**Introduction**

You may find this laboratory to be different than those you have experienced up to this time. It was designed with several objectives in mind. First, it is intended to supplement the lecture course EE3005 and can only be carried out with the maximum benefit if you are acquainted with the topics being discussed there. The experimental topics are synchronized with the EE3005 lectures so that EE3005 covers the topics either before the experiment is done or while the experiment is being carried out. Second, the laboratory is intended to develop your self-confidence in laboratory procedures and in drawing conclusions from observations. As a consequence the instructions are very spare and assume you will be able to extract conclusions from each experiment and will relate parts of the total lab to each other without being explicitly asked to do so. In particular the laboratory manual will not specify what typical results you should expect from your measurements. In most cases you will be able to estimate what values to expect as part of your preparation before coming to the laboratory to do the experiment.

**Important Points**

- Your grade in this course will depend principally on your in-lab work.

- You are expected to maintain a lab notebook. It must contain a running account of the experiment. It is not intended to be a book into which you copy notes previously gathered on the back of an envelope. It must however be legible and coherent. Write in such a way that another person could perform the same experiment based on your account, and that same person could understand the conclusions that you drew from your data. It is not necessary to hide your mistakes. If you make a mistake in an entry simply draw a line through that entry and start over - you will not be penalized for this.

- The lab notebook should have the following characteristics:
  - It should be a bound notebook (spiral bound is OK).
  - Lab entries should be dated, and should include:
    - Complete circuit diagrams.
    - Explanation of circuit, methods, procedures, etc.
    - All calculations for designs.
    - All measurements (including component values).
    - All analysis and comparisons of data with theory.

- There is no formal lab homework or pre-lab work in this course, but it will pay great dividends for you to make a careful reading of the experiment description before arriving in the laboratory. You will also note that some parts of the "experiments" involve analytical work which can be better done elsewhere. **Most problems students have with this course are due to lack of preparation prior to coming to lab.** If after reading through the lab and consulting the relevant section of your EE3005 text you do not understand something, seek out either your TA or the faculty member in charge of the lab.

- **MILESTONES.** In each experiment there will be a few “milestones”. These are specific tasks which must be accomplished and demonstrated to the TA or professor before going on to the
next item. All milestones must be completed or you will not pass the course. If the milestones are not completed by the end of the quarter you will receive an F for the course. While the milestones are not a part of the grade formula, delays in milestone completion will unavoidably delay the submission of your lab notebook with the corresponding grade penalty. **Lab notebooks and lab reports will not be accepted if the milestones for the corresponding lab have not been completed.**

- Grades will be determined from the following components of the course:

  Lab Notebooks - 30%
  Lab Practical Exams - 40%  
  Lab Reports - 30%

  Lab notebooks will be collected up to three times during the quarter. They will be due at 4:30 PM three working days after the scheduled completion date of a lab. Lab reports will be collected one week after scheduled completion of the corresponding lab. You will be given a schedule during the first week of class which will contain all lab practical exam dates and notebook and lab report due dates.

- **Late Penalties.** The penalties for late notebooks or lab reports are as follows:

  1 or 2 days late: 3% deducted from your FINAL SCORE (total score for the entire course, not just the lab report or lab notebook).
  3 or 4 days late - an additional 3% deducted from your FINAL SCORE.
  and so on...

- You will receive a separate handout detailing the requirements for the lab reports.
Experiment #1

Introduction to EE3006 and Equipment Familiarization

Duration: 1 Week (week #1)

The lab instructor will go over the procedures and expectations for this course. He will then demonstrate the use of the digital multimeter, oscilloscope, function generator, and dc power supply. The student should then spend the rest of the lab period trying out the equipment to become more familiar with it.

1. Display a 4 V peak-to-peak sinewave at a frequency of 1 kHz on the oscilloscope. Obtain the sinewave from the function generator.

2. Measure the amplitude of this ac waveform with the DVOM set on the ac voltage mode. Compare this reading with the base-to-peak value you observe on the oscilloscope.

The voltage measurements in step #1 and step #2 should have different values. The DVOM is calibrated to display the rms value of a sinewave which equals 0.707 of the base-to-peak value of a sinewave.

