EE221L Lab Experiment #1

**Topic:** Equipment Familiarity and Power Measurements

**Date:** 25 January 2007

**Preliminary:**
1. Bring your lab notebook and textbook.
2. Review the “Memorandum Reports for EE/CENG Projects” (attached) for guidelines on using your lab notebook and writing your lab report.

**Introduction:**

The purpose of this experiment is to get familiar with or review the lab equipment, and to reinforce the material covered in chapter 11 of the text.

**Prior to Lab Period:**
1. General: Read the entire experiment and plan your equipment setup ahead of time. Place the sketches and schematics in your lab notebook.
2. Prepare a sketch of the equipment setup, including power supply, components, and measurement equipment which you plan to use to make the **CURRENT AND VOLTAGE** measurements. Super neatness isn’t important here, this is your plan, which may change when you actually get to the lab and see what test equipment is actually available.
3. Draw a schematic of the circuit, including the measurement equipment, which you will use to take the voltage and current measurements.
4. Prepare a sketch of the equipment setup, including power supply, components, and measurement equipment, which you plan to use to make the **POWER** measurements.
5. Perform a PSpice simulation of each schematic. Output of the simulation should at least contain:
   a. Voltage across each circuit element
   b. Current through each circuit element
   c. Power generated by or absorbed by each circuit element.
   d. Place the data from a) through c) in your lab notebook.
6. Perform a “hand analysis” of the circuit to obtain:
   a. Voltage across each circuit element
   b. Current through each circuit element
   c. Power generated by or absorbed by each circuit element
   d. Place results of your hand analysis in your lab notebook.
   e. The reason for this is to completely understand what you are expecting from the circuit. It is very common, but not very wise, to trust a fancy chart generated by an expensive simulation tool which may only be producing the “garbage out” part of the equation.

**Circuit:**

1. This experiment involves investigating the following circuit elements connected in parallel:
   a. \( v_s(t) = 56.57 \cos(377t) \) volts. The source will be the output of a variac connected to the 120vac power mains. \( f=60 \) Hz. \( V_{rms} = 40 \) volts.
   b. \( L = 100 \text{ mH} \), \( R_L=6.6 \Omega \)
   c. \( C = 25 \mu\text{F} \)
   d. \( R = 100 \Omega \).
In the Lab

1. In several of the sections below, you are asked to have the TA review the setup before proceeding to the next step. This is to minimize the chance of damaging or destroying our department’s test equipment, and to ensure your own personal safety. As you become more familiar with the test equipment, you will be able to confidently make measurements without undue risk.

2. The most common **MISTAKES** made in the formative years of lab work (and also occasionally by the most seasoned practitioners) are:
   a. Applying short circuits across power sources causing lots of heat, sparks, and smoke (be careful with test lead placement and low values of impedance across the output of the power source).
   b. Making voltage measurements with the test leads in series with the component (voltages are always measured with the meter leads across a component, and the circuit is powered up).
   c. Making current measurements with the test leads in parallel with the component (current is always made with the meter leads in series with the component, and the circuit is powered up, but a break in the circuit is required to add the current meter in series).
   d. Making resistance measurement with power applied to the component (always remove one leg of the component from the circuit, or the entire component from the circuit, to make a resistance measurement).
   e. Making measurements with the range selector of a meter in a low range, accidentally causing too much current to flow through the meter destroying the meter movement or digital measurement device (start at higher ranges, and then work down toward the lower values until expected meter deflections or digital values become evident).
   f. Touching a bare wire with your fingers and receiving a shock (always make measurements with one hand only – don’t put yourself in a position where current can flow through your arms and chest, or from your arms through your body to your feet which might be near ground potential).

3. Keeping a reasonably neat benchtop during the experiment helps to ensure that you maintain the proper connections, and that jumper wires remain securely connected to the components.

