LINEAR SYSTEMS I
LABORATORY MANUAL

EE 216

UNIVERSITY OF MISSOURI SCIENCE & TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

Rolla, MO 65409-0040

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Forward

The laboratory that accompanies Linear Systems I (EE 216) is a computer-based laboratory. It is designed to provide the student with an introduction to and experience with using the MATLAB® High-Performance Numeric Computation and Visualization Software†. The student will be required to use this software in a number of EE courses that follow EE 216. Also, it is a commonly used software package in industry.

The initial laboratory experiment introduces the basic MATLAB concepts including software package operations, data entry, available functions, programming, and plotting techniques. The remaining experiments guide the student in the utilization of MATLAB to illustrate and perform linear systems analyses for continuous-time systems.

†MATLAB is a registered trademark of The MathWorks Inc., 3 Apple Hill Drive, Natick, MA, 01760

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THE LABORATORY NOTEBOOK

I. INTRODUCTION

The technical notebook is a basic tool for any experimental work, whether it be basic research, product development, or engineering design. It is primarily for the experimenter's own use, but another person with similar technical background should be able to understand and duplicate any experiment, data, and conclusion, or to prepare a technical report by following only the lab notebook details.

There are many reasons to keep an accurate and complete record of experimental work. Among these are:

1. to establish the authenticity of the work.
2. to defend patents.
3. to act as a basis for technical reports and articles.
4. to avoid duplication of effort.
5. to avoid repetition of erroneous procedures.

The nature of the work and the purpose of the experiment will influence the content and format of the laboratory notebook. Many companies have rigid internal requirements tailored to their specific needs. The notebook formats which follow should not be interpreted as "industry standards". Rather, they are intended to suit laboratory work in the EE 266 Laboratory, and to provide experience in following some acceptable format.

II. CONTENT REQUIREMENTS

A. General

The general format for the lab notebook in the EE 266 lab is different from that used in other EE lab courses. This is true since this laboratory is designed to provide the student with an introduction to and experience with using MATLAB. The data produced in each experiment is in the form of computer code and computer generated data and graphs. These data are produced on 8.5 by 11 inch paper by the computer printer. Therefore, the bound “computation book” used in other labs is not used. Instead, the student is to number the computer printout pages successively, three-hole punch them, and keep them in an Accopress binder. Accopress binders are available at the bookstores.

Your instructor may ask you to turn in only the portion of the laboratory notebook dealing with the current or previous lab. When the graded material is returned to you, you should place it into the lab notebook (Accopress binder). Your instructor may ask to see the entire lab notebook periodically during the semester. You will need to complete laboratory notebook for the practical exam at the end of the semester.

Since the lab notebook will consist primarily of MATLAB printout pages, the student may include answers to questions posed in the laboratory manual in the printout itself by using comment lines. Alternatively, a student may write directly on the printout or an additional three-hole punched sheets having page numbers consistent with their location in the report, using a blue or black ball-point pen in either case. Errors, mistakes, and blunders are not erased, but

simply marked through with a single line.

Use only the front side of each sheet for the notebook record. Use the back of the sheets for sketches, rough calculations, and reminders to yourself.

B. Organization

1. Preliminary – For the experiments with a Preliminary section, the work in that section should be performed before coming to the laboratory. The work for the Preliminary section should be placed in the laboratory notebook either as computer printout pages or as legible handwritten pages in blue or black ink.

2. Procedure – The MATLAB code, comments, output, and answers to any questions posed in the laboratory manual are placed next in the lab notebook, organized section by section. A sample template which illustrates this type of organization and which shows how to document (comment) MATLAB code is shown on the next page.

```
%*************************************************************************
% Student's Name
% Experiment #
% Due September 21, 1889
% Template.m
%*************************************************************************

clear all; close all; clc;          % Clears workspace, figures and windows
format compact                      % Sets ouput to a compact format.

% Part 1
%*************************************************************************

% 1.a
% Description of this part of the experiment. May include procedures,
% theory and variable descriptions.

disp('Info for side comments -->')  % Side comments are optional.
                                    % Their purpose is to clarify step
                                    %   by step what is happening.
                                    % They should not be long and sections
                                    %   should be aligned.

for i = 1:3,                        % Loop through all values of  i
   for j = 1:3,                     %  and j.
    a(i,j)                          % Display element (i,j) of matrix a.
    pause(1);                       % Delay execution for one second.
   end
end

% 1.b
% Display a mesh plot of the matrix 'a' and give the plot a title.

meshz (a);                                  % Display a mesh plot of a
title('Mesh plot of sample 3 x 3 array')    % Add a title to the mesh plot

%*************************************************************************
% Answers to any questions asked in this part of the experiment.
% May include computed quantities or written answers.
%*************************************************************************

% Part 2
%*************************************************************************
% Note, the end of the long line of asterisks dividing sections is the end
% of where text can be entered in the Matlab debugger before the printer
% will auto. wrap around the text. For B/W printing use the following :
% Preferences -> Editor/Deubgger -> Printing -> Print as styled text.
```

