PREFACE

This laboratory book for Electrical Networks was first introduced in 1990 and since then it has been revised several times in order to be up to date with curriculum changes, laboratory equipment upgrading, and the latest circuit simulation software.

Every effort has been made to correct all the known errors, but nobody is perfect. If you find any errors or anything else that you think is an error, please contact Dr. Kasparis at: kasparis@ee.ucf.edu

The contribution of Mr. Enrique Tecincella who diligently worked to re-draw all the figures in this manual needs to be acknowledged.

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Spring 2005
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Safety Rules and Operating Procedures

1. Note the location of the Emergency Disconnect (red button near the door) to shut off power in an emergency. Note the location of the nearest telephone (map on bulletin board).

2. Students are allowed in the laboratory only when the instructor is present.

3. Open drinks and food are not allowed near the lab benches.

4. Report any broken equipment or defective parts to the lab instructor. Do not open, remove the cover, or attempt to repair any equipment.

5. When the lab exercise is over, all instruments, except computers, must be turned off. Return substitution boxes to the designated location. Your lab grade will be affected if your laboratory station is not tidy when you leave.

6. University property must not be taken from the laboratory.

7. Do not move instruments from one lab station to another lab station.

8. Do not tamper with or remove security straps, locks, or other security devices. Do not disable or attempt to defeat the security camera.

9. ANYONE VIOLATING ANY RULES OR REGULATIONS MAY BE DENIED ACCESS TO THESE FACILITIES.

I have read and understand these rules and procedures. I agree to abide by these rules and procedures at all times while using these facilities. I understand that failure to follow these rules and procedures will result in my immediate dismissal from the laboratory and additional disciplinary action may be taken.

___________________________________   _______________
Signature     Date       Lab #
Laboratory Safety Information

Introduction

The danger of injury or death from electrical shock, fire, or explosion is present while conducting experiments in this laboratory. To work safely, it is important that you understand the prudent practices necessary to minimize the risks and what to do if there is an accident.

Electrical Shock

Avoid contact with conductors in energized electrical circuits. Electrocution has been reported at dc voltages as low as 42 volts. Just 100ma of current passing through the chest is usually fatal. Muscle contractions can prevent the person from moving away while being electrocuted.

Do not touch someone who is being shocked while still in contact with the electrical conductor or you may also be electrocuted. Instead, press the Emergency Disconnect (red button located near the door to the laboratory). This shuts off all power, except the lights.

Make sure your hands are dry. The resistance of dry, unbroken skin is relatively high and thus reduces the risk of shock. Skin that is broken, wet or damp with sweat has a low resistance.

When working with an energized circuit, work with only your right hand, keeping your left hand away from all conductive material. This reduces the likelihood of an accident that results in current passing through your heart.

Be cautious of rings, watches, and necklaces. Skin beneath a ring or watch is damp, lowering the skin resistance. Shoes covering the feet are much safer than sandals.

If the victim isn't breathing, find someone certified in CPR. Be quick! Some of the staff in the Department Office are certified in CPR. If the victim is unconscious or needs an ambulance, contact the Department Office for help or call 911. If able, the victim should go to the Student Health Services for examination and treatment.

Fire

Transistors and other components can become extremely hot and cause severe burns if touched. If resistors or other components on your proto-board catch fire, turn off the power supply and notify the instructor. If electronic instruments catch fire, press the Emergency Disconnect (red button). These small electrical fires extinguish quickly after the power is shut off. Avoid using fire extinguishers on electronic instruments.

Explosion

When using electrolytic capacitors, be careful to observe proper polarity and do not exceed the voltage rating. Electrolytic capacitors can explode and cause injury. A first aid kit is located on the wall near the door. Proceed to Student Health Services, if needed.
INTRODUCTION

This first laboratory in Electrical Engineering has the objectives to familiarize the student with the operation of basic laboratory instrumentation such as oscilloscope, function generator, multimeter, frequency counter, and also with personal computers and circuit simulators such as Pspice and Workbench. Another goal is to reinforce theoretical knowledge with practice and vice-versa, and also to learn correct laboratory procedures and techniques. This is accomplished by building, testing, and taking measurements on simple circuits.

In the execution of the experiment, highest benefit is gained if someone can distinguish between performing the experiment by following step-by-step instructions, and actually understanding the reasons and the methodology behind the various parts. To understand the experiments you must understand the theory of the circuits under test, and the instruments used to test them. To convey the experimental results, you must learn to write a correct laboratory report.

