60 W light bulb?
6. **Resistance:** To some extent, nearly every material resists the flow of electric charge, so if we connect a battery to a tungsten filament lightbulb, the amount of current I flowing through filament depends both of the voltage V of the battery, and on the resistance R of the filament. Twice as much voltage pushes twice as much current, and if the resistance increases, then the current decreases. The current equals the voltage divided by the resistance: \( I = \frac{V}{R} \). Equivalently, we can say that the voltage V required to push a current I through a resistance R is \( V = IR \). This is **Ohm’s Law**, and students usually memorize it this way. If a 100,000 ohm resistor is connected to a 1.5 V battery, how many amps of current flow through it? \( \_\_\_\_\_\_\_\_\_\_A \)

Not all materials obey ohm’s law, so what this really means is that the resistance R is the Voltage V divided by the current I. This DEFINES what we mean by resistance: \( R = \frac{V}{I} \). Saying that something obeys Ohm’s law simply means that R in this equation is approximately constant. The unit of resistance is the ohm, abbreviated with a capital Greek letter omega \( \Omega \). \( 1 \Omega = 1 \) V/A, or equivalently, \( 1V = 1A \times 1 \Omega \). If a 100 W headlight is connected to a 12 V car battery, what are the current being drawn from the battery and the resistance of the lamp? \( \_\_\_\_\_\_\_\_\_\_A \) and \( \_\_\_\_\_\_\_\_\_\_\Omega \)?

7. **AC and DC current:** AC is alternating current, and comes from generators. DC is direct current, and comes from batteries. Current flows from the positive terminal of the battery through a circuit, and then returns to the negative terminal. AC current flows alternately one way and then the other way through a device, and then returns to a grounded wire. In cars, electronic instruments, and other devices using DC, power wires are usually color coded with red wires connected to the positive battery terminal, and black wires connected to the negative battery terminal. We will follow that convention, so black wires will be used for “ground” wires.

8. **House wiring:** In house wiring there are three wires colored green, white, and black. The color coding is that green is a ground wire used for safety devices, which does not ordinarily carry electric current, WHITE is the current-carrying ground, and BLACK is the wire with the high voltage. If you touch the bare wire you will get a shock. It will probably not injure you, because of your high skin resistance. But if your hands are wet, or well connected metal, then the current may be high enough to be dangerous. 100 milliamps of current from one arm to the other is enough to cause your heart to malfunction (fibrillate), and 10 mA may cause loss of muscular control, which can be dangerous. “10 mils kills” is the handy expression. When working around electricity, remove all metal from your hands.

9. **The Metric Prefixes.** To remove the need to use exponential notation (e.g. \( 6.02 \times 10^{23} \)), the metric system makes use of prefixes representing various powers of 10. These are heavily used in electronics, so you need to learn them for this course.

<table>
<thead>
<tr>
<th>Name</th>
<th>Prefix</th>
<th>Factor</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>pico- (peeko)</td>
<td>p</td>
<td>( 10^{-12} )</td>
<td>A small capacitor is a few pF (picofarads)</td>
</tr>
<tr>
<td>nano-</td>
<td>n</td>
<td>( 10^{-9} )</td>
<td>A transistor can turn on in 1 ns (nanosecond)</td>
</tr>
<tr>
<td>micro-</td>
<td>µ</td>
<td>( 10^{-6} )</td>
<td>Typical circuit noise is 10 µV (microvolts)</td>
</tr>
<tr>
<td>milli-</td>
<td>m</td>
<td>( 10^{-3} )</td>
<td>The finest division on a 1 ft ruler is 1 mm (millimeter)</td>
</tr>
<tr>
<td>kilo-</td>
<td>k</td>
<td>( 10^3 )</td>
<td>A kilogram (kg) weighs 2.204 pounds</td>
</tr>
<tr>
<td>mega-</td>
<td>M</td>
<td>( 10^6 )</td>
<td>Hydrogen bomb energies are typically 1 Mton (Megaton)</td>
</tr>
<tr>
<td>giga- (as in giggle)</td>
<td>G</td>
<td>( 10^9 )</td>
<td>Microwave ovens operate at 2.4 GHz (gigahertz)</td>
</tr>
</tbody>
</table>

If a 0.47 M\( \Omega \) resistor is connected to a 1.6 V battery, what is the current in \( \mu \)A? \( \_\_\_\_\_\_\_\_\_\_\mu A \) (Since the resistance and voltage are given to 2 digit precision, the answer should be also.)

**Homework:** Memorize these, and know that \( V=IR \), and \( P=IV \) (Ohm’s law and electric power)
10. **The Resistor Color Code** is a convenient way to tell what the resistance is for a particular resistor. There are 4 colored stripes, and the LAST stripe is gold for a 5% accurate resistor or silver for 10%. The first two stripes give the resistance to 2-digit accuracy, and the 3rd tells how many zeros must be added. Tables showing the code are posted around the lab, and included here for completeness: Each color represents one of the ten digits. (See the table at the right.)