FORMAL REPORTS

The written formal report is one of the most frequently used forms of communication in industry. It is a vehicle that carries the specialist engineer's information to colleagues, supervisors and managers. Therefore, it is important to develop the skills of good technical writing. Depending on the course, one or two formal reports are required in each lab course.

The formal report should be a narrative presentation of the background, theory, laboratory work, and results of the experiment. The text, graphs, and tables should tell a coherent story to a reasonably intelligent reader. The "story" should be written in an interesting and organized fashion without boring the reader with trivial details and unnecessary words. Obviously, judgment and careful planning are required to write a good formal report.

The bulk of the following material was prepared by Ann Kruse, a former English teacher, and should facilitate the preparation of a satisfactory formal report. The requirements of the format resemble a formal technical paper quite closely. You may look at a technical paper (for instance, in an IEEE Transactions) to get an insight into the "formalities". Note the differences from a typical lab notebook, technical diary, homework, or other "informal" routine writings.

1. **Title Page:** The title page of your report should contain the experiment number, an appropriate title, the author's name, and department centered on the page. The title should be carefully chosen so that it summarizes the whole work in just a few words. It should not be too long. For example the following may appear in the center of the title page of a formal report.

Experiment No. 5

DESIGN AND TESTING OF AN A-D CONVERTOR
David C. Jones
Department of Electrical and Computer Engineering
University of Missouri-Rolla

In the lower right quarter of the page, the following should appear:
1. Laboratory course number and section letter
2. Group members
3. Date submitted.

2. **Abstract:** The abstract is, in essence, the report in a "nutshell". It gives a quick synopsis of the work in just a few sentences without the reader having to dig through the report. The abstract should preferably be brief. In most cases, no reference has to be made to any equation, figure or table; stand-alone words are enough.

The abstract should be a short synopsis of the work reported in the paper. An experienced reader of technical reports turns to the abstract first with specific questions he or she wants answered. Usually these questions concern whether the report suits his or her purpose. If it does, the reader will continue to the conclusions. If it does not, the abstract should be sufficient to let the reader know. It needs to summarize the main idea of the purpose in one or two sentences. Then, the general method needs to be summarized in one

or two sentences, followed by one or two sentences summarizing the main points of the results. The abstract needs to be a synopsis of what was done in the investigation being reported, not what can be done. It needs to tell what the paper does present, not what it should present. An abstract should state the purpose, but it is not a statement of objectives. Details are not appropriate in an abstract. Much care should be taken in wording the abstract.

Put considerable thought into the writing of the abstract. It may be best to write the abstract after the results are carefully analyzed. Before writing the abstract, the writer needs to understand clearly the purpose, procedure, and results. An IEEE Transactions, available in the library, is a good source of examples of abstracts.

3. Table of Contents

4. Introduction: The introduction should introduce or lead the reader into the report by discussing the main idea of the experiment or research, its nature, and scope. It should orient the reader to the main theme. If the investigation being reported was motivated by a previous investigation, the introduction might mention this. The introduction might include something about the organization of the report. Extensive discussions of theory, details of the procedure, or results and conclusions do not belong in the introduction. A little overlap with the abstract can occur.