3. Repeat steps #1 and #2 for a triangular wave of amplitude 4 V p-p (peak-to-peak) and 1 kHz.

4. Repeat steps #1 and #2 for a square wave of amplitude 4 V p-p and 1 kHz.

Experiment #2

Voltage and Current Measurements and Voltage Source Characterization

Duration: Two Weeks (weeks #2 and #3)

1. Measure the open-voltage of a nominal 1.5V AAA battery to the nearest millivolt.

2. Determine experimentally the value of a resistor, that, when placed across the battery, will make a measurable change in the measured battery voltage.

Select resistor values to try with some care in mind - the battery can be damaged by excessive current draw.

3. Measure the resistance value found in step #2 directly with the DVOM in the resistance mode. Calculate the internal resistance of the battery.

4. Design a voltage divider to provide a voltage that is approximately 1/3 of the battery voltage.

Use resistances in the kΩ range and measure the output of your divider when driven by the battery.

5. Redesign your divider so that the resistors are in the MΩ range and measure the output. Compare the results with the result of step #3 and with theory.

MILESTONE #2-1: Demonstrate your voltage divider of step #5. Be prepared to show how it compares with theory.

6. Design a current divider that will provide a 1/3 - 2/3 current splitting ratio.

Use resistances in the kΩ range and power the circuit from the 1.5 V AAA battery. Measure the current splitting ratio. You will need to place a resistor in series with this current divider in order to keep the current at a reasonable level.
7. Redesign the current divider so that the resistors are less than 100 ohms but maintain the same 1/3 - 2/3 splitting ratio. Again use a third resistor in series with the divider to keep the current at a reasonable level. Measure the current splitting ratio. Compare this result with that of step #5 and theory.

8. Repeat steps 1-3 using the function generator. Use a sinewave and set the open circuit voltage of the function generator to 4 V peak-to-peak and a frequency of 1 kHz.

MILESTONE #2-2: Demonstrate the reduction in the measured function generator output voltage when loaded with the resistor. Be prepared to explain how you estimated the source resistance of the function generator.

Quiz on Exp. #2
(Week #4)

Experiment #3
Rectification and DC Power Supplies

Duration: 2 Weeks (weeks #5 and #6)

1. Examine the output of this circuit (termed half-wave rectifier) for 1 kHz sinusoidal input amplitudes from 0.5 V to 5V b-p.

\[ V_S(t) \rightarrow 2.2\, \text{k}\Omega \rightarrow V_0 \]

Use the 1N4148 diode in this circuit.

2. Determine the effect of reversing the diode in the circuit of step #1.

3. Examine the output of the full-wave rectifier shown below for 100 Hz sinusoidal input amplitudes from 0.5 V to 5V b-p.

\[ V_S(t) \rightarrow 2.2\, \text{k}\Omega \rightarrow V_0(t) \]

Be observant of ground connections on measuring instruments and equipment to avoid unwanted short circuits. The function generator ground and the oscilloscope ground are both connected together. The oscilloscope channel A or B cannot be connected to the output $V_o(t)$ without shorting out the diode on the lower right hand side of the diode bridge. Consult your lab instructor about how to measure the output voltage versus time with the scope.

MILESTONE #3-1: Demonstrate the operation of the full-wave rectifier.

4. Place a 10 µF capacitor in parallel with the 2.2 kΩ and determine the effect when $V_S(t)$ is a 5 V b-p 100 Hz sinewave.

Be sure to observe the proper polarity when connecting the electrolytic capacitor.

5. Place a second 10 µF capacitor in parallel with the first and repeat step #5.

6. Construct the unregulated dc power supply circuit shown below. Determine both the dc voltage and ripple voltage as functions of the dc current through the load.
resistor. Limit the dc current to a maximum of 10 mA. Use the data to estimate the thevenin equivalent circuit for the dc power supply.

The circuit should be constructed on the protoboard as much as possible. The transformer and diodes will be provided by the laboratory instructor. Do not use the diodes in your laboratory kit. They do not have the appropriate operating capabilities.