4. Thanks in advance for your attention to personal and equipment safety.
Equipment Familiarization & Review

1. Work in groups of 2 or 3.

2. 9202 Digital Multimeter
   a. The 9202 is a hand-held multimeter that we will use to measure voltage and resistance. We will NOT use it to measure current or power.
   b. Plug a red test lead into the “VΩmA” receptacle.
   c. Plug a black test lead into the “COM” receptacle.
   d. Turn the function select rotary switch to the 2000 Ω scale. Separate the ends of the test leads so that they are not touching. The left-most digit of the display should read “1”. This indicates that there is an open circuit (R=∞ Ω). If there is no display readout, check with the TA to make sure that the batteries in the meter are ok.
   e. Short the ends of the test leads together. The display should read “000”. This indicates a short circuit (R=0 Ω).
   f. Record the following data in your lab notebook:
      i. the date and time
      ii. the types of measurement equipment you are using (make & model #, serial # if there is one).
      iii. function switch setting.
      iv. the circuit you are testing. In this case, it will only be a “resistor” of 0 or ∞ value.
      v. results of the short and open circuit test (the display reading).
      vi. a tentative conclusion. Perhaps something like: “The multimeter seems to be measuring resistance as expected.” Or “I was expecting to see a readout of “000 ∞”, but I saw “020 ∞ instead. There is an offset being introduced somewhere. The test lead contacts were cleaned because they looked corroded and shouldn’t be adding resistance due to corrosion.” Or anything else that is noteworthy or unexpected.
   g. Note: this may seem like a lot of obvious information to enter in your log book. But it is useful if, after going back to your desk or office and analyzing your data, something doesn’t make sense. You can then go back to the lab and re-take your measurement. You will often find that you did not document nearly enough of your setup and measurements to decide where a problem may lie after the fact, and you are many miles and hours distant from the lab. Sometimes you will be able to isolate a faulty piece of test equipment if you document all of your settings and some details about the equipment. There probably isn’t such a thing as too much information entered in your log book. Don’t confuse your data taking activities with your reporting activities. Your report should look organized and professional, with some well thought out conclusions. But your raw data can be in any format that you (or someone else) can figure out later. Don’t be afraid to enter questions that come to mind, or something that didn’t quite look right.
   h. Record this same information - per i) through vi) above - for each of the measurements taken in the remainder of the experiment.
3. Power Resistor
   a. The power resistor is a large potentiometer (pot). Review section 2.8.2 of your text. Its physical configuration and schematic are shown below:

   ![Power Resistor Box](image1)
   ![Schematic of Power Resistor Box](image2)

   b. For the following measurements, nothing except the multimeter should be connected to the pot.
   c. Adjust the pot so that the indicator is approximately in the 12:00 position.
   d. Select the 2000 Ω range of your multimeter.
   e. Connect the black test lead to the red terminal of the pot. Connect the red lead to the yellow terminal of the pot. Record the resistance.
   f. Reverse the red and black test leads. Record the resistance.
   g. Connect the black test lead to the green terminal of the pot. Connect the red lead to the yellow terminal of the pot. Record the resistance.
   h. Reverse the red and black test leads. Record the resistance.
   i. Connect the black test lead to the red terminal of the pot. Connect the red lead to the green terminal of the pot. Record the resistance.
   j. Does it make any difference which way the test leads are connected when making a resistance measurement? Why?
   k. Would you ever want to make a resistance measurement in a circuit that is powered up?
   l. With the red test lead connected to the red jack, and the black test lead connected to the yellow jack, make a table of resistances vs. adjustment knob position. For example:

<table>
<thead>
<tr>
<th>Position</th>
<th>R Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full CCW</td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td></td>
</tr>
<tr>
<td>9:00</td>
<td></td>
</tr>
<tr>
<td>....</td>
<td></td>
</tr>
<tr>
<td>4:00</td>
<td></td>
</tr>
<tr>
<td>5:00</td>
<td></td>
</tr>
<tr>
<td>Fully CW</td>
<td></td>
</tr>
</tbody>
</table>

   m. Record the serial number of your pot.
   n. Record the maximum amperage specified for this pot (indicated on the front of the pot, no measurements to be done).
   o. Re-draw the schematic of the pot in 2.a above. Indicate its maximum and minimum resistance values.
   p. Do you think it would be more likely to destroy this pot (remembering that p=iv) with its setting near its CCW or its CW position? Why?
4. Power Inductor
   a. The power inductor is a coil of wire wound around a magnetic core. Review section 6.4 of your text. Its physical configuration and schematic are shown below:

   ![Power Inductor Diagram]

   b. Bring your inductor to the TA to get a measured value of its inductance.
   c. Since the inductor consists of turns of wire, it will have resistance. Measure the resistance of the inductor.
   d. Draw an equivalent circuit of the inductor (showing its resistance and inductance).
   e. What is its impedance in rectangular representation? In phasor representation?