5. Body of the Report: The portion between the sections named Introduction and Conclusion is important and should be titled appropriately based upon the experiment. Sections included in the body of the report may vary depending on the purpose of the report. For most formal reports for laboratory classes, <u>background and theory</u>, and <u>procedure, results, and analysis</u> need to be discussed. The material should be logically sequenced and divided into appropriate sections with a name for each. The text may be supported by <u>graphs, figures, tables, equations</u>, etc., as necessary. A technically sound report will have an adequate explanation of purpose. It is also important to furnish reasoning or theoretical justification of the "happenings". However, it is undesirable to make statements about things that are very obvious.

<u>Background and Theory</u>: Background for a report might include a discussion of previous investigations that are important to the investigation being considered. It might also include other information that aids the reader in understanding the report.

Presented theory predicts results. All theory necessary to understand and explain the investigation should be discussed. Equations should be presented and numbered. Short derivations may be included in this section. Longer derivations need to be in an appendix with the result in the body of the report. The appendix needs to be referenced by name and page number. Theory should be discussed in a logical progression.

<u>Procedure, Results, and Analysis</u>: The procedure section should contain a detailed account of exactly how the investigation was performed. The reader should be able to repeat the experiment based on the information in this section. Details that do not explain how the experiment was conducted, such as equipment lists and serial numbers, should be included in an appendix.

All results, whether observations or data, need to be included. Long tables of data need to be in an appendix. When deciding whether to include data in the body of the report, think about whether it is necessary for the reader to understand what occurred. If it is necessary, put it in the body; otherwise, it may detract from the readability of the report. Again, it is important to reference the appendix. Graphs or charts belong in this section. If a calculation is necessary to understand the results, it belongs in the body; otherwise, sample calculations belong in an appendix that should be referenced.

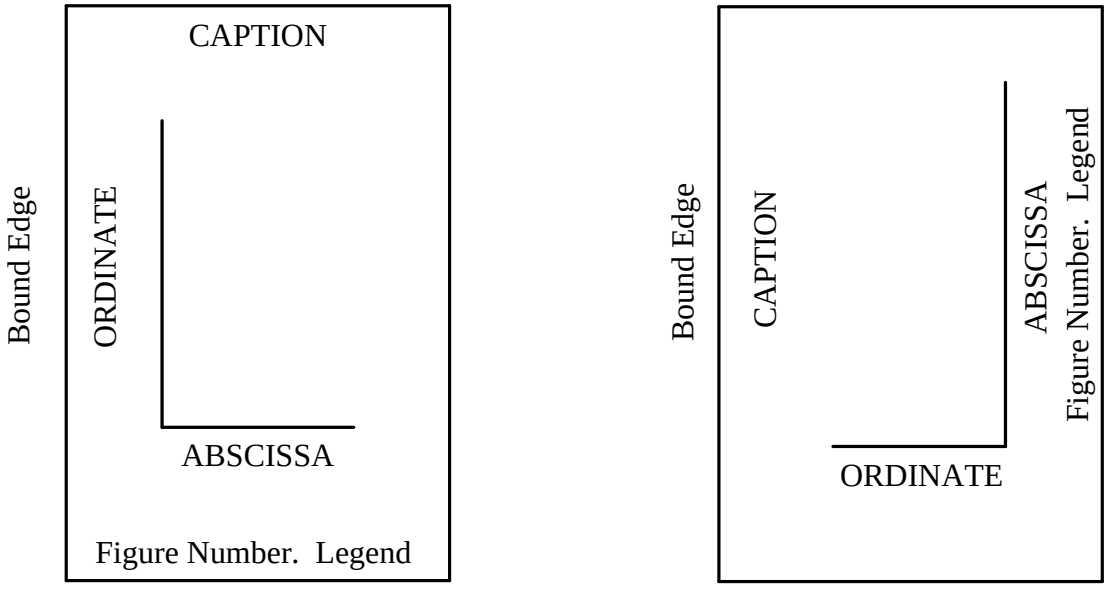
Results must be thoroughly analyzed and explained. Actual results need to be compared to theoretical results. Percentage error may need to be included. Discrepancies need to be discussed. Possible reasons for error need to be included. "Human error" is not a legitimate explanation. An honest statement of the actual and possible errors resulting from a close inspection and impartial observation will strengthen rather than weaken the report. If part of the experiment is comparing different quantities, such as results from different circuits, the similarities and differences need to be discussed. If graphs and charts are included, they should be used in this discussion. Reasons for results should be discussed. Results need to be discussed in specific terms, not with vague or general statements.

