1.0 Purpose of Laboratories

Labs are a very important part of any ECE course. It is vital that all electrical and computer engineers become proficient in using measuring equipment; failure to achieve this is like *being a tailor who can't use a tape-measure* - you won't get much repeat business. So there are three main purposes of these labs.

1.1 Familiarity with equipment

You will be introduced to the basic equipment in an electrical laboratory, i.e. power supplies, voltmeters, ammeters, ohmmeters, function generators, and oscilloscopes.

1.2 Tie-in to theory

This is two-fold. First, you will see that classroom theory is borne-out in practice. Second, you will see that the first point is not achieved perfectly!!! There will always be some experimental error in your readings and you must account for this.

1.3 Develop problem-solving skills

Engineers are people who solve problems. Some of these are *design* problems, while others are *equipment operation* problems. You will encounter many of the latter in the lab. This will probably be irritating at first, but de-bugging circuits is an essential skill of any working electrical or computer engineer.

2.0 Materials

The following items need to be brought to each lab. *Your lab grade will be reduced if you do not bring these items*.

- This laboratory manual.
- A laboratory log book.
- The pre-lab work (usually contained in the log book).
- The parts kit for the course. You will purchase this from the Instrument Room (D118).

3.0 Equipment

Each bench in the lab has six pieces of equipment on it. When you enter the lab you should check that these are present and working.

- 54622D Oscilloscope: 4 channels.
- E3631A Programmable dc power supplies: 0 to 6 V @ 5A, and ±25 V @ 1A, all floating w.r.t. ground.
- Two 34401A Digital Multimeters (DMM). These can be set to measure voltage, current, or resistance.
- Two 33220A Function generators. These can output sine, square, triangle, or ramp waveforms.

4.0 What is Expected of You

The first thing that is expected of you is *Professional Work*, i.e. the kind of work that you would expect to be paid for when you are working (the fact that it is you who are paying us is irrelevant!!)

This means that you are expected to know the procedures and requirements of each lab. Saying "I didn't know we were supposed to do that" is not acceptable, *your lab grade will be lowered* for not knowing you were supposed to do that.

It is essential that you read the complete lab ahead of time and if there are parts you do not understand; see the instructor to get them resolved.

Most labs will be made-up of three distinct parts:

- Pre-lab assignments. These help you prepare for the actual lab and are usually predictions of what you will measure. Do all pre-lab work in your lab logbook and turn in a *photocopy* of the pre-lab as instructed.
- Actual lab work. This usually consists of constructing circuits, troubleshooting problems, making measurements, recording data, etc. Instructions will be given in a lot of

detail in the early labs, but this level of detail will reduce as you are expected to become more independent as the labs progress.

- Post-lab assessment consists of analysis of lab results. Be sure to read the lab sheet ahead and leave enough time for this.

5.0 Lab Journal

All engineers have to develop a habit of recording what they are doing (or have done). Sometimes this is done interactively, e.g. when supervising a power system, or chemical plant; but most times it consists of paper and pencil, which is transferred to a computer record later. The purpose of your lab logbook is to get you started on this habit.

Typically the record kept by a working engineer shows the steps taken when developing a new circuit or system. It sometimes becomes a legal document in such things as patent applications, or liability issues; obviously, the accuracy of such a record is vital.

Each lab partner needs to have a lab logbook (two book per group) as the book will be turned in at the end of each lab and will not be returned in time for you to complete the pre-lab assignment for the next lab (the lab books will *leap-frog*). The owner of the lab book will record all the data, while the other partner builds the circuits etc. Obviously, these duties rotate for each lab session. The lab log must record *all actions that were taken* in the lab, even mistakes and "dead-ends" have to be recorded. You are also expected to supplement this with your own initiative, e.g. if it says "compare your experimental results with the theoretical predictions" you are expected to calculate and present experimental errors.

The following URL is for the ECE Department's Writing Standards, pages 15 & 16 describe lab logs: http://ece-1.rose-hulman.edu/ece/images/stories/files/ecewritingstandards.pdf

The following points will help you to keep a satisfactory lab logbook.

- Number all pages (in ink) as soon as you get the book.
- Create a "Contents" page and enter the title of each lab (with its page number) when you start it. The instructor may want to put the lab grade here.
- Do not tear-out any pages. Write on the front page and leave the back page for such things as handouts, diagrams, graphs, etc.
- Make all entries (except graphs) in ink. If you make a mistake, cross it out with a single line.
- Treat the lab book as a "diary" and write down everything that was done, so that your steps could be repeated exactly by someone else.
- The first page of each exercise is the title page. Write the title in large letters and follow this by the bench number and any equipment that was additional to the items in part 3.0 above. Include your name, your partner's name, the bench number, room number, and date.
- Place the pre-lab after the title page. A photocopy of this is due at the start of the lab.
- Each member of the team *must* sign and date the last page of the record.