The experiments are organized as follows: for each experiment a brief background is given. This background does not completely cover the theory behind each experiment, but provides highlights. References at the end of each experiment are provided for more details. The preparation part provides all the theoretical calculations that a student must prepare before coming to the lab. The key to a successful and beneficial experiment is to understand the theory, be prepared, and know what you expect to get in the lab. It is essential that all students come to the lab prepared. Most experiments have a computer simulation part. Circuit simulators provide the capability to do an experiment without going into any lab, and without building the actual circuit. The simulation part of each experiment duplicates the preparation part, and provides the student with a confirmation that the theoretical calculations are correct. However, no simulator can substitute the actual experiment. In the experimental part the student performs the actual experiments, where he/she obtains "hands on" experience on how to correctly connect circuits, and use the various laboratory equipment. The design part gives the student the opportunity to create a circuit, or freely select component values to meet some specifications. No experiment is complete without a report. In the report the student presents all the work involved in an experiment, and also all the benefits that were gained.

Most experiments are designed to be one week experiments, if properly prepared. However, usually expectations do not meet reality, and therefore time can be allowed, if needed.
GUIDELINES FOR LABORATORY NOTEBOOK

The laboratory notebook is a record of all work pertaining to the experiment. This record should be sufficiently complete so that you or anyone else of similar technical background can duplicate the experiment and data by simply following your laboratory notebook. Record everything directly into the notebook during the experiment. Do not use scratch paper for recording data. Do not trust your memory to fill in the details at a later time.

Organization in your notebook is important. Descriptive headings should be used to separate and identify the various parts of the experiment. Record data in chronological order. A neat, organized and complete record of an experiment is just as important as the experimental work.

1. **Heading**: The experiment identification (number) should be at the top of each page. Your name and date should be at the top of the first page of each day's experimental work.

2. **Object**: A brief but complete statement of what you intend to find out or verify in the experiment should be at the beginning of each experiment.

3. **Diagram**: A circuit diagram should be drawn and labeled so that the actual experiment circuitry could be easily duplicated at any time in the future. Be especially careful to record all circuit changes made during the experiment.

4. **Equipment List**: List those items of equipment which have a direct effect on the accuracy of the data. It may be necessary later to locate specific items of equipment for rechecks if discrepancies develop in the results.

5. **Procedure**: In general, lengthy explanations of procedures are unnecessary. Be brief. Short commentaries along side the corresponding data may be used. Keep in mind the fact that the experiment must be reproducible from the information given in your notebook.

6. **Data**: Think carefully about what data is required and prepare suitable data tables. Record instrument readings directly. Do not use calculated results in place of direct data; however, calculated results may be recorded in the same table with the direct data. Data tables should be clearly identified and each data column labeled and headed by the proper units of measure.

7. **Calculations**: Not always necessary but equations and sample calculations are often given to illustrate the treatment of the experimental data in obtaining the results.

8. **Graphs**: Graphs are used to present large amounts of data in a concise visual form. Data to be presented in graphical form should be plotted in the laboratory so that any questionable data points can be checked while the experiment is still set up. The grid lines in the notebook can be used for most graphs. If special graph paper is required, affix the graph permanently into the notebook. Give all graphs a short descriptive title. Label and scale the axes. Use units of measure. Label each curve if more than one on a graph.

9. **Results**: The results should be presented in a form which makes the interpretation easy. Large amounts of numerical results are generally presented in graphical form. Tables are generally used for small amounts of results. Theoretical and experimental results should be on the same graph or arrange in the same table in a way for easy correlation of these results.

10. **Conclusion**: This is your interpretation of the results of the experiment as an engineer. Be brief and specific. Give reasons for important discrepancies.
TROUBLESHOOTING HINTS

1. Be sure that the power is turned on.

2. Be sure the ground connections are common.

3. Be sure the circuit you built is identical to that in the diagram. (Do a node-by-node check.)

4. Be sure that the supply voltages are correct.

5. Be sure that the equipment is set up correctly and you are measuring the correct parameter.

6. If steps 1 through 5 are correct, then you probably have used a component with the wrong value or one that doesn't work. It is also possible that the equipment does not work (although this is not probable) or the protoboard you are using may have some unwanted paths between nodes. To find your problem you must trace through the voltages in your circuit node by node and compare the signal you have to the signal you expect to have. Then if they are different use your engineering judgment to decide what is causing the different or ask your lab assistant.
EXPERIMENT # 1  
DC MEASUREMENTS  
DC POWER SUPPLY, DIGITAL MULTIMETER

OBJECTIVE: To introduce the measurements of DC voltage and current, and resistance.

EQUIPMENT:
- Digital multimeter (DMM)
- Power supply
- Resistors

BACKGROUND:
To measure voltage, a voltmeter is connected between the two points where the voltage is to be measured (see fig.1). Since this is a parallel connection, an ideal voltmeter should have infinite internal resistance, so that the value of the unknown voltage will not be affected by the voltmeter connection. To measure the current through a branch, the branch has to be broken and an ammeter is inserted in the branch (see fig.2). Since this is a series connection, a good ammeter should have very small internal resistance. Ohmmeters convert resistance measurement into voltage or current measurement. An ohmmeter has an internal voltage source, and when an unknown resistor is placed across its terminals, a closed-loop is formed (see fig.3).