<table>
<thead>
<tr>
<th>Color</th>
<th>Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
</tr>
<tr>
<td>Gray</td>
<td>8</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
</tr>
</tbody>
</table>

Thus, if left to right, the colors on the resistor are orange, yellow, green, and gold, then the corresponding digits are 3 4 5 5% and the meaning is 3400000 $\Omega \pm 5\%$ or 3.4 M$\Omega$.

**Lab exercise:** Pick quarter-watt resistor from the supply bin WHICH IS DIFFERENT THAN THAT CHOSEN BY YOUR NEIGHBORS, and hold it so the gold or silver stripe at the right.

What are the four colors left to right? ______________________________

What are the corresponding 3 digits and tolerance? ______ $\pm$ __% 

What is the value of the resistance in ohms? _________________________

If this resistor is connected to a 5V supply, how much current flows through it, in amps? ______

From the above two answers, how much electric power in watts would it dissipate (turn into heat)? _________________________

Have your instructor initial this page and record that you're done for the day, put away your stuff, and enjoy the day. Initials: _________________________
WEEK 2. Using the protoboard

The prototyping board, or "Protoboard" provides a convenient way to assemble components into a working electronic circuit without having to solder.

Running down the center of the board is a gap called the channel. ICs (integrated circuits) must be inserted with each of the two rows of pins on either side, spanning the channel. Usually an IC is oriented with pin 1 on the upper left. On each side of the channel is the matrix consisting of holes into which components and stripped 22-gauge single-conductor wire are inserted to build a circuit. In the matrix, 5 holes are connected together in horizontal rows, on each side of the channel.

The matrix is used to connect various components together according to the plan of the designer. On each side of the matrix are 2 or 4 long strips of 5O holes called "buses". These should be used to distribute electric power around the protoboard. Exercises: First use red and black wire to distribute power to the buses. Keep the wires short and low to the board. Cut each wire to the right length, and strip off about 1/4 inch of insulation from each end of the wires. (0.3 inches is close enough, and that's the spacing of 3 holes on the board.)

After connecting the power buses, apply power to the board from a 5V modular power supply. Then install a power indicator in the lower left corner of the board. This will consist of a 150 to 220 ohm resistor, in series with an LED (Light-emitting diode). The diode only allows electricity to flow one way, so if it doesn't light up, try turning it around.

Lab exercise: Distribute power and install a power indicator on the board as described above. Then insert a transistor and an integrated circuit in the board properly, so that no two of the pins are "shorted together" (connected to each other). Connect a 5V modular supply to the board so that the LED's light. Then have your instructor initial this page and record that you've completed this experiment, then continue right on to the first two pages of the next lesson.

Completed: ___________________
WEEK 3: Learning to use multimeters to measure voltage, current, and resistance

Shown at the right is a multimeter which is typical in our teaching labs.

Looking at the list, you see the various sockets, and regions of the dial which select different functions.

Inexpensive multimeters are widely available in retail stores, and are so useful that there should be one in each of your homes, after you have completed this course. They can be used to see if there is electricity in a particular outlet, if your toaster is burned out, if a battery is "good", and to check for continuity in car wiring.

Things to remember:

1. The current scales have very LOW resistance. If you connect them directly to a battery or power supply, you may blow a fuse in the meter.

2. The voltage scales have very HIGH resistance. If you insert them into a current flow they will block the flow, and change what is happening in the circuit.

3. From item 1 above, you measure the current THROUGH a resistor or other circuit element by beaking into the circuit and inserting the current meter in series with the resistor. THE METER CAN ONLY MEASURE CURRENTS WHICH ARE FORCED TO GO THROUGH IT. The current being measured flows into the meter at the V, Ω, mA input, and out of the com (common) input.

4. From item 2 above, you measure the voltage ACROSS a resistor or other element, directly connecting two leads going to the meter to each side of the resistor. The meter displays the voltage at the V, Ω, mA input MINUS the voltage at the com input.

5. If the display seems frozen and unresponsive, then the Hold button has been pushed. Push it again to fix the problem.

6. Always leave the selector dial in the OFF position to avoid running down the battery.

We will now run through a number of laboratory exercises to learn how to use the protoboard.

Do all calculations and measurements to 3-digit accuracy. Using the most sensitive scale which works.
I. Ohm's Law and Measuring Resistances with a Multimeter

From Ohm's Law, \( V=IR \), the resistance of an conductor is the voltage difference of the two ends divided by the current through it: \( R=V/I \). The unit of resistance is the ohm (\( \Omega \)). \( 1 \Omega = 1V/1A \). Then \( 1 \, k\Omega = 1V/1 \, mA = 1V/1mA \).

Conductance is the inverse of resistance. The unit of conductance is the Siemens (S). \( 1S = 1/(1\Omega) \). The inverse of a \( k\Omega \) is a mS. Let the conductance of resistor \( R_1 \) be \( G_1 = 1/R_1 \), and so on for \( R_2 \), etc.

