

## Chapter 5 The Details

This chapter is intended to address the detailed contents of a laboratory report. The intent is to give guiding principles and brief examples of good usage, rather than comprehensive details. This chapter is supplemented with several appendices that do provide additional details and examples for those interested in them. For much of what this chapter addresses, other resources for particular software tools or situations can be found. This manual will not attempt to replace those resources. The student should have a copy of Wilkes University's official writing guide, the *Little, Brown Handbook* (H. Ramsey Fowler and Jane E. Aaron, *Little, Brown Handbook*, 12<sup>th</sup> ed, Longman, 2011). Use it. Online help or supplemental manuals can be found for most general purpose software tools, such as Microsoft Word or Excel, or more specialized tools such as MATLAB, AUTOCAD, and ORCAD/PSpice. This Manual does not attempt to be a tutorial on any of those software tools.

### **Sentences and English Usage:**

As mentioned earlier, the entire formal report is built around the flow of text, with callouts pointing to additional material in other forms such as figures, equations, tables, and appendices. The basic unit of text is a sentence. Construction of good sentences is a matter of general English usage, conditioned by the style needs of the document, as described earlier in Chapter 4. Most of the normal rules of English usage apply to laboratory reports. A few basic points of emphasis are given below. These are things that often give students trouble.

1. Keep sentences short and concise. Do not use a compound sentence unless there is good reason. A sentence should convey one thought. If a sentence extends more than two lines, examine it carefully to see whether it can be broken up.
2. Third person, passive voice, is preferred to first person in describing the procedure, for reasons discussed in Chapter 4, the Style chapter, earlier. But the use of "first person" is better in describing things like how the system works, that is, when the subject is not the person writing or conducting the exercise. For example, "The power supply provided 5 Volts for the collector terminal," is preferred to, "The collector terminal was provided 5 Volts by the power supply."
3. Think carefully about the prepositions you use. A preposition is the English language expression of the relationship of one part of a system to another. If the preposition is wrong, your system may not be understandable.
4. Be careful with pronouns, especially in long or compound sentences. When you see the pronoun "it" in a sentence, for example, there should be no ambiguity in what that pronoun refers to. If there are several component nouns mentioned earlier, and "it" might be understood as referring to the wrong one, the reader will become very confused. In that case, you need to simplify the sentence, or replace the pronoun with the appropriate noun, or both.

5. Use articles. When a noun is singular, the article “a” or “the” is usually needed, especially for the subject of a sentence. This is particularly an issue for non-native English speakers whose native language does not include an equivalent construct. Briefly, “the” is used when the item is a particular one under consideration, for example, “The first digit of the display.” “A” is used when the item is indefinite, such as “A transistor was tested and used in the common base amplifier....” Here, “A” conveys that the choice was arbitrary, it wasn’t a particular or special transistor that was chosen. In the next sentence “The” might be used to refer to this particular transistor, that was chosen in the process described in the preceding sentence. Plural nouns also need “the” as an article when a particular collection of objects are referred to collectively, for example, “The resistors used were of 5% tolerance.” (Without the “The,” the collection is indefinite; some group of resistors was measured, not necessarily the ones of interest. That does not fit with the verb “used,” creating some confusion and a perception of error.)
6. Use commas. There are rules for comma use. Modern English has drifted toward less frequent use of commas in places where use was once traditional. However, in a long sentence, commas are essential for organizing the sentence, by delimiting the different clauses. Failure to adequately use commas leads to confusion.
7. Numbers agreement: When a singular subject is used, a singular form of the verb must be chosen to match, and the same requirement to match is true for plurals. For example, “The beam was put under load.” There is one particular beam (singular) that “was put” (singular verb) into a loaded condition. Or, “The resistors were measured.” Here “The” is used, because it is a collective set (singular) of particular resistors. But the resistors were individually measured, so for purposes of “numbers agreement” with the verb, “resistors” and “were” are both plural. English can get pretty tricky sometimes.

Appendix A contains a number of examples of problematic sentences, their issues, and suggested corrections. If you struggle with English usage issues, and many students do, these examples may be helpful.

### **Paragraphs:**

The biggest problem students have with paragraphs is making them too long. A paragraph should contain sentences that revolve around a central idea. Usually the first sentence contains the key point, and the remaining sentences elaborate on that thought, perhaps with a summary sentence at the end. If a paragraph goes more than several sentences, more than likely the train of thought has drifted away from the initial point. That’s an indication that a new paragraph is needed.

