Chapter 3 Organization

The organization of a technical report, and a laboratory report in particular, should follow the principle:

1) Tell them what you are going to tell them.

2) Tell them.

3) Tell them what you told them.

This isn't a bad idea for other forms of communication as well, such as viewgraph presentations (such as those using PowerPoint or comparable media) and strictly oral presentations. The point is that a short introduction is needed so that the reader will have a context of understanding and will be prepared for the body of the report. Then, after it is all over, the paper is reviewed in summary form, so that the reader will again return to an overview and carry away the most important conclusions.

For a laboratory report or similar technical communication, additional organization is needed for the middle "Tell them" part, which makes up the bulk of the report. There are different ways to do this, depending on the nature of the report. The report outline given below is offered as a guide that will probably be useful most of the time. Variations on it will be discussed later. (The "style" of the report, including issues of whether and how to number sections, is a somewhat different issue addressed later.)

Typical report sections are:

1) **Abstract:**
This is where you "Tell them what you are going to tell them." The abstract allows a potential reader to briefly find out what the report is about, and decide whether he will spend the time reading the rest of it. It compactly describes the whole report, and must state what the report is about, the nature the work described (the design, analysis, or experiment), what was found out in general terms, and the most important conclusions or recommendations. If the work was unsuccessful, the writer owes it to the reader to state that fact here up front as part of summarizing the conclusions. An abstract should have no footnotes, no figures, and no equations. Those appear in the body of the report. Abstracts should typically be on the order of 100 words. Importantly, the Abstract is not really part of the report proper; it stands alone, and may be published without the rest of the report. It is usually best to write the abstract last.

2) **Background:** This is where the report lets the reader know anything that should be known in order to understand what the report is about and what it should demonstrate. Since the abstract is not really part of the report, you need to "Tell them what you are going to tell them" again here. The Background section sets the reader up for the rest of the report. In a laboratory report, doing this in detail is occasionally unnecessary, because the theory or principles are so simple that they do not need a whole section; they can be slipped into the beginning of the Procedures section. For example, if the

purpose is to demonstrate Ohm's Law, then that can be done with one sentence and an equation. If the background simply explains why the laboratory report is being done, then "Purpose" makes a better heading. On the other hand, if the report is an analysis of a complex circuit, the Background section needs to describe what the issue is (why the analysis is being done), what the piece of equipment is supposed to do, why it doesn't or might not, and review the theory of operation and the particulars of the system that may need to be examined with particular care. In such cases, the Background section may need to be split into separate sections for these different purposes. If the report is a design exercise, the specifications for the system may be put in the background section, or possibly a separate "Specifications" section. At the end of the Background section, the reader should know the purpose of the exercise being reported, and the general method used in the exercise and report, in considerable detail.

Within the Background section, illustrations and graphs (called "Figures") and tabular data, "Tables," and equations are formally used where appropriate for conveying details that are best expressed in those forms rather than text. Depending on the degree of formality of the report, equations may be embedded in the text, or given in a more formal numbered format. Additional details that a reader might not need or want to see should be called out and put in an appendix at the end of the report. The Background or Purpose section can be as brief as a few sentences to a few pages. If it needs to be longer than a few pages, it should be subdivided. If the entire report is more than a score of pages, a chapter format might need to be considered. (See the Division of Engineering and Physics Thesis Guide.) For such a document, each "section" described here typically becomes a chapter. The introductory chapter should end with text outlining the remainder of the document, describing how those chapters will bring the reader to the conclusion.

3) **Procedure:** This is where the report tells the reader how the project was done. The most important principle here is that the Procedure needs to convey all of the details necessary for someone to repeat the analysis, design, or experiment. If the reader does repeat the experiment and might get different results, additional details, such as the make and model of equipment used, if those might affect the results, are needed as well.

For example, measurements made with laboratory grade Voltmeters typically have a 10 Meg Ohm input impedance, but less expensive meters such as the Digital Multimeters (DMMs) in the student kits typically have only 1 Meg Ohm impedance. Inexpensive analog meters may have an impedance in the tens of K Ohms. If the Voltage being measured has a 1 Meg Ohm source impedance, the laboratory grade meter will have an error of around 5%, the inexpensive DMM will be off by 50%, and the analog meter is hopeless. In such a case, the reader needs to know what kind of meter you used, and maybe the range setting on the meter. (Give manufacturer and model number. If you think someone might need to identify a defective unit, or in critical work, also give the serial number.)