Two resistors are in series if exactly the same charges flow through each. The picture at the right shows several different arrangements of resistors wired in series. Resistances in series ADD. So the resistance from top to bottom of the three labeled resistors is \( R_S = R_1 + R_2 + R_3 \).

If \( R_1 \), \( R_2 \) and \( R_3 \) are each 10 \( \Omega \), what is \( R_S \)? _________

Two resistors connected in parallel are shown at the right. Resistors are in parallel if exactly the same voltage is applied across each. Because the wires have nearly zero resistance, Ohm's law tells us that there is no change in the voltage as we move along wires. Then all places along connected wires are at the same voltage. For resistances connected in parallel, the conductances add up to give the total conductance. So for the parallel combination of resistances shown at the right, the total conductance is \( G_P = G_1 + G_2 \), or equivalently, \( 1/R_P = 1/R_1 + 1/R_2 \).

If \( R_1 \) and \( R_2 \) are each 10 \( \Omega \), what is \( R_P \)? (Be careful on this one.) _________

Now select a 22 \( k\Omega \) and a 33 \( k\Omega \) resistor from the bins, and fill in the following table. Use the resistance scales to measure and record the actual values of \( R_1 \) and \( R_2 \). Connect \( R_1 \) and \( R_2 \) in series. Then measure the series resistance \( R_s \) using your meter _________

<table>
<thead>
<tr>
<th>Resistors in series</th>
<th>( R_1 )</th>
<th>( R_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal R values</td>
<td>22 ( k\Omega )</td>
<td>33 ( k\Omega )</td>
</tr>
<tr>
<td>Color Codes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured R values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductances ( G_1 ) and ( G_2 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculate the series resistance \( R_1 + R_2 \) from the table values ____________________

Do they agree within a few percent? ________ If not, correct your mistakes.
Calculate the parallel conductance from the table \( G_p = G_1 + G_2 \) ________________

Calculate the parallel resistance \( R_p = 1 / G_p \) ________________

Connect \( R_1 \) and \( R_2 \) in parallel. Measure the parallel resistance \( R_p \) ________________

Do the measured and calculated values of \( R_p \) agree within a few percent? ________
If not, correct your work.

What resistance would you put in series with YOUR 33kΩ resistance to get 35.0 kΩ? ________________
Pick a near value, wire it up on your protoboard, and measure the series resistance: ________________

What resistance would you put in parallel with YOUR 22kΩ resistor to get 20.0 kΩ? ________________
Pick a near value, wire it up and measure the parallel resistance: ________________

For the next part, we will use the voltage and current scales on the multimeter to check Ohm's law for resistors and an LED.

Get three 1/4 W resistors from the drawers, and an LED, and install them in lower left corner of your protoboard, as shown in the picture at the right. Then fill out the following table.

Measure the actual power supply voltage \( V_O \):
The supply voltage is \( V_O = \) ________V.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal R-values</td>
<td>Color Code</td>
<td>Measured R-values</td>
<td>( V_{LED} )</td>
<td>( V_R = V_O \cdot V_{LED} )</td>
<td>Current I</td>
<td>( V_{LED/l} )</td>
<td>( V_{R/l} )</td>
</tr>
<tr>
<td>150 Ω</td>
<td>Ω</td>
<td>V</td>
<td>V</td>
<td>mA</td>
<td>Ω</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>330 Ω</td>
<td>Ω</td>
<td>V</td>
<td>V</td>
<td>mA</td>
<td>Ω</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>560 Ω</td>
<td>Ω</td>
<td>V</td>
<td>V</td>
<td>mA</td>
<td>Ω</td>
<td>Ω</td>
<td></td>
</tr>
</tbody>
</table>

The columns are filled in as follows:
B. Read and record the color code, starting with the end which is NOT the gold stripe.
C. Measure and record the resistances using your ohm meter
D. Connect the AC power, and record the measured supply voltage \( V_O \). Then measure the voltage at the right-end of the LED when it is connected to each resistor consecutively using about 2 inches of wire. The COM jack on the meter must be connected to ground--which should be the BLACK wires.
E. Calculate this from $V_O$ and column D.

F. Remove the wire which connected the LED to a resistor, and disconnect the black lead of the meter from protoboard ground. Plug the red lead of the meter into the V-Ω-mA jack of the meter, and the black lead into the COM jack. Connect the right end of the LED to the black meter lead, and select the 200 mA current scale. Then consecutively connect red meter lead to the right ends of the 3 resistors, recording the currents flowing through the resistors, meter, and LED.

Questions: In column C, the resistance of the resistors was measured using the 1.5V battery in the meter. In column H, R was measured using the voltage $V_R$ shown in column E. IF the 56Ω resistor were obeyed Ohm's Law, then in the bottom row of the table, the resistances shown in columns A, C, and H should be approximately the same number. Did the 56Ω Ohm resistor obey Ohm's Law? __

Did the 15Ω resistor obey it? ________

Did the 33Ω resistor obey it? ______

If the resistance is constant when the current through the element changes, then we say it obeys Ohm's Law. Did the LED obey Ohm's Law? ________

SHOW your results, including measurements to your instructor, get checked off, then put away your stuff, and then have a nice day.