As an example, in the Procedure section of a laboratory report, an initial paragraph might detail the test equipment and system configuration: what items are used and how are they connected and arranged. If the individual items of test equipment, that need to be identified by make and model (and perhaps serial number),

are numerous, it may make sense to extract that information and put it in a separate paragraph, or even in a table.

When the topic under discussion drifts from configuration to how that equipment is used to conduct the laboratory exercise, a new paragraph would be called for, unless the earlier material is very brief. Similarly, when discussion moves on to how the data was measured or recorded, a new paragraph is also likely to be needed.

The key principle is that the reader needs to keep all of the material in a paragraph in mind at one time, and exits with the central thought which was supported by the detailed information in the paragraph. If the paragraph gets too long, it's not possible to remember everything, or the mental model that the paragraph is expecting the reader to construct collapses. The result is confusion and loss of focus by the reader.

In the "Procedure" example above, the paragraph describing the details of the exercise configuration leaves the reader understanding the nature of the system and its test context. He does not need to remember model numbers or calibration issues. The paragraph that says what is done with that test configuration leaves the reader with the idea of what kind of data is produced, and he does not need to remember all of the details of how the system was operated. He can go back to that by re-reading that paragraph if necessary. That sets the reader up to focus on the data. The end of each paragraph releases the reader from the burden of those details just considered, freeing the mind for the next subject to be discussed.

### **Equations and Calculations:**

Equations show mathematical relationships that are important to the report. Equations are most often given in the Background section where supporting theory is given, in Design or Procedure sections where the rationale for the experimental design is set forth, or in Results where data is processed. The most important equations should normally be numbered in a formal report, as in the case below, which gives the equation for the Fourier series. (This is a "canned" equation from Word 2016.)

$$f(x) = a_0 + \sum_{n=1}^{\infty} \left( a_n \cos \frac{n\pi x}{L} + b_n \sin \frac{n\pi x}{L} \right) \quad (1)$$

In the text that immediately follows the equation (or perhaps precedes it) an explanation needs to be given for all of the symbols used in the equation. For this example,  $n$  is the harmonic number of the sinusoidal component,  $a_n$  and  $b_n$  are the coefficients that define the magnitude and phase of the harmonic, and  $L$  is a constant that defines the relationship to wavelength and fundamental frequency.

Word 2016 (and other versions supporting the .docx format) include equation support. (If you have to save the document in other forms, such as .doc or .rtf, you may lose the equations.) If you must do equations without word processing equation support, one option is to construct the equation as an image that is pasted in as a graphic. Another option is to use a text convention for rendering an equation borrowing from computer programming, using "\*" for multiplication, "^" for exponents, and such.

That is undesirable and may be explicitly prohibited for particular courses. A hybrid text convention using normal word processing tools to the extent possible would render the above equation as:

$$f(x) = a_0 + \sum_{n=1}^{\infty} (a_n \cos(n\pi x/L) + b_n \sin(n\pi x/L)) \quad (2)$$

This isn't as nice looking, but may well be acceptable, and does get properly rendered in earlier document formats.

Note that the equation is indented, and the equation number is given right justified. Equations may be called out, but they do not have to be. The purpose of an equation number is to allow reference to the equation later in the text. If an equation is not numbered, it cannot be so referenced. See specific guidelines for your course and any prescribed format if applicable.

In addition to equations, in some reports it is desirable to show calculations. For example, the following equation may be used to find the gain of an amplifier:

$$A_v = gm (R_L || R_C) \quad (3)$$

In a Design section, a student may need to show how this equation was used to calculate Voltage gain for his specific design:

$$A_v = gm (R_L || R_C) = 38.5 \text{ mS} (1.0\text{K}\Omega || 1.0\text{K}\Omega) = 38.5 \text{ mS} (.50 \text{ K}\Omega) = 19.3 \text{ V/V}$$

In this case, what is shown isn't really an "equation" in the general sense, but a calculation done using an equation. Such a calculation is not normally numbered. Notice that units need to be given with each number, and carried throughout the calculation, with cancellations taking place appropriately. This calculation is done on one line but more complex ones will need multiple lines, typically one for each step.

The number of significant digits carried should be reasonable. For example, in the last step the final value would come out on a calculator as 19.25, but since earlier values had only two or three digits, showing four significant digits is excessive. Simply "19 V/V" would also be acceptable. The actual value of  $A_v$  is unitless, in that units of mS and  $\text{K}\Omega$ , when multiplied, cancel. Volts per Volt is still retained to help convey the meaning of  $A_v$ , "Voltage gain": the ratio of Voltage output to Voltage input.