On the other hand, there is a lot that you do not have to include. It typically does not matter in what order components are assembled to make a circuit. So, don't go into those details; simply tell the reader that the circuit shown in a particular figure was constructed. In schematics, include the details that matter. For example, if a 100 Ohm resistor is used that is typically dissipating 10 mWatts or less, you don't really need to specify that you used a ¼ Watt resistor (the cheapest and easiest kind to use). But if that component must dissipate ½ Watt, you need to specify the power rating of the resistor, so that someone attempting to duplicate your work does not make the mistake of using too small a component, and thus getting different results. Typically, it is not necessary to specify manufacturer or lot or serial number and such for common circuit components; part number or ratings are sufficient. However, in critical work in industry those details may well be necessary. Likewise, it is usually unimportant how you might have physically arranged the components on a solderless breadboard. But, for high frequency work, and in reports where there is a mechanical component, including such details is usually necessary. To repeat, the guiding principle is that what the reader needs to know to be able to duplicate the work is reported.

One thing you generally want to avoid in the Procedure section is a description or reference directly to results. So, instead of writing "The results were obtained as shown in Table 3," or such, simply say that results were recorded, for example "Peak Voltage and phase were recorded for each of the frequencies in the range 20 Hz to 20 KHz." The problem here is that, if you mention Table 3, that table needs to come immediately after the callout paragraph. But, you don't want it here; you want it in Results. So, avoid the explicit callout.

This issue can actually be tricky, since for some circuits or systems it is necessary to make measurements in order to select or adjust components. Selecting components is a design step, and rightly belongs in "Procedure." Thus, you need to include in Procedure any measurements needed for design. In like manner, making measurements in order to calibrate a circuit, such as by setting a potentiometer so that a meter gives full scale deflection, is also part of Procedure, and the measurements and settings made also need to be in this section. One solution to this problem is to distinguish "Design" from "Procedure", and have a separate "Design" section before "Procedure," in which you describe design steps. This might include even measurements conducted in the laboratory. In that case, you may need to have a separate design development, design laboratory procedure, and analysis and conclusions subsections related only to the design steps.

As with the Background section, you should formally call out figures and tables as necessary, and use explicit equations either informally or in formal numbered style depending on the requirements of the report. Additional details, for example pictures of the apparatus, mechanical layouts for circuits, detailed parameters for components, and like material, that is not necessary to understand the procedure, but may be of interest in some cases, should be in an appendix.

See the separate material in this manual on schematics in Appendix D for more information on how such figures should be drawn and presented.

4) **Results:** This is where you provide the reader with a record of the data recorded in the course of doing your analysis, testing a design, or in the course of conducting an

experiment. Generally, the results need to include all of your raw data: all of the numbers you actually recorded in the laboratory. (If the raw data is too bulky, it should go in an appendix called out early in this section.) Results also includes information calculated from the raw data. For example, the raw data might be the mechanical position of a mass recorded against a measuring stick attached to the apparatus. Once the steady state position is known, the positions can then be referenced to the steady state position, which would be processed data for position. Often it is appropriate to put both in the same table.

You must have text. A common error in formal reports is to simply throw into the "Results" section all of the tables of data with no text. But in a formal report, everything starts with text. For every table or figure there must be a "callout". A "callout" is where you refer the reader to a particular figure or table, with the figures and tables numbered starting with Figure 1 and Table 1, up to as many figures and tables as there are in the report. (In a thesis or book which is organized into chapters, figures and tables are often numbered as a separate series within each chapter, such as "Table 2-3" which would be the third table in Chapter 2. That is done in this manual. However, in an ordinary laboratory report this is inappropriate.