The order of procedure, results, and analysis might vary depending on the nature of the investigation. Some experiments are better presented by giving the procedure for a portion, then the results for that portion, before proceeding to the next portion. Other experiments might be better presented by giving all the procedure then all of the results. The most important thing is that the reader is clearly able to understand the investigation.

Graphs: Care should be taken when making graphs so that they are easy to read and show what is intended. If a certain graph is specified, that type of graph is to be used. Otherwise, the type of graph should be chosen so that it clearly illustrates the concept intended. Graphs must be computer-generated. The axes must be neatly and descriptively labeled. Key points or ranges should be labeled on graphs. Examples are half-power frequencies or bandwidths. If two things, like two different circuits, are being compared, they are usually best compared on the same graph. A legend should clearly identify what the curve or curves are. All graphs should have descriptive captions. The reader should be able to understand the graph and its significance without having to refer to the text of the report.

Figures and Tables: Figures and tables need to be neat and easy to understand. The reader should be able to understand them without referring to the body of the report. Captions should explain the figures. Each figure needs to be numbered. When referring to a figure in the body of the report, the number and page should be given. Information in tables should be organized for easy reading. Long data and results tables should be in appendices. The appendix should be referenced with appendix letter or number and page. Figures and tables should not be crowded. They need to be visually distinct from the body of the report, i.e., there should be enough space both above and below figures and tables to easily distinguish them from the text.

The figures should be drawn with graphical aids, rather than by free hand. Tables, graphs and figures should be neat enough to interest the reader. Two possible orientations of figures/graphs are given below. Graphs may need a legend or brief explanation. Also note that it is desirable to caption or title all figures, graphs, etc.



Diagrams, graphs and charts are designated by sequential Figure Numbers; tables by Table Numbers. They should be properly referenced in the text by these "call numbers" and located close to the first place of reference.

6. Conclusions: It is very important that the Conclusions section be well-written. This part is as important as the abstract. Experienced readers of technical reports turn to the conclusions after reading the abstract, and then the rest of the paper (if they are still interested!) Conclusions should briefly summarize the purpose, what was done, and how it was done. Key results should then be summarized. Comparisons may be included here. No new information about the procedure, results, or analysis should be included in the conclusions. The summary should be specific, but not detailed. Examples of statements that are not specific are: "After recording the data and analyzing the plots, it was seen that the findings appeared to conform with theory.", "The behavior of the filter proved to be as anticipated.", and "the cascade effect of a certain type of filter." The conclusions may also give additional insight and suggested uses. They should tell what the significance of the investigation is. Conclusions might give suggestions for further investigation. Conclusions should stand alone. References to diagrams, graphs, or charts are usually not appropriate in conclusions. Since the Conclusion is a part that requires much thought from the author, ask yourself, "Have I convinced the reader that I know what I am talking about? Have I sold my point of view?"

7. Appendices: Usually details are pushed into appendices when, if included anywhere else in the report, they hinder its readability. Appendices to the report usually contain

information that is not vital to preliminary understanding. The author should recognize such material which deserves to be "isolated" from the rest of the report. More than one appendix may be needed, in which case the appendices may be numbered in numerals or alphabetic characters and logically arranged. In a report, there may not be an appendix or there may be several. All the appendices must be referenced properly in the text of the main report. Also, in one appendix, keep only one type of information; do not make an odd mixture within an appendix.

For this laboratory course, the appendices may include longer tables of data, long computer code lists, etc. A sample set of calculations for theory and computer computation comparison may be included if necessary. In general, the fundamental symbol equations should be given first (if possible) and the numerical values substituted in the same order in the next step. Always include units if applicable.

Appendices should be lettered or numbered sequentially. They need titles and brief explanations. The reader should be able to understand the appendix without referring to the body.

8. **Acknowledgment:** This section is optional. It recognizes significant help obtained by any individual or association in any form. While this is almost always found in research papers, you may omit this part in the formal lab report.

9. **References:** The references are to credit the work of previous authors used in the report. References to previous reports, articles, books, patents, etc. pertaining to the investigation are listed in this section. References are specifically referred to in the text and should be numbered in order of appearance. When referring to reference number 1, write [1] at the appropriate place in the text.