Instructors initials: ________________
WEEK 4: MULTISIM TUTORIAL

Start

Click on Start → All Programs → National Instruments → Circuit Design Suite 11 → Multisim.

1. **Open/Create Schematic**

A blank schematic Circuit 1 is automatically created. To create a new schematic click on File – New – Schematic Capture. To save the schematic click on File /Save As. To open an existing file click on File/ Open in the toolbar.

2. **Place Components**

To Place Components click on Place/Components. On the Select Component Window click on Group to select the components needed for the circuit. Click OK to place the component on the schematic.
For example to select resistors and the DC source shown in Figure 3 click on Place/Components. In Group select Basic scroll down to Resistors and select the value of the resistor needed to construct the circuit, for this example select 1k. To place DC source click on Sources in Group and select DC Source. As shown in Figure 1 and Figure 2 respectively.
Virtual Components

Components can also be placed on the circuit using Virtual components. Click on View – Toolbars and select the toolbar needed for the circuit.

4. Rotate Components

To rotate the components right click on the Resistor to flip the component on 90 Clockwise (Ctrl +R) and 90 Counter Clockwise (Ctrl+Shift+R).

5. Place Wire/Connect Components

To connect resistors click on Place/Wire drag and place the wire. Components can also be connected by clicking the mouse over the terminal edge of one component and dragging to the edge of another component. Reference Figure 6.
6. **Change Component Values**

To change component values double click on the component this brings up a window that display the properties of the component. Reference Figure 7. Change R1 from 1k Ohm to 10 Ohms, R2 to 20 Ohms, R3 to 30 Ohms, and R4 to 40 Ohms. Also change the DV source from 0 V to 20 V. Figure 8 shows the completed circuit.
7. **Grounding:**

All circuits must be grounded before the circuit can be simulated. Click on Ground in the toolbar to ground the circuit. If the circuit is not grounded Multisim will not run the simulation.

![Ground](image1)

**Figure 9:** Grounding

8. **Simulation:**

To simulate the completed circuit Click on Simulate/Run or F5. This feature can also be accessed from the toolbar as shown in the Figure 10 below.

![Simulation](image2)

**Figure 10:** Simulation
Analyzing Components

Multisim offers multiple ways to analyze the circuit using virtual instruments. Some of the basic instruments needed for this lab are described below.

1) **Multimeter**

Use the Multimeter to measure AC or DC voltage or current, and resistance or decibel loss between two nodes in a circuit. To use the Multimeter click on the Multimeter button in the Instruments toolbar and click to place its icon on the workspace. Double-click on the icon to open the instrument face, which is used to enter settings and view measurements.

![Multimeter](Image)

**Figure 11: Multimeter**

To measure Voltage place multimeter in Parallel with the component (Resistor, Voltage etc). To measure Current place the multimeter in series with the component. Reference the Figure 12 and 13.

![Measure Voltage](Image)

**Figure 12: Measure Voltage**

![Measure Current](Image)

**Figure 13: Measure Current**
2) **Wattmeter**

The wattmeter measures power. It is used to measure the magnitude of the active power, that is, the product of the voltage difference and the current flowing through the current terminals in a circuit.

![Wattmeter Icon](image1.png)

**Figure 14: Wattmeter**

To use the instrument, click on the Wattmeter button in the **Instruments** toolbar and click to place its icon on the workspace. The icon is used to wire the Wattmeter to the circuit. Double-click on the icon to open the instrument face, which is used to enter settings and view measurements. Reference Figure 15 for more details.

![Wattmeter Connection Diagram](image2.png)

**Figure 15: Wattmeter Connection**
3) Agilent Multimeter

1. The Agilent Multimeter Instrument can also be used to measure and simulate circuits with more accuracy. To use the multimeter click on the Agilent Multimeter tool button, place its icon on the workspace and double-click on the icon to open the instrument. Click on the Power button to switch on the instrument. For more information Reference MULTISIM Instruction Manual.pdf

![Figure 16: Agilent Multimeter.](image)

4) Ammeter:

The ammeter offers advantages over the multimeter for measuring current in a circuit. It takes up less space in a circuit and you can rotate its terminals to suit your layout. **Always connect the ammeter in series with the load.** To place Ammeter click on View--- Toolbar --- Select Measurement Components. See Figure 17 on how to use the Ammeter.

![Figure 17: Ammeter](image)
5) Voltmeter

The Voltmeter offers advantages over the multimeter for measuring voltage in a circuit. Always connect the voltmeter in parallel with the load. The voltmeter can be found in the measurement toolbar.

Figure 18: Voltmeter

Note: This tutorial offers an introduction to Multisim which includes description and examples on how to use basic instruments needed for GSCI104 labs.
WEEK 5: VOLTAGE DIVIDERS

In electronics, a voltage divider (also known as a potential divider) is a simple linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Voltage division refers to the partitioning of a voltage among the components of the divider.