The actual table or figure must immediately follow the callout, typically after the paragraph in which the callout occurs. You are not to simply collect them and put them all at the end. Sometimes a figure can be put in the middle of a paragraph, especially if it would otherwise get pushed onto the next page. Figures or tables that take up a whole page should go on the next free page. Never split a table over more than one page where the top with all the labeling is on one page and some of the table is on another. If a table takes up more than a whole page, continue it to another page, but repeat the labeling, including the title (with "continued" or some such indicator that this is not a new table).

Usually results need to be presented in a tabular form. Tables are usually compiled in Excel and copied into Word, but sometimes they may be prepared directly in Word. Whether they are boxed or open is a matter of style preference and necessity. The larger and more complex the table, the more likely you should provide a grid or matrix for the values. Table numbers and titles are at the top of the table, unlike for figures, where they are at the bottom.

Often it is useful, or even required, to present the data in both tabular and graphical form. Graphs are figures. Like other figures, the figure number and title are to be underneath the figure. In slideshow presentations, that is not the case; titles are typically at the top. Beware; Excel will want to put them at the top! Preparing good figures, especially graphs, is a complex and important topic, dealt with later in separate material within this document. See Chapter 5 for those details.

Tables and figures should be carefully explicit in identifying the quantities that are measured. A symbol used in a table, for example, "Vo," should match exactly the same symbol as it might appear on the schematic and in the text. In the text, there should be an explanation of what the symbol or recorded values stand for, if it is not completely obvious. Appropriate units should be used. Most often, the units for a given column are given at the top of the column. All of the entries in the column should usually have the same format and number of significant digits. The exception is where there is a wide dynamic range. For example, a frequency might vary from 10 Hz to 10 MHz. In such a case, the units should usually be in the column with the numbers. (Note that units derived from a person's name are capitalized: Volts, Amperes, Ohms, Hertz, and so on, while those which are not are not capitalized: seconds, meters, cycles, etc.)

It is very important in tables of data to use an appropriate number of significant figures, and in some cases, perhaps explicitly designate the degree of uncertainty of the results. For example, in informal conversation one might refer to a resistor as having the value "1K." However, in a formal written report, there is a significant difference between 1 K, 1.0 K, and 1.00 K Ohms. The use of one significant digit, "1 K," implicitly suggests that the actual value might be as large as 1.4 K Ohms, and maybe as small as 700 Ohms. The actual labeling of the resistors we typically use, having a "tolerance" of 5%, would be "1.0 K" for this part, which means the actual value could be as large as 1.05 K Ohms, or as small as 950 Ohms. If the resistor was actually 1.1 K, it would have different labeling. When you record a value of 1.00 K Ohms, you are implying that the value is good to within a percent or so. Notice that one significant digit of "1" implies a lot more uncertainty in a percentage sense than one significant digit of "9." So, if your range of numerical values goes from about 6.0 to 20.0, you should probably use two significant digits at the bottom of the range and three at the top.

Using significant digits to imply the degree of uncertainty is an informal method sufficient for most formal laboratory reports in an undergraduate engineering academic setting, but in critical or scientific work it is often necessary to be explicit in giving the degree of uncertainty, especially for observations made, such as 1.20 Volts +/- .02 Volts. For some data having a wide dynamic range it may be more appropriate to give uncertainty in units of percent (of the reading, unless stated otherwise) rather than units.

Remember that the purpose of the Results section is to let the reader know what data you recorded, with the idea that if there is a repeat of the procedure, the data recorded should give results that are comparable to yours.

Within the results section it is also usually appropriate to perform computation on the data necessary to put it into a more meaningful form. Often this is included in the same table as the raw data. For example, two columns in the table might record the Voltage and current for a particular setting, but the actual value of interest is the ratio of voltage to current: the impedance. The text that calls out the table or figure should describe how any such calculations are made, giving equations if appropriate.