PREPARATION:
In the circuits of Figures 4 and 5, 6 and 7 select any available values for all resistors in the range above 1 KΩ and below 56 KΩ. You choose the values. Resistors with the same name have the same value, but resistors with different names should not have the same value.

a) In the circuit of Fig.4 calculate V₁, V₂, and I. Verify the voltage divider rule and KVL (by verifying that V₁ + V₂ = 9V).
b) In the circuit of Fig.5 calculate I₁, I₂, I, and Vₓ. Verify the current divider rule and KCL (by verifying that I₁ + I₂ = I).
c) In the circuit of Fig.6 calculate the equivalent resistance between points AB and also between points CD (How?). Assume that all resistors have the same available value of your choice.
d) In the circuit of Fig.7 calculate voltage Vₓ.
e) The DVM has an internal resistance of 10 MΩ typically. Assume that in the circuit of fig.8, a DVM is used to measure the voltage Vₓ. Calculate the reading if:
   1) R = Any value between 1 KΩ and 10 KΩ
   2) R = Any value above 2 MΩ

EXPERIMENT:
The purpose of the experiment is to experimentally verify the theoretical results calculated in the preparation. Use the same resistor values as in the preparation.

a) Use the DMM as an ohmmeter and measure the values of all resistors to be used. Compare the actual with the nominal value. The nominal value can be determined from the color code on the resistor.  
   **Note:** When taking a resistance measurement do not touch both resistor terminals with your fingers. The resistance of your body can alter the reading.
b) Connect the circuit of Fig.4 and measure V₁, V₂, and I. Verify KVL, and Ohm's law by computing R₁ = V₁/I and R₂ = V₂/I. Verify also the voltage divider rule.
c) Connect the circuit of Fig.5 and measure I₁, I₂, I, and Vₓ. Verify the current divider rule, and KCL.
d) Connect the circuit of Fig.6 and measure the resistance between points AB, and CD.
e) Connect the circuit of Fig.7 and measure Vₓ.
f) Connect the circuit of Fig.8 and measure Vₓ for both cases as in preparation part (e).

REPORT:
In your report compare all the theoretical and experimental values and make comments on any discrepancies. Write all conclusions.
FIGURES

Figure 1: Voltage Measurement

Figure 2: Current Measurement

Figure 3: Resistance Measurement

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8
EXPERIMENT # 2

AC MEASUREMENTS
OSCILLOSCOPE, FUNCTION GENERATOR
FREQUENCY COUNTER

OBJECTIVES:
To introduce the oscilloscope, the function generator, and the frequency counter in measuring AC parameters of signal.

EQUIPMENT:
Oscilloscope
Function generator
Frequency counter
Resistor substitution box
Capacitor substitution box

BACKGROUND:
An AC (time varying) signal requires several parameters to be completely described. The problem of measuring AC signals is how to determine these parameters. The frequency counter can be used to measure the frequency or the period of a periodic signal of any waveform. AC multi-meters produce a DC value proportional to an AC parameter of the signal to be measured. Most multimeters are calibrated to display the RMS value of sinusoid waveforms only. The oscilloscope can be used for any AC measurement. The wave-shape can be visually examined on the screen of the instrument. It should be emphasized that only periodic waveforms can generate a stationary pattern on the screen of an analog oscilloscope. Modern digital scopes can capture, store, and display sections of arbitrary waveforms. The function generator is a versatile AC signal source. It can provide several wave-shapes, and the amplitude and the frequency can be adjusted.

PREPARATION:

a) Familiarize yourself with the instruments in your station on the bench.
b) Study the instrument's user manuals if available.
c) Calculate the period of a waveform of frequencies 100 Hz, 1kHz, 100 kHz.

EXPERIMENT:

A) Oscilloscope general

1) Connect the output of the function generator to ch.1 of the scope, and also to the input of the frequency counter. Set the trigger to ch.1, coupling DC.

2) Select sinusoidal waveform on the generator. Vary the frequency and the amplitude on the generator and observe the results on the scope.

3) Vary the gain and the time-base of the scope and observe the results.

4) Set the frequency counter to measure frequency and compare the reading with the frequency indication on the function generator.

5) Set the amplitude on the generator for 5V peak. Adjust the "level" control on the scope until the waveform just becomes stationary.

6) Decrease the amplitude from the generator, and observe that triggering is lost (waveform starts running). Why?

7) Readjust the "level" control for stationary waveform.
8) Select any waveform and frequency and adjust the "DC offset" control on the generator. Observe the result on the scope.

9) Set the coupling on the scope to AC and repeat step 8. What do you observe? Make comments.

B) **Voltage measurements**

1) Set the generator to a sine wave of frequency 100 Hz and 10V amplitude.

2) Connect the DMM to the output of the generator and set it to measure AC voltage. Verify that the DMM reads the correct RMS value of the sinusoid (equal to 7.07V).