As a final point, *neatness does count*. While you will not be penalized for crossing out errors, hurried lettering, or spelling errors, remember someone else has to read and interpret what you've written. In the near-term this will be the grader, but you will be required to refer back to your record on later labs *including labs in later courses*. Also, you need to develop the habit of producing readable records quickly for work in industry.

6.0 Circuit Diagrams

These are the "lifeblood" of circuit analysis. No circuit is so simple that you can wire it "in your head"; you always need to have the diagram in front of you. Also, a circuit diagram without labels is next to useless, this means that all sources, all element values, and all pin numbers need to be labeled; the polarity of all voltages and currents need to be indicated.

Your instructor will not help you de-bug your circuit unless you have an up-to-date circuit diagram.

Schematic Diagrams do not display the exact physical layout of a circuit but, as the name implies, they show a *scheme* of the wiring — there are several ways to actually wire the circuit that will obey the connections of the schematic.

Figure 1 shows a correctly laid-out schematic diagram of an op-amp inverter. Note the following:

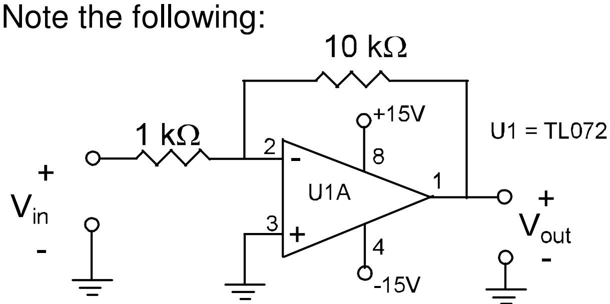

Figure 1 — Proper Schematic Diagram

- It is laid-out from left to right because this is the direction that the signal is flowing.
- Standard symbols for the devices (resistors and the op-amp chip) are used, not outlines of their physical shapes.
- The chip pin numbers for the semiconductor are included.
- The ±15 V power supply voltages a labeled, while the power suppl themselves are omitted.
- Integrated circuits are labeled w their standard numbers (TL072), they are given a "U" number that referenced elsewhere.
- The "A" on "U1A" means that this is one of the op-amps on the U1 chip; the other op-amp is labeled "U1B".

If you modify the circuit during the lab, be sure to update the diagram. Small changes (e.g. changing a resistor value) can be made on the original diagram, but for larger ones you'll need to re-draw it.

7.0 Wiring Breadboards

Breadboards are a quick and easy way to construct circuits. They enable changes to be made and errors to be corrected rapidly.

There are many ways to construct a circuit on a breadboard and if you do not follow *orderly procedures* your wiring will be chaotic and error-prone. Here are some simple tips to avoid "spaghetti-wiring". If your board looks like a bowl of spaghetti, your instructor will refuse to help you de-bug the circuit.

- Connect the power supplies to the long strips along the top of the breadboard, then run short links into the circuit. Use the long strip at the bottom for grounds.
- Build your circuit from left to right in the same direction as the "signal flow" of your circuit diagram.
- Don't crowd components — you can always use links to connect them when they are well spaced.
- Use the shortest link that will do the job and flatten-out "humps" of wire so that they don't get caught as you make adjustments.

Figure 2 shows these tips applied to an op-amp circuit.

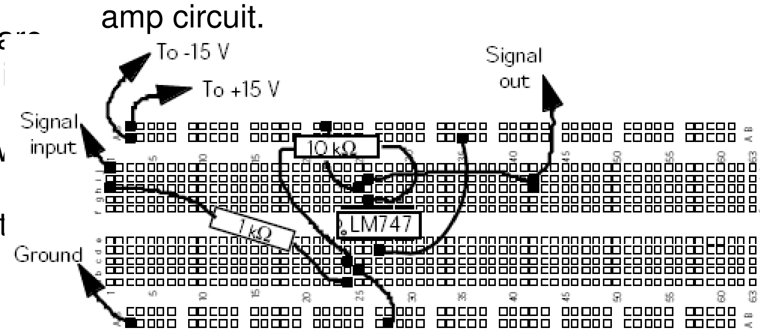

Figure 2 — Proper Breadboard Layout

8.0 Using the Oscilloscope

The oscilloscope is probably the most useful piece of measuring equipment that an engineer can use. It shows you the shape of the waveform that you are working with.