The formula governing a voltage divider is similar to that for a current divider, but the ratio describing voltage division places the selected impedance in the numerator, unlike current division where it is the unselected components that enter the numerator.

A simple example of a voltage divider consists of two resistors in series or a potentiometer. It is commonly used to create a reference voltage, and may also be used as a signal attenuator at low frequencies.

A voltage divider referenced to ground is created by connecting two electrical impedances in series, as shown in Figure 1. The input voltage is applied across the series impedances Z1 and Z2 and the output is the voltage across Z2. Z1 and Z2 may be composed of any combination of elements such as resistors, inductors and capacitors.

Applying Ohm’s Law, the relationship between the input voltage, Vin, and the output voltage, Vout, can be found:

\[ V_{out} = \frac{R_2}{R_1 + R_2} \]

Materials:
DC Power Source 2-10KΩ Resistors 9 Volt Battery
DMM 1-22KΩ Resistors 47 Ω Resistor
Protoboard Variable Resistor Box 1 kΩ Resistor
1.5 kΩ Resistor 1.8 kΩ Resistor 3.3 kΩ Resistor
4.7 kΩ Resistor

Procedure:
1. Use the DVM as an ohmmeter. Check out socket board using the 2 kohm scale. Stick resistors into holes (see the illustration). Use the ohmmeter to determine which rows are connected. What is your “zero” reading (obtained by shorting red to black on your ohmmeter).
2. Measure $V_{AD}$, $V_{AB}$, $V_{BC}$, $V_{CD}$. Choose, as you always should, the scale that gives you the most digits without being overloaded. Don’t remove anything from your board.

3. Voltage Divider.

If you’re clever you can go from circuit in Fig. 2 to the one in Fig. 3 by moving one end of one wire.

GROUNDS & COMMON: Notice that we want you to “measure V”. The first time you might ask “V with respect to what?” or “V across what object?”. The answer always is: UNLESS SPECIFIED, we mean V with respect to ground (or common). In this circuit we take the bottom of the battery (negative side) to be ground, and common. True grounding would imply you’ve connected the negative of the battery (our common) to a water pipe and hence to ground. Ground and common are very confusing at first - in the lab you often don’t have a true ground in your circuit, just high and low voltages. We take the negative side of the battery to be common by custom and convenience.

You are expected to come up with the appropriate formula for V in Figure 3 terms of $V_o$, $R_1$, and $R_2$. Check your text or class notes.

Lastly but not last, construct and simulate the VOLTAGE DIVIDER circuit above in MultiSim.

Instructor’s Initials:________
WEEK 6: SINGLE POLE SINGLE THROW (SPST), AND DOUBLE
POLE DOUBLE THROW (DPDT) SWITCHES

In the simplest case, a switch has two pieces of metal called contacts that touch to make a circuit, and separate to break the circuit. The contact material is chosen for its resistance to corrosion, because most metals form insulating oxides that would prevent the switch from working. Contact materials are also chosen on the basis of electrical conductivity, hardness (resistance to abrasive wear), mechanical stress, low cost and low toxicity.

Sometimes the contacts are plated with noble metals. They may be designed to wipe against each other to clean off any contamination. Nonmetallic conductors, such as conductive plastic, are sometimes used.

Switches come in different sizes and shapes. In this lab we will explore two types of switches, mainly SPST, and DPDT.

1. SPST also called SINGLE POLE SINGLE THROW switch is the simplest ON/OFF switch (Fig.1).

![Figure 1 SPST switch]

2. DSDT also called DOUBLE POLE DOUBLE THROW switch is equivalent to two SPDT switches controlled by a single mechanism: A is connected to B and D to E, or A is connected to C and D to F (Fig. 2).

![Figure 2 DSDT switch]

In this experiment we will control a lamp with one, two or three switches.
**WEEK 7: OPERATIONAL AMPLIFIERS**

In this section, we will see some of the magic which can be done with operational amplifiers, or “op amps”. We will use simple op amp circuits using the Black magic of negative feedback to do calculations electronically, and using positive feedback to create a “Schmitt trigger” which we will use a thermostat. (Note: I call negative feedback Black magic, because it was invented by an engineer named Harold Black.) Negative feedback gives smoothed controlled signals. Positive feedback on the other hand gives rapid sudden changes in quantities. For example, in economics, positive feedback is getting rich on flipping houses when prices are rising, and getting poor when people don’t want to sell (or buy!) because house prices are falling. Electronics can emulate economics!

The calculation we will do will be to use an op amp to eliminate the 0.5 V “error” in $V_T$, more precisely to get $V_{T2} = 0.01 \ T \ V^\circ C$, and then to use an op amp to also give a voltage proportional to the Fahrenheit Temperature, letting the electronics do the conversion.