C) **Frequency measurements**

1) Set the generator to sinusoid of frequency 100 Hz and measure the period of the waveform on the scope. Repeat for 1 kHz and 100 kHz, and confirm the results found in part (e) of the preparation. Set the frequency counter to measure period to get an additional confirmation that your measurements are correct.

   Note: The period can be measured on the oscilloscope as the time between two successive peaks or two successive zero crossings.

2) Repeat step (1) for triangular and square-wave.

REPORT:

In your report describe the work you have done in the lab, and present the measurements you have taken. Compare theoretical and experimental results and make comments. Write all conclusions.
EXPERIMENT # 3

MESH AND NODE EQUATIONS
THEVENIN AND NORTON EQUIVALENTS
SUPERPOSITION THEOREM

OBJECTIVES:

To use node and mesh equations to analyze a resistive network. Verify Thevenin and Norton theorems, and the principle of superposition, and the maximum power transfer theorem.

EQUIPMENT:

Power supply
Function generator
Digital voltmeter
Oscilloscope
Resistors
Resistance box

BACKGROUND:

Analyzing a network means to calculate the voltage and current of each element. Two systematic methods for analyzing networks are node and mesh equations. Thevenin’s theorem is a powerful theorem in modeling any linear circuit. The dual is Norton's theorem. Refer to your textbook for more details.

PREPARATION:

Consider the circuit in figure 1. For all resistors choose available values in the range 1K to 50K. You can use the same value twice, but do not make all resistors equal.

1) Assume that points AB are shorted. Assign mesh currents, write and solve the mesh equations. From the mesh currents calculate the voltage across each resistor, and the current through AB.
2) Assume that points AB are not shorted. Write and solve the node equations. From the node voltages calculate the voltage across each resistor, and the voltage between points AB.
3) Use data calculated in parts (a) and (b) to find the Thevenin and Norton equivalents
4) Assume that a resistor box is connected between points AB. Calculate the current through this resistor for values 1 kΩ, 2.2 kΩ and 4.7 kΩ. (Hint: use the Thevenin equivalent).
5) Set E2 and E3 to zero and calculate the voltage between points AB. Repeat this step two more times by setting E1, E2 and E1, E3 to zero. Check if the sum of the three voltages checks with the one found in part (2).

SIMULATION:

Use your circuit simulator to verify the theoretical results you have found in parts (1) (2) (4) and (6).

EXPERIMENT:

The purpose of the experiment is to experimentally verify the results you have calculated in the preparation, and you have also simulated. Since all resistors have tolerances, use the ohmmeter to measure the actual value of all the resistors used.

Wire the circuit of Figure 1 using the values you have chosen in the preparation.

Note: To be able to independently adjust the positive and the negative outputs of the power supply, you must set the "Tracking ratio" to "variable" position.

Warning: In the subsequent sections, the phrase "set a voltage source to zero," means disconnect the terminal from the power supply and connect it to ground. Under no circumstances short any power supply output to ground.
A) **Mesh equations:**
1) Short points AB and measure the voltage across each resistor.
2) Use the ammeter to measure the current through AB.
3) Compare the results with the ones found in part (1) of the preparation.

B) **Node equations:**
1) Open points AB and measure the voltage across each resistor.
2) Measure the voltage between points AB.
3) Compare with part (2) of preparation.

C) **Thevenin and Norton equivalents**
1) Set all the sources to zero and use the DMM to measure the resistance between points AB.
2) Compare the result with part (3) of preparation.
3) Connect back all the voltage sources and connect the resistance box with the ammeter in series between points AB. Select values as in part (4) of the preparation and measure the current. Compare with the expected results.

D) **Superposition theorem:** Remove the resistance box from points AB
1) Do the steps described in part (5) of the preparation. Check if the sum of the three individual voltages agrees with the one found in part B.2 of the experiment.
2) Set E1 to zero and measure the voltage at points A, B due to E2 and E3. Next, set E2 and E3 to zero and measure the same voltage due to E1. Check if the sum of the two agrees with the voltage found in part B.2 of the experiment.

**REPORT:**
In your report present the measurements you have taken in the lab and compare them with the theoretical and simulated. Write all your comments and conclusions.
EXPERIMENT # 4
FIRST-ORDER CIRCUITS

OBJECTIVES: To study the step response of first order circuits

EQUIPMENT:
- Oscilloscope
- Function Generator
- 100 mH inductor
- Resistor substitution box
- Capacitor substitution box

BACKGROUND:
Consider the series RC circuit shown in fig.1a. The capacitor voltage is given by:

\[ V_c(t) = E(1 - e^{-t/RC}), \quad t \geq 0 \]

This voltage is illustrated in fig.1b. The voltage across the resistor can be found to be:

\[ V_R(t) = Ee^{t/RC}, \quad t \geq 0 \]

and it is plotted in Figure1.c. Similar analysis can be done for the RL circuits of fig.2.