Often when something is going wrong with a circuit and the cause of the trouble is not obvious, looking at the waveform gives the answer — you may be thinking you were working with a pure sine wave until the 'scope shows that the top is cut off by saturation.

We will also be looking at sine waves that have been produced by a dc power supply; so this will be a good time to learn some basic oscilloscope conventions.

- Channel 1 should display the input signal, with the trace toward the upper half of the screen.
- Channel 2 should display the output signal, with the trace toward the lower half of the screen.
- Make the waveform as large as possible, i.e. don't display six cycles if you only need to see one.
- Simple images can be sketched into your lab book, but complex images need to be captured, printed-out and attached to the book.

9.0 Tables & Graphs

These are important ways to convey significant amounts of information in very compact forms. Here are a few tips.

- Use tables to present data, not sentences. Every table *must* have a title and clear column headings.
- Put units at the top of the column to save space.
- Make tables large; there should be enough room in the table to cross-out an entry and insert a correction.
- Every graph *must* have a title and each axis *must* be labeled.
- Axis divisions *must* be "reasonable", i.e. 1, 2, 5, 10, etc.
- Always show the zero point on each axis, unless you are making a logarithmic plot.
- Draw a smooth curve through the points. You will need to exclude "obviously bad" data points to do this — ideally, you should re-take these points if time permits.

When attaching pages to the lab book make sure they are permanently fastened (do not leave loose pages in the book). Also, all work should be read with the book in the upright position if possible. If you need to turn it sideways, make the *right side* of the page become the *bottom*. As shown in Figure 3.

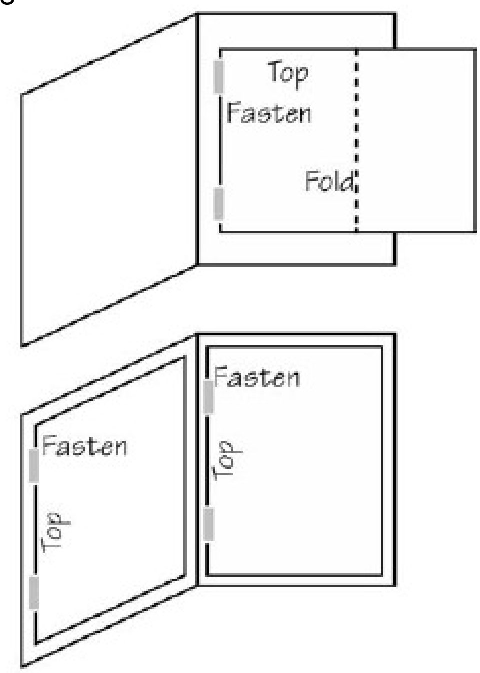

Figure 3 — Fastening Pages

10.0 Safety

The old cliché which says that "safety is no accident" rings true — safety doesn't just happen any more than accidents just happen.

We all have to pay attention to what we are doing at all times. There are two things we need to be aware of. First there is the electricity — it's not to be feared, but it *must* be respected and secondly there is physical equipment that can hurt you.

Let's consider the second item first. When you are in a lab there is equipment that can fall on you or snag loose items, so following these rules is essential.

- Proper footwear is *required*, you are not permitted to wear sandals or go barefoot, sneakers are OK.
- When working with machinery, e.g. motors do not have loose clothing, remove all jewelry (especially rings), and if you have long hair tie it back.
- Keep the workspace tidy and don't place equipment near the edge of the bench.

The first item is concerned with electric shock. You may be thinking that in this lab we will only be working with a few volts so this is not an issue. Hopefully, that will be the case but remember things like the ±15 V dc power supply are powered by 120 V ac and any piece of equipment can malfunction — safety is about staying safe when things go wrong!!

Electric shock does several things to the body, in extreme cases it stops the heart and/or lungs and the victim needs emergency measures to survive, lesser effects are burns, but the most common injury from electric shock results from people jumping, tripping and falling.

Electric shock happens when you become part of the circuit and current flows through your body, the best way to avoid this is to follow these rules.

- Turn off the circuit before working on it, this will also protect the electronic chips that can be damaged by open circuits.
- Treat a circuit as if it were energized (even when you know it isn't) so never put both hands on parts that could be live. Never have your feet touching ground, correct footwear should ensure this.
- Never work alone, that way if the unthinkable happens you have someone to help you.
- If you are the "someone" called upon to help in the above situation, always disconnect the power at the main supply (this means you need to know where the main supply switch is) *before* going to assist the victim. You don't know what caused the accident and you don't want to become the next victim.
- Being certified to administer CPR is highly recommended. You should also encourage your friends and potential lab partners to do the same — after all the only person you cannot administer CPR to is yourself!!