In making measurements with the oscilloscope be careful to note that the outer conductor of the connector on the front panel is connected to the building ground (the third terminal on the ac power cord). If you put channel A of the scope across the transformer secondary and channel B across the load resistor, some of the diodes will be shorted out. The lab instructor will demonstrate the proper way to use the oscilloscope to obtain the needed information.

Read the specification sheet for the 7805T to determine how to use it. Limit the output current from your regulated supply to 20 mA max.

**Experiment #4**

**RC Networks: Transient Response and Frequency Response**

**Duration: 1 week (weeks #7)**

**Introduction**

In this lab you will determine the transient and sinusoidal steady state responses of various RC networks and study some examples of their use in circuit design.

**Experiment**

**Time Constants and Rise Time Measurement**

1. Construct a simple RC single time constant circuit of the form shown.

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\begin{center}
\begin{circuitikz}
\node[ buurtVT, label=above:{$V_{in}$}] (V) at (0,0) {};
\node[ condC, label=above:{$V_{out}$}] (C) at (2,0) {};
\node[ rL, label=above:{$R$}] (R) at (1,0) {};
\node[ cC, label=above:{$C$}] (C) at (1,0) {};
\draw (V) -- (R) -- (C) -- (V);
\end{circuitikz}
\end{center}
```

Choose component values such as to make the time constant about 0.1ms and determine the time constant experimentally by observing resistor and capacitor voltages when a square wave is applied to the input port.

2. Determine the rise and fall times of the output waveform for the circuit in step #1.

The rise time is the time required for a waveform to rise from 10% of its final value.

**MILESTONE #3-2:** Demonstrate the operation of the unregulated dc power supply. Show the ripple voltage across the load for a 1 kΩ load resistor.

7. Use the circuit of step #6 and the 7805T voltage regulator in your parts kit to make a 5 V regulated dc power supply. Repeat the measurements of step #6.
to 90% of its final value. The fall time is the time required for the waveform to fall from 90% of the initial value to 10% of the initial value.

**Milestone #4-1:** Demonstrate the measurement of rise and fall time in step #2.

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**RC Low Pass Filter**

3. Investigate the amplitude and phase of the output of the original RC circuit in item 1 as the frequency of the driving sinusoid is varied over a suitably wide range.

Determine the frequency at which the amplitude is down to 0.707 of the value it has in the low-frequency limit. Also determine the frequency at which the output is phase shifted by 45 degrees with respect to the input.

**Differentiator**

4. Design a simple circuit based on the work of the preceding items which will generate a sharp spike whenever the square wave input changes sign.

Many applications require that a sharp pulse be generated to mark the time at which a rapid change occurs in a signal.

**RC High Pass Filter**

5. Repeat the measurements of step #3 on the differentiator circuit of step #4.

**Coupling and Blocking Capacitors**

6. Construct and test a circuit which will generate a $5 + 1 \sin(2 \pi f t)$ V signal, with $f = 10$ kHz.

Do not use the DC offset of the signal generator for this purpose.

**Experiment #5**

**Logic Circuits**

**Duration: 2 weeks** (weeks #8 and #9)

1. **Measure the dc transfer characteristic ($V_Y$ vs $V_A$) of one of the inverters on the 7404-N hex inverter chip.**

The 7404-N hex inverter chip (16 pin package) is not included in your lab kit and so will be provided by the lab instructor. You can obtain a spec sheet for the inverter chip on the WWW (for example at the website of Digi-Key, www.digikey.com, a company which sells many types of electronic components).

2. **Construct the five-stage ring oscillator shown below using 7404-N hex inverter IC. Measure the oscillation frequency and use this data to estimate the propagation delay of a single inverter stage.**

**Milestone #5-1.** Demonstrate the operation of the ring oscillator and show your estimate of propagation delay to the instructor.
3. Construct a two-input NOR gate using the 7404-N IC. Verify operation as an NOR gate by direct measurements.

4. Construct a two-input OR gate using the 7404-N chip. Verify operation as an OR gate by direct measurements.

5. Construct a two-input NAND gate using resistors and the 7404-N IC. Verify operation as a NAND gate by direct measurements.

6. Construct a two-input AND gate using the 7404-N IC. Verify operation as an AND gate by direct measurements.

7. Construct an exclusive-OR gate using the 7404-N IC. Verify operation as an exclusive-OR gate by direct measurements.

**Milestone #5-2**: Demonstrate the operation of your exclusive-OR gate.

8. Construct an RS flip-flop using 7404-n IC. Verify operation as an RS flip-flop by direct measurements.

**Quiz on Exp. #5**
(Week #10)

**Experiment #6**

**RLC Circuits and Filters**

**Duration: 2 week** (weeks #11 and #12)

1. Design a series RLC circuit (similar to that shown) which has a resonant frequency of 5 KHz and a $Q = 5$. Measure the magnitude and phase of the transfer function $V_o/V_i$ a wide enough frequency range so that the complete frequency-dependent behavior of the impedance is determined.