PREPARATION:

a) Consider the circuits in Figure 2. For each circuit derive analytical expressions for \( V_o(t) \) when \( V_i(t) = Eu(t) \) (step of amplitude E). Assume zero initial conditions. Plot \( V_i(t) \) for each circuit.
b) Repeat part (a) assuming that \( V_i(t) \) is a symmetric square-wave of amplitude ±E, and period \( T_s = 10 \) RC. (Hint: use superposition).

SIMULATION:
For the circuits of figures 1 and 2 assume \( R = 1K, C = 0.1 \) µF, \( L = 100 \) mH, \( R1 = 2.2 \) K, \( R2 = 2.2 \) K. The input is a symmetric square-wave of amplitude ±5V and frequency of 1 kHz. Run simulations to plot \( V_o(t) \).

EXPERIMENT:
The purpose of the experiment is to experimentally verify the results you have derived in the preparation, and also have simulated using. The steps below apply to all circuits in figures 1, and 2. Use the same component values as in simulations.

a) Wire one circuit at a time. Connect \( v_i(t) \) to the function generator, set at 1 kHz frequency, and square-wave output of amplitude ±5V.
b) Connect ch.1 of the oscilloscope to \( v_i \) and ch.2 to \( v_o \). Set the trigger to ch.1
c) Observe and sketch the output voltage and compare it to the expected one.
d) Take measurements on the oscilloscope to determine the time constant of the circuit, and compare the result with the actual one.

REPORT:
In your report present and compare the results that you have obtained theoretically, experimentally, and via computer simulation, and make comments. Write all conclusions.
EXPERIMENT # 5
SECOND ORDER CIRCUITS

OBJECTIVES: To study the step response of RLC circuits.

EQUIPMENT:
- Oscilloscope
- Function Generator
- 100 mH inductor
- Capacitor Box
- Resistance Box

BACKGROUND:
Second-order circuits have a step-response depending on the nature of the roots of the characteristic equation.

PREPARATION:
A) Consider figure 1. Assume zero initial conditions.

1) For \( L = 100 \text{ mH} \) and \( C = 0.01 \mu \text{F} \), calculate the ranges of values of \( R \) for overdamped, critically damped, and under damped response.

2) Assume the response to be the voltage across the capacitor. Plot the response due to a step input for:
   - a) \( R = 22 \text{ K} \)
   - b) \( R = 6.8 \text{ K} \)
   - c) \( R = 2.2 \text{ K} \)

3) Let \( R = 470 \text{ Ohm} \). Calculate \( \alpha \), \( \omega_n \), and \( \omega_d \). Plot the voltage across the capacitor due to a square-wave input of frequency of 400 Hz, and amplitudes of \( \pm4 \text{V} \).

B) Consider figure 2:

1) Find the characteristic equation and the poles.

2) Repeat part (A.1) for the same values of \( L \), \( C \).

3) Repeat part (A.2) for:
   - a) \( R = 680 \text{ Ohm} \)
   - b) \( R = 1.5 \text{ K} \)
   - c) \( R = 4.7 \text{ K} \)

4) Repeat part (A.3) for \( R = 22 \text{ K} \)

SIMULATION:
Simulate parts A.2, A.3, B.3 and B.4 of the preparation.

EXPERIMENT:

a) Connect the circuit of fig.1. In place of the resistor and the capacitor use the substitution boxes.

b) Connect the input to the function generator. Set to a square-wave of 400 Hz and amplitudes of \( \pm4 \text{V} \).

c) Connect ch.1 of the oscilloscope to the generator output, and ch.2 at the capacitor voltage. Set the trigger to ch.1.

d) Observe and sketch the capacitor voltage for \( R = 22 \text{ K} \), \( R = 6.8K \), and \( R = 2.2 \text{ K} \). For each case indicate whether the response is over damped or under damped.

e) Let \( R = 470 \text{ Ohm} \). Sketch the output voltage and using the oscilloscope measure \( \omega_d \).

f) Repeat part (d) for the circuit of fig.2 and resistor values \( R = 680 \text{ Ohm} \), \( R = 1.5 \text{ K} \), and \( R = 4.7 \text{ K} \).

g) Repeat part (e) for fig.2 with \( R = 22 \text{ K} \)

REPORT:
In your report, present and compare theoretical, computer simulated, and experimental results, and make comments. Write all conclusions.
OBJECTIVES: To compute the power factor of a passive circuit and verify the Conservation of energy in sinusoidal steady state.

EQUIPMENT:  
- Oscilloscope
- Capacitors
- Power Supply
- Resistors
- Function Generator

BACKGROUND:  
Sinusoidal state-state is very important in practice since sinusoidal waveforms are very common. Power calculations are also very important since the main goal of power systems is the transfer of power. Consider the circuit of Fig. 1. The average power delivered by the source is:

\[ P_{av} = \frac{1}{2} V_m I_m \cos(\theta) \]

where \( V_m, I_m \) are the peak values of the voltage and the current. The average power is proportional to \( \cos(\theta) \), the power factor. Notice that \( \theta \) is actually the phase difference between the voltage and the current.