An operational amplifier is a high-gain, high-input-resistance difference amplifier. It is often in an 8-pin DIP (dual in-line package), and may also be purchased 2 or 4 amps on a chip, which makes them cheaper than transistors. Typical voltage gains are $A_V = 10^7$ to $10^8$, and typical input resistances are $10^7$ to $10^{12}$ ohms. There are many different op amps on the market. We will be using the Op-1. The pin-diagram and schematic are shown at the right. The input pins are $V^-$ and $V^+$. Notice that the voltages we’ll use are $+ 12 V$. Op amps can be used with 0 and 5V supplies but it is simpler to use $\pm 12 V$. Your instructor will show you how to use the triple power supplies which provide outputs color-coded as shown below.

The behavior of an op amp is summarized by the equation $V_{OUT} = A(V^+ - V^-)$, where A is a large number (typically a hundred thousand to a million. However, the output voltage must be between the positive and negative supply voltages. So what the above sentences means is that the op amp is good at amplifying small voltage differences.

<table>
<thead>
<tr>
<th>Triple Power Supply Connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground</td>
</tr>
<tr>
<td>5V</td>
</tr>
<tr>
<td>+12V</td>
</tr>
<tr>
<td>-12V</td>
</tr>
</tbody>
</table>
WEEK 8: DIGITAL TO ANALOG CONVERTER

In this lab we will learn how to convert digital data 4-bit words data (e.g. 0000) into analog data (e.g. 0, 1, 2, 3 …). The circuit consist of two 741 op-amp, and 10 resistors that have values ranging from 800 Ω to 8 KΩ. The schematic of the inverter and digital to analog converted (DAC) is presented below:

Figure 3 (DAC) Digital to Analog Converter

As you can see the whole circuit is made up of a inverter circuit (shown on the left side) and a DAC circuit which is actually a simple adder. The reason we have to use the inverter circuit is because we don’t have a source of -10 V, therefore a adder circuit takes a voltage input of 10 V and inverts it to -10 V which in turn becomes the input of the DAC circuit.

P1. Draw the circuit diagram in Multisim and verify that is working by performing a simulation. Put the results of the simulation in your lab reports including the multisim diagram.

P2. By closing different switches on the DAC (in our case, by connecting wires on the -10 V rail, because we don’t have so many switches), complete the table listed below:
<table>
<thead>
<tr>
<th>SW4</th>
<th>SW3</th>
<th>SW2</th>
<th>SW1</th>
<th>Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>1</td>
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<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

If you need any help connecting the op-amps please read the instructions below or ask the instructor to show you how to do it.

GOOD LUCK!
On the left we show an Opamp (741) with all wires indicated on the schematic diagram. The power supplies (+12 and -12 Volt) are shown as separate batteries, but of course they are going to come from an electronic power supply. On the right is a sketch of how the wire and your power supply might actually be connected.

You should notice where ground is: the black terminal between +12 and -12 is the "common" and becomes ground when you connect it to a ground on the oscillator or on your oscilloscope. The power supply also has a +5 Volt output (the right hand side) which is used in the second experiment. ITS BLACK TERMINAL "FLOATS" - you must connect the two black terminals if you're using both of the power supplies.

The input voltage (from an oscillator, for example) isn't shown but we assume that you will connect the low or ground of the input to the ground shown.

CONNECTING:

Where's PIN 1? Look at the data sheet (next page, look for the notch on the IC package OR look for the little dot on the package and you should be able to orient your chip properly). If you retained the pin diagram for the 555 timer, there is also a diagram of an 8-pin DIP package in that diagram

Do the +12 and -12 connections first. They're ALWAYS needed and never change. Use stripped wires – not alligator clips or banana plugs for these permanent connections.

It's NICE to make the outside strips on your socket be the power supplies OR be ground. The picture above has ground going directly to Pin 3 of the OP AMP. This is NOT the best way because for a later circuit Pin 3 is NOT ground, and we will have to move the ground wire from the power supply. Better to make the inner strip on the socket board ground and run the -12 V supply directly to pin 4.
### Op-amp parameters

<table>
<thead>
<tr>
<th>Power Supply Type</th>
<th>Output swing</th>
<th>Input slew rate</th>
<th>fcutoff</th>
<th>A open-loop</th>
<th>Input offset (V/us) MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP07</td>
<td>15 V, max</td>
<td>Bipolar VCC -1.0 V VCC -1.0 V</td>
<td>0.17 0.6</td>
<td>200 K</td>
<td>10 µV</td>
</tr>
<tr>
<td>411</td>
<td>15 V, max</td>
<td>Bipolar VCC -1.0 V VCC -1.0 V</td>
<td>15 4</td>
<td>100 K</td>
<td>500 µV</td>
</tr>
<tr>
<td>741</td>
<td>15 V, max</td>
<td>Bipolar VCC -1.0 V VCC -1.0 V</td>
<td>0.5 0.6</td>
<td>20 K</td>
<td>6 mV</td>
</tr>
<tr>
<td>356</td>
<td>15 V, max</td>
<td>Bipolar VCC -1.0 V VCC -1.0 V</td>
<td>12 4.5</td>
<td>200 K</td>
<td>10 mV</td>
</tr>
<tr>
<td>LT1013</td>
<td>10 V, max</td>
<td>Unipolar rail-rail +rail to -rail</td>
<td>0.2 0.6</td>
<td>2000 K</td>
<td>100 µV</td>
</tr>
</tbody>
</table>

### Diagrams

- **8-Fin DIP (Op Amp)**
- **Dual Op Amp**
- **Quad Op Amp**
WEEK 9: OSCILLOSCOPES

Purpose: To learn the basic operation of the oscilloscope, and use it to measure voltage and frequency.