5. Capacitor Bank
   a. The capacitor bank contains 6 capacitors that may be configured in series or in parallel. Each of the 6 capacitors has a value of approximately 25 µF. Its physical configuration and schematic are shown below. In this experiment, we will only use the capacitor bank with all of the knife switches in the right-most position. This will place only the top-most capacitor into the circuit, with the other five shorted out.

   ![Capacitor Bank Diagram]

   b. Why does the configuration in 5.a above result in a capacitance value at the black and red terminals of 25 µF? Bring your capacitor bank to the TA to get a measured value of the capacitance bank configured for this experiment.
6. Variac
   a. The variac is a variable transformer used to convert the 120 vac from the power mains to a lower value of voltage in an adjustable, continuous manner. Adjusting the control knob on the front of the variac to the fully CCW position reduces the output of the variac to nearly 0 vac. Adjusting the control knob fully CW increases the variac output voltage to its maximum value. Its physical configuration and schematic are shown below:

   ![Variac diagram]

   b. Use the 9202 multimeter (Caution! Function selector in 200 VAC position!) to complete the following table:

<table>
<thead>
<tr>
<th>Control Knob Position</th>
<th>Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully CCW</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Fully CW</td>
<td></td>
</tr>
</tbody>
</table>
7. MA-12821 Watt Meter
   a. Review section 11.9.1 in the text which provides a nice review of how a watt meter operates, and how to connect a watt meter into a circuit.
   b. Please be careful with the watt meters. Make sure to connect them to the circuit properly. If in doubt on any point when using the watt meter, ask the TA.
   c. The watt meter is a device that measures AC current through, and AC voltage across, a circuit element. Use the watt meter to measure voltage across, current through, and power absorbed by each of the components separately as per i) through vi) below. The general hookup for the watt meter is:

   ![Diagram of watt meter connection]

   i. Connect the circuit as follows to measure values for the resistor:

   ![Diagram of resistive circuit]

   ii. Measure \( V_{rms} \), \( I_{rms} \), \( P_{avg} \) for the resistor.

   iii. Connect the circuit as follows to measure values for the capacitor:

   ![Diagram of capacitive circuit]

   iv. Measure \( V_{rms} \), \( I_{rms} \), \( P_{avg} \) for the capacitor.
v. Connect the circuit as follows to measure the inductor:

vi. Measure $V_{rms}$, $I_{rms}$, $P_{avg}$ of the inductor.

d. IMPORTANT! Compare your measurements with your previous calculations so that you understand the relationships among:
   i. Phasor values that you previously calculated
   ii. Peak and rms values of voltage and current that you previously calculated vs. meter readings per this section.
   iii. Average powers that you previously calculated vs. meter readings per this section.
AC Power, Voltage, and Current

1. Before connecting the components together to form the circuit, or plugging the variac into the 120 vac outlet, use the 9202 multimeter to set the power resistor (pot) to approximately 100 Ω.

2. The objective is to take the following measurements:
   - $I_{\text{rms leg current}}$
   - $V_{\text{rms leg current}}$
   - $P_{\text{avg power dissipated in the leg}}$
   for each leg of the circuit, AND
   - $I_{\text{rms current}}$
   - $V_{\text{rms current}}$
   - $P_{\text{avg power}}$
   for the circuit as a whole.

3. Configure the circuit and the power meter as follows to take the measurements for the circuit as a whole:

4. Have the TA inspect your circuit setup.

5. Before plugging in the variac, turn the voltage adjustment knob fully CCW. Plug the variac into the 120 vac mains and flip the variac power switch “on”. Increase the variac output slightly to see if the meter readings are tending to show a slightly positive reading. If you notice anything suspicious, turn the variac off immediately and investigate the problem.