PREPARATION:  
Consider the circuit of Fig. 2 with component values as shown (or the closest available). Assume \( V_m = 8V \) and a frequency of 3 KHz.

a) Compute the equivalent complex impedance seen by the source.
b) Compute the power factor.
c) Compute the voltage and current in each element in the circuit.
d) Compute the average power dissipation in each element in the circuit.
e) Compute the average power delivered by the source and verify the conservation of energy.
f) Show that if the voltage labeled \( V_x = V_{xm} e^{j\theta} \) is known (measured), then the power factor can be computed from \( \text{PF} = \cos(\theta) \), where:

\[ \theta = \tan^{-1} \left( \frac{\sin(\phi)}{\frac{V_m}{V_{xm}} - \cos(\phi)} \right) \]  

SIMULATION:  
By using simulations verify your preparation results.

EXPERIMENT:  
1) Wire the circuit on Fig. 2. Since the oscilloscope has only two channels, measuring the power factor is tricky, however, it can be done by using the results in part (f) of the preparation.
2) Use sinusoidal input from the generator with amplitude and frequency as described in the preparation.
3) Display the input voltage and voltage \( V_x \) on the scope. Measure their peak values and their phase difference (see experiment 2). Compute the power factor using equation (2) above.
4) Measure the peak voltage across each element and compute the power dissipation.
5) Verify the conservation of energy.
NOTE: Measure the exact value of each resistor. Assume ideal capacitors and inductors.

DESIGN:

a) Investigate experimentally whether there are frequencies between 1 KHz and 20 KHz where the power factor becomes unity.
b) If the answer to both (a) and (b) is "yes" check the agreement between the results.
c) Compute the power delivered by the source under these conditions, and verify the conservation of energy.
d) Give a physical explanation as to what happens at these particular frequencies.
e) Use simulations to verify your results.

REPORT:
In your report present experimental results and compare them with the theoretically expected results. Discuss any discrepancies, make comments and write conclusions.
EXPERIMENT # 7
SERIES AND PARALLEL RESONANCE

OBJECTIVE: To study the series and parallel LC circuits.

EQUIPMENT:
- Oscilloscope
- Function Generator
- Frequency counter
- 100 mH inductor
- Capacitance substitution box
- Resistor substitution box

BACKGROUND:
Consider the series RLC circuit of fig. 1. Frequency \( \omega_0 = \frac{1}{\sqrt{LC}} \) is called the resonance frequency. Similar frequency exists for a parallel RLC circuit.

PREPARATION:
1) Consider the circuits in fig. 2 with sinusoidal input and at steady-state. For each circuit:
   a) Derive the transfer function and plot the frequency response of the magnitude.
   b) Calculate the resonance frequency, the half-power frequencies, and the bandwidth.

2) In the circuit of fig. 3 assume \( L = 100 \text{ mH}, C = 0.1 \mu \text{F}, v_i = V_m \sin \omega t \). Calculate the peak value of \( v_c(t) \) if:
   a) \( R = 1 \text{ K\Omega} \) (or close value)
   b) \( R = 330 \text{\Omega} \) (or close value)

SIMULATION:

a) Assume \( R = 1K, L = 100\text{mH}, C = 0.1\mu\text{F} \) and \( v_i(t) = 5\sin \omega t \). Use simulation to verify the theoretical results of part (1) of the preparation.

b) Use simulation to verify the results of part (2) of the preparation.

EXPERIMENT:
The purpose of this experiment is to experimentally verify the theoretical and simulated results and notice any discrepancies.

a) Connect each of the circuit in figures 1, 2, and 3, with \( L =100 \text{mH}, C = 0.1 \mu \text{F}, R = 1 \text{ K} \), and \( v_i(t) = 5 \sin \omega t \). Use the frequency counter to measure frequencies and the oscilloscope to observe waveforms.

b) Vary the frequency and record the frequency response of each circuit (magnitude only). Measure the resonance frequency, the half-power frequencies, the bandwidth, and the quality factor. Compare with the expected values. Check if the resonance frequency is the geometric mean of the half-power frequencies.

c) For the circuit of fig. 3 measure the peak value of the capacitor voltage at the resonance frequency, when \( R = 1 \text{ K} \) and when \( R = 330 \text{ \Omega} \). Measure also the phase-shift from the input voltage. Compare with the theoretical values.

REPORT:
In your report provide simulated and experimental responses, and compare theoretical, simulated, and experimental results, Make comments on any discrepancies and write conclusions.
EXPERIMENT # 8
TRANSFER FUNCTIONS

OBJECTIVE: To study the transfer functions of various RC network.