In equation 3 above and in the subsequent calculation, the symbol " $||$ " is used for "in parallel with." This symbol is informal, as a compact way of expressing the reciprocal of a sum of reciprocals. It certainly simplifies the expression. However, such symbols, and this one in particular, may not be allowed in formal reports by some instructors or formats. If you are in doubt about whether this or another less formal mathematical symbol can be used, check your report format guide or with the instructor.

## Graphs:

Of the different kinds of figures used in laboratory reports, graphs are both the most common and the most prescribed. There are definite right and wrong things to do in graphs, more so than for other types of figures. Furthermore, there are well established terms used to refer to the different parts of a graph, and you should be familiar with that nomenclature in order to use software tools such as Excel effectively.

Graphs come from two kinds of sources. One is a spreadsheet program (I'm assuming Excel for purposes of this manual). The spreadsheet is used to tabulate and then graph the data, or to graph calculated results derived from the data. Doing a good graph depends on the student using the software tool, Excel, properly, to get a satisfactory image prior to pasting it into a word processing program. (Here we assume Word is being used.) The details of doing that are addressed in Appendix B. In this chapter the focus is on what the end product, the graph pasted into the report as a figure, should look like. However, a good graph generally needs to be preceded by a properly formatted table containing the data from which the graph is derived. Table 5-1 below gives an example, and is the table of data graphed later in this section.

Table 5-1 Capacitor Voltage and Current

Time (s)	Voltage (V)	Current (mA)
0.00	0.00	0.100
0.10	1.97	0.061
0.20	3.16	0.037
0.30	3.88	0.022
0.40	4.32	0.013
0.50	4.59	0.008
0.70	4.85	0.003
0.90	4.94	0.001

Several things should be noted about this table:

1. The title is above the table. (Figure titles are below the figures.)
2. The sequence number for the tables is separate from figure sequence.
3. Columns identify the quantity measured and give units.
4. The number of significant digits is used to show precision (not necessarily indicative of accuracy). That is why time is "0.10" etc. rather than ".1".
5. The table and its title are centered. (The table elements are right justified.)
6. There is some space between the title and the preceding text, and below too.

An example graph from the preceding table (in Excel) is shown as Figure 5-1 below.

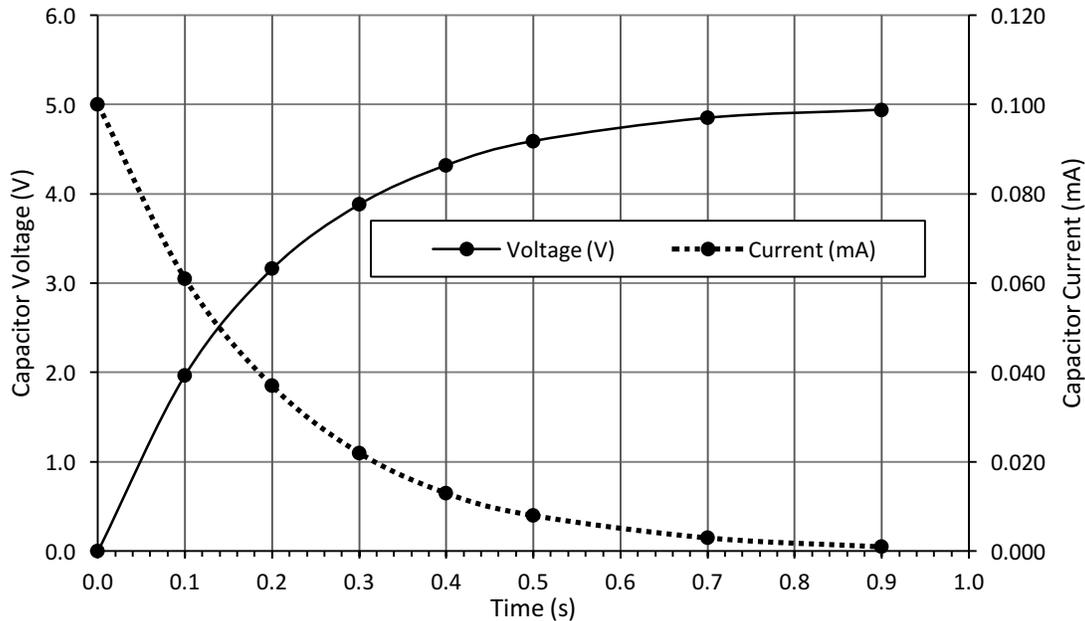


Figure 5-1 Graph of Capacitor Voltage and Current versus Time.