6. Once you are confident that everything is correct, slowly increase the variac output until the proper voltage is reached ($V_{\text{rms}} = 40$ volts). If you notice anything suspicious, turn the variac off immediately and investigate the problem.

7. Configure the circuit and the power meter to take measurements for EACH LEG of the circuit using the following as an example (for measuring the capacitor leg by itself):
8. Enter your measured data in a table similar to the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{rms}}$ circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{\text{rms}}$ circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{\text{avg}}$ circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{\text{rms}}$ capacitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{\text{rms}}$ capacitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{\text{avg}}$ capacitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{\text{rms}}$ inductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{\text{rms}}$ inductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{\text{avg}}$ inductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{\text{rms}}$ resistor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{\text{rms}}$ resistor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{\text{avg}}$ resistor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Power down the circuit and disassemble.

**Analysis and Conclusions:**

1. Compare the results of your hand analysis, simulation, and measurements in a Memorandum Report per the guidelines.

For example:

a) Did the currents, voltages, and powers you expected from your hand analysis match the outputs of the simulation and your measurements?

b) How close to calculated or simulated results were the measurements? Don’t do a detailed error analysis, but were you able to actually set the variac to exactly 40 volts? Were you able to set the power resistor to exactly 100 $\Omega$? If your hand analysis showed an expected value of, say, .112 amperes, how close was the measured value to it? Probably you would say that if your measurement was off by a “little bit”, you wouldn’t be concerned that you made a mistake in your analysis, simulation, or measurement. But if the measurement was off by “quite a bit” you would start to suspect that an error was made somewhere. At what point would you start being concerned? (No numerical calculations necessary – just discuss how you would decide that you have a problem or not with agreement among your calculations, simulation results, and measurements.)

c) Did you have trouble using the test equipment? Was it operational? Was it usable? Was it marked so that you could put the experiment back together again using the same equipment?

d) Was the experiment written in a way that you could understand what was being asked of you?

e) Suggestions welcome…..
Memorandum Reports for EE/CENG Projects
(http://www.hpnet.org/upload/directory/materials/9829_20060829141544.doc)
(Dr. Hemmelman’s CENG 244 Course Materials page)

A few comments:

1. A memorandum should be as short as possible and as long as necessary. Don’t waste your reader’s time with unneeded pages.

2. Subheadings are very useful in memoranda as in other reports.

3. A memorandum of technical information may be as formal as a technical report. The degree of formality depends on your perception of the reader to whom the memorandum is directed. For EE/CENG lab reports you should assume that the reader has about the same level of technical expertise as you (the writer) have, but is not very familiar with the details of what you did in lab.

4. Good grammar, proper spelling and clarity are important in any writing, including memorandum reports. Do not write from the perspective that you are giving someone instructions to follow. Rather, the memorandum should report what has been done.

5. Equations, graphs, circuit diagrams, etc., should be referred to in the text and should follow the reference on that or the next page if possible. Tables of data used to construct a graph are oftentimes not crucial to a concise and coherent presentation and may thus be relegated to an appendix or an attachment as backup material.

6. Each figure, graph, circuit diagram, table, etc., must have a number and a title just as in any engineering textbook or technical article in a journal. This information should appear below figures, graphs, and circuit diagrams and above tables.

7. Your log book is a chronological record of what you did and should supply all the data needed for your report. The reader of your report should not need to refer to your log book.

8. The report may be typed, handwritten in ink if your writing is legible, or printed in ink. If written, use engineering paper. If you use a page in ‘landscape’ orientation, it should be read by rotating the report 90° clockwise. Staple the upper left corner of your report. Do not use any plastic or paper cover for the report. “In-class” memorandum reports will be handwritten.

9. You may find the following suggestion, regarding organization, beneficial:
   a. Introduction
   b. Theoretical Analysis
   c. Experimental Procedure
   d. Experimental Results
   e. Analysis of Results (comparing theory with experiment)
   f. Conclusions