EQUIPMENT:
- Oscilloscope
- Function generator
- Frequency counter
- Resistors
- Capacitors

BACKGROUND:
A two-port linear network can be in general described by a transfer function

\[ H(j\omega) = \frac{V_i(\omega)}{V_o(\omega)} \]

Given a sinusoidal input voltage \( V_i(t) = V_m \sin(\omega_o t) \), the output voltage will be:

\[ V_o(t) = |H(j\omega_o)| \cdot V_m \sin(\omega_o t + \theta(\omega_o)) \]

where \(|H(j\omega_o)|\) and \(\theta(\omega_o)\) are the magnitude and the phase of the transfer function at frequency \(\omega_o\).

PREPARATION:
For all circuits select component values so that RC is any value from 0.1 mS to 0.01mS.

A) Refer to the circuits in fig.1.a and 1.b.
1) For each circuit, find the sinusoidal steady-state transfer function.
2) Assume that the input is a sinusoid. Find the frequency where the output voltage will be 45° out of phase, than the input voltage. Find the amplitude of the output voltage at this frequency.
3) Find the frequency where the amplitude of the output voltage is 1/4 of the amplitude of the input voltage.

B) Refer to the circuit in figures 2 and 3.
1) Verify that the transfer function is the one given in each figure.
2) Assume sinusoidal input. Find the frequencies where the phase difference of input and output voltages is either +90 or -90 degrees. Find the amplitude of the output voltage at these frequencies.
3) Repeat part (2) for 0° or 180° phase shift.

SIMULATION:
Run simulations to verify the theoretical results found in the preparation. The amplitude of the sinusoidal input is 10V.

EXPERIMENT:
a) Connect the circuits of figures 1.a and 1.b. Use component values as in the preparation and simulations.
b) Experimentally verify the results you have calculated in parts A.2 and A.3 of the preparation. What is the maximum phase shift that can be achieved with these circuits? Are there any limitations in achieving this phase-shift?
c) Connect the circuits of figures 2 and 3, with component values as in the preparation.
d) Experimentally verify the results you have calculated in parts B.2 and B.3 of the preparation.

REPORT:
In your report present your work, and compare the results you have obtained theoretically, via simulation, and experimentally. Write any comments and conclusions.
EXPERIMENT # 9

FREQUENCY RESPONSE

OBJECTIVES: To study the frequency response of various RC network.

EQUIPMENT:

- Oscilloscope
- Frequency counter
- Function Generator
- Resistors
- Capacitors

BACKGROUND:

Refer also to the previous experiment. Frequency response refers to the variation of $|H(j\omega)|$ and phase $\{H(j\omega)\}$, when $\omega$ varies. This variation can be plotted either in a linear or a logarithmic scale.

PREPARATION:

a) Derive the transfer function of the circuits in Figures 1 and 2.
b) Find the 3db frequencies as function of the component values.
c) Roughly sketch the magnitude and the phase plots on a linear scale, and indicate whether these circuits are low-pass or high-pass filters. For figures 1 and 2 find the phase-shift at the 3 db frequency.

SIMULATION:

For all circuits select reasonable and available component values. For the circuit of Figure 3.A select $C_1 >> C_2$. Do not use electrolytic capacitors. Use circuit simulation to obtain the frequency response of each circuit in the range 100 Hz to 100 kHz. Verify any theoretical results you have derived in the preparation.

EXPERIMENT:

The input is connected to the function generator, adjusted for a sinusoid waveform of amplitude 10V. Use the frequency counter to measure frequencies.

a) Connect the circuits of Figures 1 and 2 and vary the input frequency from 100 Hz to 10 kHz, while observing the output voltage. Take enough measurements to enable you to plot the magnitude and the phase of the transfer function.
b) Find the 3db frequency, and the phase shift at this frequency. Compare to the theoretical values.
c) Connect the circuits of fig.3 and take measurements to plot the magnitude only of the transfer functions in a frequency range of 100 Hz to 100 kHz. Measure the 3db frequencies and the bandwidth. Make comments about the shape of the curves.

REPORT:

Print the frequency responses obtained by, and on the same graphs superimpose the experimentally obtained plots. Provide these plots in your report and make comments about any discrepancies, and state all conclusions.
EXPERIMENT EVALUATION FORM

COURSE: EEL 3123
SEMESTER: COURSE INSTRUCTOR: 
LAB INSTRUCTOR: EXPERIMENT:

Please write comments on the following issues

PART A (experiment):
1) Was the experiment successful?
2) Did the experimental results match the theory?
3) Was the material covered in the lecture?
4) Was the experiment instructive?
5) Was the lab manual clearly written

PART B (facility):
1) Did all the instruments work properly?
2) Were all the needed parts available?
3) Any other problems?

PART C (Lab Instructor):
1) Was the lab instructor helpful?
2) Did he/she know the experiment?
3) Was there any brief lecture in the lab?
4) Did the lab instructor know how to operate the instruments?
5) Any comments that may help the lab instructor improve?

Your name (optional): Please return to your course instructor
APPENDIX

Resistor and capacitor values that are normally stocked in the lab.