Some things to note about this figure are:

1. The figure number and title are below the figure.
2. The figure number and title are in the same size and font as the text.
3. The figure and its title are centered.
4. The title just says what the figure is. It does not include text describing or making notes about the figure. Such notes or remarks belong in the text.
5. There is no box surrounding the whole figure. There is not a separate title above the figure. (Excel will by default give you both.) Some laboratory instructors or formats do allow the figure to be boxed.
6. The axes are labeled, and indicate the units. In this case, with two quantities being graphed having very different unit quantities, a secondary axis (on the right) with labels is needed.
7. The numbers and labels are easily readable, being slightly smaller than the text in size.
8. The different points and trend lines connecting them are monochrome, not color. Different line styles are used to distinguish them.
9. Tick marks are used for both axes, but in this case minor tick marks are shown only for the horizontal axis.
10. Grid lines are used for both axes. In this case, reasonably closely spaced major grid lines suffice. For some figures minor grid lines may be needed as well. That is particularly true for logarithmic charts on which judging the value of a point is more difficult. (See the remarks below concerning whether vertical grid lines are needed.)
11. The “legend” (identifying which line is which) is needed because there are two sets of points. It is placed in an out of the way spot on the graph, where it doesn’t waste space, but also doesn’t interfere with reading the graph.

12. The color black (not grey!) is used for all of the lines and labels except the grid lines, which are a distinguishable darker shade of grey. (Don't accept the Excel defaults of light grey!) The background color is white. (Not grey!)

This one example graph doesn't address all of the possibilities that may occur in laboratory reports, but the basic principles remain the same. Use high contrast, label things clearly, and in general put a premium on clarity.

An interesting issue is whether vertical grid lines are needed. If the numbers for the horizontal (independent variable) dimension are known, because they were chosen as part of the procedure, vertical lines may not be needed. That could be the case here. Horizontal grid lines are almost always needed in order to read the values of the dependent variables, which are usually the experimental results. However, for some plots, both the horizontal and vertical plots are arbitrary, and you need both sets of grid lines. If you start off your plot as an "X-Y Scatter chart", you probably need both sets. You will also need vertical grid lines if the graph is used to find the horizontal coordinate where some feature is found, such as the low frequency cut-off of an amplifier or filter.

The second source of graphs is from applications that generate graphs as an analytic product, such as MATLAB, PSpice, or LTSpice. In these cases the data source isn't a table, it's the result of a simulation run or some other analysis method. Often, as with Excel, the defaults result in unsatisfactory figures when pasted into Word. The key to getting better graphs is to use the graphic features of the program to make the graph as close to what you want as possible before capturing it for transfer to your document. Appendix C, "Transporting Figures", describes how to get decent figures from MATLAB, PSpice, and some other sources. (Appendix E looks at cases where things went wrong.)

In most programs that are the source of figures for transport, you can choose font sizes, the grid line and axis settings (such as linear or log, axis crossings, and scale), and how the data is presented (color, marker format, line style and such). In MATLAB there are many labeling and formatting options that you need to take advantage of either in MATLAB code (before the graph is generated) or in prettying it up later in the graph editor. The following Figure 5-2 is an example of such a graph, this one from LTSpice. (This one needed later editing in a graphics program to reach the appearance shown before pasting it into Word.)