Background: In direct current circuits (dc), the current and voltage do not change direction with time. However, in alternating current (ac) circuits, both current and voltage vary in magnitude and direction. The time for one complete cycle of the voltage or current is called the period, T, and is measured in seconds. The inverse of the period is called the frequency, f.

Frequency is measured in cycles per second or hertz (Hz).

In the United States the electric utility companies supply current and voltage with a frequency of 60 Hz. Alternating currents and voltages are generally specified in terms of their root mean square (rms) values. The rms value, \( V_{\text{rms}} \), is related to the peak value, \( V_{\text{pk}} \), by

\[
V_{\text{rms}} = \frac{V_{\text{pk}}}{\sqrt{2}}
\]

and

\[
I_{\text{rms}} = \frac{I_{\text{pk}}}{\sqrt{2}}
\]

where

- \( V_{\text{pk}} \) = peak voltage (maximum voltage)
- \( I_{\text{pk}} \) = peak current (maximum current)

A peak to peak voltage \( V_{pp} \) is also sometimes used. The peak to peak voltage is the voltage difference between the maximum and the minimum voltages obtained by the signal. For sine wave dependences \( V_{pp} \) will be twice \( V_{pk} \).

The oscilloscope is a tool for displaying voltage as it varies with time. The observed variation of the voltage with time is called the waveform of the voltage. The variation of current with time may also be observed by measuring the voltage produced by a current flowing in a resistor of known value.

---

1K.L. Giovanetti
Copyright: "James Madison University"
**OPERATION AND USE OF THE OSCILLOSCOPE**

The oscilloscope is described in many text books. You may need to read more about their use and operation outside of the classroom. Examine the front of the oscilloscope. Some of the control knobs perform simple and obvious functions others allow the oscilloscope to be used as a sophisticated signal analysis instrument. NOT all of the controls need to be mastered to perform this lab. For a description of any of the features of the oscilloscope not adequately described in this handout the student is referred to the oscilloscope instruction manual. This manual will be available during the lab if requested.

Using the oscilloscope in a straightforward manner is simple. However the student is typically overwhelmed by the number of options and settings available. Any written description of the operation of the oscilloscope tends to get complicated by the many uses of the oscilloscope. At the beginning of this lab period the instructor will demonstrate how to operate the oscilloscope. Students are expected to follow the operations demonstrated and repeat them at their lab station. Students should pay particular attention during this introduction. This lab contains some step by step (but not all) procedures for accomplishing the required measurements in parentheses. However if the student has grasped the fundamentals presented in the introduction, he/she can merely adjust the oscilloscope so as to make the required measurements. If you are confused consult your instructor.

**Procedure**

I. Oscilloscope

1. Begin by setting the controls as indicated by instructor. Turn on the power. One or two horizontal lines should be displayed on the oscilloscope.
2. Adjust the brightness and the focus.
3. Adjust so that the positioning of the traces on the display seems reasonable.
4. Choose a channel. Note how the trace appears. Change the setting of the sweep time until you obtain a clear understanding of the sweep control. You should be able to slow down the oscilloscope sweep until a dot is seen moving across the screen.

II. **Measuring DC Voltage**

1. Set the sweep time to 1 ms. Note the vertical position of the trace.
2. Connect a battery or your DC power supply across the input of channel 1. (Inputs are BNC connectors. The cables on the wall have ends that attach to the scope (BNC) and ends that attach to batteries (banana plugs).
3. Adjust the Volts/cm so that the power supply shifts the trace 2 to 3 centimeters. Make sure the red knob is in the calibration position (fully clockwise). Continue to adjust the Volts/cm. Observe the effect on the display.

   The input voltage can be measured according to the following formula:

   \[
   \text{MEASURED VOLTS} = (\text{trace displacement (boxes)} \times \text{(Volts/cm)})
   \]

4. Measure and record the voltage of the power supply.
5. Reverse the battery connection to the input. Measure and record the voltage of the battery in this configuration.
III. AC Voltage Measurements.

1. Connect the 5 volt ac terminals on the transformer to the channel 1 input. Connect the transformer to the 120 Volt ac power (same as the above description for connecting the battery).
2. Adjust the Time/cm control so that several periods of the ac sine wave form are displayed (Be sure that you can see a trace on the screen. A setting of 10 ms should work.)
3. Adjust the trigger level and notice how the starting point of the trace changes. If the oscilloscope were to trace a regular pattern starting at random starting points on the pattern, the result would be confusing. Imagine taking a pile of transparencies all with the exact same image but oriented randomly. The image would only be discernable if the transparencies were aligned. An oscilloscope uses trigger circuitry to insure that the voltage pattern is displayed in the aligned form. By playing with the trigger adjustments you can see how to choose the starting point on the displayed waveform.