<table>
<thead>
<tr>
<th>Capacitor Value</th>
<th>Resistor Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1uF</td>
<td>0.047uF</td>
</tr>
<tr>
<td>470pF</td>
<td>560pF</td>
</tr>
<tr>
<td>680pF</td>
<td>820pF</td>
</tr>
<tr>
<td>0.0018uF</td>
<td>0.002uF</td>
</tr>
<tr>
<td>0.0022uF</td>
<td>0.0027uF</td>
</tr>
<tr>
<td>0.0033uF</td>
<td>0.0056uF</td>
</tr>
<tr>
<td>0.0068uF</td>
<td>0.005uF</td>
</tr>
<tr>
<td>120pF</td>
<td>180pF</td>
</tr>
<tr>
<td>0.0012uF</td>
<td>0.0015uF</td>
</tr>
<tr>
<td>0.0047uF</td>
<td>0.001uF</td>
</tr>
<tr>
<td>0.0039uF</td>
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</tr>
<tr>
<td>22MΩ</td>
<td>15MΩ</td>
</tr>
<tr>
<td>9.1MΩ</td>
<td>7.5MΩ</td>
</tr>
<tr>
<td>6.2MΩ</td>
<td>4.3MΩ</td>
</tr>
<tr>
<td>3.6MΩ</td>
<td>3MΩ</td>
</tr>
<tr>
<td>2.7MΩ</td>
<td>2.4MΩ</td>
</tr>
<tr>
<td>1.8MΩ</td>
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<tr>
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<tr>
<td>1.2MΩ</td>
<td>1.2MΩ</td>
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<td>360KΩ</td>
</tr>
<tr>
<td>430KΩ</td>
<td>510KΩ</td>
</tr>
<tr>
<td>620KΩ</td>
<td>150Ω</td>
</tr>
</tbody>
</table>
How to read Resistor Color Codes

First the code

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

How to read the code

First find the tolerance band, it will typically be gold (5%) and sometimes silver (10%).

Starting from the other end, identify the first band - write down the number associated with that color; in this case Blue is 6.

Now 'read' the next color, here it is red so write down a '2' next to the six. (you should have '62' so far.)

Now read the third or 'multiplier' band and write down that number of zeros.

In this example it is two so we get '6200' or '6,200'. If the 'multiplier' band is Black (for zero) don't write any zeros down.

If the 'multiplier' band is Gold move the decimal point one to the left. If the 'multiplier' band is Silver move the decimal point two places to the left. If the resistor has one more band past the tolerance band it is a quality band.

Read the number as the % Failure rate per 1000 hour' This is rated assuming full wattage being applied to the resistors. (To get better failure rates, resistors are typically specified to have twice the needed wattage dissipation that the circuit produces) 1% resistors have three bands to read digits to the left of the multiplier. They have a different temperature coefficient in order to provide the 1% tolerance.
Examples

Example 1:

You are given a resistor whose stripes are colored from left to right as brown, black, orange, gold. Find the resistance value.

Step One: The gold stripe is on the right so go to Step Two.

Step Two: The first stripe is brown which has a value of 1. The second stripe is black which has a value of 0. Therefore the first two digits of the resistance value are 10.

Step Three: The third stripe is orange which means x 1,000.

Step Four: The value of the resistance is found as $10 \times 1000 = 10,000$ ohms (10 kilohms = 10 kohms).

The gold stripe means the actual value of the resistor may vary by 5% meaning the actual value will be somewhere between 9,500 ohms and 10,500 ohms. (Since 5% of 10,000 = $0.05 \times 10,000 = 500$)

Example 2:

You are given a resistor whose stripes are colored from left to right as orange, orange, brown, silver. Find the resistance value.

Step One: The silver stripe is on the right so go to Step Two.

Step Two: The first stripe is orange which has a value of 3. The second stripe is orange which has a value of 3. Therefore the first two digits of the resistance value are 33.

Step Three: The third stripe is brown which means x 10.

Step Four: The value of the resistance is found as $33 \times 10 = 330$ ohms.

The silver stripe means the actual value of the resistor may vary by 10% meaning the actual value will be between 297 ohms and 363 ohms. (Since 10% of 330 = $0.10 \times 330 = 33$)

Example 3:

You are given a resistor whose stripes are colored from left to right as blue, gray, red, gold. Find the resistance value.

Step One: The gold stripe is on the right so go to Step Two.

Step Two: The first stripe is blue which has a value of 6. The second stripe is gray which has a value of 8. Therefore the first two digits of the resistance value are 68.

Step Three: The third stripe is red which means x 100.

Step Four: The value of the resistance is found as $68 \times 100 = 6800$ ohms (6.8 kilohms = 6.8 kohms).

The gold stripe means the actual value of the resistor may vary by 5% meaning the actual value will be somewhere between 6,460 ohms and 7,140 ohms. (Since 5% of 6,800 = $0.05 \times 6,800 = 340$)