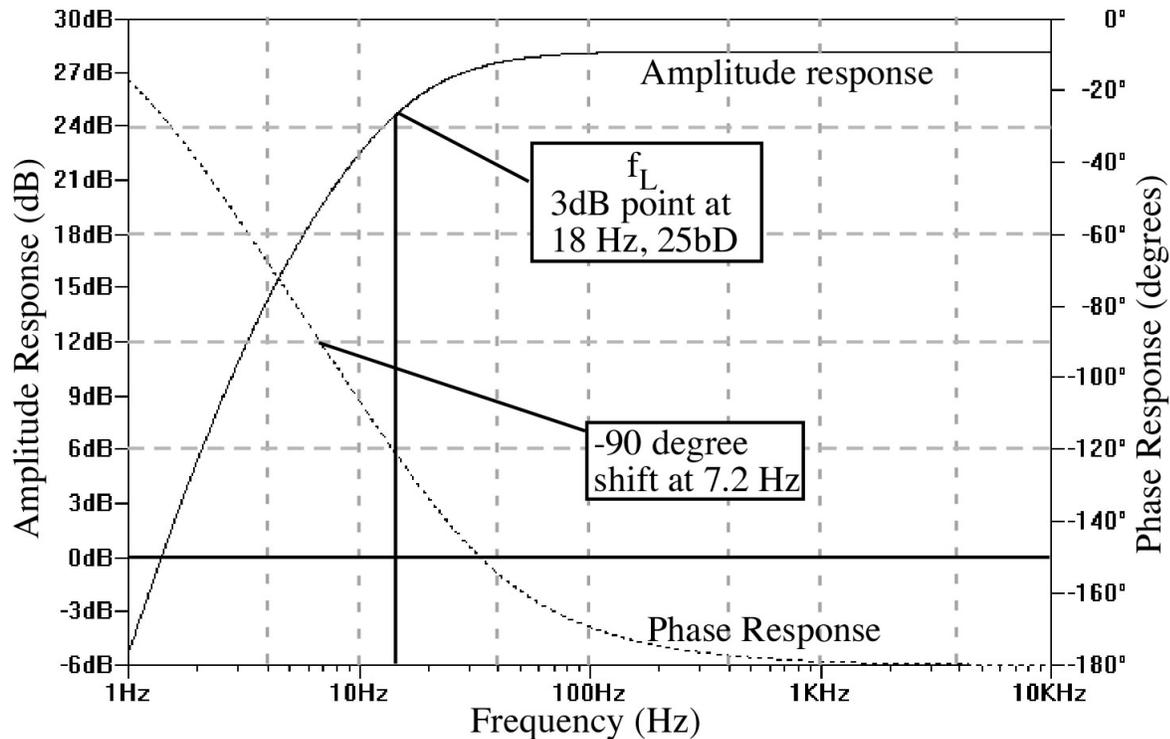


Figure 5-2: Bode Plot for original bias point

A few points about this figure (which is borrowed from Appendix E) are made:

1. The principles for graphs described earlier apply here as well. The difference is that coming out of some other application you don't have as much control as you do coming from Excel.
2. In this particular case, the raw graph did not include the grid lines or axis titles. Those needed to be added later after the image was copied from LTSpice (via screen capture) using a graphics program. (The most readily available graphics program is "Paint", a Microsoft Windows accessory application. PowerPoint can also be used this way.)
3. In this case the "zero" value on the vertical axis is NOT at the bottom, yet, usually (as here) the best place to put the axis and labels is at the bottom.
4. In this case annotations were added for the -3dB point and -90 degree point. Such annotations are particularly useful where finding such a point is one of the most important functions of the graph.

Additional information on porting figures is given in Appendix C.

Occasionally you may find it necessary to use "Three Dimensional" graphs. These are difficult to adequately present because the paper surface is inherently flat, as is a computer monitor that may be used for viewing the graphic. In such cases, basic principles remain: clear labeling, readable lettering, and an emphasis on helping the reader focus on what is important. In three dimensional graphs, choices such as how to use wire mesh, shading, or color, are complex and very dependent on the particulars of the graph and the nature of the report. No adequate treatment of this topic can be given

in this manual. However, it is often helpful to include supplementary graphs which are two dimensional cross sections or cuts through the 3D image. Those would follow the principles outlined above.

### **Schematics:**

A schematic is a diagram that represents a physical reality but in a simplified form intended to convey the most important aspects of the system being portrayed. It is conceptually intermediate between graphs, which portray abstract mathematical relationships, and photographs or drawings of systems, which show the physical reality but without necessarily making clear what is going on. Schematics are used for electrical, mechanical, fluid, pneumatic, and even software systems. Each of these has its own history, symbols, and conventions. In this chapter, only the more universal concepts and principles will be addressed. Further discussion and examples may be found in Appendix D, a schematic guide for electronic circuits, and Appendix F, which looks at schematics with problems. Simple examples from the electrical and mechanical domain will be presented here to illustrate some of the more important principles.

A key idea in a schematic is that the drawing is organized around what is most important. If the system is processing a signal, then the signal flow is the primary axis, left to right, with components disposed in the order that the signal reaches them. Likewise, if a force or motion is being portrayed, a left to right orientation is generally used, although in a mechanical system alignment equivalent to the physical relationship may be chosen. In an electrical system, the physical placement of the real components is generally ignored; it is the signal path that is all important.

A schematic shows the relationships among system components. Usually these are lines representing physical connections, such as wires, pipes, belts or rods. Components may be at nodes or along arcs of the diagram. Each domain has symbols for the various sorts of components appropriate to the discipline, and it is important to use the appropriate symbols. Likewise, it is also important to label components to identify them as a unique item within the system, and to give any quantitative information that characterizes them. Often the latter is in the form of a “part type number” that a reader can use to refer to other sources giving the component specifications.