For this laboratory course, the following format should be used for references:

1. Author, "paper title," name of periodical, published date, pages.
2. Author, "book title," publisher, year published, pages referenced.

It is very important to remember that listing a document on your references page does not give you the right to copy or paraphrase anything you want from the document without giving a citation in the body of the report. Refer to the policies listed below when preparing the formal report.

a. FIGURES

All figures which are not your own original work must be referenced when used in the formal report (e.g., if you use figures from the lab manual in your formal report you must footnote each one).

b. EQUATIONS

You must provide references for equations used in the formal report unless they are extremely fundamental (e.g., V=IR, etc.). In general, if you can derive the equation given a blank piece of paper, then it is not necessary to reference it.

c. TEXT

All text (objectives, introduction, procedures, conclusions, etc.) should be in your own words. If you paraphrase something from the lab manual or another book, you must provide a footnote in the body of the report near the appropriate text. Paraphrasing is more than just rearranging the words or clauses in a sentence.

PLAGIARISM

Plagiarism is defined as "the act of taking the ideas, writings, etc. from another and passing them off as one's own." (Webster's New Universal Unabridged Dictionary, 2nd Ed., Dorset & Baker, 1983.) It is a form of academic dishonesty and may result in a grade of zero for the formal report, failing the course, and/or dismissal from the university! So, always remember to use a reference for anything in your report that is not your own work.

ADDITIONAL NOTES ON REPORT WRITING

1. A novice author may have a tendency to write very long paragraphs. Proper paragraphing is an essential ingredient of good writing.

2. Whenever appropriate, present the data in the form of a table, with its structure suitably chosen and labeled.

3. Good writing is uniform and balanced in its content and information density.

4. The pages of the report should obviously be numbered.

5. Appearance: A report that is well-spaced, accurately typed, illustrated as required, and neatly bound creates the impression of professional competence. Correct punctuation, clear titles and subtitles, and consistent use of indentation contribute to ease in reading.

6. Use 8 1/2" x 11" paper. Use only one side of each sheet. Type the report.

7. Write the report in the past tense, passive voice. Avoid any use of personal pronouns. Exercise care to insure proper use of the English language. All slang expressions and phrases like "hooked up the circuit," and "that would blow the whole purpose" should be avoided. Contractions are not proper in formal writing.

8. The formal report should be concise. Omit obvious steps in derivations and calculations and avoid wasting sentences in trivial arguments.

9. Spend some time thinking about and outlining the report before beginning to write. At least the crucial sections like Abstract and Conclusions should be phrased properly on a scratch pad and then transferred to the report.

10. Time should be taken to proofread the report because obvious errors and typos detract from the credibility of the report.

FORMAL REPORT GRADING

The purpose of the following material is to help you understand how your laboratory reports are to be graded and to help the laboratory instructors know what to base the grades on and to help them grade consistently.

Determining what grade you have earned on each lab report is one of the most difficult tasks a lab instructor must do. Grading and evaluation generally have subjective processes present, either consciously or subconsciously, so that the results may, unfortunately, depend on whim or personal prejudices instead of only your efforts. One particular reader may prefer neatness and good grammar to a technical discussion. Another reader may stress validity of your conclusions over how you make references to graphs and diagrams. In an effort to eliminate such inconsistencies and to inform you of the emphasis, your reports will be graded as follows:

Presentation - 35%
Clarity - 35%

Technical Content - 30%

There is more emphasis on Presentation and Clarity than on Technical Content because good-looking, neat, clear, readable, and understandable reports are usually more impressive and better received than those done otherwise, even though the technical details are somewhat incomplete.

PRESENTATION - 35%

You should make a finished product of the reports you turn in. They are prepared either by typewriter or by word processor. All graphs, diagrams, charts, tables, etc., need to be neatly prepared and properly identified for the reader's benefit.

Organize the material according to the required format. If you use other than the required format, explain why.

Use only one side of standard 8 1/2 x 11 inch plain white paper. Small, large, or mixed sizes of paper are awkward to handle. Do not use ruled or crosshatched paper. Multiple copies of industrial reports are often made and sometimes photocopied for microfilming, and lines reproduce just as well as typed letters, resulting in unnecessary clutter which complicates reading.