```
L
C
R
Vo
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Use the 10 mH inductor in your parts kit.

**MILESTONE #6-1**: Demonstrate that the circuit has the proper resonant frequency and $Q$.

2. Drive the circuit of step #1 with a 100 Hz square wave and observe the voltage across the resistor. Repeat for a square wave of 5 kHz.

3. Determine the resonant frequency ($f_0$) of the series RLC circuit of step #1 when the capacitor $C$ is varied from 0.001 μF to 0.1 μF.

Determine the functional relationship between $f_0$ and $C$.

5. Design a parallel RLC circuit with a resonant frequency of 5 kHz and $Q = 5$.

Measure the magnitude $|Y(jω)|$ admittance $|Y(jω)|$ as a function of frequency over the same range as used in step #1.

6. Design a circuit that strongly attenuates signals in a narrow bandwidth centered about 5 kHz (a so-called bandreject filter). Verify its proper operation.
Experiment #7
Operational Amplifiers

Duration: 2 weeks (week #13 & #14)

Be sure to get a complete set of specification sheets for the 741 op amp, including the pin-out configuration, before starting this experiment.

Amplifiers Using Op Amps

1. Design a noninverting amplifier with a voltage gain of 10. Measure the transfer curve (Vo versus Vi) over the full range of input voltages.

2. Using resistors in the several kΩ range, design a voltage divider to produce an output of 5 V when the input is 15 V.

Determine the load on the divider which will drop the output voltage to 75% of its no load value.

3. Construct a buffer amplifier (non-inverting, gain of unity) using a 741.

Drive it with the unloaded voltage divider from step #2 and load the output of the buffer with the load determined in step #2.

4. Design a differential amplifier having a gain of 50. Use it to amplify the output signal from the circuit shown below.

Use a 1 V b-p 1 kHz sinewave for Vs(t). Remember that an oscilloscope channel (either A or B) cannot be directly connected across the 10 ohm resistor without shorting it out. (Recall the similar problem in Exp. #3 with the dc power supply.)

Comparators

5. Construct the comparator circuit shown below. Monitor its output when the input is varied a few millivolts on either side of zero.

6. Interchange the roles of the input terminals and repeat step #5.

7. Design a circuit that will indicate whether an unknown voltage is greater or less than a given reference voltage.
The reference voltage should be capable of being varied between -5V and +5V.

8. Add red and green LEDs so that the green is on when the input voltage is less than the reference and the red when it is greater.

The red and green LEDs are found in your parts kit. Use resistors in series with the LEDs to limit the total current through them to 20 mA maximum.

Thermocouple Sensor

The thermocouple is a device commonly used to measure temperature differences. Familiarize yourself with the operating characteristics of the thermocouple before continuing with this experiment.

9. Design an op amp interface between the copper-constantan thermocouple and the DVOM such that a 0 to 100 mV output will be obtained for a temperature range of 0 to 100 °C.

Use an ice bath for the reference junction. Determine the temperature of various items in the room.

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MILESTONE #7-2: Demonstrate your temperature measuring system at zero degrees C (ice water will be provided and body temperature).

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Quiz on Exp. #7

(Week #15)