## Basic Lab Procedure

This installation of N.E.R.D discusses basic lab procedure. The equipment referenced here is found in the Undergraduate Electronics Lab at the University of Houston. Topics covered in this document are as follows.

Safety<br>Basic Laboratory Practice<br>Prototyping<br>The Power Supply<br>The Multimeter<br>Reporting Results<br>Accuracy, Precision, and Significant Figures<br>Error

## Safety

Whenever you are working in the laboratory, safety must be given the highest priority. Electrical shock is the main concern in an electrical engineering laboratory. An electrical potential of only 42 [V] has been recorded as the cause of death by electrocution. The most important factor in an electric shock is the amount of current flow through the heart muscles. Consequently the electrical potential the body comes in contact with is not as important as the value of the equivalent body resistance and resulting current paths. This is the origin of such rules as using only "one hand" in working around "dangerous" electrical systems and keeping the "feet dry". When working with any electrical circuits think "safety". However, if you are working in the laboratory with dry hands, most voltages you will be using are safe.

## Basic Laboratory Practice

Prototyping: Neat prototyping of circuits is something of an art, and an important one to a circuit designer. We offer some general rules for building circuits on prototype boards...
a) Be neat.
b) Keep your wires short. It is a good idea to get into the habit of cutting wires to length, as you need them. Wire is cheap.
c) Keep the wires as close to the board as you can. This will facilitate measurements and make the wires easier to follow during debugging. Some people only allow their wires to make right angle turns. Although this is somewhat nerd-like, it can make the connections easier to trace.
d) Throw away old wires. Wire is cheap.

The power supply: If your circuit indicates a ground connection, be sure it is connected to the ground on the power supply. The power supply has three independent outputs, each of which is "floating". This means that although the voltage difference between the output terminals is fixed, the voltage at either terminal is not fixed with respect to ground. For some purposes we wish to connect one of these terminals to ground. Do this by connecting one of the two outputs (either positive or negative) to the ground terminal. It is a good habit to check voltages set on the power supply with a voltmeter and not count on the accuracy of the voltage indicator of the supply.

The multimeter: some general procedures for use of the multimeter are as follows.
a) Always make a mental estimate what you are going to measure so that you have an idea of whether the result is accurate. Be sure you are on the correct setting: making a voltage measurement with the meter set to measure current or resistance can damage the meter.
b) Be aware of the polarities of your probes. Be sure that the current you are about to measure is in the direction you think it is; be sure that the polarity of the voltage you are measuring is what you think it is.
c) Never attempt to measure resistance with power applied to the circuit under test. Also remember that if you attempt to measure the resistance of a component while it is still in the circuit, you will be measuring everything in parallel with it as well.
d) Think first, then measure.

Reporting results: In reporting results, always show what you actually measured. Too often experimenters modify their results to agree more closely with what they expect to measure, and not what they actually measure. Do not get into this bad habit. Make your measurements as carefully as you can; you can always explain why you think they came out unexpectedly.

## Accuracy, Precision, and Significant Figures

The term accuracy has various shades of meaning but is commonly used to indicate the reliability of the results of a physical measurement. It is defined in Webster's New Collegiate Dictionary as "freedom from mistake or error; correctness". We should distinguish accuracy from precision, which according to Webster's is "the degree of refinement with which an operation is performed or a measurement stated". We generally consider that a voltmeter which has been designed and built according to good engineering practice and which is correctly calibrated will be accurate. However, two accurate voltmeters may be capable of making measurements with different degrees of precision. For example, a simple hand-held voltmeter may give a reading of 3.442 [V]. A more elaborate (and more expensive) voltmeter may be capable of measuring to within a microvolt and would read 3.442374 [V]. Both are accurate, but the second is more precise.

The number of significant figures used to express the voltage reading in the example above is an indication of the precision with which the measurement has been made. When comparing such measurements with theoretical predictions, the comparison should be made at a meaningful level of precision. There is a tendency on the part of many students to retain too many figures in numerical computation, which suggests a fictitiously precise result. If one were interested in comparing the first of the voltage measurements in our example ( 3.442 [V]) with a calculation of the theoretical value, there would be no point in reporting the theoretical value as "3.476659141 [V]". Rather, the calculation would be rounded to the nearest [mV] and reported as "3.477 [V]".