(Triggering is probably the most difficult aspect of scope usage. Be sure that the triggering buttons on the input module are set so that your input will trigger the scope. Ask your instructor for help if you cannot figure out how to trigger your scope.)
4. Measure the peak voltage of the waveform and calculate the rms voltage of the transformer.
5. Measure the period of the waveform and calculate the frequency.

IV. Waveforms and the sine wave generator.

1. Attach an output of the signal generator to one of the input channels of the oscilloscope. Switch the signal generator to the sine wave mode. The switch is located on front of the signal generator.
2. Adjust the oscilloscope to get a reasonable display.
3. Measure and record the period, frequency, peak voltage and the percent difference between the dial reading and the measured frequency of this 300 Hz wave.
4. Repeat for sine waves of 3000 Hz and 30,000 Hz.
5. Switch the signal generator to square wave mode.

V. Lissajous Figures and Frequency Measurement.

When sine waves are connected so as to control both the vertical and the horizontal displacement, the resulting display depends on the frequency ratio and the relative phase of the two input signals. When the frequency ratio is a simple integer, a definite pattern known as a Lissajous figure is formed. If the two frequencies are exactly the same, either an ellipse or a straight line will be observed. By adjusting frequency so that a Lissajous figure is formed between a known and an unknown oscillator the unknown frequency can be set or measured within the accuracy of the known oscillator frequency. If the two frequencies have an integer ratio some other Lissajous pattern is formed. If the ratio is nearly (but not exactly) an integer, the pattern varies with time. In order to use the oscilloscope in this manner, the two sine waves are input into the oscilloscope. One sine wave is applied to the channel 1 input and the other applied to input 2.

1. Connect the 5-volt ac transformer to the channel 1 input and set the volt/cm control. Assume that the transformer is operating at 60 Hz. This will be the known oscillator.
2. Connect the sine wave generator (input 2). Set the sine wave amplitude to 1 Volt and the frequency to 60 Hz. The generator will be considered the unknown frequency.

At this point you can view both signals on the scope. By switching the triggering back and forth between the two channels you can adjust the oscilloscope and the oscillator so that both signals have about the same frequency and amplitude.

3. You now need to set the oscilloscope to x-y mode. This allows one input to push the dot up-down while the other input controls the left-right motion. The time base mode that we have been using uses the inputs as up-down and moves left-right based on the chosen time/division setting. X-Y mode is set by moving the channel select slide to x-y and choosing x-y (rather than normal) on the trigger panel.

Note: A useful exercise is to remove the channel one input to see what happens and then replace channel 1 and remove channel 2. The frequency generator can be set to a very low frequency and it can be used to perform an additional test where you input into one channel only a very slowly changing voltage. Now you can see how each channel responds in x-y mode because the changes are occurring slow enough to see with the naked eye.

4. Carefully adjust the oscillator frequency until a stationary elliptical or circular pattern is displayed. Make a sketch on your data sheet.

4. Find the Lissajous patterns for the sine wave generator frequencies of 120 Hz, 30 Hz, 20 Hz, 180 Hz, 40 Hz, and 100 Hz. Sketch these patterns on your data sheet. (Note: The frequency dial on your generator may be accurate to only 10 % and may have to be adjusted slightly to get the stable figure.)

Microphones are available so that sounds can be converted into electrical signals and these can be displayed on the oscilloscope. The microphones are small metal cans with a red and black wire attached as shown in the top figure. The bottom figure shows how to make the electrical connections. Ignore the components shown in the box. They are the internal part of the microphone. The two lines coming out of the box are the red and black wires. The diagram tells you that one wire from the microphone (red) will go to a resistor and also to the oscilloscope (use a special scope cable). The other wire (black) needs to be attached to ground. Complete the circuit as shown above and then set the oscilloscope to the settings shown.
Appendix A: Debugging Circuits

Steps in debugging a circuit.
1. If something smells hot, PULL THE PLUG! Then find the overheating component, and replace it if necessary.

2. Do a visual inspection, seeing that wires are connected where they should be, and aren't where they shouldn't be. If you find an error, fix it, and try the circuit again.

3. Check the power supply connections: Disconnect the power supply, and connect one of the multimeter leads to the 5V terminal. Set the multimeter to the continuity checker, and make sure it beeps for continuity. Then use the other multimeter lead to probe all pins making sure that pins which should have 5V are connected, and those which shouldn't be aren't.

4. Repeat step 3 for the power supply ground.

5. Check the operating voltages: Re-energize the circuit being tested, connect the circuit ground to the multimeter com jack, and in the V-c-mA jack insert a lead with an alligator clip, and securely fasten a piece of 22 gauge wire to the alligator clip. Then check the circuit voltages on the pins to see if the voltages are right or reasonable. If you find one that isn't try to find the cause of the incorrect voltage.

6. Locate the instructor and stand up and call out "Mayday! Mayday!" which is French for "Help me!" Hey, that's what you're paying him for.