By the end of the Results section, if the data are supposed to form a pattern such as a linear or logarithmic or exponential relationship, the reader should be able to easily discern that relationship from the tables and graphs provided. That means that the format of tables, and especially of graphs, need to be appropriate to the data. If what you are showing is a linear relationship, then you should use linear or log-log plots, depending on whether your data has a small or large dynamic range. If it is logarithmic or exponential, you need to use a semi-log graph so that the relationship forms an easily discerned line. Usually the form for presenting the data and derived values should be fairly obvious, given the purpose of the exercise on which you are reporting. In some cases, especially where unusual results occur, you may have to use some imagination. For example, at the extremes of a range of data, results might deviate from the expected semi-log relationship. You might be able to use a linear plot for that part of the data, to show that for the extreme cases the relationship approaches linear instead of log.

Occasionally it is appropriate to describe the degree to which the results fit the expectations. Whether this is done as part of the Results section or part of a separate Observations section is a matter for judgment. If the results are unusual or need discussion, the latter is probably best. If the fit is good and results expected, then a terse mention of the measure of goodness of fit can be put in Results. Generally, when you do a fit to a linear or exponential curve using Excel or MATLAB, the fit goodness is provided. (It is best not to leave it on the graph; put it in the text.)

5) **Conclusions:**

This is where you wrap up the report. Often for a simple report this can just be one paragraph that describes the results in qualitative terms, and says that the results were what was expected. If the report includes a design that was demonstrated, the conclusions should state that the demonstration was successful (or not), and that it was witnessed on a particular date by a given individual with oversight responsibility, typically the instructor for a lab report. It is this conclusion that, in much more compact form, is included in the abstract.

If a numerical comparison is needed, a summary table is appropriate. For example, in a design exercise there is typically a specification of what the design is supposed to do, the performance expected from the design, perhaps simulation results, and laboratory results. The reader is expecting a comparison of these numbers in the conclusions section, and particularly a comment on whether the design meets the specifications.

However, there are complications that might require a much more extensive Conclusions section, or even separate sections for “Observations,” “Conclusions,” And “Recommendations.”

When results are not what were expected, you owe the reader an explanation. In any profession, forthrightness is a requirement. If something did not work as expected, you should not try to hide it. That is dishonest, and in industry will cause greater expense (and probably your job) when the problem becomes apparent. Managers need to know if there is a problem, so that they can allocate resources to do something about it, or alert their superiors, in a timely manner. These issues are discussed in Chapter 5.

You will need a separate Observations section if explaining unexpected results gets fairly involved. Usually you need to suggest very explicitly why the results were different than theory or previous similar exercises would have suggested. (Vague references to tolerance of components or inaccuracies of equipment are not satisfactory;

be explicit.) Sometimes it is necessary to repeat the procedure with a modification necessary to correct some problem. In such a case, the original results would be relegated to an appendix, cited from the Procedure, Observations or Conclusions section, and the revised data now used in the Results section of the report proper. If resources (time and effort) are not available to correct bad results, the corrections needed (and the cost, if appropriate) need to be detailed. It may be appropriate to include a separate section on diagnosis and fault detection (debugging) if that required an involved or innovative procedure worthy of inclusion in the report.

If the purpose of a report is to recommend some course of action to a decision maker, typically an executive with budget authority, there should be a separate "Recommendations" section. This is where you say how the results of your work should affect the decision, typically of what technical approach to take, product to buy, or whether to change the way some procedure is done. (In industry, you would detail the cost.) In the typical laboratory report, this might be appropriate if you want to recommend a change in the equipment or instructions governing the laboratory exercise. The recommendations section should clearly tie the recommendations made to the conclusions and results of the report.

6) **Acknowledgements:** Often this is not needed in a school laboratory report. This is the section where you credit those people whose work you have utilized, or who provided unusual help. This is extremely important in a business setting; it is where you give credit to those who have helped you. It is part of professional courtesy. If your report is good and brings credit to you, some of that credit reflects on the people you mention here. (If your report is a piece of trash, it may actually hurt the people you list here, so be careful!) It is also where you give credit to any organization which provided the funding for the project, of which the report is a product.

7) **References:** This is where you list references, with sufficient specificity that the reader can actually find them. This is especially important for any sort of web reference. See the Little, Brown Handbook for additional information. Often you may need to include a manufacturer's data sheet in a report. You may include appropriate excerpts in an appendix, but in that case, you also need to give your source. You should not just point the reader at an entire book or web site, but include the specifics such as page number so that a reader can reasonably expect to find the material cited.