An example of an electrical schematic is shown below in Figure 5-3. Signal flow goes left to right, from source  $V_s$  through to  $V_{out}$  on the right. The two terminal components (resistors, capacitors, and Voltage source) occur along the arcs representing wire connections. Transistor components occur at nodes where three wires come together. This schematic is notional: component values are not yet specified. That is appropriate in a design exercise for showing the circuit topology prior to the calculation of component values. The components are identified with each having a unique symbol,  $R_s$ ,  $C_E$ , etc. Those labels need to be consistent with the symbols used in the text, for example, the equations used for calculating the component values. Inevitably, some wires will have to cross others. It is important that the reader be able to distinguish whether there is a connection or not. Here, the convention of showing a “dot” at connecting intersections is followed. There are other conventions. Generally, the

schematic topology should be as simple as possible. For example, instead of having a wire connecting all of the ground connections (as here), the use of separate ground symbols de-emphasizes ground and would reduce clutter. The same can be done for power. There is a convention that positive supply Voltages are at the top and ground at the bottom. The actual arrangements of these components in the physical circuit may look very different; the schematic is not trying to address physical relationships.

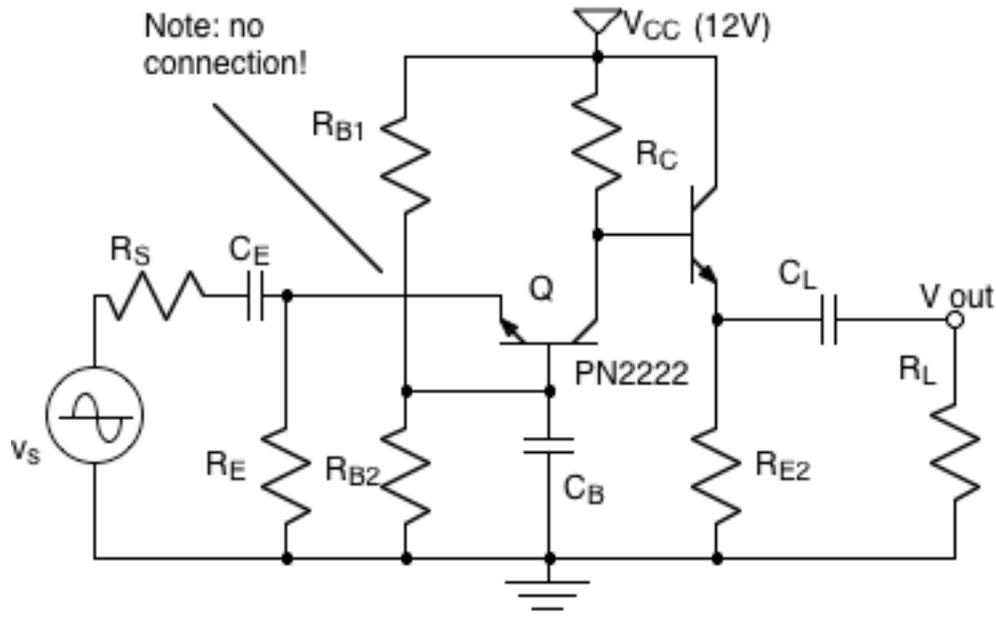


Figure 5-3: Cascaded Common Base and Common Collector Amplifiers

Figure 5-4 shows a mechanical schematic of a simple system. Notice the common elements with the electrical schematic. There is a “ground”: a reference frame that is the unmoving context in which mechanical position measurements are made. Arcs in the form of lines show mechanical connections. Symbols are used for a spring and a resistive/friction element, a damper. The components are each uniquely labeled. Interestingly, the “input” or forcing function is shown on the right rather than the left. (I’ve seen that done both ways.) The major axis of movement is horizontal.

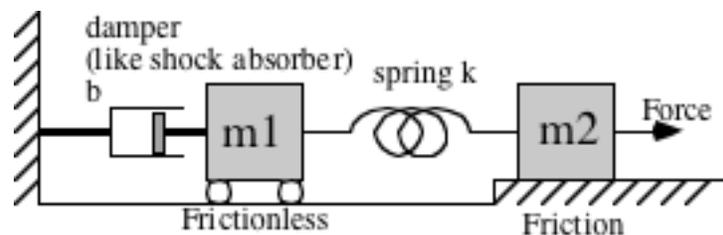


Figure 5-4 A Simple Mechanical System

In mechanical design, often the use of drawings, which are accurate physical portrayals of components and the system, reduces the need for schematics in simple systems, since the operation of the system can be imagined from the drawing. A

schematic generally does not attempt to accurately portray dimensions or other features needed for a qualitative understanding of the system.