The grammar, spelling, and punctuation should not impress the reader as being poorly done, otherwise a report is subject to immediate rejection. If you have typists put your rough draft into final form, do not expect them to make even minor corrections to your draft. In fact, you should definitely proofread their work to locate their errors so that corrections can be made before submitting a report.

Staple everything together. Staples do not get loose like paper clips can and they help keep a large number of reports from getting messed up. In some laboratories, a specific type of holder is required.

CLARITY -35%

Clarity pertains to your ability to communicate effectively. Clarity refers to ease of reading and understanding, discussed as follows.

EASE OF READING includes how your ideas are tied together for a smooth progression. Prefer short, familiar words arranged in short, simple sentences instead of unfamiliar vocabulary, big words, and long complicated sentences. Complex verbiage does not make a simple idea profound. Warn the reader before making a sudden change in your point of view or subject. Omit irrelevant or illogical information. Stress important ideas in proportion to their inherent significance.

UNDERSTANDING refers to reader response. Effective communication means that the reader understands your report. You don't want him to misinterpret your report or wonder what it is about. Try to convince the reader that you know what you are doing, which means that you must know. If you include in the report any graphs, diagrams, charts, tables, computer results, derivations, or calculations, the reader must be able to follow references to each one and understand how you take information from each. Computer data printouts and lengthy

derivations generally belong in appendices. The reader benefits if you convert computer data output into a more useful form, such as a plot, when needed. Include in the report only the pertinent computer material.

TECHNICAL CONTENT - 30%

The technical material is what you are reporting. It begins with a brief statement of the problem. Then any assumptions, theory, and formulas which are used must be applied correctly. Methods used to obtain results must be such that they lead as directly as possible to the solution of the problem. The methods used may be any combination of such things as hand or computer calculations, experimental laboratory measurements on the actual apparatus, computer simulation, a literature search, analyzing results of a questionnaire, or a phone call to a friendly and trusted expert of your acquaintance. A discussion of errors and discrepancies shows the depth of your technical knowledge.

Finally, evaluate what you have created. Recheck everything. Be tough on yourself. Are there situations where the results and conclusions are not valid? If so, mention them. Describe an interesting and worthwhile feature of your work just finished. Mention an application or two. Let the reader know that you have some creative ability to contribute. After all, the report will bear your name and you should create a product which represents your best efforts. Be proud of it!

SUMMARY OF REPORT GRADING

The various items which determine the report grade are summarized on the check sheet called "Report Critique." It is used by the instructor to indicate those items which, in his opinion, need improvement and his estimate of your grade for each of the three main parts. He will usually mark any discovered errors on the report itself, and summarize the grading on the "Report Critique."

REPORT CRITIQUE

Student Name: _____ Course EE _____
Report: _____ Instructor _____

PRESENTATION - 35 %

Format (does not follow required format, parts missing, wrong order)
Neatness (printing, drawings charts, stapling, inking)
Paper (color, mixed sizes, rough edges, too thin, transparent, dirty)
Legibility (poor handwriting, broken type, needs improving)
Graphs, diagrams, charts, etc. (poorly done, needs improving)
Spelling (some misspelled words, typos, inconsistent spelling
Punctuation (hyphenation, periods, commas)
Abbreviations (inconsistent, non-standard)
Other: _____

Grade: _____%

CLARITY - 35%

Ease of reading (jumps around, extra material, simplify, stress)
Understanding (misleading, not convincing, vague, like double-talk)
Use of graphs, diagrams, etc. (references to them poor, numbered wrong, cannot follow their use, titles missing)
Use of computer results (references to them poor, meaningless output, titles missing, extra material, use appendix)
Use of derivations (references to them poor, too long, use appendix, do not apply, used poorly, inadequate, not necessary)
Calculations (references to them poor, some not necessary, simplify)
Other: _____

Grade: _____%

TECHNICAL CONTENT- 30%

Statement of the problem (vague, abstract, simplify, not convincing)
Accuracy (calculations, computer, discrepancies, some errors)
Correctness (theory, formulas, assumptions, graphs, diagrams, use of instruments, poor measurements)
Methods used (not suitable, improperly used, poor procedures, odd)
Evaluation of results (how do conclusions follow results, justify assumptions, validity, recommendations, applications
Other: _____

Grade: _____%

Report Letter Grade: _____