For laboratory reports, you often will not need references. The laboratory exercise instructions typically can be referred to explicitly in the Procedure or Background section rather than being part of a reference list. You don't need to include references for common knowledge in the technical community, such as Ohm's Law, that can be easily found in appropriate textbooks. You don't have to cite manufacturer's literature for most common parts that you may use; a technically astute reader can find such materials without needing a citation. If you find or use an unusual part or piece of equipment, you might want to include a reference to further information about it. That usually is not the case in undergraduate laboratory exercises.

Occasionally, deviations from the above organization is needed. One such case is when there are two or more separate parts of the lab exercise that are done in sequence. In such a case, there are two choices:

1) Have a separate section for each part, in which subsections describe procedure and results and possibly observations, or

2) There is one Procedure section with subsections for each part, then a Results section with subsections for each part.

Your choice will depend on circumstances. For EE283, the second approach is currently required. For other courses, there may be flexibility. I usually find the first approach better. If in doubt, consult any explicit reporting directions for the exercise, or in the course syllabus, or other applicable materials. If that fails to make the requirement clear, ask the instructor.

Laboratory reports actually report on several different kinds of exercises, some of which will require a bit different treatment. These might be classified as:

1) **Experiment:** An experiment is the test of a hypothesis. In science classes, where the most typical object of a laboratory exercise is to confirm the operation of some scientific principle, an experiment is most often what is done. The hypothesis may be that Ohm's Law (V=IR) is true, or that mechanical Friction is linear with velocity (typically it isn't!). The hypothesis to be tested needs to be stated in the Background or even in its own section prior to Procedure. The laboratory exercise then is a test of the hypothesis, the Results section collects the data, and the Conclusion is that the hypothesis is confirmed (as expected for V=IR and "resistor" components) or denied (as for V=IR for diodes, and for mechanical friction under most circumstances). Experiments are so pervasive in science classes that students may begin to believe that any laboratory exercise is an experiment. That is not the case. Ask yourself, "What is the hypothesis?" If you can't identify one, it probably should not be called an experiment.

2) **Characterization:** This is an exercise where the purpose is to determine some parameter or parameters associated with a component, often with a goal of comparing actual performance in the laboratory with theory, or with the manufacturer's specifications. This is a common type of laboratory exercise in early undergraduate engineering experience. For example, in EE283 the students compare the Voltage versus current characteristics of resistors, capacitors, and inductors to the relationships described by theory. The point is to determine whether the results match what theory or the given characteristics would lead one to expect. Usually the "correct" answer is "Yes!" If you get results that do not match theory, you have probably done something wrong. You need to explain why the results do not match expectations. You could call a Characterization exercise an Experiment if you state a hypothesis that the component matches a specification or a behavior predicted by theory.

3) **Analysis:** An Analysis is an expansion on the idea of a Characterization. But what is sought is a deeper understanding of the system. In this kind of exercise, the student is presented with a system, perhaps a circuit, and the point of the exercise is to describe what the system does in useful and quantitative terms. The procedure and background sections need to include a description of the metrics and analytical method to be used to assess the performance of the system. A measurement and analysis strategy needs to be designed. Often test circuits are needed, such as a circuit to stimulate the system or to provide a load. In a case like this, the expected performance of the system may or may not be known. It may be appropriate for the student to model the system, perhaps using MATLAB, PSpice, or some other software, to assess what is expected of the system, based on its design or specifications. If so, the reporting on that model and its performance could constitute a separate section, typically after Background but before Procedure. So, in general, the report organization above should suffice, with appropriate modifications as described.

4) **Design:** In this kind of exercise, the student performs the design of a system, then characterizes its performance and compares it to what might be expected based on the design specifications and theory and modeling. The degree to which design is open can vary widely. For example, in common emitter amplifier design, usually the circuit topology is given, and the student merely has to select appropriate values for components. On the other hand, other design exercises are open ended, with the student allowed broad leeway in choosing the design approach.