Sometimes both electrical and mechanical components are combined into a single schematic, as seen in Figure 5-5 of a crushing system for recycling aluminum soda cans. The conventions of each domain are followed in that portion of the schematic.

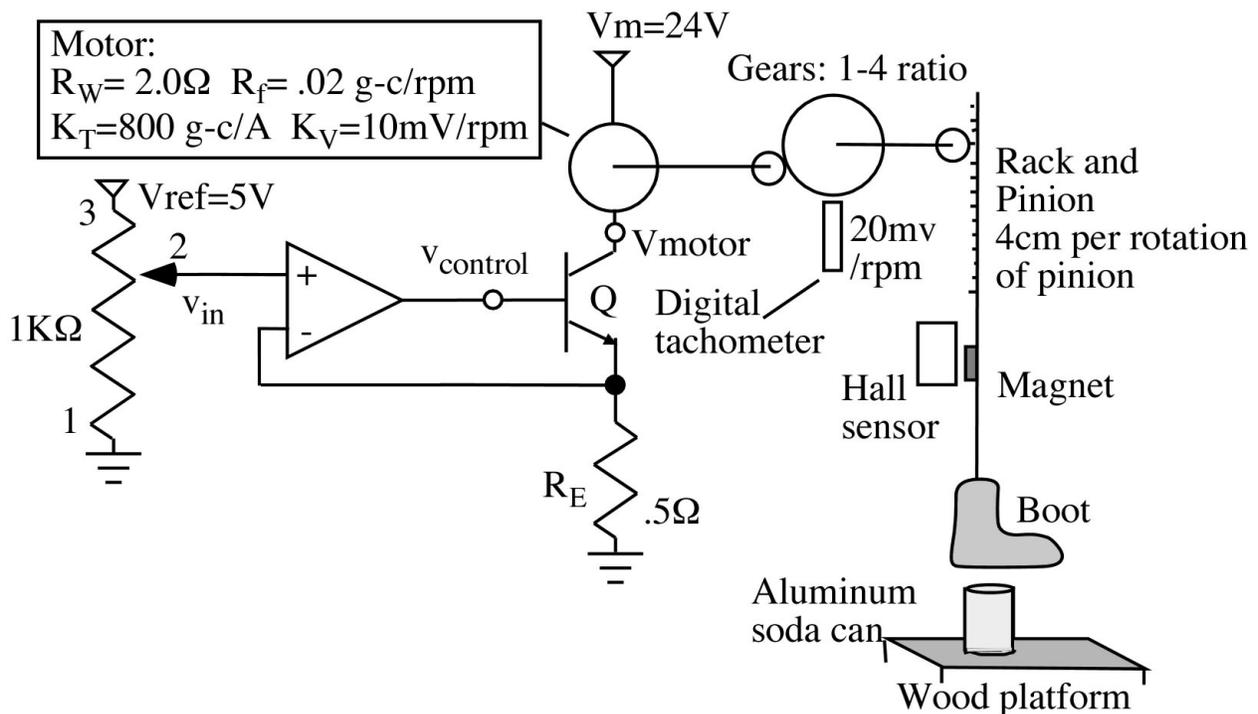


Figure 5-5 Schematic of an Electro-Mechanical Can Crusher with Test circuit

In this case, the motion of the mechanical system, at least that portion acting linearly, is shown as vertical since that would be the orientation in the physical world, and the bias of gravity is significant. Notice that this example includes both rotational and translational components. No attempt is made to depict any of these elements with accurate drawing. (A number of details such as component names and some connections to other parts of the system were omitted in this schematic, which is notional with respect to some aspects.)

[What is a good reference for further instruction on mechanical schematics?]

In ME reports, and sometimes in EE reports, it is appropriate to include engineering drawings in addition to or instead of schematics. Doing good engineering drawings is beyond the scope that this manual attempts to address. Making those drawings clear when they are used in a report means following the general guidelines given for graphs and schematics. Make sure lines are easily seen, use high contrast (black on white is best), make sure labels, numbering, and other symbols are easily read, and aim for clarity. Avoid outer boxes, grey or black background, and minute features. If a drawing cannot be rendered in a satisfactory manner, use a schematic supplemented

by drawings or drawing excerpts, showing particularly important points. Unsatisfactory drawings are very common in student reports. In most cases the drawing has little value other than saying, “We did a drawing,” because the details cannot be read or understood.