Note that the "theoretical" value differs somewhat from the "measured" value in our example. It is reasonable to expect some discrepancy between calculated and measured results, but the question arises as to how much discrepancy should be tolerated. The answer to this question is a function of the measurements being made as well as the circuit components and equipment being used. In our example, we have said that the voltmeter is reading 3.442 [V]. Frequently, what will be displayed on the voltmeter will vary slightly with time. For example, one might notice the reading changing from 3.442 to 3.445 , then to 3.441 and back to 3.442 . Such behavior is acceptable as long as the variation is not too large. Here, the meaning of "too large" is something
the student will learn to judge with experience. We might decide in this case that the most accurate value is 3.442 [ V ] because this value appeared most often. We would then report the value as 3.442 [V], but we would bear in mind that the digit in the [mV] position, i.e. the " 2 ", is "doubtful", that is, this digit may be " 3 " or " 1 ".

In the ECE Department at UH , we will adopt the following conventions concerning significant figures.

1. In recording the result of a measurement or calculation, retain one "doubtful" digit.
2. Do not carry addition and subtraction operations beyond the first column that contains a doubtful figure. For example, if v1 is measured and expressed correctly as 5.64 [V] and v 2 is 6.852 [ V ], the sum $\mathrm{v} 1+\mathrm{v} 2$ should be expressed as 12.49 [V]. If $\mathrm{v} 1=8.581$ [V] and $\mathrm{v} 2=8.42$ [V], the difference $\mathrm{v} 1-\mathrm{v} 2$ should be expressed as 0.16 [V].
3. In multiplication and division, the precision of the result is determined by the quantity with the fewest significant figures. For example, if a dc voltage source $\mathrm{v}_{\mathrm{s}}$ is 10.44 [V] and the current supplied by the source is $i_{s}=2.15$ [A], the power supplied by the source, $p_{\text {del,source }}=v_{S} i_{S}$, should be expressed as 22.4 [W] (the current is reported with 3 significant digits).
4. In rounding off, the last figure retained should be unchanged if the first figure dropped is less than 5 , and should be increased by 1 if the first figure dropped is greater than 5 . If the first figure dropped is 5 , the preceding digit should be unchanged if it is an even number but increased by 1 if it is an odd number. Examples: 3.455 becomes $3.46 ; 3.485$ becomes 3.48; 6.7901 becomes 6.790 .
5. In reporting calculations to be compared with measurement, retain as many significant figures as there are in the corresponding measurement.

There are some numbers that may be taken to have an unlimited number of significant figures. The expression for $\pi$ and e (the base of the natural $\log$ function) are two examples. When using such numbers in a calculation, it is good practice to express these to one more significant figure than the number required by the measured values in the calculation. This practice is also
applicable to numbers, which are not the result of a physical measurement, for example the ' 2 ' in the expression $2 v_{s}$.

In writing your lab reports, both informal and formal, you will be expected to report your results and calculations with an appropriate number of significant figures. Refer to the discussion above in determining the number of significant figures to report in a measurement or calculation.

## Error

The term error is commonly used to indicate the difference between two quantities of which one is a reference. In laboratory work, the reference is often a known or theoretically calculated value, but it can also be a measurement defined as the reference. The error is usually expressed as a percentage of the reference quantity, i.e.

$$
\begin{equation*}
\% e r r o r=\frac{X-N}{N} \times 100 \tag{1}
\end{equation*}
$$

where X is the quantity in question and N is the reference quantity. Note that negative error indicates that the measured quantity is less than the reference.

As an example, suppose you are asked to measure a voltage between a specific pair of terminals in an unknown circuit and your measurement gives a value of 11.34 [V]. If you calculate the expected voltage as $10.50[\mathrm{~V}]$, then the \%error determined from the formula above is $+8.0 \%$. Note that in this case, the measurement is the "quantity in question", and the calculation is the "reference quantity", since the calculation is considered to be correct. However, in some other cases, where a new calculation is being proposed, and tested by comparison to experiments, then the measurement will be the "reference quantity", and the calculation will be the "quantity in question". In this second case, the \%error would be $-7.4 \%$.

While the above discussion seems to be academic, it most assuredly is not. Many important discoveries have been the result of careful consideration of accuracy and error. If the error expected from a detailed error analysis of the circuit discussed in the last paragraph is $10 \%$, it is likely that the solution is correct. On the other hand, if the maximum error is calculated to be within $2.0 \%$, it must be assumed that either the analysis was done incorrectly or the physical principles on which the analysis is based are incorrect; this conclusion is indeed significant.