11.0 Reading Components

The parts you will be using are very small and don't have room for labeling their values, so they are coded. Being able to interpret the codes is essential to any electrical or computer engineer.

11.1 Resistors

These have either three or four colored bands with the following meanings:

Black…..…0	Blue………6
Brown…….1	Violet……..7
Red……….2	Grey………8
Orange…...3	White……..9
Yellow……4	Gold….0.01 or 5%
Green…….5	Silver…0.1 or 10%

If you have difficulty remembering the code, just think of: **B**lack **B**eer **R**ots **O**ur **Y**oung **G**uts **B**ut **V**odka **G**oes **W**ell – **G**et **S**ome **N**ow.

Then arrange the resistor so that the band closest to one end is on the left (see Figure 4) and start reading the bands, as follows:

1st band — The tens digit of an integer.
2nd band — The units digit of an integer.
3rd band — The multiplier as a power of 10.
4th band — % tolerance (20% if no band).

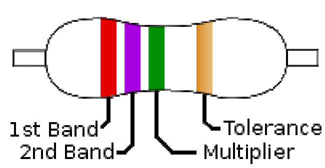

Figure 4 — Resistor Alignment

For example, if the bands are: red-violet-orange-gold, then the resistor's value is given from red = 2, violet = 7, orange = 3, and gold = 5%, which is:
27 x 103 = 27 kΩ. The tolerance of 5% means that the actual value could be anything between 25.65 and 28.35 kΩ.
Here are some other examples.

green-blue-brown = 56 x 10 = 560 Ω
brown-green-red = 15 x 10^2 = 1.5 kΩ
grey-red-silver = 82 x 10^{-1} = 8.2 Ω

11.2 Operational Amplifiers

The operational amplifier (op-amp for short) is a highly versatile device that can provide a wide range of gains, can change the resistance seen by other devices, and block unwanted signals. The standard symbol for an op-amp is shown in Figure 5.

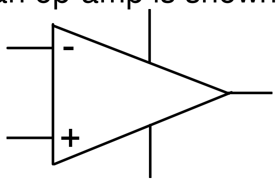

Figure 5 — Standard Symbol for an Op-Amp

The op-amp that will be used in this course is the TL072, which comes in an 8-pin *dual in-line package* (DIP). The *pin-out* is interpreted by looking down on the chip with the notch or dot (sometimes both) at the top as shown in Figure 6.

The pins are spaced to fit directly into the breadboard with the op-amp *straddling* the gutter in the middle of the breadboard.

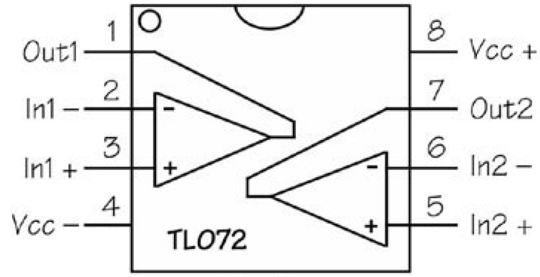

Figure 6 — Pin-Out for the TL072 Op-Amp

As can be seen, there are actually two op-amps on the chip and each has two inputs. The *inverting* and *non-inverting* inputs to unit 1 are pins 2 & 3respectively, while those for unit 2 are pins 6 & 7. The *output* of unit 1 is pin1, while that of unit2 is pin 7. Each unit needs positive and negative external power supplies and these are provided by pins 8 & 4. Note that the voltages V_{cc}^{+} and V_{cc}^{-} are with respect to ground, which is not needed by the chip itself but is needed by all other signals. The correct power supply connections are shown in Figure 7.

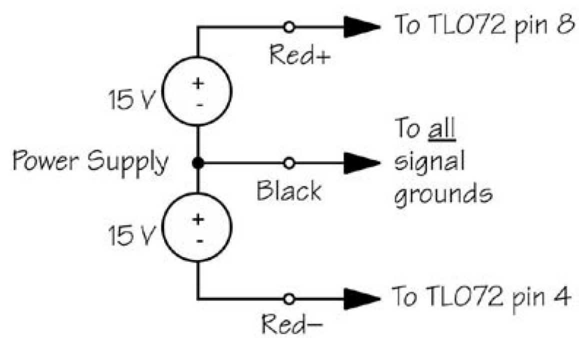

Figure 7 — Power Supplies for the TL072