Either way, the report needs to include documentation of the design process. If it is simply a matter of calculating component values, the design procedure might be appropriate to include in an appendix called out by the Procedure section. On the other hand, an open-ended design should probably be given a complete "Design" section for the design approach, and possibly two sections if there is a preliminary design step of defining the specifications for the design. Note that in the case of a design laboratory exercise, the schematics and other documentation must be more rigorous, in that they specify more particularly how the system was built, sufficient so that someone could build that system the same way. In schematics, that means including details such as pin numbers, device numbers, and power supply details such as bypass capacitor usage and location. Often the design process includes analysis of the design, as described for an analysis report, using modeling or hand calculations, prior to actual system construction. Such analysis, if it is sufficiently involved, may be put in its own section.

The procedure section, then, would describe how the system was tested, and its functioning verified, and its performance measured. In that sense, it becomes similar to the Analysis project above. The results section shows the extent to which the system performs as expected, and the conclusions may include recommendations concerning other approaches for solving the problem: was this approach or design better than the alternatives? In some cases, students might try more than one design (using simulation) prior to reaching a decision, in which case the alternatives should be discussed, and perhaps all of the details put in an appendix.

In a design exercise, the Conclusions section should have some kind of comparison between specifications, expected performance based on the design, simulated performance for the design if available, and laboratory performance. This comparison is best presented in a table. If many characteristics need to be compared, the details of this table and comparison could be put near the end of the Results section and just the most important results cited in the Conclusions.

Design oriented laboratory exercises are typically much more open ended, and consequently will need more flexibility in the organization of the report. Usually, unless instructions dictate otherwise, you should feel free to use judgment in the organization. The point is to communicate clearly, and that considerations should take priority.

Table of Contents, Lists of Figures, Tables, Index and Title page:

Do you really need these things in a lab report? The general answer should be "No." They should be included only if they will be useful. But a laboratory report is generally so short that there's no point in tables of contents, figures, and tables. The only times I have seen these in lab reports is when the student is trying to make the report seem more substantive than it really is. An index won't be worthwhile either.

A title page is another story. Some laboratory report instructions require a title page, and often specify a particular format. Occasionally the title page must be signed by the student submitting the report, indicating it is that student's own work. (That should be implied anyway; it's unlikely a fellow student will submit a report on your behalf, and any work in your report that is not yours should be properly attributed.) A title page does serve one practical function: it allows the ugly red marks on the returned lab report's first page to remain hidden as the lab reports are distributed, saving the student from unneeded embarrassment. Check the requirements for your particular course.

Overall Structure:

The overall laboratory report seemingly has a linear structure. One word follows another, with punctuation and formatting effects as appropriate, from the first word to the last. If a laboratory report was to be done entirely with text with no tables, figures or appendices, that would be exactly the case. This structure is common in works of fiction, where words convey the entirety of the story.

The actual structure of a laboratory report is more tree-like. Think of that linear text that starts with the title of your report and ends with the period completing your last section as the trunk of a tree. Anything else in your report must be attached to the trunk, the text of your report. Those attachment points are called "Callouts". If something is there but there is no callout for it, a reader strictly following the text will never see it; its purpose is lost. The branch falls to the ground at the first windstorm. So, for every table or figure, yes, even those embedded in the text, a callout within the text is necessary. This is also the case for an appendix. A callout at an appropriate place in the text calls the reader's attention to the fact that additional information, generally stuff that isn't critical to understanding the report, is located in an appendix. When the sheer mass of information being presented is so bulky that it distracts the reader from the central message of the report, that bulk ought to go into an appendix instead. (There are some forms of formal writing, such as military operation orders, where the body of the document is miniscule, and the vast bulk of the document is the appendices, attachments, and annexes.)

Educational Objectives:

Sometimes laboratory exercise instructions specify what the student is supposed to learn by conducting and reporting on the laboratory exercise. It is a matter of policy for a particular course whether these matters are to be addressed at all in the laboratory report. (In my courses, I don't want any of this; it gets in the way of the "role playing" where the student is focused on the technical material.) If your instructor wants educational objectives addressed in your report, then in your background section you will need to state these. In your conclusions section, you will need to address whether you learned what you were supposed to. If instructions concerning lab reports are ambiguous on this point, you should ask.