**Other Diagrams:**

In addition to graphs, schematics, and drawings, reports often need to include other diagrams. These fall into several categories. One is a diagram to show the relationship between the physical and electrical aspects of a component. For example, the “pinout diagram” for a component shows how the electrical connections are made. Figure 5-6 is an example of such a diagram. (The need for such a diagram can often be avoided by using pin numbers in the schematic.)

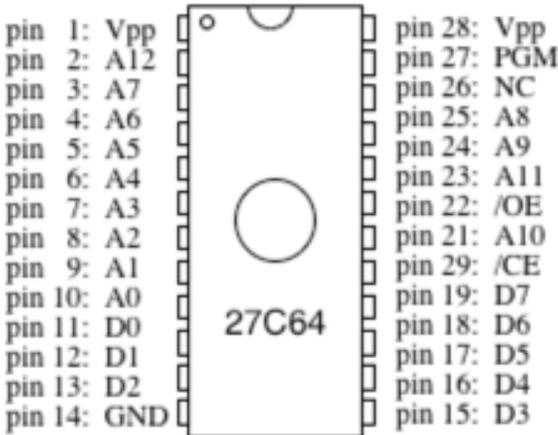


Figure 5-6 Pinout Diagram for 27C64 Electrically Erasable Read Only Memory (EPROM)

More common is the “Block Diagram” used to describe a system at a granularity above what is appropriate in a schematic. For example, Figure 5-7 shows a block diagram of a superheterodyne radio.

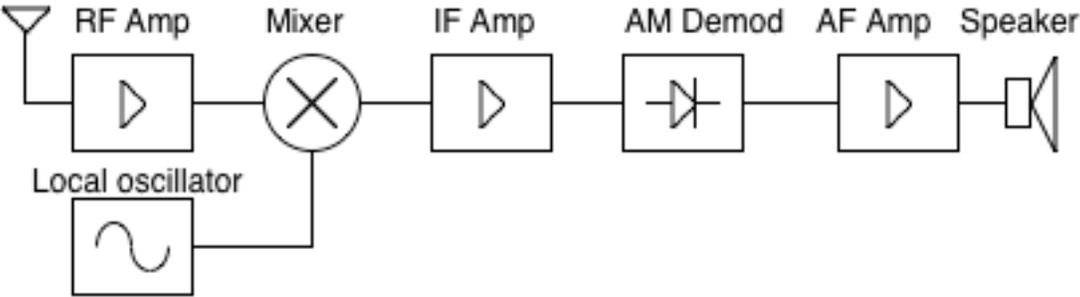


Figure 5-7 Superheterodyne AM Radio

In a block diagram, there is often no attempt to use schematic symbols, although some may be used where appropriate (such as a rightward pointing triangle for amplifiers). Only the most important relationships are included. Here, that is the left to right signal flow. Each of the boxes includes what could be a very complicated subsystem. No power connections or other incidental effects are shown. The focus is entirely on the most important concept in understanding the system.

Often block diagrams are used in diagramming business communications, management structures, and logistics relationships. PowerPoint includes useful facilities for drawing such diagrams, though if detailed drawings are needed that program is entirely inadequate. Remember, if you use PowerPoint, to follow the conventions for report figures rather than presentation slides. The figure should be done to match the document text, there should be no box around the figure, and there is to be no title at the top. The importance of high contrast, clarity, and readability remain paramount.

**Photographs:**

In addition to diagrams, photographs are often used in laboratory reports where it is necessary to illustrate the physical appearance of the system. Often such photographs are used where a block diagram or schematic would be more appropriate. A photograph should never be used as a substitute for a properly annotated graph. (A photograph may be the starting point for a decent graph where necessary. See the examples in Appendix E.)

Photographs, where used, should be done with high contrast, so that when copied on a copier they will be satisfactorily rendered. Color should be avoided if possible for two reasons. Color photographs take up a lot of memory in a digital format, increasing load times and storage requirements. On paper, they are more expensive to reproduce, or the color information will be lost when reproduced in monochrome. Be sure to frame and zoom a photograph to focus on the truly important part prior to capturing the image for transfer to a document. You may also want to add helpful annotations in a photo editing program (like Paint) prior to moving it to your document. Render your photograph in a resolution appropriate to the medium (paper or digital). Usually you want higher resolution for a quality paper report.

Photographs are figures. The same general principles apply as for other figures.